Optical Bridges For Fiber Optic Local Area Networks

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Abstract

Progress in optical fiber communications allows ever increasing channel capacity for local area networks (LAN's). However, there are still many problems to solve with respect to bridges interconnecting these LAN's which constitute a system bottleneck. To eliminate the bridge bottleneck in the interconnection of fiber optic LAN's, a high speed bridge using optical technology is proposed. The proposed optical bridge uses bistable optical devices, such as interference filters, as essential components of its design. Since these devices can be easily fabricated, the implementation of this optical bridge is feasible.

1. Introduction

The use of optical fibers in local area networks (LAN's) has increased its rate tremendously from that available through electronic transmission [1], [2]. The increased bandwidth which optical fibers supply has made it possible for LAN's to offer more services, including data, voice, facsimile, and conference video, at faster rates. However, the applications of these fiber-optic LAN's are by no means limited to the local networking of devices attached to it, but should also cover services to other LAN's for many reasons. First, as LAN installation grows, it may exceed the design parameters of an individual LAN. Restrictions such as physical extent, number of stations, performance, and media may be alleviated by the interconnection of multiple LAN's. Further, as new LAN architectures are introduced, a simple method of connecting these to existing LAN's would be valuable. The functions needed for interconnecting these LAN's together are provided by specific devices called bridges [3], [4], [5].

With the advent of fiber optics which will enable these LAN's to operate at rates exceeding hundreds of megabits per second, the data rate and capacity requirements for a bridge must be considerably higher to prevent it from becoming a bottleneck in these interconnected LAN's [6]. Thus new and improved methods are needed for designing these bridges to accommodate the increase in bandwidth through the use of optical fibers. In this paper, we are interested in the problem of designing high speed bridges using optical technology to interconnect high speed fiber optic LAN's. Optical technology offers an attractive solution to high speed bridges since such a device can allow a signal to propagate theoretically at the speed of light, which is essentially independent of the number of components receiving that signal [7]. On the other hand, the speed of an electrical system can be quite low due to slow charging time of the loading capacitance of the gates.

This paper is organized as follows. In the next section, a brief description of the architecture of a bridge is given, and its conceptual design is provided. In section 3, optical logic gates which are the basic elements in designing optical digital circuits are introduced. In section 4, the design of an all-optical storage device which is the basic component of the buffering system in a bridge is shown. The design and operation of electronic shift registers and optical shift registers are explained in section 5 and section 6 respectively. These optical shift registers constitute the whole buffering system in a bridge. Finally, the implementation of an optical look-up table needed for packet processing in a bridge is provided in section 7.

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2. Bridges

A bridge (also referred to as a media access control (MAC) bridge or data link) is a device which interconnects LAN's and allows stations connected to different LAN's to communicate as if both stations were on the same LAN as shown in Fig. 1. Bridges provide a basic routing and store-and-forward function. Packets of information are buffered in a bridge until they are transmitted on the appropriate local network or the next bridge. The bridge memory space is partitioned into two separate shift register pools, one for each data-flow direction; see Fig. 2.

In high speed fiber-optic LAN's capable of operating at data rates exceeding 100 Mbits/s, the state-of-the-art bridges are likely to become the bottlenecks of data flow in the interconnected LAN's [6], [8]. This is owing to many factors. First, the electronic components of the bridge are not capable of operating at speeds comparable to the optical fiber's bandwidth. Second, there is a big time delay associated with the electroptical control which can be rather slow due to the slow response time of photodetectors and laser diodes in the optoelectronic interfaces needed for the optical/electronic conversions. Third, packet processing needed for routing packets in the interconnected LAN's takes a long time as compared to the packet transmission time in fiber optic LAN's. These factors could be overcome if packets remain in optical form during transmission and processing in these bridges. This could be done by designing optical bridges since optical components have a higher bandwidth and faster switching time than electronic components [7]. Moreover, optics can provide a great advantage of flexibility in routing optical signals. Since these signals do not encounter significant cross-coupling, their routing within the bridge is not restricted. The main objective of this paper is to propose a conceptual design of an optical bridge in order to achieve higher bandwidth in the interconnected LAN's. This will be done by designing optical shift registers to replace the electronic shift registers in the electronic bridges, and by performing the packet processing using an optical look-up table.

3. Optical Bistable Devices

Electronic digital circuits are based on combinatorial binary logic gates. In principle, only a single binary logic gate plus negation is required for the design of any digital signal processing system. However, in order to minimize the total number of logic gates it is useful to have at least OR and AND gates, together with their inverted forms NOR and NAND. Thus, if we can implement these basic logic gates in optics, we have the components to build an all-optical digital computer or an all-optical digital circuit needed for the transmission of packets of information between these computers.

A large part of the research concerned with the realization of optical digital circuits have concentrated in attempts to make binary logic gates. This requires the use of an optical bistable device where it has two stable states; in one it blocks most of the light falling on it, and only transmits a very small portion of it. In the other it transmits light efficiently. Optical bistable devices have the potential for high speed signal processing and computing [9], [10]. In this paper, the proposed optical bridge uses bistable nonlinear interference filters (NLIF's) as the basic optical device for its various components. A nonlinear interference filter is an optical bistable device, which exhibits reproducible bistable operation [11], [12]. These devices are all-optical, that is, they allow light to control light. Also, ZnS and ZnSe bistable nonlinear interference filters have been used to demonstrate digital optical circuits, pattern recognition, and symbolic substitution [13], [14], [15], because they can operate in the visible spectrum and are relatively easy to fabricate [16]. The nonlinear interference filters can operate in different modes depending on the initial choice of detuning [17]. They can provide logic functions when operating in either the transmission mode or the reflection mode. It has been shown that an AND or OR gate can be realized in transmission mode [16], [17]. Of much more interest in the NLIF case is the reflection mode of operation where latching gates and NOR, NAND, and NOT logic functions can be realized [16], [17].

4. Optical Storage Devices

One class of storage elements which are capable of storing a single bit of information is the flip-flop [18]. It has the capability of storing 1 bit of information because it has 2 stable states. The flip-flop remains in fixed state (stable) until it is strobed by a clock pulse which causes it to change its state. Every flip-flop must have at least one input line which determines which state it will assume next and at least one output line so that its present state can be determined. The ability of the flip-flop to retain its logic state, is the basis for information storage and transmission in computer networks. In this paper, these flip-flops will be used to design the optical shift registers in an optical bridge.

Different types of flip-flops have been built and demonstrated using different optical devices [19], [20], [21]. In our design of an optical flip-flop, we use optical bistable devices which are nonlinear interference filters. A possible optical implementation of a flip-flop is shown in Fig. 3. This design consists of two NLIF's, one pulsed laser source with intensity equivalent to logic 1, and two polarizing beam splitters (PBS's) for directing the beams to the appropriate NLIF. The nonlinear interference filters can have a multimode operation characteristic; that is, they can operate in the reflection mode, transmission mode, or absorption mode, each of which depends on the type of application needed. NLIF1 operates in the transmission mode and essentially acts as an AND gate for a two-level signal (with levels of 0 logic or 1 logic) as desired. NLIF2 acts as a latching gate by operating in reflection mode. It has the ability to store one bit of information as long as the clocked laser source is present. The flip-flop clock pulse (Ckt) allows sampling of the input data. Once the clock is ON, it drives NLIF1 to high transmittivity, causing the input data to propagate. Hence it provides a synchronized sampling process needed for the serial data input to the flip-flop and consequently allows shifting of two-state data into the optical shift register which uses a cascaded set of these flip-flops as will be seen in section 5. It is assumed that the beam with level logic 1 is *p*-polarized. The idea of having the beam polarized in a certain direction is to be able to control its propagation.

The input of laser are pulsed (clocked) and produce appropriate polarized signal. Moreover, the pulsed laser source must maintain constant output for a sufficient duration so that the state of the flip-flop is stable for the purpose of sampling by the next cascaded flip-flop. However, this source must be turned OFF momentarily to reset NLIF2 and makes it ready to store new input data. Thus the output of the flip-flop is a signal of level 0 logic or 1 logic (*p*-polarized). This flip-flop can provide a basic building block of an optical shift register which can be used to shift packets with two levels of information units.

5. Optical Buffering in Bridges

Shift registers represent one of the oldest concepts for electronically storing and transmitting packets of information in computer networks. An electronic shift register is a synchronous sequential logic circuit which uses logic gates and storage devices such as flip-flops [18]. It is capable of shifting its binary information either to the right or to the left. The logical configuration of a shift register consists of a chain of flip-flops connected in cascade, with the output of one flip-flop connected to the input of the next flip-flop. Synchronization is achieved through a common clock pulse (Ck). the clock pulses from a generator are distributed throughout the system in such a way that the flip-flops change their state only with the arrival of the synchronization pulse. An *n*-bit shift register consists of *n* flip-flops and a control logic to perform the shift operations.

To assure proper operation of the shift register, the change of state of the flip-flops must be delayed until the shift pulse is completed; otherwise several shifts could occur for one pulse. The necessary delay can be built into the flip-flop, in which case the shift pulse width must be less than the flip-flop delay. Alternatively, the flip-flop can be designed to respond to the trailing edge of the pulse, in which case the pulse width is not important. In any case, the operation of the shift register is synchronized by using a common shift pulse so that the flip-flops change state simultaneously after the pulse is over.

The design of these all-optical shift registers is based on mimicking the functionality of the electronic shift registers described above. Based on the optical flip-flops proposed in section 4, an optical shift register is designed as a series of optical flip-flops cascaded in a chain, with the output of one flip-flop connected to the next flip-flop and is equivalent to the electronic shift register. Each flip-flop can store one unit of information, with possible levels of logic 0 or logic 1. It is a synchronized system which is controlled by a single clock (Ckt). The proposed optical shift register is clocked and can allow shifting of data through the register and hence allows serial loading of input data into the register. However, for proper operation, care must be taken in specifying the width of the clock pulse (Ckt) so that several shifts do not occur during one clock pulse. To do that, the clock pulse should be turned ON only when we need to change the states of the flip-flops and to shift data in the shift register. Moreover, the duration of the clock pulse should be close to the delay of a single flip-flop.

6. Optical Routing Tables

A bridge must assure that packets arriving from one network are transmitted toward their ultimate destination. Any bridge that is not directly connected to the destination local network must send the packet to the next bridge in the chain from source to destination; the address of this next bridge is the next-hop address. The bridge examines the destination address of a received packet and determines the next hop address by using the destination address as an index to a routing table [4]. A routing table is a table of destination/next-hop address pairs that is maintained by the bridge. A routing table lookup converts an internet destination address into a local network address. If the packet destination is on the same local network as the bridge, then the next-hop is the local network address and destination. Otherwise, the next-hop is the local network address of the next bridge that brings the packet closer to its final destination.

An optical routing table can be implemented through the direct use of optical logic gates such as NAND gates or XOR gates [9], [22]. The routing table is stored by recording the interference pattern between an object beam and a reference beam of light. Such a recording allows the reconstruction of the wavefront of the object beam. Thus the reconstructed routing table image will be a 2-D array of small squares. Each line will identify the bit of the entry in the routing table. The bright square will represent a logic 1 and the dark square will represent a logic 0. The routing table is imaged on a detector array where each square has one detector. The input to the routing table should duplicated and imaged on every line of the detector array. The light used to image the input to the routing table and the light used to reconstruct the table should be out phase. Thus, if both the input and the routing table have logic 1, destructive interference will occur in these squares, and the corresponding square will be dark. However, if the input or the routing table have a logic 1, then the corresponding square will be bright. Hence, the detectors at each square will detect the XOR of the input and the routing table entries which could be implemented using nonlinear interference filters [17]. Therefore, if the input is present on the routing table, a line of all dark squares will be detected. Otherwise, every line of detectors will have at least one bright square.

This is just one way of implementing an optical routing table. There are many other ways where an optical routing table could be implemented using optical memory storage such as content addressable memories or location addressable memories [9]. These memories could be implemented using optical NAND gates.

7. Conclusion

We have proposed a conceptual design of an all-optical bridge for the interconnection of fiber optic local area networks. The high speed bridge is designed using optical bistable devices which are nonlinear interference filters. These filters exhibit reproducible bistability, which makes them attractive candidates for implementing very high-speed latching gates, and hence allow the fast transmission signals through the optical bridge. Thus we feel, in order to take advantage of the high bandwidth available through the use of optical fibers, all-optical digital circuits should replace their electronic counterparts.

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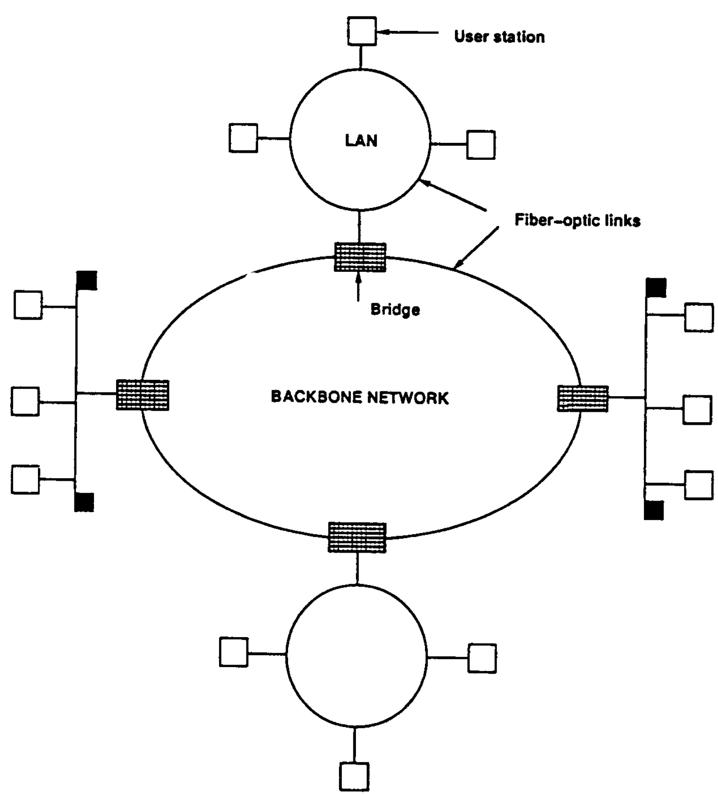

Figure 1. Interconnection of LAN's by bridges.

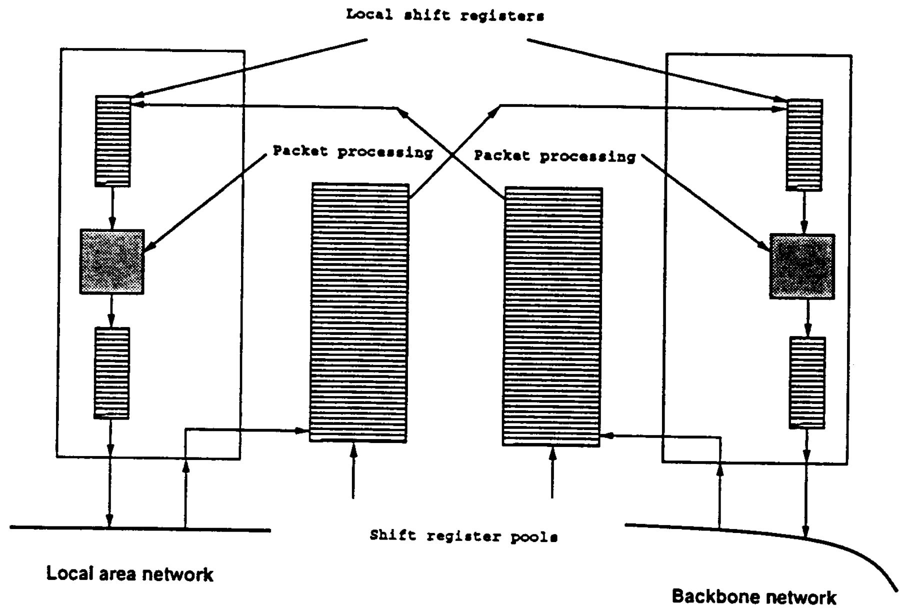

Figure 2. Architecture of a bridge

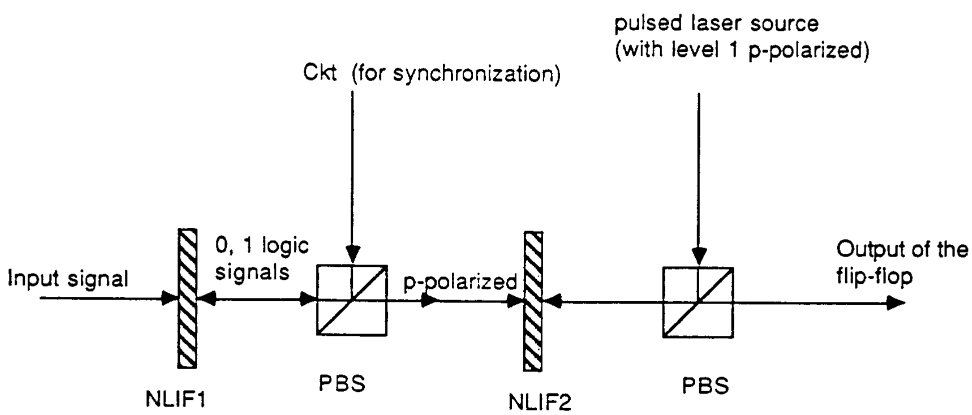

Figure 3. The optical design of a flip-flop.