WHEELNET: A Hybrid Ring/Star Architecture For Local Area Networks

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The use of optical fiber as a transmission medium in computer local area networks (LAN) has lead to the design of new protocols to take advantage of the high bandwidth of fiber. Many of these new protocols have been designed for a ring topology LAN. There has also been significant research effort devoted to designing protocols for a star topology LAN. This paper proposes a novel hybrid architecture for a LAN called Wheelnet that combines a ring and a star topology. The resulting network architecture can lead to performance improvements over a ring topology and lends itself well to certain applications.
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INTRODUCTION

Optical fiber has become the transmission medium of choice for computer communication networks. One of the major reasons is the high bandwidth offered by fiber. Fiber has been used on all local area network (LAN) topologies; ring, bus and star. With the use of fiber has come the design of new protocols to effectively utilize the bandwidth. Many new protocols have been designed for the ring topology LAN [1, 2, 4, 5, 8, 9, 15, 17] as well as for the bus topology LAN [1, 14, 19, 20]. There has also been renewed interest in the star topology LAN and many new protocols have been designed for the star [1, 7, 11, 12, 13, 21, 23]. The star topology can offer significant performance improvements over the ring topology. One area that has not been thoroughly investigated is the area of hybrid architectures, in this case a hybrid ring star architecture. We propose embedding a star on a ring. The new hybrid architecture is called Wheelnet because of its topological similarity to a motorcycle wheel.

In Wheelnet, each node must still have a direct link to two other nodes, as in a ring. It does not require that each node have a direct link to the passive optical coupler (POC) at the center of the star. The architecture is shown in Figure 1. The only device that is connected to the POC is a wavelength transfer device, or wavelength router [5, 6]. The wavelength router transmits wavelengths to the next node on the ring or to the POC. This wavelength routing can be static or dynamic as explained below. The number of nodes is divided into segments, each segment forming an arc of the ring. Figure 2 shows one segment.

The rest of this paper is organized as follows: Section 2 describes the wavelength transfer function and Section 3 describes how the device is used to facilitate the new architecture. An approximate analysis is presented in section 4; Section 5 shows the results of simulation, Section 6 discusses potential applications that would be well served by Wheelnet; and Section 7 presents our conclusions.

WAVELENGTH TRANSFER

The topology of Wheelnet appears in Figure 1. Let there be N nodes in the network. Divide the nodes into G groups g1, . . .gg. Each such group forms one segment of the ring. Let there be G wavelength devices T1, . . . Tg where device Ti lies between group gi and gi+1 as depicted in Figure 2. In Figure 2, the square device enclosing the smaller squares labeled A, B, C, D is the wavelength router.

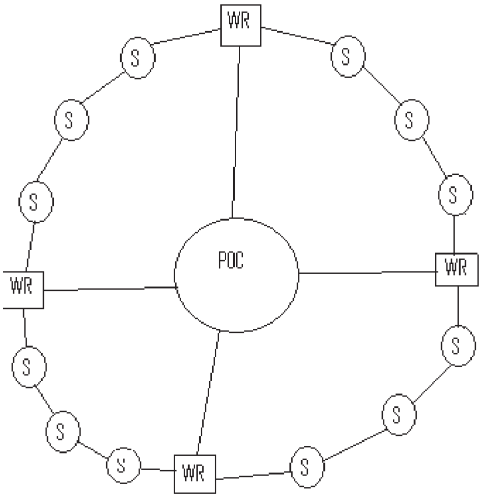

Figure 1. Topology of WHEELNET.

As stated previously, a wavelength router [5, 6] can be a static router or a dynamic router depending on network design. The network design parameter of concern is whether nodes will have fixed tuned receivers or tunable receivers.

If receivers are fixed, wavelength routers can be static. For example, if a message from a node in group gi is destined for a node in group gi+1 through router Ti, it can be passed straight through the router. If the message is from a node in group gi destined for a node in some group gj, then router Ti must route the message through the POC of the star. Since receiver wavelengths are fixed and the router can be a very simple device, it can be implemented entirely in hardware.

If receivers are tunable over a range of wavelengths, the router must be a dynamic device. It must be capable of routing discrete packets of information on an individual basis based on destination information in the packet header.

In addition to a routing function, the router can also serve as an optical amplifier and wavelength splitter/recombiner. In the rest of this section, lets demonstrate one way the network can work. For this purpose let the wavelength be divided into N+1 separate channels W0, W1, . . . WN. Channel W0 is used as a control channel. Wavelengths W1 through WN are data channels. All nodes have one fixed tuned receiver permanently tuned to the control channel. Each node is assigned a unique wavelength for reception and has a fixed tuned receiver permanently tuned to this wavelength. Each node is equipped with a tunable transmitter capable of being tuned to any wavelength. In addition, all nodes know the assignment of receive wavelengths of all nodes on the network. Each node is capable or removing from the fiber any signal on its receive wavelength [5]. Time on the data channel is slotted into fixed length data slots. Time on the control channel is slotted into fixed length control mini slots.

To further illustrate how the wavelength router works, consider an arbitrary router Ti connected between the POC and segment gi and gi+1. Consider the transmission of a node in segment gi. The signal traverses segment gi until it comes to the router Ti. If the signal is intended for a receiver in segment gi+1, Ti acts as an optical amplifier boosting the signal before transmitting the signal out to segment gi+1. The router must be sure there is no collision between the signal coming from segment gi and a signal coming from the POC. A buffer or

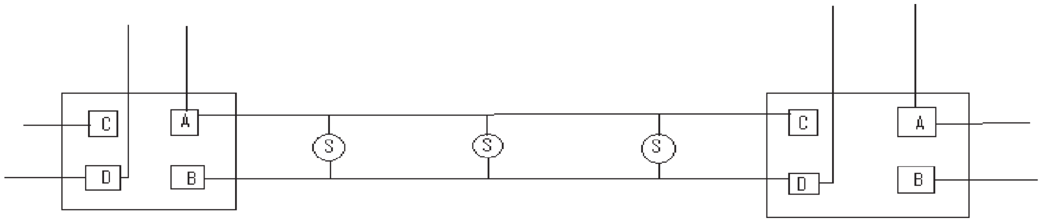

Figure 2. One segment of the Wheel.

fiber delay line can be provided to delay one of the signals for one slot time. The signal is then transmitted onto segment gi+1.

If the signal from the node in segment gi is intended for a node on some segment gj then when the signal arrives at router Ti, it is routed to the POC. When the signal arrives at router Tj-1, it is transmitted onto segment gj. If a signal comes across the POC to router Tl-1 and it is not intended for a node on segment Tl, it is dropped.

Signals on the control channel must be treated differently to prevent them from circulating forever. Details of the control channel will appear later. For now we concentrate on preventing the control slots from circulating around the network forever. At the start of each control frame, which is a series of control mini slots, one bit is reserved to indicate that the router receiving the control slot should remove the signal from the fiber. When a router Ti sees a control frame coming from segment gi with this reserved bit not set, the router passes the frame along towards the POC which transmits it to all routers. When router Ti sees a control frame coming from the POC, it sets the reserved bit and passes the frame to segment gi+1. When a router Ti sees a control frame from segment gi with the reserved bit set, it indicates that the control frame has already traversed all segments of the network so the router removes the control frame from the fiber

By having the control frame go through the POC to be delivered to destinations, it ensures that all nodes will receive the same control information at the same time. Many protocols have been presented in the literature that are designed to operate on a star LAN [1, 7, 11, 12, 13, 21, 23]. Any of these protocols can be used to coordinate activities on the network.

PROTOCOL

Recall that time on the data channel is slotted into fixed size slots large enough to hold one fixed size data packet. Time on the control channel is also slotted into fixed length slots, each slot is further subdivided into N control minislots. Each minislot is assigned for use by a predetermined node.

The control minislots are used to indicate one nodes intent to transmit to a specified destination and the number of data packets to be transmitted starting in the next available data slot. Since all nodes have a fixed tuned receiver to the control channel, all nodes get control information at the same time. In case two nodes have data to transmit to the same destination at the same time, the message with fewer data packets can take precedence, or some other criteria can be used to choose between the two transmitting nodes. Since all nodes have all control information at the same time, all nodes use the same scheduling algorithm and make the same decisions, thus implementing a distributed queue [10, 18] of messages intended for one destination. Once the node at the head of the queue has finished transmission, the next node in the queue can begin transmission.

APPROXIMATE PERFORMANCE ANALYSIS

The model of the system is developed based on the following assumptions:

1. There are N nodes in the network.
2. The arrival process for each channel is an independent Poisson process with a rate of L packets per second.
3. The number of data packets per message is exponentially distributed.

From the description of the protocol, each channel can be modeled as an M/M/1 queue. This is the model adopted in this analysis.

The following notation is used in the remainder of this section.

T – average delay
L – arrival rate of packets

N – number of nodes
U – average packet service rate
G – number of segments on the ring
g – number of nodes per segment

Results for M/M/1 queues are well known [24]. The average delay per packet is:

$$T = (1/U) / (1 – L/U)$$

Design parameters of interest include the number of segments on the ring (G) and the number of nodes in each segment (g). These parameters can be determined based on the desired performance of Wheelnet over a ring.

In a ring, the average distance between source and destination is N/2. In Wheelnet, however, by choosing the number of nodes per segment and the number of segments, the average distance between source and destination can be chosen to achieve a desired level of performance. In Wheelnet, on average, the source will be in the center of one segment and the destination will be in the middle of another segment, the distance between them is g nodes, plus the distance to and from the POC.

For example, consider making Wheelnet perform as if the average distance between source and destination is 1/x of a ring network, then the number of nodes per segment is chosen to be g = N / (2 * x).

As a concrete example, consider a ring network with 100 nodes. The average distance between source and destination is 50 nodes. However, for Wheelnet we can choose to have the distance be 1 / 10 of a ring, thus g = 100 / (2 * 10) = 5 nodes per segment. The average distance between source and destination in this case is only 5 nodes, plus twice the distance to the POC., a significant improvement. With 5 nodes per segment, there must be 20 segments on the ring, each segment having 5 nodes. Consider a network with 100 nodes placed 100 feet apart. For a ring, a signal must traverse on average 5000 feet. If we allow 100 feet between a router and the POC in Wheelnet, the signal must traverse only 700 feet. This distance is a significant improvement.

It is also important to have an analytical tool to choose G and g. Here we present a simple way to use delivery time of a packet on Wheelnet compared to delivery time around a ring. Assume for this approximate analysis that time to propagate a packet from one node to the next node around the ring is t. Assume that the time to propagate a packet from a router to the POC is an integer multiple of t, let this be b*t. On average, a packet must traverse half the nodes on a ring, this takes (N * t) / 2. On the Wheelnet a packet propagating through the POC on average will traverse half a segment from source to router, half a segment from router to destination, plus the time from source router to the POC and from the POC to the destination router. This propogation time is ((g * t) / 2) + 2 * b * t. For Wheelnet to provide better performance, we must have ((g * t) / 2) + 2 * b * t < (N * t) / 2 so that g < N + 4 * b. Once group size is determined, it is simple to find the number of groups, this is G = N / g.

It is also important to look at the state of the system as a whole instead of focusing on one node or one segment. For this purpose we will model the system state as a two dimensional Markov model. The state transition diagram is shown in Figure 3. Since the state space is so large only representative equations of the state changes are shown in equation form. This is a set of linear equations. In equilibrium the flow into each state is equal to the flow out of each state.

Assume there are N nodes in the network and W available wavelengths. Our system state considers the use of only one wavelength. We also assume two classes of traffic, class 1 which is transmitted around the ring, and class 2 which is transmitted across the star. Packets arrive at a Poisson rate of L1 for class 1 traffic and L2 for class 2 traffic. Service time for both traffic classes is U. Each state is represented by a 2-tuple (i, j) where i is the number of class 1 packets and j is the number of class 2 packets. We allow limited space in the node to hold a maximum of R class 1 packets and a maximum of C class 2 packets. Thus the state space for the node contains R * C states. We adopt the convention that P(i, j) is the probability that the system is in state (i, j).

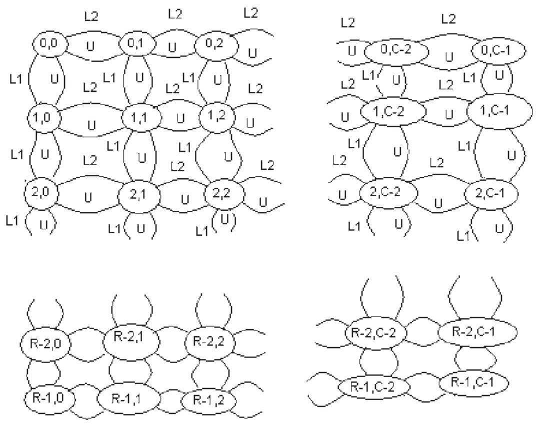

Figure 3. System State Transition Diagram.

The equations for the first row are:

0 = -L2 * P(0,0) – L1 * P(0,0) + U * P(1,0) + U * P(0,1)

0 = -L2 * P(0,2) – L1 * P(1,1) – U * P(0,1) + L2 * P(0,0) + U * P(1,1) + U * P(0,2)

0 = -U * P(0,2) – L2 * P(0,3) – L1 * P(1,2) + L2 * P(0,1) + U * P(0,3) + U * P(1,2)

0 = -U * P(0,3) – L2 * P(0,4) – L1 * P(1,3) + L2 * P(0,2) + U * P(0,4) + U * P(1,3)

. . . .

to the last node on the row

0 = -U * P(0,C) – L1 * P(1,C) + L2 * P(0,C-1) + U * P(1,C)

the equations for the first column

0 = -U * P(1,0) – L1 * P(1,0) – L2 * P(1,1) + L1 * P(0,0) + U * P(2,0) + U * P(1,1)

0 = -U * P(2,0) – L2 * P(2,1) – L1 * P(3,0) + L1 * P(1,0) + U * P(3,0) + U * P(2,1)

0 = -U * P(3,0) – L2 * P(3,1) – L1 * P(4,0) + L1 * P(2,0) + U * P(4,0) + U * P(3,1)

0 = -U * P(4,0) – L2 * P(4,1) – L1 * P(5,0) + L1 * P(3,0) + U * P(4,1) + U * P(5,0)

. . . .

to the last node on the column

0 = -U * P(R,C) – U * P(R,C) + L1 * P(R,C-1) + L2 * P(R-1,C)

to the last node in the last row and the last column

0 = -U * P(R,C) – U * P(R,C) + L1 * P(R,C-1) + L2 * P(R-1,C)

and

1 = Σ (i = 0 to R) Σ (j = 0 to C) [P(i,j)]

To solve the set of linear equations they can more compactly be written as

y = p * Q

where y is the vector y = (0, 0, 0, 0, . . . 1) and p is the vector p = [P(0,0) P(0,1), P(1,0) P(0,2) P(2,0) . . . .P(R,C)]
and the matrix Q is

-(L1 + L2) 1
u 1
u 1
0 1
0 1

5 Simulation

A small simulator was built in C++ and used to simulate the operation of both a ring and

Wheelnet. The parameters included number of nodes in the network, distance between nodes, and packet length. Each segment of Wheelnet contained 1/10 of the nodes in the network. Table 1 tabulates the results of simulation.

Table 1. Simulation Results.

Number Of Nodes	Distance between nodes	Packet length bytes	Ring (msec)	Wheel (msec)
50	50	1000	6.19	1.75
50	50	5000	6.25	1.79
100	100	1000	24.9	6.0
100	100	5000	25.04	6.06

For all combinations of parameters studied, Wheelnet showed superior performance in regard to delivery time. As the size of the network grew, the performance of a large version of Wheelnet was even better than for a small version of Wheelnet.

APPLICATIONS

An obvious question is what type of applications can be supported by this architecture. Clearly the architecture can be used for text only traffic providing better time delivery for transmission to nodes on the far side of the network. The architecture can also support both high priority and low priority traffic. Low priority traffic can be routed around the ring while high priority traffic can be routed across the star. In addition, the architecture can support better service to real time traffic over non-real time traffic. Non-real time traffic can be routed around the ring while real time traffic can be routed across the star thus providing better service to traffic that has timing constraints.

Although fixed receivers and static routers are cheaper and easier to implement, a static assignment offers certain limitations, notably lack of flexibility and restrictions on expandability. Though these limitations are not insurmountable, they certainly offer a challenge to network expansion. To expand a static network requires man hours of manually reconfiguring the network.

Tunable receivers and dynamic routers overcome the above limitations far more easily. Nodes can be added to the network easily, and the network can adapt almost automatically by simply having each new node announce itself on the network and letting everyone know of its presence and operating parameters. A dynamic router can be built and programmed to adapt to this kind of change quite easily by updating its routing tables appropriately.

A dynamic network thus lends itself to flexibility and expansion more easily than a static network. Given a choice, a dynamic network is the best choice for a growing enterprise.

A dynamic network also provides a better cost/performance benefit. A dynamic network can be grown as need arises without a major affect on the existing infrastructure of the organization. With the growing importance of data and the growing demand that certain information must be delivered in as short a time as possible, Wheelnet offers a speed/performance benefit that cannot be matched by most any other LAN technology, including the popular high speed Ethernet. With the value placed on data and the growing importance of speedy delivery, Wheelnet can provide a very cost effective solution to a companies data processing needs.

CONCLUSION

This paper has presented a new network architecture called Wheelnet, a hybrid ring/star topology along with a protocol designed for efficient operation of the network. By choosing appropriate design parameters, the new network showed significant performance improvements over a ring network and is well suited to a variety of applications.

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Received March 9, 2007; Accepted September 10, 2007