An Improved Approach to Fault Tolerant Redundant Fiber Optic Ring Design for Polled Data Networks

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(ABSTRACT)

This research investigates alternate methods of implementing a redundant communications ring for polled network applications. FDDI and a unique solution (the tone method) designed specifically for this application are compared. In polled networks one of the most critical parameters is the time required to interrogate all of the nodes in the network. This parameter, called the poll time, is compared for the two solutions under various operating conditions, including the instances when the ring is intact and when the ring has experienced a failure, causing it to operate in the redundant mode. As expected, the solution designed specifically for this application performed better than FDDI. The tone method, which requires very little overhead and is not limited by distance or number of nodes, is described in detail, as are the results of poll time comparisons.

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Chapter 1. Explanation of Application

Today, most network communications architectures are based on the assumption that the goal of a network is to allow any node within the network to communicate with any other node in the network most effectively. There are important exceptions to this model, for example, networks whose purpose is to collect data to a central point, or to control remote devices and receive instructions from a central point. Known as “star” networks, the information gathering devices may be geographically separated from the central point by many kilometers.

These types of networks are useful in applications such as remote weather monitoring stations, sonar sensor arrays, network management system (NMS) networks which monitor the status of other networks, and intelligent transportation systems (ITS). This paper will concentrate and expand on the use of such networks in ITS applications.

1.1 Polled Traffic Control Applications

ITS is an advanced traffic management system responsible for a number of functions such as traffic control, maintenance planning and road tolls. The goal of ITS is to make the overall highway system more economical and reliable by increasing traffic flow efficiency and reducing congestion. However, in order to alleviate traffic congestion, plan maintenance schedules, determine safety and develop successful traffic policies, extensive data needs to be available to the road operators, traffic engineers and Department of Transportation (DOT). Especially in high-density traffic, there is a great need for more efficient means of vehicle detection, classification, and weigh-in-motion to supply data and analyze traffic flow.

To increase the efficiency of traffic on roads, sensors are being installed along highways to monitor traffic flow; based on the sensor output, traffic signals can be automatically adjusted to the current flow of the traffic being monitored. Although this technology is not new (sensors, for example, have been used for years to indicate the presence of a car in the left turn lane, thereby signaling the light to change), it has been limited to specific intersections or lanes. There is now a push to improve overall traffic efficiency by interconnecting many sensors and signals so that traffic flow can be controlled over an extended area.

Basically, data from many sensors could be analyzed and the results used to control and step many signals. In order to do this, the data from the sensors must be relayed to a central point, referred to as the master node, for analysis; commands to the signals would then emanate from this central location back to the original sensor sites, known as remote nodes.

There are several ways to communicate with these remote nodes. One, radio transmission, has the advantage of lower infrastructure cost compared with other methods, but issues involving interference, jamming, and spectral allocation arise. Another method, copper line communication, eliminates many of the problems associated with radio transmission, but lighting strikes and signal attenuation over long distances can be a problem. Fiber optic communication lines, on the other hand, are immune to electromagnetic interference and are resistant to corrosion. They also have a small size, low profile and extremely high information-carrying capacity. Therefore fiber optic communications cables would provide the most reasonable solution for use in such a network.

Whether using radio, copper or fiber, any fixed network has one inherent drawback over a wireless network: it is prohibitively expensive to run a separate fiber from the central controller to each node in the field in the “star topology”

configuration (see *Figure 1-1*). Another drawback of the star topology is that any cable break will isolate a field node from the central controller.

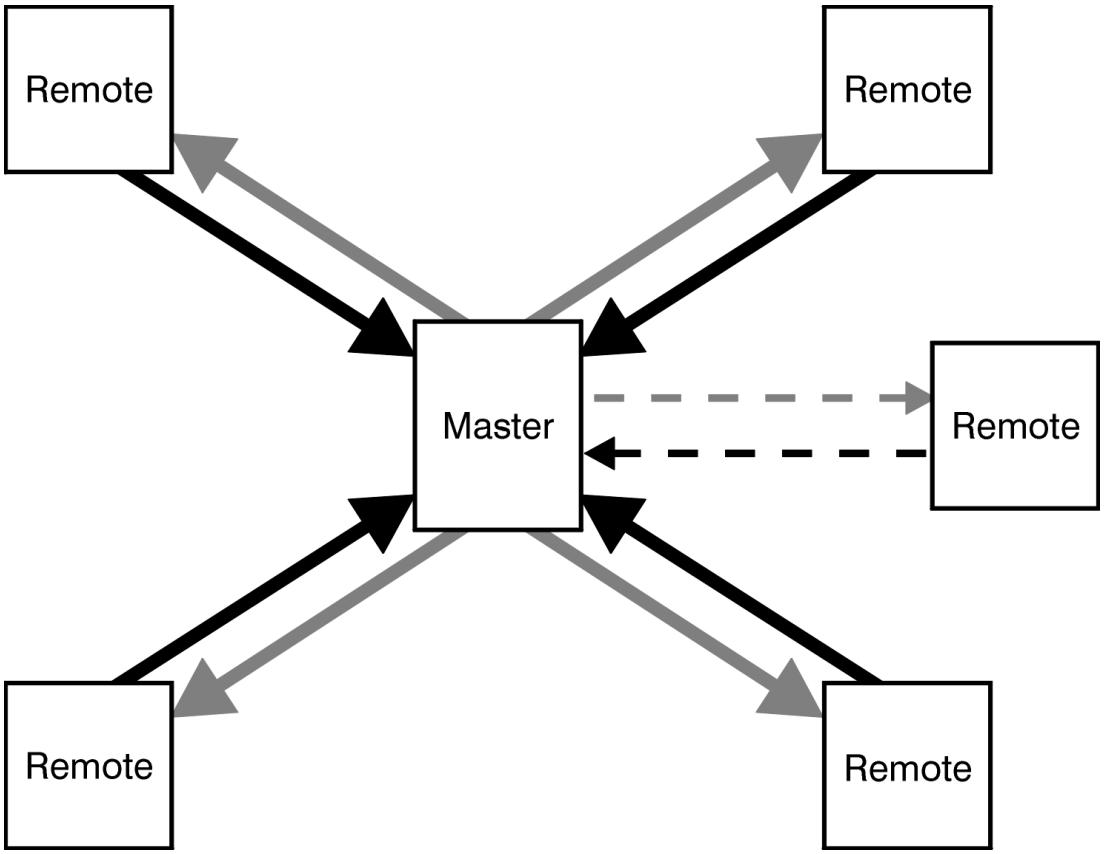

Figure 1-1 Star Topology

To avoid the drawbacks of the star topology, a linear bus topology may be used (see *Figure 1-2*). In this configuration, information from the master node is transmitted to the remote node closest to the master node, and from there it is retransmitted downstream to the next remote node further down the line until the end of the chain is reached. Data from the remote nodes is transmitted back upstream to the master node in a similar fashion. However, there are also problems associated with the linear bus; if power is lost at one of the intermediate nodes downstream, nodes can no longer communicate with the master. Similarly if a cable break occurs somewhere in the middle of the bus, the downstream nodes can no

longer communicate with the master. Adding a battery backup to each node has solved the loss-of-power problem, but this is expensive and requires maintenance.

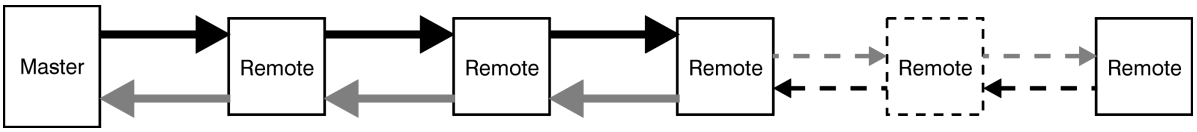

Figure 1-2 Linear Bus Topology

A more robust data network takes the node furthest downstream from the master in the linear bus topology and also connects it to the master node. In this case there are two connections from each node to the master node, and in the case of a single cable break, there is still one connection between each of the remote nodes and the master node. This allows communication between each of the remote nodes and the master node. This type of network, analyzed here, is called a redundant ring (See *Figure 1-3*).

There are more complex types of networks that can accommodate more cable breaks, but they go beyond the scope of this research. This thesis intends to show that it is possible to design a redundant ring specifically for polled applications that has advantages over an existing and standardized redundant ring design, not specifically designed for polled applications.

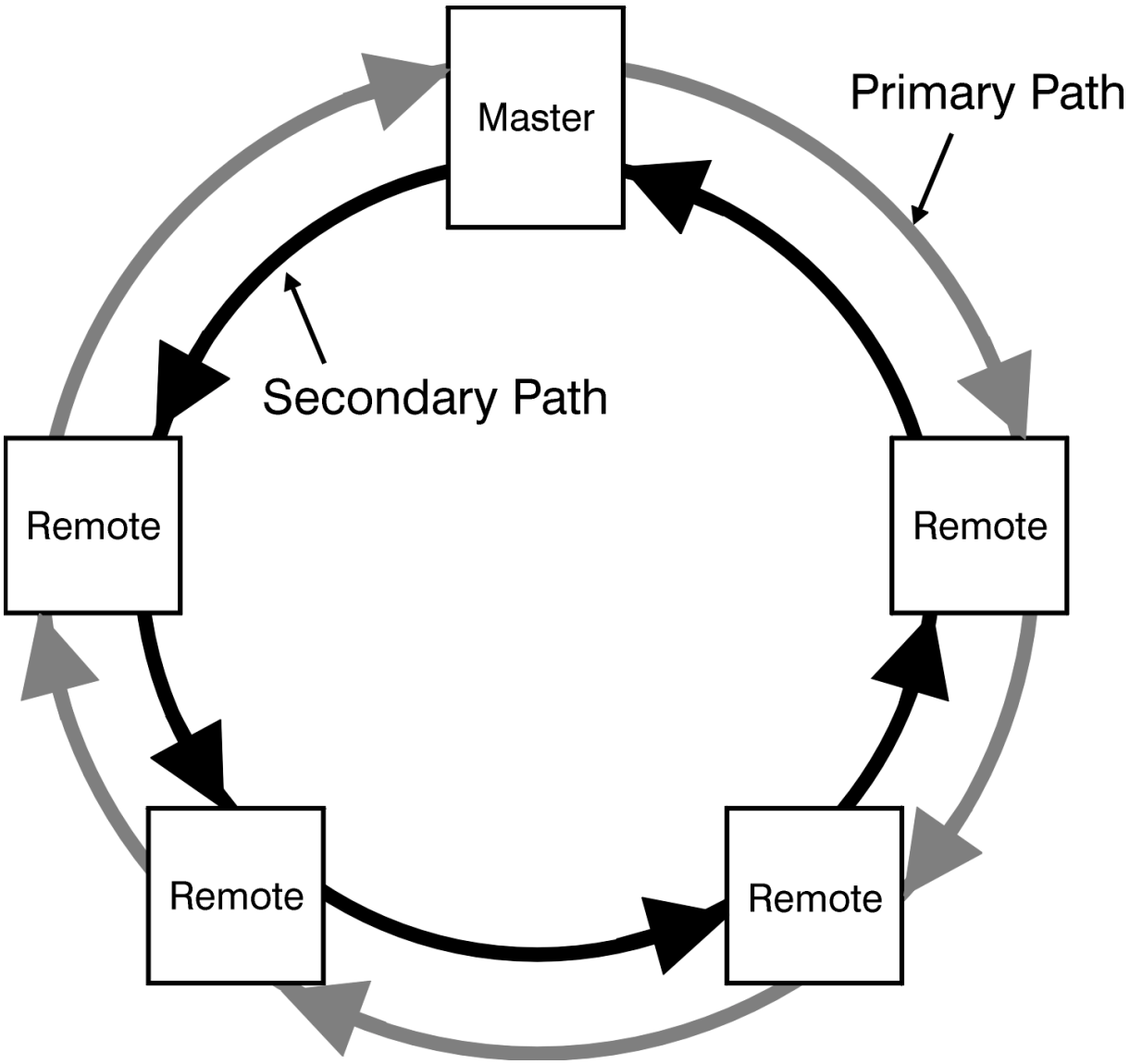

Figure 1-3 Redundant Ring Topology

1.2 Thesis Organization

Chapter 1 briefly describes networks and the thesis organization. Further, it explains that an optical fiber-based communications solution to polled ITS networks already exists. However, creating a more robust solution that incorporates path redundancy is a challenge. One solution uses an existing, well-defined, redundant

ring protocol called the token ring. Alternatively, it may be possible to modify the existing polled ITS network to provide redundancy. To determine the better approach, the performance of both solutions must be compared. This thesis is organized to allow the comparison of possible solutions that meet the requirements of ITS polled redundant ring application.

Chapter 2 further describes the application and defines its requirements. It also presents the fiber-based solutions that work for ITS polled applications and an initial comparison of their performance.

Chapter 3 gives the overview of network performance parameters, and it defines how the network performance is determined. This allows the performance of two solutions to be properly compared. Finally, a set of the most critical performance parameters, used to compare the performance of the two methods, is isolated and studied.

Chapter 4 offers a detailed explanation of the particular networks being considered. It describes the operation of a token ring protocol modified for the polled network application, as well as how the performance parameters deemed appropriate are affected. This chapter also introduces and explains the tone method, which is a modification of the existing polling method used in ITS applications.

Chapter 5 offers results from a comparison of the two approaches as measured against critical parameters defined earlier.

Chapter 6 offers conclusion from this study based on the comparison results and shows distinct advantages of the tone method over the token ring approach in the polled ITS application.

Chapter 7 makes recommendations for further study and lightly explores the feasibility of applying this method to other polled non-ring redundant network topologies.

Chapter 2. Polled ITS Networks

A complete ITS communication system consists of many different sub-systems having different goals. Some of these goals include traffic management, emergency services, traveler information and system management. Each of these sub-systems may use several different communications technologies [1]. In many cases, these sub-systems rely on polled networks to gather information and control field micro-controllers.

2.1 Center-to-Field Communications Requirements

The sub-system that handles traffic management depends heavily on communication between traffic control centers and roadside computer based traffic controllers. These roadside controllers include:

1. Traffic signal controllers at intersections.
2. Variable message signs.
3. Ramp detectors.
4. Control for video cameras.

How this communication is achieved is addressed in *The National Transportation Communications for ITS Protocol (NTCIP) Guide* [2]. The NTCIP protocol is based on the Simple Network Management Protocol (SNMP). This guide describes two types of ITS communications: communication between traffic control centers, and communication between a single traffic control center (the master) and field based traffic controllers (remotes). This thesis focuses on the second type of communication. The NTCIP guide describes a variation of a center-to-field protocol

used in polled networks as such: “Each device is assigned an address that is unique on that line or channel. The management system can communicate with any of the devices at any time by sending a message addressed to that device. However, it can communicate with only one of the devices on the line or channel at a time. Devices can send a message to the management system only when requested to do so by the management system. The NTCIP protocols enable broadcast messages intended for all devices (e.g., a time clock update). No devices can reply to a broadcast message [3].” Thus, a true polled network varies in that the management system cannot broadcast messages intended for all devices.

The theory behind polled networks is that one particular node in the network, the master node, interrogates each of the other remote nodes in the network. The remote nodes respond only when they are queried, and they respond only to the master node. For this type of network to work each of the remote nodes connected to the network must have a unique address. Although each of the remote nodes can only communicate with the master node, information can be passed from one remote node to another but must be re-transmitted by the master node. In this type of network, data collisions are easy to avoid because only the master node accesses the network at will. In addition, the master node must not send a query to another node before the first node has responded. This type of network is ideally suited for data collection where the collection point corresponds to the master node. The master node is also well suited for sending commands to each of the remote nodes.

While NTCIP does a good job of defining the protocol, it allows many options on the subnetwork and plant level for how the protocol is actually transmitted to and from the field controllers[4].

2.2 Fiber Optic Redundant Ring Requirements

System designers currently impose the requirements for a fiber optic transport system that can carry the NTCIP protocol described above by determining a list of specifications that must be met so that the field units can communicate with the central node. For the system to function, an interface must be used. This interface is often called a fiber optic data transceiver or a fiber modem, but there is no current standard for modem requirements. This thesis will compare different modem designs. The list below is a composite of the typical specifications required by the system designers.

1. The fiber optic data modems shall provide redundant, fault tolerant self-healing operation [5].
2. System bandwidth shall be 0 – 56 kbps [6].
3. Operating mode shall be full duplex, asynchronous.
4. The modems shall not echo the polls sent from the master node back to the master node.
5. The modems must not present responses from one field unit to another field unit, only to the central node.

2.3 Overview of Network Topologies that May Work for Polled ITS Application.

Since the NTCIP does not specify a standard for the data transport at the physical layer, many different existing standards and protocols can be converted to the specification. Some of the more promising standards are compared, and a new

method developed specifically for the polled ITS is also described and compared to the existing standards.

2.3.1 SONET

The Synchronous Optical NETwork, SONET, is a communications standard used extensively by telephone companies to provide high-speed, constant data rate connections between many nodes. SONET is designed to carry many digitized voice channels by time division multiplexing these channels and adding overhead information. The overhead contains information that can be used to verify the integrity of the optical link as well as information that indicates how to de-multiplex the channels. SONET is versatile in that multiplexing and de-multiplexing can be done without decomposing the entire bit stream [7]. The complex multiplexing scheme used by SONET makes this system excellent for peer-to-peer communications, by allowing many nodes to use the same fiber at the same time independently of each other. This multiplexing scheme is unnecessary in polled traffic control networks whose goal is to collect information to a single node.

SONET can also re-route the data streams if there is a break in one of the communication paths provided that more than one path exists [8]. SONET's excellent redundancy provisions can certainly be used to fulfill the requirements of the polled traffic modem but the multiplexing scheme defined by this standard is relatively expensive to implement, eliminating this method as a possible solution to redundant polled traffic network.

2.3.2 Ethernet

Ethernet is the most widely used Local Area Network, LAN, technology today. It too is designed for peer-to-peer communications and uses Carrier Sense Multiple Access with Collision Detection, CSMA/CD, to manage data collisions, which occur when two stations attempt to send data at the same time [9]. Ethernet would work well in the polled traffic modem application, but it would have to be modified because standard 10BASE-F does not define redundant links [10]. Because it depends on CSMA/CD Ethernet does not normally work as a ring. Used in a ring, the transmitting modem would always detect its own carrier at its receiver and assume that a data collision has occurred. To eliminate this condition some modification would have to be incorporated into the Ethernet specification, making it non-standard.

The other reason Ethernet is not a good choice for polled ITS applications is that the maximum network span is limited to 400m, severely limiting its usefulness in polled traffic applications [11].

2.3.3 Token Ring/FDDI

Token Rings and Fiber Distributed Data Networks, FDDI, are designed to have two data transmission paths which provide redundancy should one of the two paths become unusable. FDDI can be implemented as a higher speed version of a token ring and is designed to work over fiber. This standard is also designed primarily for peer-to-peer communications but can certainly be used for the polled traffic modem. The underlying principle of the token ring is that access to the communications ring is limited to one modem at a time: A single modem transmits its message around the ring. Then, once the message travels completely around the ring, the modem removes the data from the ring and passes control (the token) to the

next modem in line. This method promises to be an effective method of distributing data and will be described in detail in chapter four.

2.3.4 The Tone Method

The tone method is a modification of existing drop-and-repeat methods currently used in polled ITS applications. In existing fiber optic polled modems, the queries from the master are broadcast to each field unit by the fiber modem connected to that particular field unit and simultaneously retransmitted to the next fiber modem downstream from the master modem. Responses from the field units are relayed back to the master modem through each fiber modem in the chain. The addition of a single control signal, or tone, enables the linear bus to be configured as a redundant ring by informing each field modem which of its data ports is connected to the master modem. The tone is a way of adding minimal overhead to the existing data stream to provide signal routing information to each field modem. The tone method is described in detail in section 4.2.

Since FDDI and the tone method appear to hold the most promise for polled ITS application, these two methods will be compared in detail.

Chapter 3. Overview of Network Parameters

Before defining network performance parameters, a brief definition of the purpose of a network may provide insight. The goal of any communications network is to move information (data) from one device connected to the network, referred to as a node, to another node in the network. Performance can be classified in four major categories. (1) Throughput, (2) response time, (3) data reliability and (4) network cost.

These categories consist of performance parameters that are not always independent. For example, increasing throughput may increase network cost, and a trade-off may be necessary depending on the network application.

3.1 Throughput

In a general sense throughput is defined as being the rate that one node in a network can transfer data to another node in the network [12]. In general the upper limit on the throughput is equal to the maximum data rate achievable between the two nodes. If however the data is encrypted, for error detection or to eliminate DC content, the throughput of the network will be reduced. For example, if 4B/5B encoding is used the throughput of the network will be reduced to 80 percent of the maximum data rate.

Throughput is also reduced by the addition of overhead information used by the network. In SONET for example a frame consisting of 810 bytes contains only 774 bytes of actual user data. This reduces the throughput of the network by approximately 5%.

For comparison reasons it will be assumed that the throughput for both the Tone Method and FDDI are equal.

3.2 Response Time

The response time of a data network, also called the round-trip time (RTT), is defined to be the amount of time required to send information from one node in the network to another node in the network, and back again to the first node. This delay, or latency, can be broken into three components. (1) The propagation delay, (2) the transmission delay and (3) the queue [13].

The propagation delay is given by:

$$Pr = d / c \qquad \textit{Eq: 3-1}$$

Where: Pr = Propagation Time

d = Distance

c = Group velocity in the transmission medium

The transmission delay is given by:

$$Td = S / B \qquad \textit{Eq: 3-2}$$

Where: Td = Transmission Delay

S = Number of bits Transmitted

B = Data Rate (Bandwidth)

The queue delay is the time required for each node to determine how to handle the packets it receives and depends greatly on the type of protocol being used. The queue delay can be subdivided into several parts, which include the addition of overhead, node latency, and access time.

Most network protocols add some additional information to the data packet being sent which tells the network how to route the data. Generally, this added data is referred to as overhead, and the more overhead added to a transmission, the higher the queue delay. The amount of overhead depends on the type of network being implemented. It may also be comprised of several segments; for example, FDDI overhead includes a start delimiter, access control, frame control, the destination address, the source address, a frame check sequence field, and an end delimiter (see *Figure 3-1*) [14]. By comparison, the tone method adds no overhead.

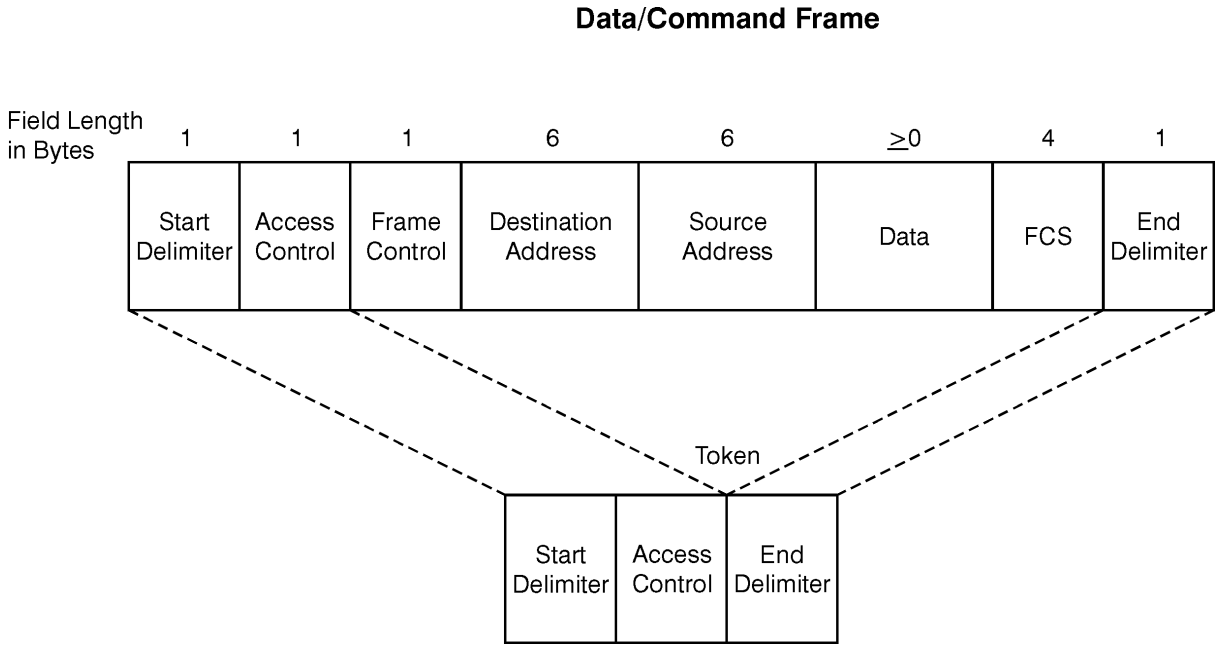

Figure 3-1 FDDI Frame Format

Another parameter that affects queue delay is called node latency. Node latency is the amount of time that the node requires to determine what should be

done with an incoming data packet. If using FDDI, each node must determine if it was the node that sent the packet; if so, the added data should be removed, or if not, the entire packet should be retransmitted to the next node.

The tone method, on the other hand, adds no latency. In the master query direction the remote node simultaneously re-transmits queries from the master as it presents them to the local field controller. In the response direction the remote nodes simply retransmit all data back to the master node.

Finally there is the question of access time. In peer-to-peer networks this is measured as an average access time, the time that is required before one node in the network can successfully transmit data to another node in the network. For Ethernet this depends primarily on whether or not a data collision has occurred. For the FDDI network it depends on how long the node has to wait for the token. For the tone method it depends on whether or not another field node is presently responding. No matter which network is implemented the access time is dependent on the number of nodes connected to the network.

3.3 Data Reliability (Redundancy)

There are several ways to maximize the chances that data sent from one node arrives intact at another node in a network.

One method involves sending data over different routes from the transmitter to the receiver. These routes can be used at the same time, and the receiver can decide which data to accept. The data can also be sent over one path until that path is no longer available, at which time it is sent over another path. Polled ITS networks require this second type of redundancy.

Data reliability can also be increased by adding some error detection/error correction information to the data packet being sent. FDDI adds a form of error detection in the frame check sequence field; the tone method adds no error detection at all. The usefulness of error detection/ error correction in a fiber network is questionable because fiber optic data links are usually designed to have bit error rates of less than 1×10^{-12}. Error detection in a fiber network is useful if a fiber break occurs during the transmission of a data packet. The data being transmitted in the polled ITS networks already contains a cyclical redundancy check (CRC) code which is evaluated by the master and the remote units regardless of the transmission method used for communication [15]. Therefore, having the communications network which also incorporates error detection/ error correction is unnecessary, since the devices connected to the network already perform this function.

3.4 The Network Cost

The cost of the network depends on many factors, most of which will be identical using either FDDI or the tone method. The cost differential between the two methods will depend primarily on the cost of the fiber modems themselves. Qualitatively, the system that uses a modem with more latency will cost more; this modem must analyze the data and decide how to handle it, which adds computational complexity. The FDDI modem is much more complex than the tone method modem.

3.5 Parameters Most Critical to the ITS Application

3.5.1 The Ring Poll Time

The important criteria used for comparing the FDDI approach and the tone method is called the poll time. This is the time required for the master to communicate with each remote, and it is critical in center-to-field communications in ITS applications.

"In planning a center-to-field communications network using NTCIP that involves continuous polling of field devices (e.g., a traffic signal system or transit fleet AVL system), it is important to consider the relationship between the following key variables:

- Transmission rate (bit rate)
- Transmission method (e.g., full or half duplex, sequential or overlapping)
- Transmission delay (including any modem / radio set-up / turn-around time)
- Response delay in the field device (time from receipt of request to sending response)
- Time between devices or between polling cycles (if needed)
- Length of message(s) to be sent (dynamic composite object definitions)
- Frequency of each type of message (per second, per minute, per day)
- Number of devices sharing the same line or channel
- Frequency of communication (e.g., polling period)

The first seven of these variables will determine the total time needed to communicate once with each device. If this time is then treated as fixed (say *T*), the

number of devices sharing the same line or channel (say N) and the frequency of communication with each device (say P for polling period, the inverse of frequency) are related by the equation: [16]"

$$P = N * T \qquad \textit{Eq: 3-3}$$

The two redundant ring implementations will be compared, both when there is no cable break and when there is a cable break, to determine which method gives the shortest polling time.

In comparing FDDI to the tone method the following assumptions will be made:

1. The transmission rate for both systems are equal.
2. The response delay of the field devices are zero. This parameter is beyond the control of the modem, and in the best case it will be zero.
3. The length of the message is zero. Since the same message will be sent using either implementation, and the message time is added to the overall transmission time, it can be eliminated from the calculations.

The factors most affecting the differences in polling time are the transmission delay and the transmission method.

3.5.2 Geographical Limitations of the Ring

In polled traffic applications both the number of modems in a particular ring and the distance between modems is highly variable. The more modems that can be connected in one ring the better. Similarly, the greater the distance that can be covered in one ring the better.

Chapter 4. Design of the Redundant Ring

This chapter will describe in detail how the three implementations of the redundant ring function.

4.1 The Token Ring (FDDI)

4.1.3 Overview of the Token Ring

Token rings were originally developed to avoid the situation of data collisions. Essentially, a special code is passed from one node to the next giving the node that has received this special code (token) permission to transmit data. The node removes the token from the data path, inserts its address and the address of the node where it would like to send its data, followed by the data it wants to send.

This data packet is re-transmitted around the ring and each node along the line checks to see if it is the receiving node or the transmitting node. If it is the receiving node, it copies the packet to the node to which it is connected, adds an acknowledgement that it has received the data and re-transmits the data to the next node. When the data packet has made its way back to the transmitting node, this node removes the packet from the ring and passes the token to the next node in line. [17]. One of the primary differences between the token ring (IEEE 802.5) and FDDI is that FDDI passes the token to the next node immediately following the transmission of its packet as opposed to waiting for the packet to make it way around ring before releasing the token. This can make poll time of FDDI much quicker, if the remote node has a response ready as soon as it is queried. This transmission scheme has some latency associated with it because each node must read enough of the data to

determine if it was the sender of the data before it re-transmits the data to the next node downstream [18].

For the token ring to work in a fault tolerant mode, it must know whether it is physically connected to its neighbor [19], and the sender must examine the acknowledgement bit added by the receiver before it removes the packet from the ring [20]. If a node is not connected to its neighbor, it re-transmits the token it just received back in the direction from which it came, and the packet travels around the ring in the opposite direction (See *Figure 4-1*). The cable break may occur in such a location that the packet must travel through the master node again before it reaches the receiver node; thus the master must examine the acknowledgment bit before removing the packet from the ring and passing the token to the next node.

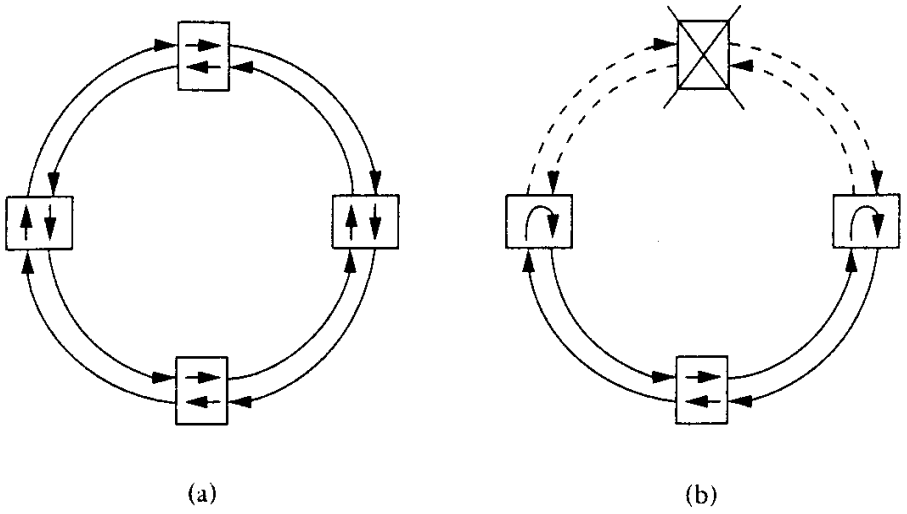

Figure 4-1 Token Ring Data Flow

If a node does not receive a token within some maximally specified time, it generates a token claim algorithm whereby a special frame is generated and passed around the ring. If this special frame makes its way back to the originating node, that node now has the token [21]. This makes the token ring useful even if more than one

cable break occurs in the ring because each of the subsections can still pass data between the connected nodes.

4.1.4 Timing Efficiency of the Token Ring

The minimum latency introduced by each node in the token ring is defined in terms of number of bits. For FDDI the latency introduced by each node is the length of the token bits (24) plus an additional 0 to 6 bits. These additional bits, called an elasticity buffer, are necessary to maintain constant ring latency. This buffer allows the FDDI nodes to use unsynchronized clocks [22]. For FDDI where the data rate is 100 Mb/s the average latency time is

$$L = 270 \text{ ns.}$$

The query-response cycle time of an intact token ring can be broken into four parts. First, the time to make the query given by:

$$QT = N(L + T) \qquad \textit{Eq: 4-1}$$

Where: QT = query time

N= total number of nodes in the ring

T= transmission time from one node to it neighbor (assume all nodes are equidistant).

Second, the time it takes to pass the token to the responding node is given by:

Eq: 4-2

$$TP1 = n * T + n * L$$

Where: *TP1*= time to pass token to responding node

n= the number of nodes plus 1 (transmission links) between the query and response node.

Note that for FDDI, which uses early token release, this time, *TP1,* reduces to zero.

Third, the time it takes to respond to the query given by:

$$RT = N(L + T) \qquad \textit{Eq: 4-3}$$

Fourth, the time it takes to pass the token back to the query node given by:

$$TP2 = (N - n)T + (N - n)L \qquad \textit{Eq: 4-4}$$

Again, note that for FDDI, *TP2* reduces to zero.

The total query-response cycle time is given by:

$$\begin{aligned} QRCT &= QT + TP1 + RT + TP2 \\ &= N(L + T) + n(L + T) + N(L + T) + (N - n)(L + T) \\ &= 3N(L + T) \end{aligned} \qquad \textit{Eq: 4-5}$$

In other words, the query must travel completely around the ring, the response must travel completely around the ring, and the token must travel completely around the ring. Note that the number of nodes between the query node and the response node has no effect on the query-response cycle time. Rather, this time depends on the total number of nodes in the ring. Using this information the poll time is given by:

$$PT = QRCT(N-1)$$
$$= 3N(L+T)(N-1) \qquad \textit{Eq: 4-6}$$

Where: N-1 is the number of remote nodes in the ring less the master node; 1 is the master node.

Notice that the poll time is proportional to the square of the number of nodes in the ring. As a numerical example consider the following:

N = 16 (16 nodes)

L $\approx$ 0 ($L << T$)

T = 5 μs (distance between nodes is 1 km) [23]

PT = 3(16)(5)(15) = 3.6 ms

To analyze the query-response time and the poll time of the token ring if a cable break occurs, some additional terms must be defined. Downstream nodes are defined as physically located so that tokens are received first on the primary data path; upstream nodes are defined as being physically located so that the tokens are first received on the secondary data path. In both cases the reference point is the master node. The terms are only defined if there is a break, otherwise all nodes receive the tokens only on their primary path (See *Figure 4-2*).

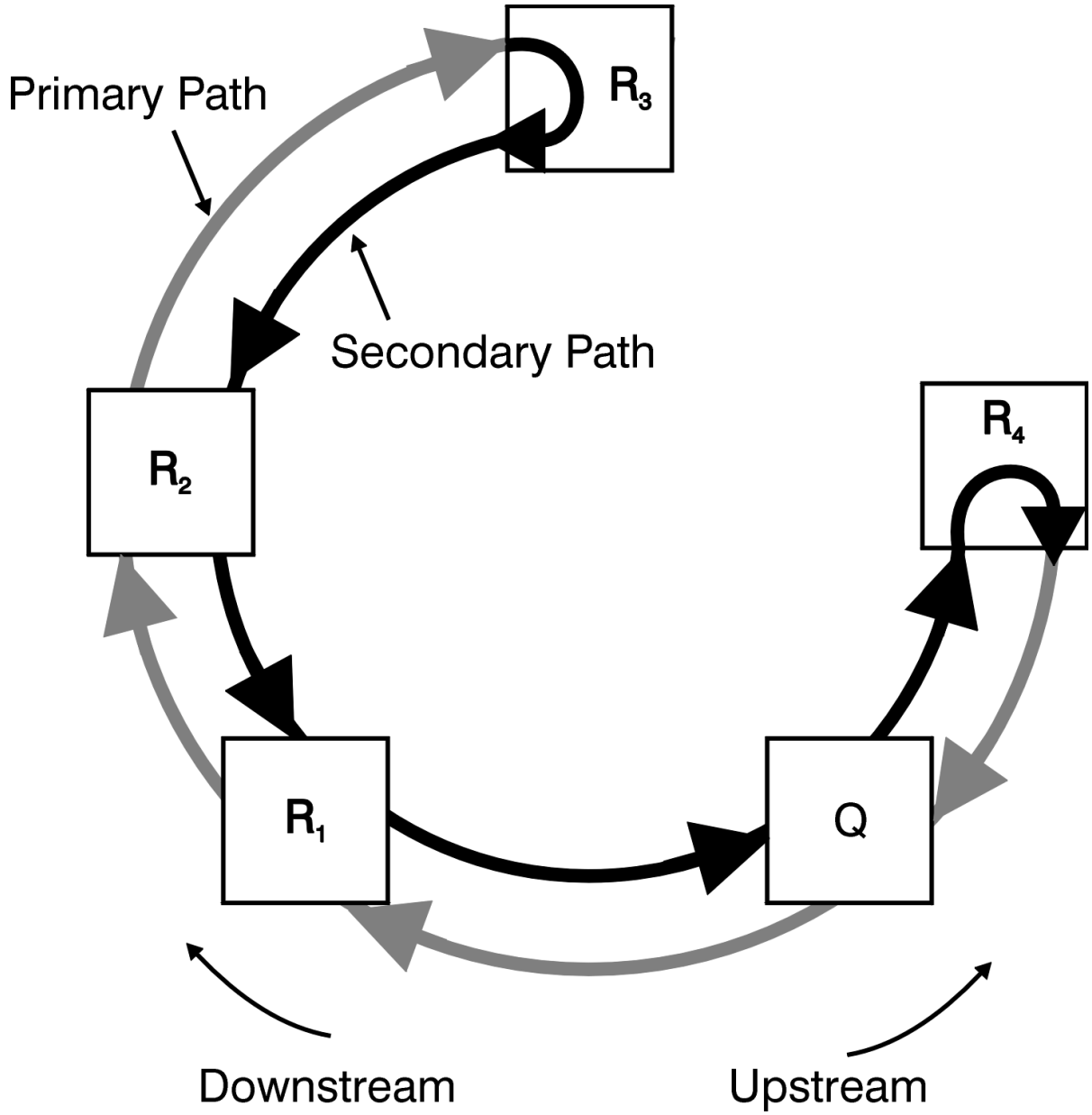

Figure 4-2 Token Ring Node Reference

If a cable break occurs the query response cycle time depends on where the break is in relation to the query node and the response node. The time required to pass the token from the query node to the response node, back to the query node is constant regardless of the break and is given by:

Eq: 4-7

$$TP1 + TP2 = 2(N-1)T + 2(N-1)L$$

The query time depends on whether the response node is upstream or downstream from the query node. If the response node is upstream from the query node then the query time is given by:

$$QT_u = 2(N-1)(T+L) \qquad \textit{Eq: 4-8}$$

If the response node is downstream from the query node then query time is given by:

$$QT_d = 2(N-1-b)(T+L) \qquad \textit{Eq: 4-9}$$

where: b= the number of nodes upstream from the query node to the cable break.

The response time also depends on the location of the response node with relation to the query node. If the response node is downstream from the query node the response time is given by:

$$RT_d = 2(N-1)(T+L) \qquad \textit{Eq: 4-10}$$

If the response node is upstream form the query node the response time is given by:

$$RT_u = 2(N-1-c)(T+L) \qquad \textit{Eq: 4-11}$$

Where: c= the number of nodes upstream from the response node to the cable break.

Therefore the query-response cycle time can be expressed separately for the upstream case by:

$$\begin{aligned} QRCT_u &= QT_u + TP1 + TP2 + RT_u \\ &= 2(N-1)(T+L) + 2(N-1)T + 2(N-1)L + 2(N-1-c)(T+L) \\ &= (6N-6-2c)(T+L) \end{aligned} \qquad \textit{Eq: 4-12}$$

and the downstream query-response cycle time:

$$\begin{aligned} QRCT_d &= QT_d + TP1 + TP2 + RT_d \\ &= 2(N-1-b)(T+L) + 2(N-1)T + 2(N-1)L + 2(N-1)(T+L) \\ &= (6N-6-b)(T+L) \end{aligned} \qquad \textit{Eq: 4-13}$$

The poll time is given by:

$$\begin{aligned} PT &= (N-1-b)QRCT_d + (b)QRCT_u \\ &= (N-1-b)(6N-6-b)(T+L) + \sum_{j=0}^{b}(6N-6-j)(T+L) \end{aligned} \qquad \textit{Eq: 4-14}$$

The worst case poll time occurs when a cable break occurs immediately upstream from the query node, b= 0. In this case the poll time is given by:

$$PT = (N-1)(6N-6)(T+L) \qquad \textit{Eq: 4-15}$$

Again the poll time increases as the square of the total number of nodes in the ring. As a numerical example consider the following:

N	= 16	(16 nodes)
L	≈ 0	($L << T$)
T	= 5 μs	(distance between nodes is 1 km)

PT =(15)(96-6)(5) = 6.75 ms

4.1.5 Geographical Limitations of FDDI

The FDDI standard is limited to a maximum of 2 km between any two nodes, a total of 500 nodes on any one ring, and a total transmission distance of 200 km (100 km if it needs to operate in the redundant mode) [24]. These limitations are due to the fact that each node in the ring needs to see a valid token at least once every 2.5 ms, or it assumes that there is a problem within the ring [25].

4.2 The Tone Method

The polled system in fiber optic ITS applications is implemented using a linear bus topology. In a linear bus, queries from the master node are transmitted downstream, away from the master on one fiber and responses are transmitted back to the master on another fiber. At each remote node the query from the master is presented to the remote field controller, and this query is simultaneously sent to the next node in the chain (called drop and repeat). The field controller determines if it is being addressed independently of the node to which it is connected. In other words all of the remote nodes see all of the queries from the master. If a node is required to respond it sends the response back to the master using the other fiber.

Nodes upstream, closer to the master node, retransmit this response upstream to the next node without echoing it to the field controller attached to that node until the message reaches the master. This means that the remote nodes are only presented with queries from the master and not responses from other nodes. Because the response data uses the other fiber, the remote nodes can respond at the same time that the master node is making a query, making this a full duplex communications

system. If the master transmits queries using both of its transmission ports and examines the responses it sees at both of its receiver ports, it can be placed anywhere along the linear bus, not just at one end (See *Figure 4-3*).

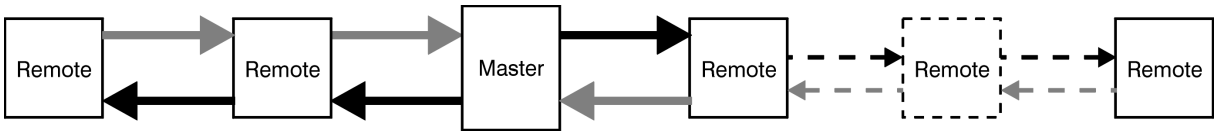

Figure 4-3 Linear Bus Topology with Master in the Middle

Essentially a linear bus can be considered a redundant ring with a cable break (see *Figure 4-4*). There are two problems that must be addressed if two remote nodes in the linear bus are connected together to form a ring. First the master must be able to distinguish queries that it has initiated from responses generated by the remote nodes, because both will be present at its receiver ports if the linear bus is connected as a ring. Second the remote nodes must have some way of knowing when they can respond to a query without creating a data collision since the master is transmitting on both rings. The problem is similar to the problem of loops created by LAN bridges. LAN bridges address the problem by using the spanning tree algorithm [26].

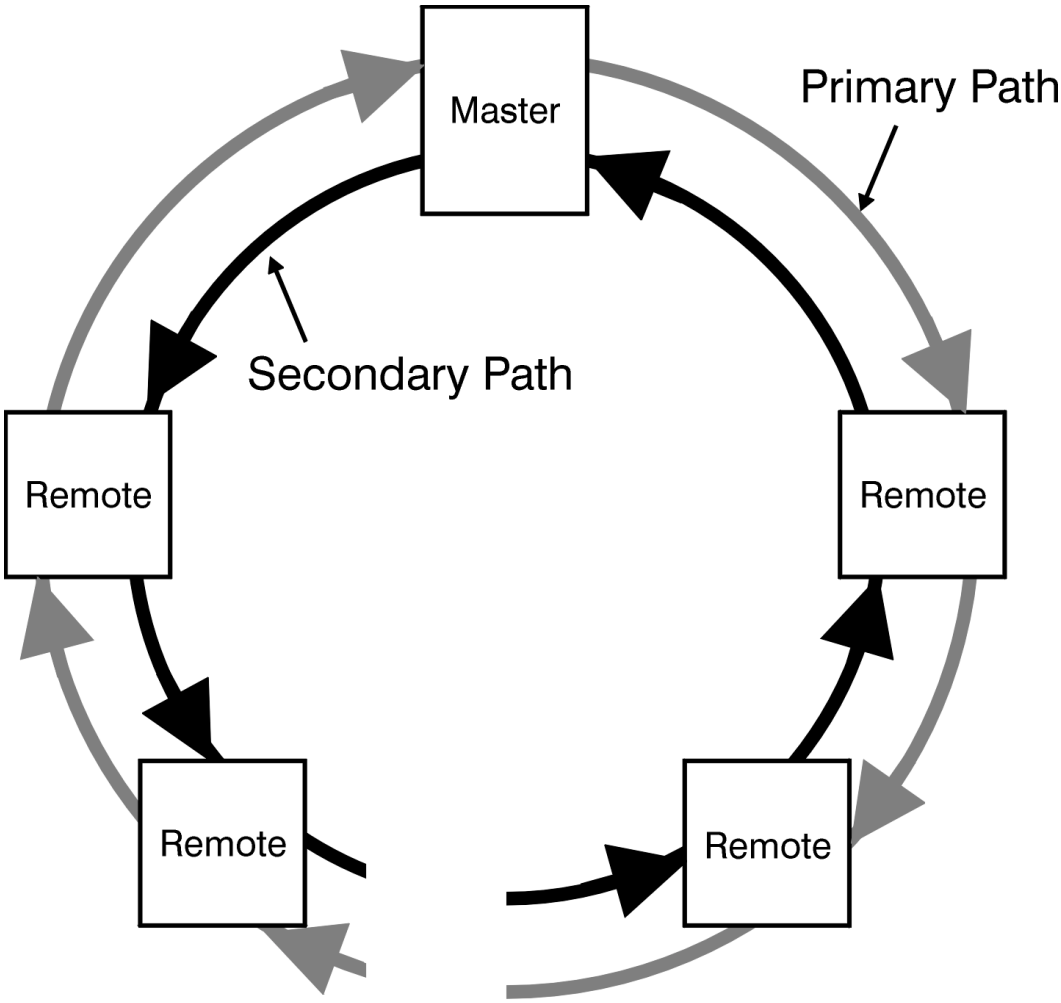

Figure 4-4 Ring Topology with Cable Break

Basically the spanning tree algorithm assigns one bridge as the root; all other bridges establish a single path to the root bridge, and that is the only path they use to transfer data (see *Figure 4-5* and *Figure 4-6*). This algorithm is designed to work in peer-to-peer networks so that the root bridge of the network can be any bridge in the network. In addition the algorithm sends out configuration messages so that it can be reconfigured when a cable break occurs, or a bridge fails [27].

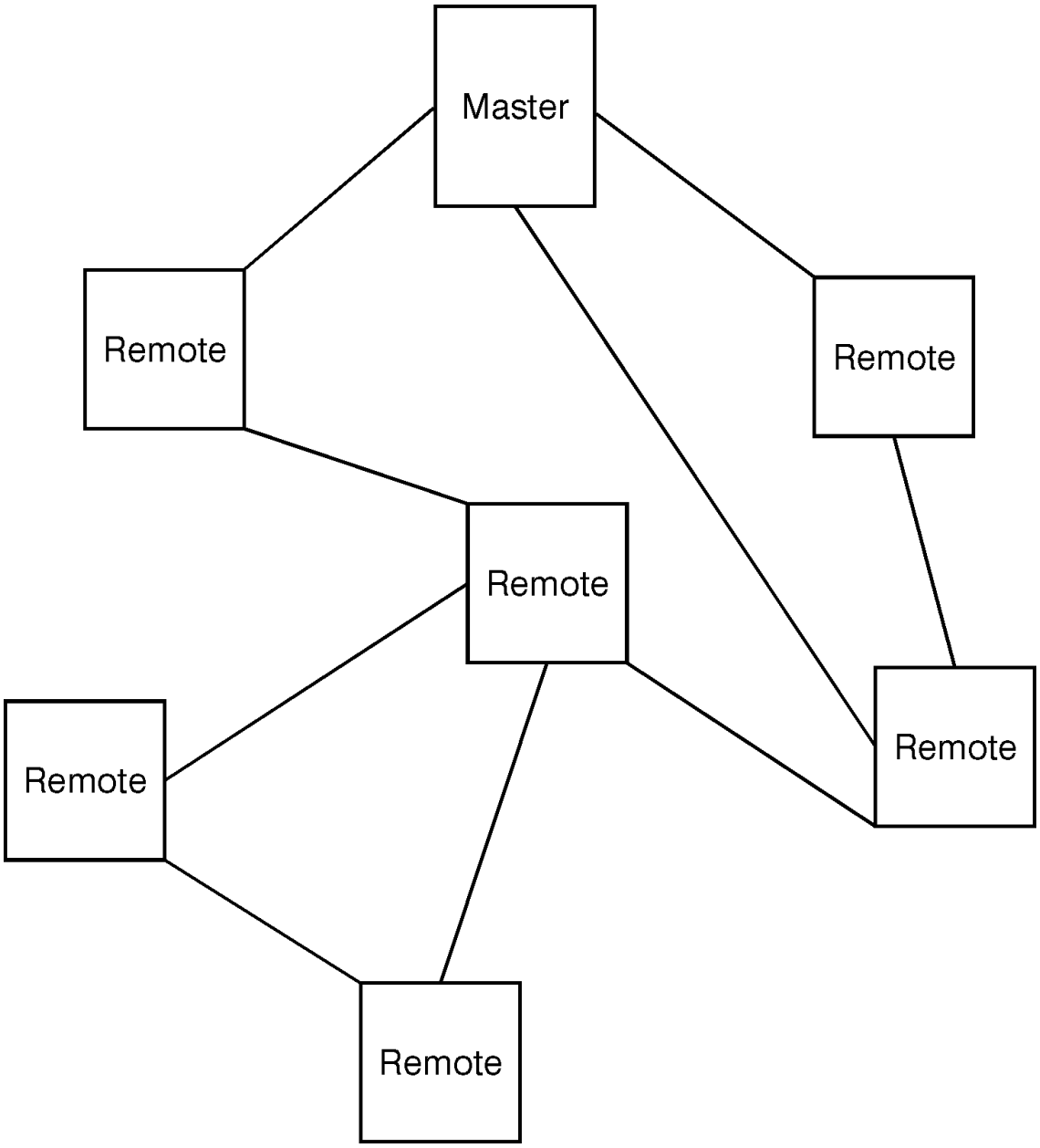

Figure 4-5 Network with Multiple Loops

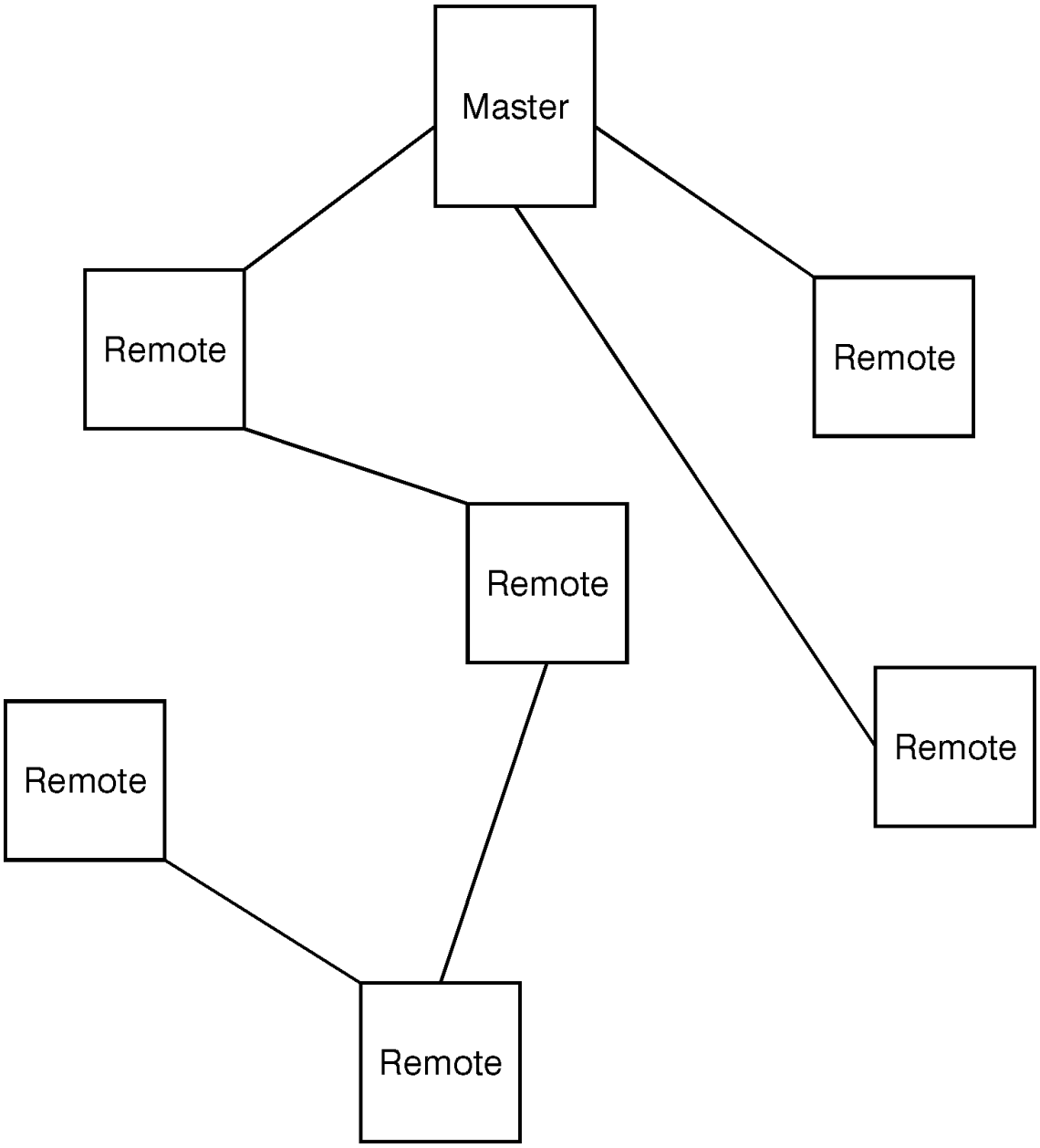

Figure 4-6 Spanning Tree Equivalent Network

In the polled ITS application the spanning tree algorithm is simplified because the root node will always be the master node. If only one path between the remote units and the master exists, the algorithm can be further simplified; this path does not need to be the shortest path. In other words, the ring problems mentioned above can be solved by merely adding one special signal, a tone, transmitted from one, and

only one, of the master ports (see *Figure 4-7*). This tone, if received by the closest remote node downstream, is simply retransmitted to the next remote node in ring. The process is repeated until the tone is received back at the master node.

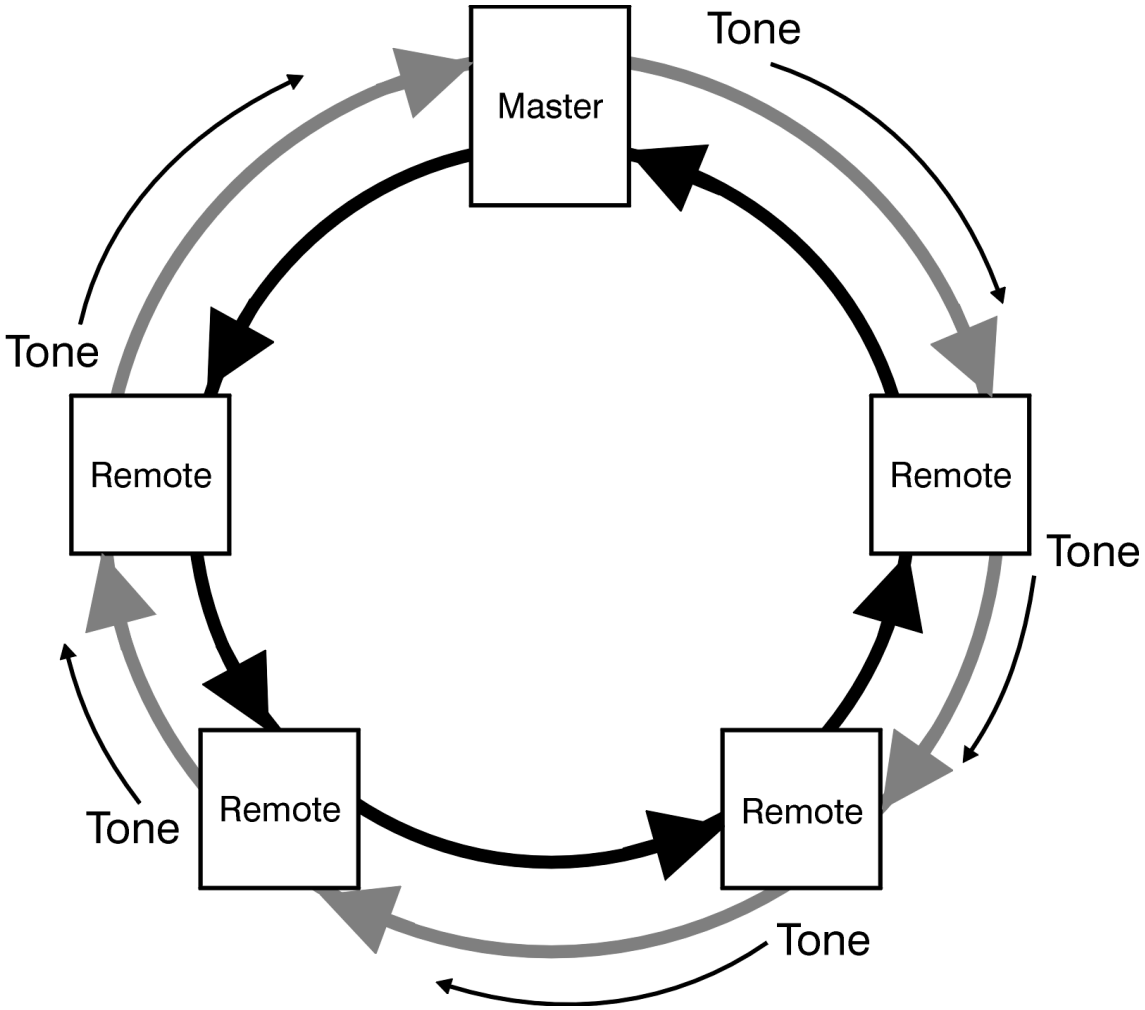

Figure 4-7 Transmission of Tone in the Tone Method

However, if there is a break in the cable, the node downstream from the break will not receive a tone; if it does not receive a tone, it will not transmit a tone to its downstream neighbor. The master node also knows that if it does not receive a tone, the ring has a cable break or one of the remote nodes in the ring has failed. If the master node receives the tone, it knows that the ring is intact. The master also knows

that if it receives a tone, it is receiving, on the (secondary) input, queries generated by the master node, and the master knows these queries can be ignored. If the ring is intact, there is no reason for the master node to transmit queries out of its secondary output, because all of the remote nodes can receive queries from their primary input.

The presence of the tone can also be used by the remote nodes to indicate which input port expects queries from the master node. If a tone is detected the remote nodes will expect queries on the primary port; if no tone is detected, the nodes will expect queries on the secondary port. Also the remote nodes can use the tone to decide which direction to return their response to the master. If they detect a tone, responses are sent back in the direction of the tone, (through their primary port) and if no tone is detected then the responses are sent back to the master using the secondary port. Since the master does not send queries through its secondary port if the ring is intact, the remote nodes do not have to wait for queries to pass on the secondary path before responding in that direction. Hence, the intact ring can still operate in full duplex mode. The remote nodes know that if no tone is detected on their primary port that there must be a cable break in the primary path somewhere between their position in the ring and the master node, and the queries from the master cannot be transmitted across that break. They can therefore respond in through their secondary port without waiting. Hence, even if there is a cable break, full duplex operation can work.

If the master detects a tone on its secondary input, it knows that the ring is intact and that all the responses from the remote nodes are being sent in the other direction; therefore, it can ignore all of the data that it receives at its secondary port. Conversely, if the master does not receive a tone at its secondary port, it knows that there is a break in the cable and that it must send its queries through both ports; it also knows that data received from either port must be responses from the remote nodes.

The tone method is “self-healing.” After a cable repair is made, the ring reverts to its original configuration. In the event of a break, the node downstream from the break does not receive the tone, but the upstream node continues to send the tone. Therefore, when the break is repaired, the node downstream from the former break once again sees a tone, and it once again retransmits this tone to subsequent nodes.

The tone that tells the ring how to route the data is completely independent of the data that is being routed. This implies that the tone signal can be generated many ways. It can be a different wavelength of light, or an analog signal modulated at a frequency higher than the highest data rate, or it can be a special data sequence which is sent between queries from the master mode. How it is sent will have an impact on the speed at which the nodes can reconfigure themselves in the event of a cable break. The only critical aspects of the tone signal are that it originates at the master node and is retransmitted by any remote node that detects it. The tone signal does not have to carry any additional information other than its presence or absence.

Physically the network is connected as a ring, but logically, if the tone method is used, the network is still connected as a linear bus that is simply reconfigured if a cable break occurs.

4.2.1 Timing Efficiency of the Tone Method

Timing efficiency of the tone method can be evaluated in a similar manner as the token ring. First, since data is not removed by any node in the ring, the data is not examine by any of the nodes reducing the latency through each node to zero.

The query-response cycle time of an intact tone method ring can be broken into two parts. First, the time to make the query is given by:

Eq: 4-16

$$QT = (n+1)T$$

Where: QT= query time

n= number of nodes between the master node and the node being queried

T= transmission time from one node to its neighbor (assume all nodes are equidistant)

Second, the time it takes to respond to the query is given by:

$$RT = (n+1)(T) \qquad \textit{Eq: 4-17}$$

The poll time is given by:

$$PT = 2\sum_{n=0}^{N-2}(n+1)T \qquad \textit{Eq: 4-18}$$

Notice that the poll time is directly related to the number of nodes in the ring. As a numerical example consider the following:

N = 16 (16 nodes)

T = 5 μs (distance between nodes is 1 km)

$$PT = 2\sum_{n=0}^{14}(n+1)5 = 10\sum_{1}^{15}1 = 1.20 \text{ ms}$$

To determine the query-response cycle time if there is a cable break, the ring must be broken into two sections: the section upstream from the break and the section downstream from the break. The query-response cycle time for the upstream section is given by:

Eq: 4-19

$$QRCT_u = 2(n+1)T \qquad n < b$$

Where: b the number of nodes between the master and the break.

The query-response cycle time for the downstream section is given by:

$$QRCT_d = 2(n+1)T \qquad n < N-b-1 \qquad \textit{Eq: 4-20}$$

The poll time is therefore given by:

$$PT = 2\sum_{n=0}^{b-1}(n+1)T + 2\sum_{n=0}^{N-b-1}(n+1)T \qquad \textit{Eq: 4-21}$$

In the worst case, the break occurs between the master and the last node completing the ring, in which $b = N-1$ and the poll time reduces to:

$$PT = 2\sum_{n=0}^{N-2}(n+1)T \qquad \textit{Eq: 4-22}$$

This is the same poll time as for the intact ring. In other words, the worst case poll time occurs when the ring is intact.

4.2.2 The Improved Polling Time of the Tone Method

The poll time can be cut almost in half if the master node knows the timing relationship between all the remote nodes. This can be done because the network is full duplex. Essentially if the queries and the responses are of the same length, then the following timing sequence can be established: the master sends a query to node one; as node one is responding, the master can send a query to node two. While node two is responding, the master can send a query to the next node in line (see *Figure*

4-8). This process is repeated until the node furthest from the master is queried. The master must then wait until it has received the completed response from this last node before beginning the cycle again. The poll time using this method is given by:

$$PT = \sum_{n=0}^{N-2}(n+1)T + (N-1)T \qquad \textit{Eq: 4-23}$$

where the summation term is the time it takes to query all of the remote nodes, and the last term is the time it takes for the furthest node's response to reach the master node. This is the time that the master must wait before restarting the polling process. Using the previous numerical example yields the following:

N = 16 (16 nodes)

T = 5 µs (distance between nodes is 1 km)

$$PT = \sum_{n=0}^{14}(n+1)5 + 15(5) = 5\sum_{1}^{15}1 + 75 = 675\ \mu s$$

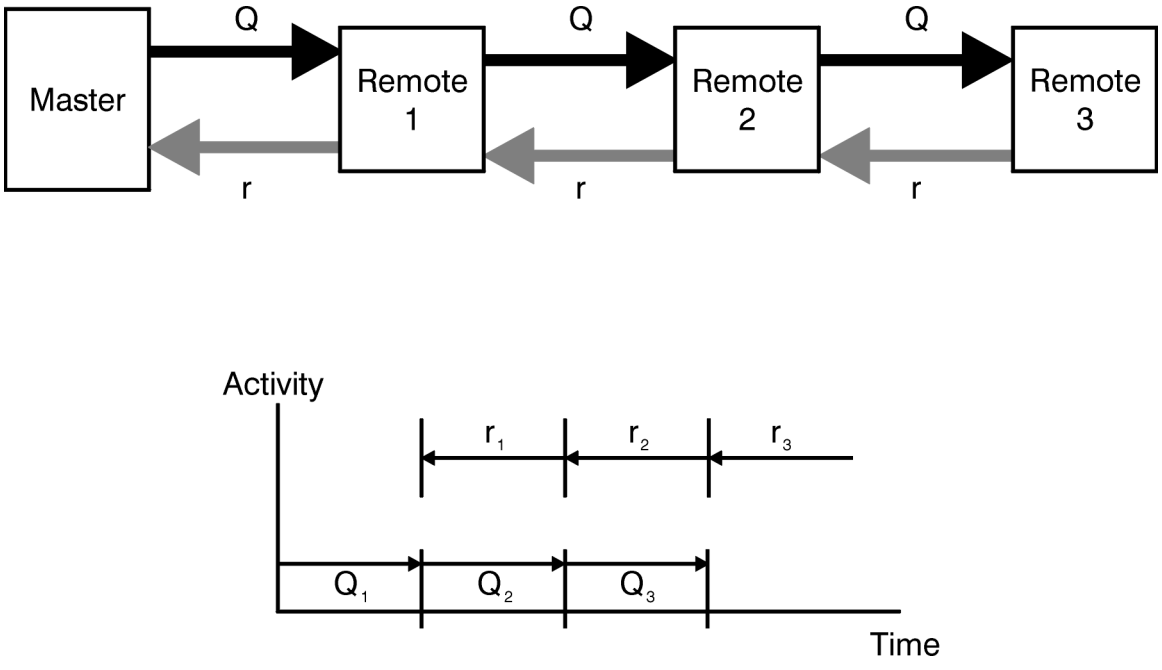

Figure 4-8 Query-Response Timing Relationship

For this method to work properly, the master node must know the query-response cycle time for each remote node. These times can be established in a training mode where the master polls each remote node individually and times the arrival of the response. These query-response cycle times must be recalculated anytime there is a change in the ring, i.e. when a node is added or deleted, or there is a break in the cable. This is primarily a software exercise and goes beyond the scope of this thesis.

4.2.3 Other Considerations For Implementing the Tone Method

Most digital fiber optic communications receivers are specified to work over some range of average optical input power. While within this range, virtually error free transmission occurs; a bit error rate (BER) of less than 10^{-12} is common. To ensure that the rest of the network can operate under the assumption that the data it receives is valid, many manufacturers incorporate a circuit that shuts off the receiver output if the average received power level falls outside the range where reliable transmission is guaranteed. Usually manufacturers guarantee that their receivers will work with minimal loss by setting the output power of the fiber optic transmitters to a maximum level. The receivers incorporate a loss of signal circuit (LOS) which shuts off the output of the receiver if the average optical power falls below a specified level. If this LOS circuit is not incorporated, the output of the receiver will have a tendency to chatter when it receives no optical input. This is because the internal amplifier stages in the receiver have such high gain that they will amplify the thermal noise associated with the photo-detector, which will generate random output states.

The tone method modems incorporate LOS circuitry for three important reasons. First, LOS circuitry prevents the modems on either side of a fiber break from

re-transmitting chatter back to the master node. Since this chatter is not in response to a poll from the master, it will cause data collisions. Second, LOS circuitry ensures that if a partial cable break occurs, the ring will act as if a complete cable break has occurred. The term “partial cable break” refers to cable breaks where only one direction of transmission is broken between two nodes. This can occur if two separate fibers are used to establish a bi-directional path between the nodes, or if one transmitter fails. In the event of this type of failure, the modem not receiving any optical signal turns off its transmitter, thereby completing the “cable break.” Finally, the modems provide an output indicating the status of the LOS circuitry to the remote nodes. This output can be used by these remote nodes to indicate to the master node where a cable break has occurred, thereby giving the user an indication of where to send the repair crew.

For the tone method to work practically, the remote modems must be able to disable the nodes connected to the modems in the event that these nodes malfunction. This prevents the malfunctioning node from disrupting the rest of the ring. In this case malfunctioning is defined as a node that transmits data in an endless stream. The tone method modems must provide a way of disabling their input if the node attached to the modem transmits data for more than some maximum time. The circuit designed to handle this contingency is called the anti-streaming circuit.

4.2.4 Geographical Limitations of the Tone Method

If a synchronous transmission scheme is used with the tone method, i.e. if the data is re-clocked at each node, there is no theoretical limitation on the number of nodes that can be connected to the system or the total size of the system. This is because its operation is dependent only on its ability to pass the tone and data to its

nearest neighbor, where it is regenerated. The maximum distance between neighbor nodes is a function of how well the optical transmitters and receivers are designed. The proposed specification, cited in Appendix A, lists a maximum distance between nodes as an optical power difference of 20 dB. This specification calls for the use of single-mode optical fiber at 1310 nm. Using this information it is possible to determine that the maximum distance between nodes, based on optical attenuation is 40 km [28]. Since the maximum frequency signal being transmitted is the tone (455 kHz), fiber dispersion is not an issue, even with the use of Fabry-Perot lasers [29].

The proposed specification in Appendix A calls for the data to be transmitted asynchronously, which will limit the number of nodes that can be connected in a ring because of the accumulation of edge jitter. In an asynchronous communications system, data transitions do not occur at the same time at the output of the receiver as occur at the input of the transmitter. This is due to the addition of noise in the system. Noise creates uncertainty in the receiver's decision circuitry so that the data transitions may happen earlier or later than intended. The result is called edge jitter. As the data is re-transmitted from one node to the next, the jitter adds the square root of the sum of the squares for systems with white noise [30]. This will limit the total number of nodes that can be connected in a ring. Most Universal Asynchronous Receiver Transmitters, UARTs, used in serial communication devices, sample the incoming data signal many times over a single bit period so that the data signal must only be correct for approximately 60% of the bit time. Using this information and the jitter specifications for the fiber nodes, it is possible to determine how many nodes can be interconnected for a given data rate. The formula is as follows:

$$U = ((.4)(1/R))^2 / J^2 \qquad \textit{Eq: 4-24}$$

Where: J = the jitter specified for the fiber node

R = is that data rate

U = the total number of units in the ring

For example:

$$U = ((.4)(1/9600))^2 / (.000002)^2 = 434 \text{ Units} \quad J \text{ is } 2\ \mu s.$$

Note that this number gets smaller as the data rate goes up if we use a data rate of 100 kbit/s:

$$U = ((.4)(1/100000))^2 / (.000002)^2 = 4 \text{ Units.}$$

Chapter 5. Results of Poll Time Comparisons

The poll times of the token ring and the tone method can be compared under various operating conditions. First they are compared when the ring is intact. Second they are compared when there is a break in the cable. In each case it is assumed that the node latency for each method is equal to zero. The final section shows how jitter caused by random noise affects the asynchronous communications link. Appendix B tabulates the numerical results from which the plots are generated. It should be noted that the distance (time) listed for the n, n-1 node in appendix B refers to the distance between the current node and the previous node; for n = 1 this distance is the distance between the first node in the ring and the last node in the ring.

5.1 Results of Poll Time, in the Case that the Ring Is Intact

The following plots show the effect on poll time with respect to the number of nodes in the ring for the case that the ring is intact (no cable breaks or node failures). The token ring is compared to the tone method and to the improved tone method. The plots differ in the distance between nodes. In the first two plots the nodes are equidistant (1 km, and 2km spacing between nodes). The plots are generated using equation 4-6 for the token ring, equation 4-18 for the tone method and equation 4-23 for the improved tone method. The third plot shows the results for a network whose nodes are randomly separated. In this case a random number is generated for each QRCT for the value of *T* (refer to equations 4-5, 4-18, and 4-23).

The fourth and fifth plots show extreme conditions where the distance from one node constitutes the major transmission time of the ring. In the fourth plot this extreme distance is placed between the master node and the first node to receive a poll from the master. In the fifth plot the extreme distance is located between the last

node to receive a poll from the master and the master; the path completing the ring. These plots are also generated by evaluating each QRCT on an individual basis.

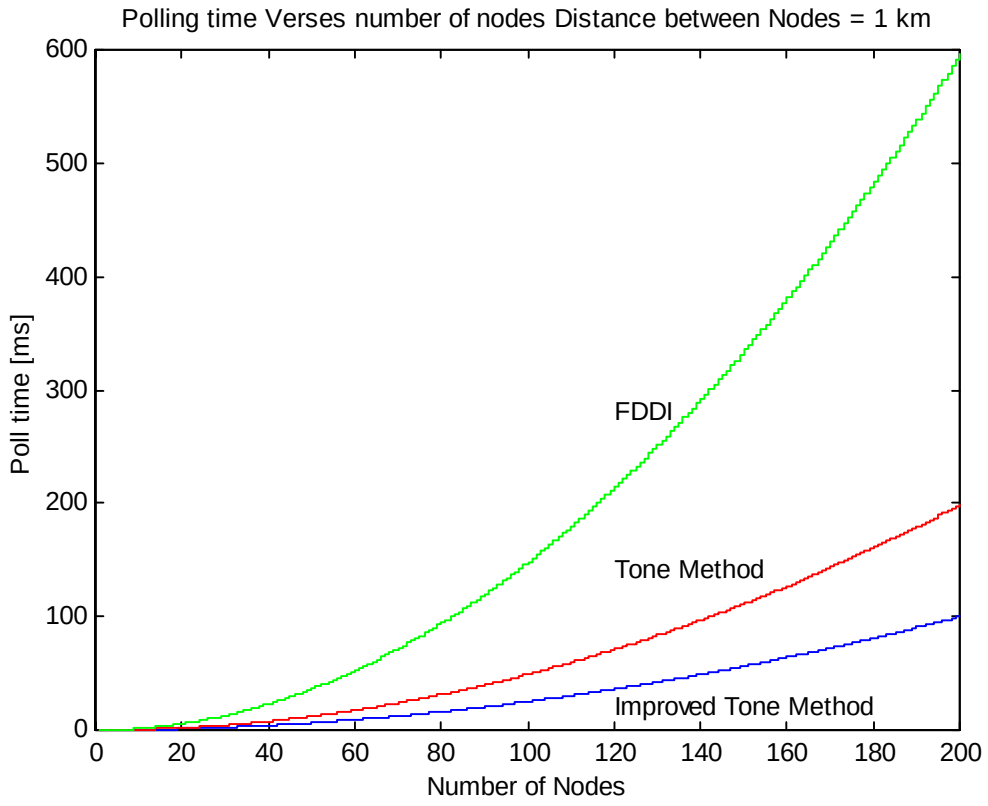

Figure 5-1 Polling Time Versus Number of Nodes; Distance = 1 km, with No Breaks in Ring

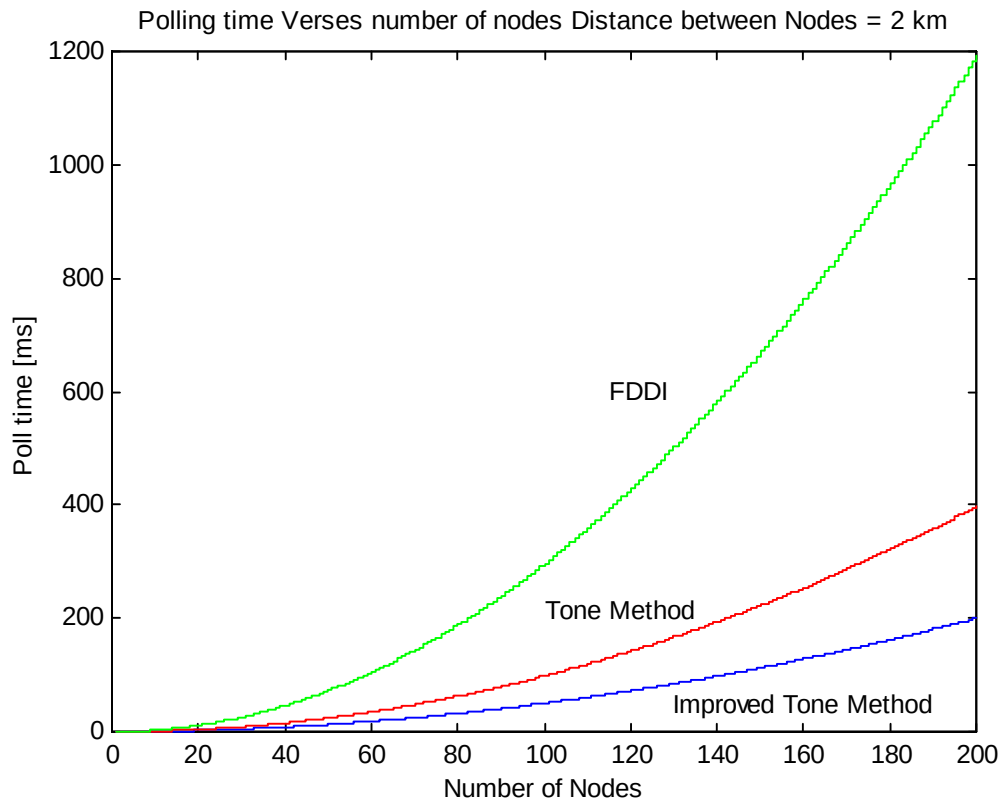

Figure 5-2 Polling Time Verses Number of Nodes; Distance = 2 km, with No Breaks in the Ring

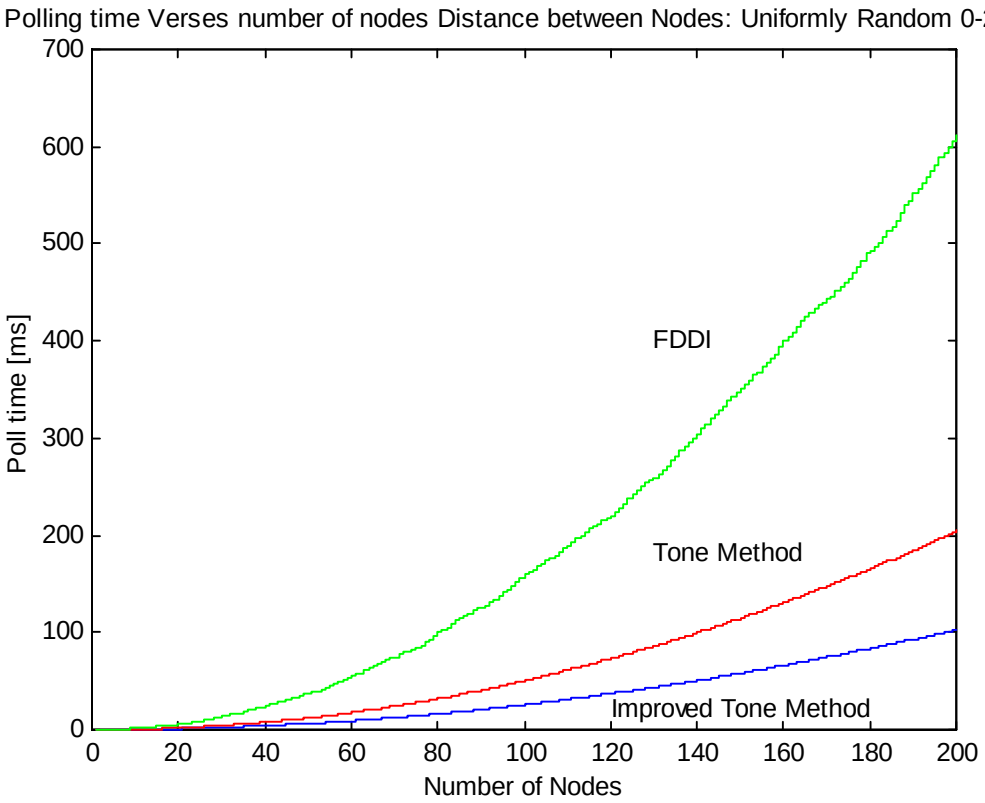

Figure 5-3 Polling Time Verses Number of Nodes; Distance: Uniformly Randomly Distributed between 0 and 2 km, with No Breaks in the Ring

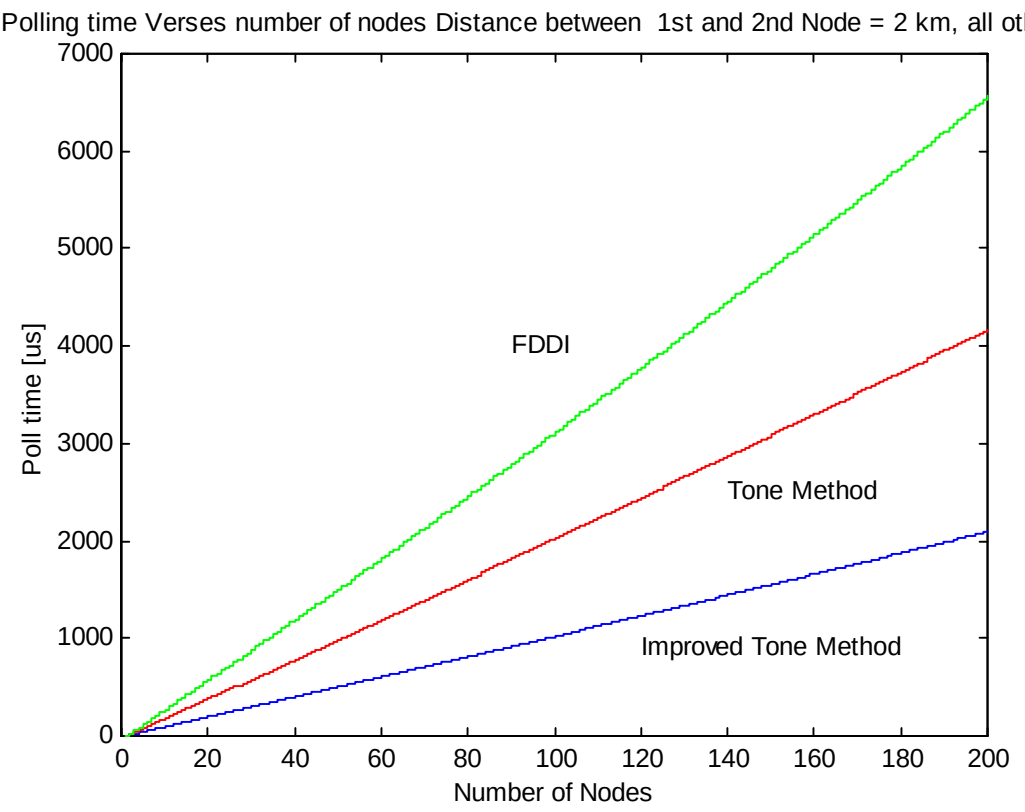

Figure 5-4 Polling Time Verses Number of Nodes; Distance Between Master and First Remote Queried 2 km; Distance between all Other Remote nodes 1 m, with No Breaks in the Ring

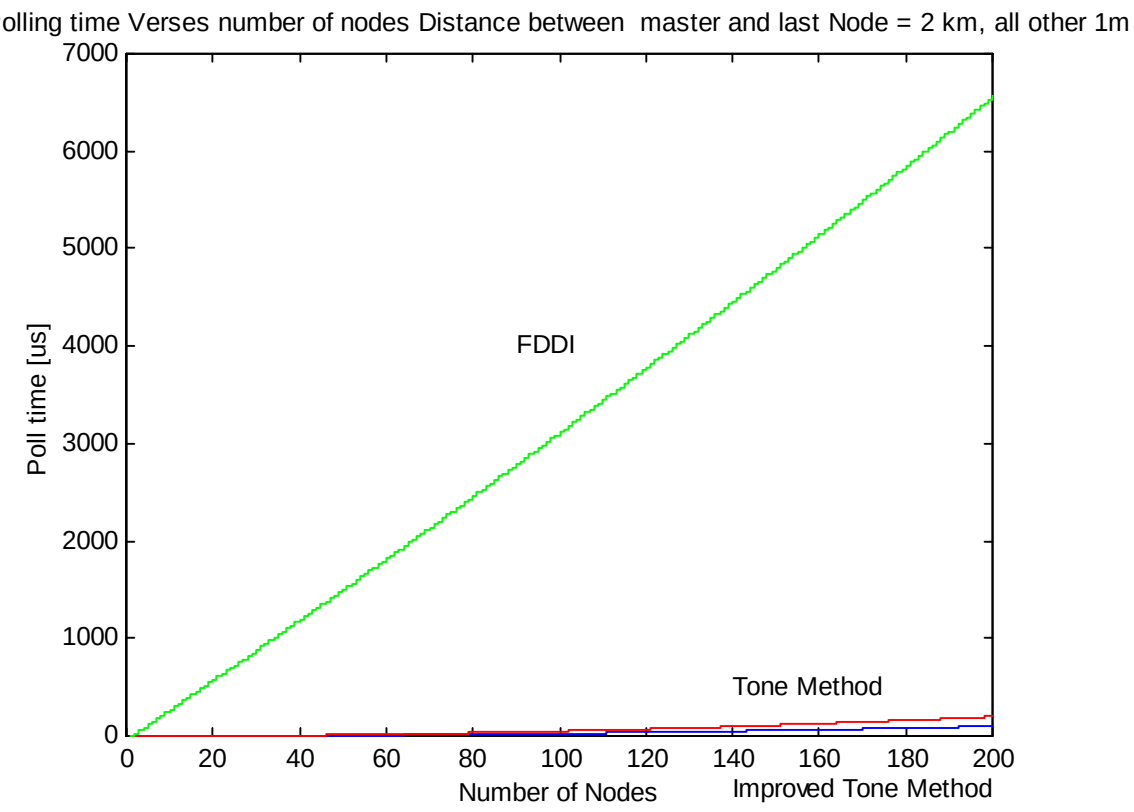

Figure 5-5 Polling Time Verses Number of Nodes; Distance Between Master and Last Remote Queried 2 km; Distance between all Other Remote nodes 1 m, with No Breaks in the Ring

Looking at the graphs reveals several things. First the tone method always has a shorter polling time than the token ring and the advantage of the tone method increases with the number of nodes in the ring. The improved tone method has a polling time, which is approximately twice as fast as the tone method, regardless of the number of nodes.

Figure 5-4 and Figure 5-5 show extreme examples of node spacing in the ring. For consistency node latency was set to zero even though $T < L$ for most of the nodes in the ring. Including node latency would increase the poll time for the token ring

and it would have no effect on the tome method, or on the improved tone method. Even though the node latency is set to zero the poll time for the tone method and for the improved tone method are still faster than for the token ring. For the token ring the poll the spacing of the nodes in the ring does not affect time because in this method the token is passed completely around the ring. The tone method on the other hand is greatly affected by node spacing. Figure 5-4 shows the poll time when each query and response passes through the long path in the ring because in this case the long path is between the master node and the first remote node. In Figure 5-5 the long path is between the master and the last remote node I the ring, the path not used by the tone method when the ring is operating normally, in this case the poll times are much shorter.

5.2 Results of Poll Time, in the Case that the Ring Has a Break

The following plots all show the effect on poll time with respect to the number of nodes in the ring when a cable break has occurred in the ring. FDDI is compared to the tone method, and to the improved tone method. The plots differ in the distance between nodes. In the first two plots the nodes are equidistant (1 km, and 2km spacing between nodes) and the third plot shows the results for a network whose nodes are randomly separated. The plots show the results assuming that the cable break has occurred in the worst case location. Chapter 4 describes the worst case location for a cable break to be immediately upstream from the master node. The plots are generated using equation 4-15 for the token ring, equation 4-22 for the tone method and equation 4-23 for the improved tone method. The third plot shows the results for a network whose nodes are randomly separated. In this case a random number is generated for each QRCT for the value of *T* (refer to equations 4-9, 4-10, 4018, and 4-23).

The fourth and fifth plots show extreme conditions where the distance from one node constitutes the major transmission time of the ring. In the fourth plot this extreme distance is placed between the master node and the first node to receive a poll from the master. In the fifth plot the extreme distance is located between the last node to receive a poll from the master and the master; the path completing the ring. This is also the path where the cable break occurs. Evaluating each QRCT on an individual basis also generates these plots.

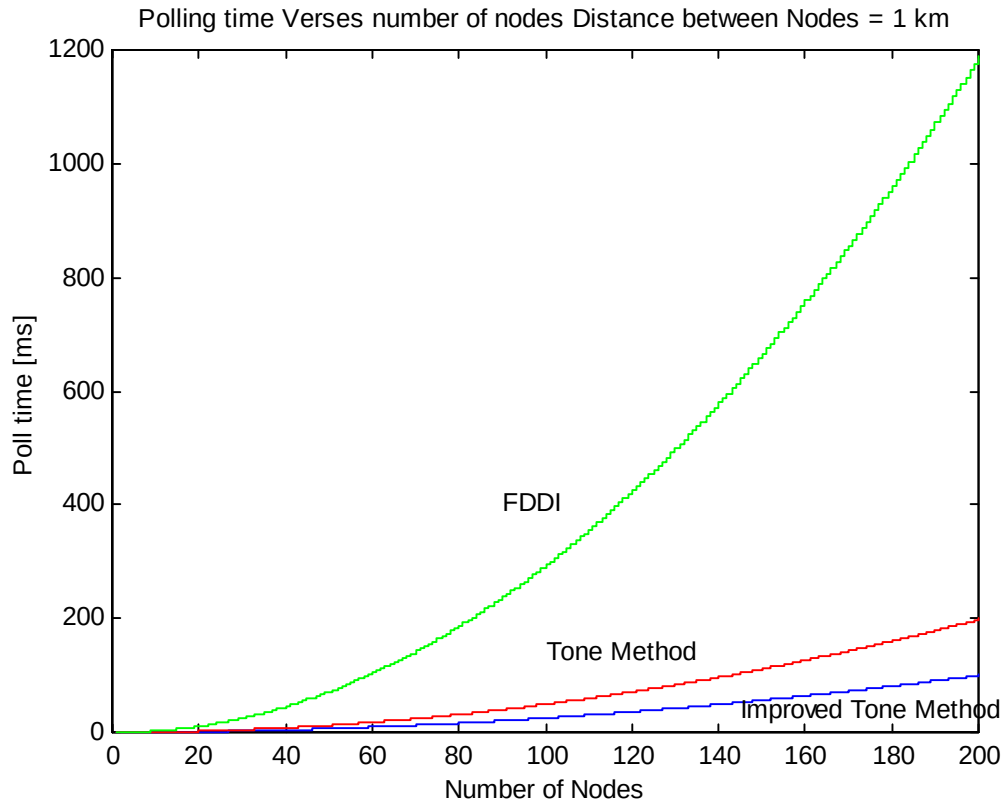

Figure 5-6 Polling Time Verses Number of Nodes; Distance: = 1 km, With a Cable Break in the Ring

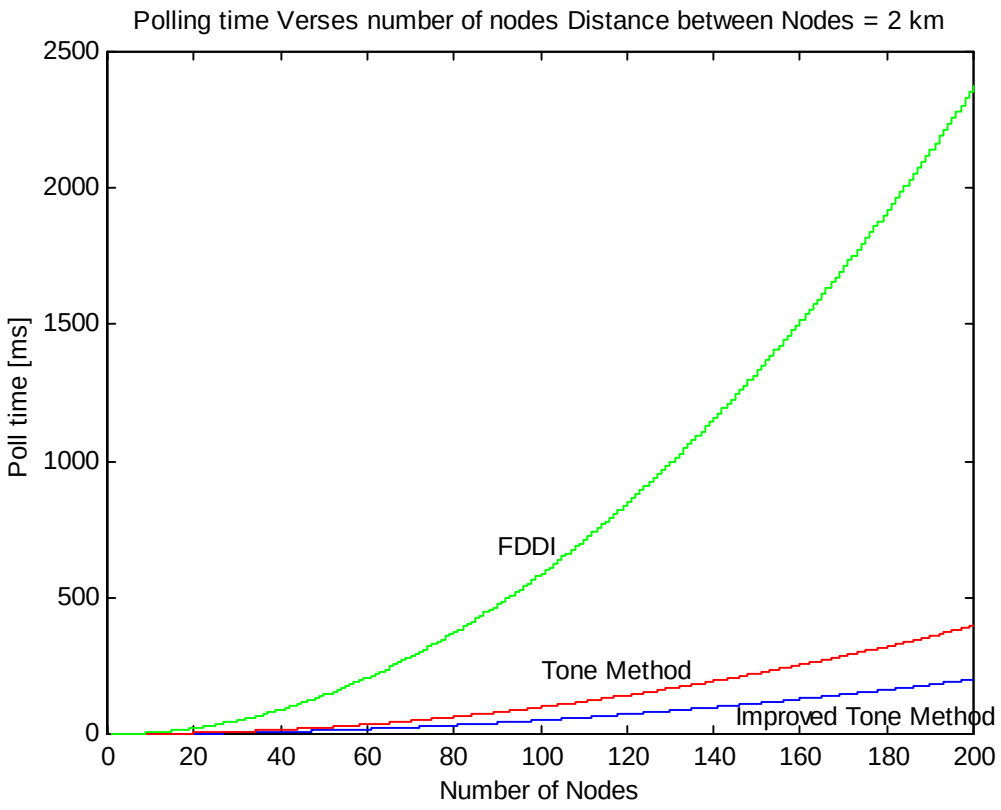

Figure 5-7 Polling Time Verses Number of Nodes; Distance: = 2 km, With a Cable Break in the Ring

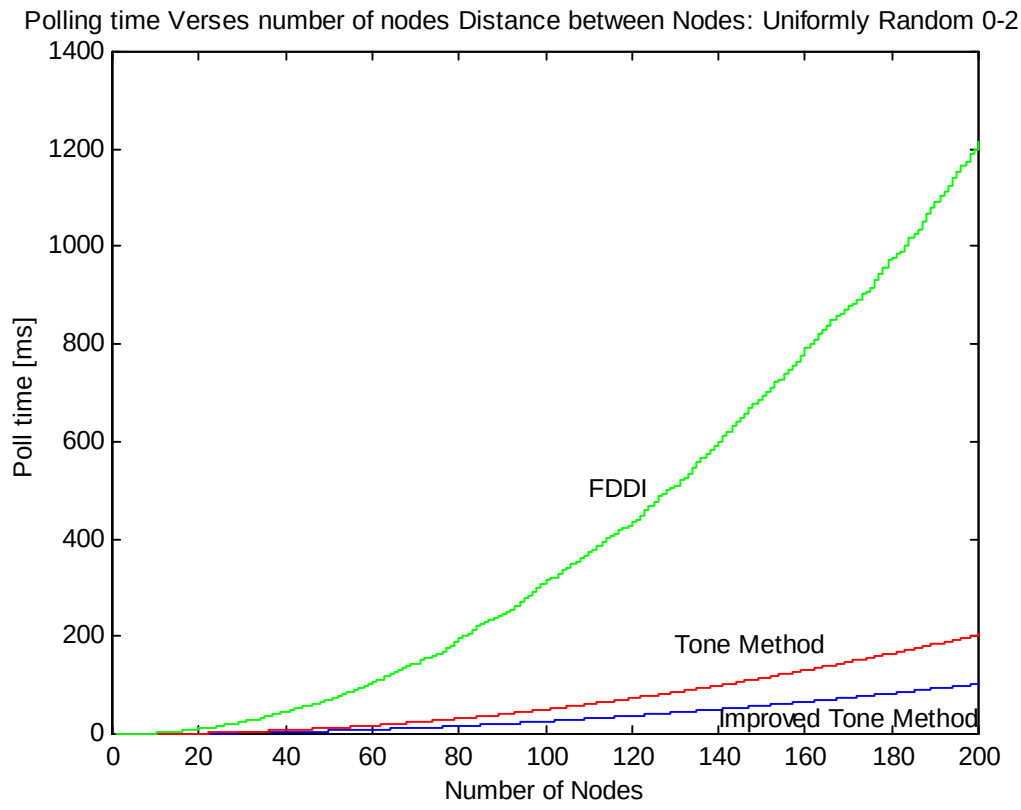

Figure 5-8 Polling Time Verses Number of Nodes; Distance: Uniformly Randomly Distributed between 0 and 2 km; with a Cable Break in the Ring

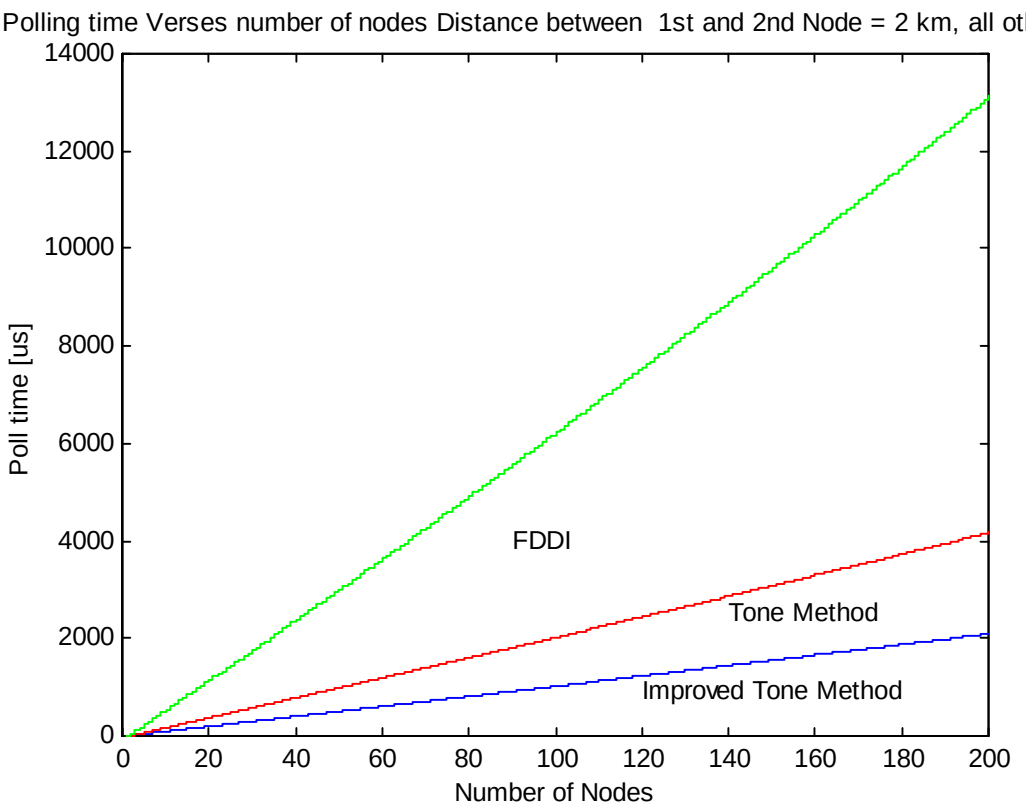

Figure 5-9 Polling Time Verses Number of Nodes; Distance Between Master and First Remote Queried 2 km; Distance between all Other Remote nodes 1 m, with a Break in the Ring

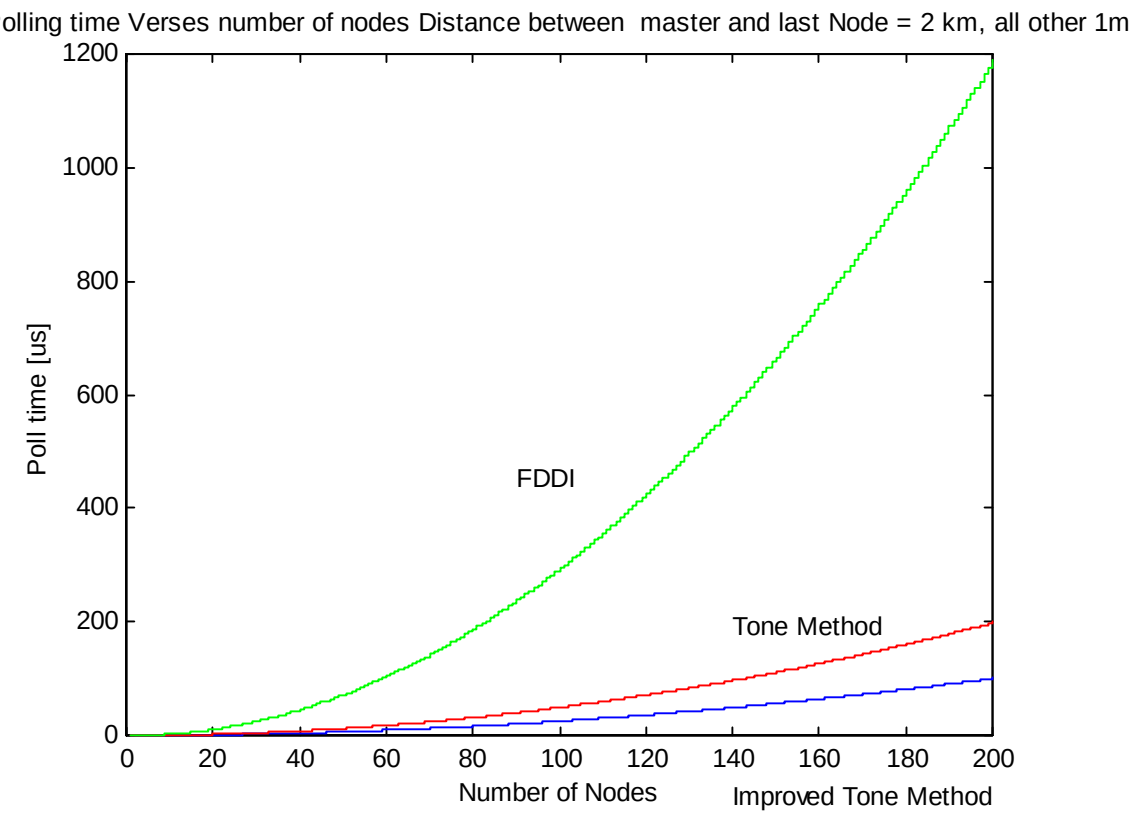

Figure 5-10 Polling Time Verses Number of Nodes; Distance Between Master and First Remote Queried 2 km; Distance between all Other Remote nodes 1 m, with a Cable Break in the Ring

In the event of a worst case cable break the tone method and the improved tone method still result in shorter polling times when compared to the token ring. In fact the polling time of the tone method and the improved tone method do not change for the worst case cable break when compared to no cable break in the ring, while FDDI increases the poll time by a factor of two. The only case where there is an improvement in polling time for FDDI is when the cable break occurs in the long path (see Figure 5-10 and Figure 5-5).

5.3 Plot of Edge Jitter Accumulation in an Asynchronous Network

The following plot shows the maximum number of nodes (modems) which can be interconnected for a given edge jitter specification and still maintain a bit period which is correct for 60 percent of the time. The edge jitter is given as a peak value for each modem. Evaluating equation 4-24 generates these plots.

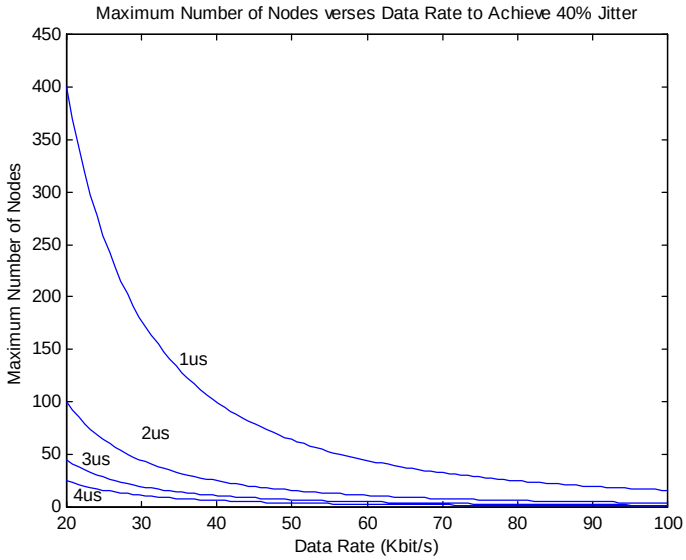

Figure 5-11 Maximum Number of Nodes that Can Be Connected in an Asynchronous Network for a Given Data Rate and Jitter Specification (in the 1 µs Range)

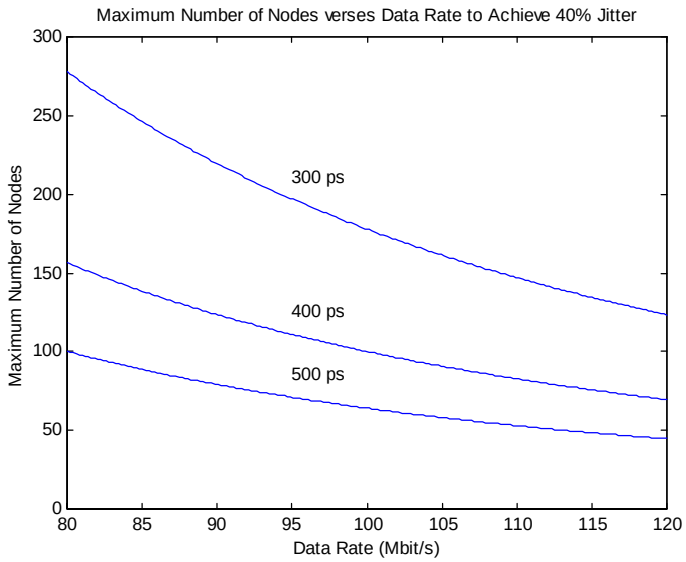

Figure 5-12 Maximum Number of Nodes that Can Be Connected in an Asynchronous Network for a Given Data Rate and Jitter Specification (in the 0.5 µs Range)

The plots shows that edge jitter greatly affects the number of nodes that can be connected in a network if asynchronous transmission is used. In fact, the asynchronous transmission method described in appendix A cannot achieve the FDDI data rate of 100 Mb/s. In order to achieve this rate the jitter specification would have to be on the order of 400 ps per node. Although this is achievable using fiber transceivers, it would make more sense to use a synchronous transmission scheme and insert the tone using time division multiplexing to build a modem that can operate at 100 Mb/s data rates.

Chapter 6. Conclusions

The results show that the poll time when using the tone method is always shorter than when the token ring is used. This is accomplished by optimizing the ring in two ways. First, the tone method does not allow each modem to act as a master modem since in this application the goal is to collect data to one center point. Second making full use of both fibers allows for full duplex transmission whether or not there is a break.

Because the tone method uses only information from its nearest neighbors to determine signal routing, this method allows any number of modems in a ring and allows for each modem to be spaced as far as the optical transmission link will allow. FDDI on the other hand has an upper limit on both the geographical area which can be covered and the number of modems in the ring because it requires an overall ring throughput in order to determine how and when its signals are routed.

The presence or absence of the tone tells the master if the ring is complete. This information is sufficient to allow the tone method to be used to create an Ethernet ring.

The tone method modems would have to be modified in the following manner in order to allow for the use of Ethernet. First, each remote modem would have to transmit data entered at that modem through both optical ports. These remote modems would have to re-transmit data seen at their inputs to their output, and also present this data to the unit connected to the modem. The remotes would function the same way whether or not a tone was present. The master modem would also have to function slightly differently. It would behave just like a remote modem in the absence of a tone. It would not re-transmit incoming signals in either direction in the presence of a token, essentially creating a break in the ring. This works even if the

master modem becomes inoperable since the remote modems do not use the tone to determine how to route their signals.

Chapter 7. Recommendations

7.1 Expanding the Tone Method to Non-Ring Networks

The purpose of ITS is to collect data from traffic conditions and to transmit commands to traffic signals. There is a benefit to having such an ITS network follow the actual network of roads. Road systems are usually not set up as rings, but rather as a more complex network. A polled data network that can follow the existing roadway infrastructure can more effectively gather data and control signals. If the network is set up in such a manner that there are more than two paths to the master modem, this non-ring network will be able to tolerate more than one cable break and still remain functional.

7.2 Features That the Tone Method Will Incorporate

The key features of the tone method when employed as a non-ring network include a single bi-directional path between each remote modem and the master modem. This path should be full duplex. The tone method must be able to reconfigure the network to find a path between the master modem and the remote modem in the event of a break. The tone method should be self-healing i.e. revert to its original configuration. The original configuration of the ring is logically a linear bus. Similarly the original configuration of any non-ring network will be a tree structure (see *Figure 4-5 and Figure 4-6*). In fact, the linear bus is actually a tree with only one branch. In the non-ring configuration the ends of the branches of the tree structure may be physically connected modems along other branches of the tree, the same idea as that of the spanning tree.

7.3 Modifications Required to the Existing Modems

When expanding the tone method from a ring topology to a non-ring topology it must be noted that not all modem variations need to be analyzed. In fact, the only important configuration is a modem having three ports that can be connected to other modems. Any number of these three-ported modems can be co-located and interconnected so that any number of paths could be connected to this location, called a super node. The relationship between the number of modems that are co-located and the number of paths connected to the super node is given by:

$$P = M + 2 \qquad \textit{Eq: 7-1}$$

Where: P = the number paths connected to the super node

M = the number of modems in the super node

The non-ring network will consist of one three-ported master modem and many three-ported remote modems, whose data and tone generation will be governed by the following rules. For ease of discussion the ports on the modems will be referred to as port #1, port #2 and port #3. These ports have unique characteristics and are not necessarily interchangeable. For the tone method to work, rules governing how the modems can interconnect must be established. In addition, rules governing how the data and tone are routed must be determined for both the master modem and the remote modems.

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[16] *The NTCIP Guide National Transportation Communications for ITS Protocol; NTCIP v02.05,* p. 23.

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[21] Peterson, p. 133.

[22] Halsall, p. 295.

[23] Goff, David, R. *Fiber Optic Reference Guide, 2nd Ed.,* Focal Press, 1999, p. 20.

[24] Peterson, p. 130.

[25] Peterson, p. 133.

[26] Peterson, pp. 211-212.

[27] Peterson, pp. 211-215.

[28] Goff, p. 33.

[29] Goff, pp. 120-123.

[30] Goff, pp. 149-150.

Appendix A

Self-Healing, Fault Tolerant Redundant Ring Specification

A.1 GENERAL:

This specification describes the minimum requirements for furnishing a stand-alone self-healing, fault tolerant fiber optic ring transceiver.

The fiber optic transceiver will be used in a polling communications configuration, which will consist of a master unit and several remote units. Each fiber optic transceiver will be field configurable (switch selectable) to be either a master or a remote unit. Data transmitted from the master will be converted to an electrical signal at each remote unit, and it will also be re-transmitted to the next remote unit. Data transmitted from each remote unit will be re-transmitted back to the master. If the remote unit is not directly connected to the master, data received by an intermediate remote unit will be re-transmitted to the master.

When the fiber optic transceivers are connected in a ring configuration (two paths to the master) this communications system will be able to adapt to a single point of failure and still transmit and receive data from each of the remote units. This adaptation will not rely on the polling frequency, data rate, or analysis of the data being transmitted. A single of point failure is defined to be a break in the fiber path, or a loss of power to one of the remote units.

The fiber transceiver shall include five bi-directional interfaces, which will be switch configurable.

A.2 MATERIALS:

The following specifications apply to the fiber transceiver:

A.2.1 Electronic Industries Association (EIA).

Specification Number	Title or Subject	Applicability
RS-232C	Serial Data Transmission, Physical, Functional and Electrical Specifications	fiber transceiver shall accommodate interface through dip-switch selection
RS-422	Serial Data Transmission with Balanced, Dual State Driver Interface	fiber transceiver shall accommodate interface through dip-switch selection
RS-485	Serial Data Transmission Utilizing Tri-State Drivers Supporting Multi-point Communications	fiber transceiver shall accommodate interface through dip-switch selection

Table A-1 Electronic Industries Association Specifications

A.2.2 Institute of Electrical and Electronic Engineers.

Specification Number	Title or Subject	Applicability
C2-1994	National Electrical Safety Code	compliance as applicable to electronic communications devices
	National Electrical Safety Code Interpretations, 1991-1993	as applicable to electronic communications devices
C62.36-1991	Test Methods for Surge Protectors Used in Low Voltage Data, Communications and Signaling Circuits	general guideline
C62.41-1991	Recommended Practice on Surge Voltage Protection in Low Voltage AC Circuits	general guideline
295-1969	Standard for Electronics Power Transformers	as applicable to power converter
1100-1992	Recommended Practice for Powering and Grounding Sensitive Electronics Equipment	general guideline

Table A-2 Institute of Electrical and Electronic Engineers Specifications

A.2.3 Federal Communications Commission (FCC).

Standard	Title or Subject	Applicability
FCC Rules and Regulations for Class A Electronic Equipment; Vol. II, Part 18	Radio Frequency Interference and Electromagnetic Compatibility	as applicable to equipment class
FCC/OST MP-4	FCC Methods of Measuring Radio Noise Emissions from Computing Devices	general guideline

Table A-3 Federal Communications Commission Specifications

A.2.4 Other Specifications.

Organization	Standard	Title or Subject	Applicability
International Standards Organization (ISO)	ISO-9000	Quality Assurance	ISO-9000 or Bellcore TR-NWT-000874 or MIL-Q-9858 applies. Intent is for product to be produced under a formal Quality Assurance Program
Bellcore	TR-NWT-000874	Reliability and Quality, General Requirements	ISO-9000 or MIL-Q-9858 or this specification applies
MIL-SPEC	MIL-Q-9858	Quality And Reliability, General Requirements	ISO-9000 or MIL-Q-9858 or this specification applies
Bellcore	TR-NWT-001089	Electromagnetic Compatibility (EMC) and Electrical Safety; Generic Criteria for Telecommunications Equipment	as applicable to EMC and safety of fiber transceiver
Caltrans	TEES March 1997	Specifications for the Mode 2070 Controller Unit	as applicable to physical and electrical interface
MIL-SPEC	MIL-I-46058C	Insulating Compound, Electrical (For Coating Printed Circuit Assemblies)	as applicable for manufacturing
MIL-SPEC	MIL-HDBK-217 Rev. F	Reliability Calculations for Electronic Equipment	used for Mean Time Between Failures (MTBF) calculations

Table A-4 Other Referenced Specifications

A.3 CONSTRUCTION METHODS:

A.3.1 General Requirements

The fiber transceiver, shall include interfaces for 8.3 ±0.5 micron single-mode fibers which support counter rotating optical ring communications utilizing the 1310 nanometer (nm) optical wavelength and which accommodate a flexible separation distance between interconnected controller devices. Two up-link single-mode fibers (one transmit and one receive) and two down-link fibers (one transmit and one receive), for a total of four fibers, shall be connected to the fiber transceiver utilizing FC/PC male connectors on the fibers and female connectors on the fiber transceiver fiber optic communications units.

A.3.2 Theory of Operation and Features:

The fiber transceiver shall incorporate the following features and perform the functions described below.

A.3.2.1 Definitions:

Throughout this document the following terms will be used:

Interface: A bi-directional communications port. The fiber transceiver has three such interfaces, which will be referenced as follows:

Interface Reference	Interface Description
DB-9	Serial Port located on the front of the fiber transceiver conforming to EIA-232 or EIA-422 (switch selectable)
O1	Optical Port located on the front of the fiber transceiver consisting of one optical transmitter and one optical receiver.
O2	Optical Port located on the front of the fiber transceiver consisting of one optical transmitter and one optical receiver.

Table A-5 Interface Reference

Input: A signal that terminates into the fiber transceiver.

Output: A signal that originates from the fiber transceiver.

Normal Operation: No fiber break, and no loss of electrical power at any of the remote nodes.

Polling Path: The optical path connecting the O2 output to the O1 input.

Response Path: The optical path connecting the O1 output to the O2 input.

"1": A positive EIA-232 Voltage or D+ < D- if referring to EIA-422.

"0": A negative EIA-232 voltage or D+ > D- if referring to EIA-422.

High Optical Output: Maximum optical output occurs when a "1" is being transmitted.

Low Optical Output: Minimum optical output occurs when a "0" is being transmitted.

A.3.2.1 Master/ Remote Selection Switch :

The fiber transceiver consists of five bi-directional communications interfaces. These interfaces are interconnected depending on the mode of operation selected and the state of the communications ring.

The fiber transceiver will operate in one of two modes; the master mode and the remote mode. Each fiber transceiver will be capable of operating in either mode, and mode selection will be switch selectable. In the master mode, the fiber transceiver routes electrical signals from its DB-9 connector to one or both of it optical ports. It receives data from one or both of its optical ports and routes these signals to the DB-9 connector. In the remote mode the fiber transceiver routes signals from one of its optical receivers to the DB-9 connector, it also re-transmits this signal through its other optical transmitter. It will re-transmit signals received at its other optical port without routing them to the DB-9 port. Signals injected from the DB-9 port will also be sent through this optical port.

A.3.2.2 Fault Tolerant Signal Routing:

Figure A-1 shows how the fiber transceiver interfaces are optically interconnected.

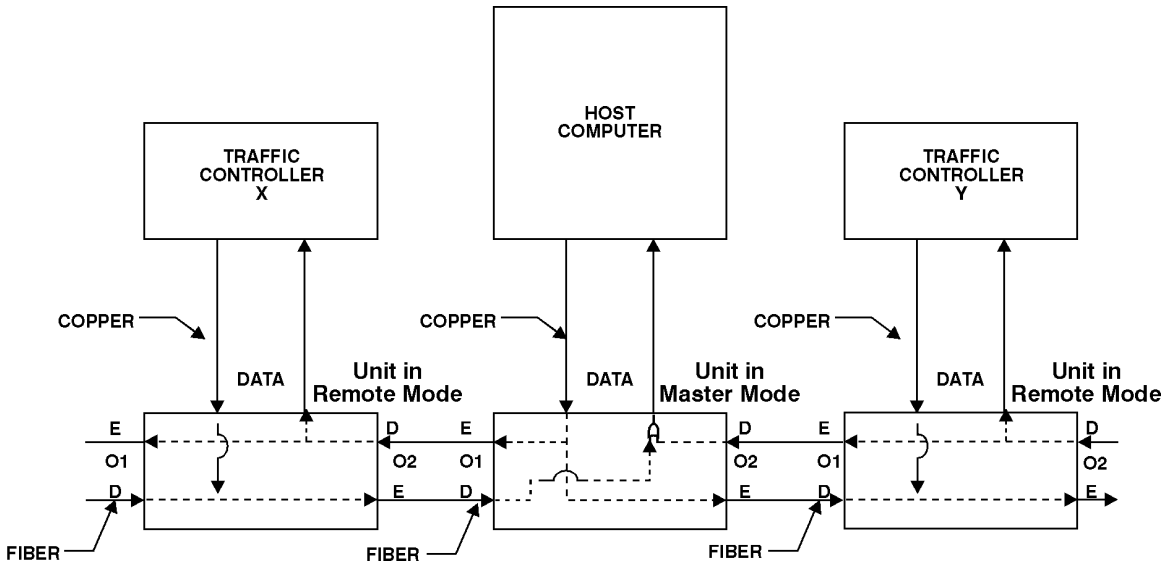

Figure A-1 Optical Interconnection of Fiber Transceiver

The fiber transceiver uses a light level indicator and a pilot tone to determine if there is a fault in the ring and how to route the signals. *Figure A-2* shows how the light level indicator and the pilot tone indicator determine how the signals are routed both in master mode and in remote mode.

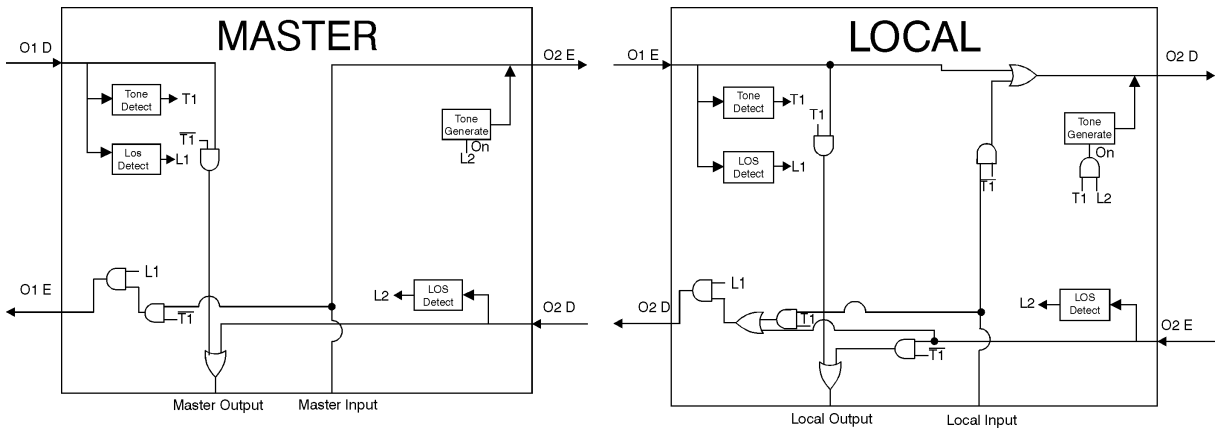

Figure A-2– Internal Signal Routing as a Function of the Pilot Tone and the Signal Presence Indicator

In normal operation, the master sends polls out of the O2 port and receives response through the O2 port; the remote units receive polls from the master through the O1 port and sends these to DB-9 and also re-transmit these polls via the O2 port. Responses are sent to the master through the O1 port. Responses from remotes further downstream are received at the O2 port and are re-transmitted out of the O1 port. Under normal operation all units detect the presence of light at both of their input ports, and all units detect a pilot tone at their O1 port. When the master detects a pilot tone at it O1 port this indicates that the fiber ring is intact and therefore data being received at the O1 port should be ignored (it will consist of the polling information, which the master has transmitted). If the fiber ring is intact, no polls will be sent out of the O1 port of the master. See *Figure A-3* for an example of signal routing when the fiber ring is intact.

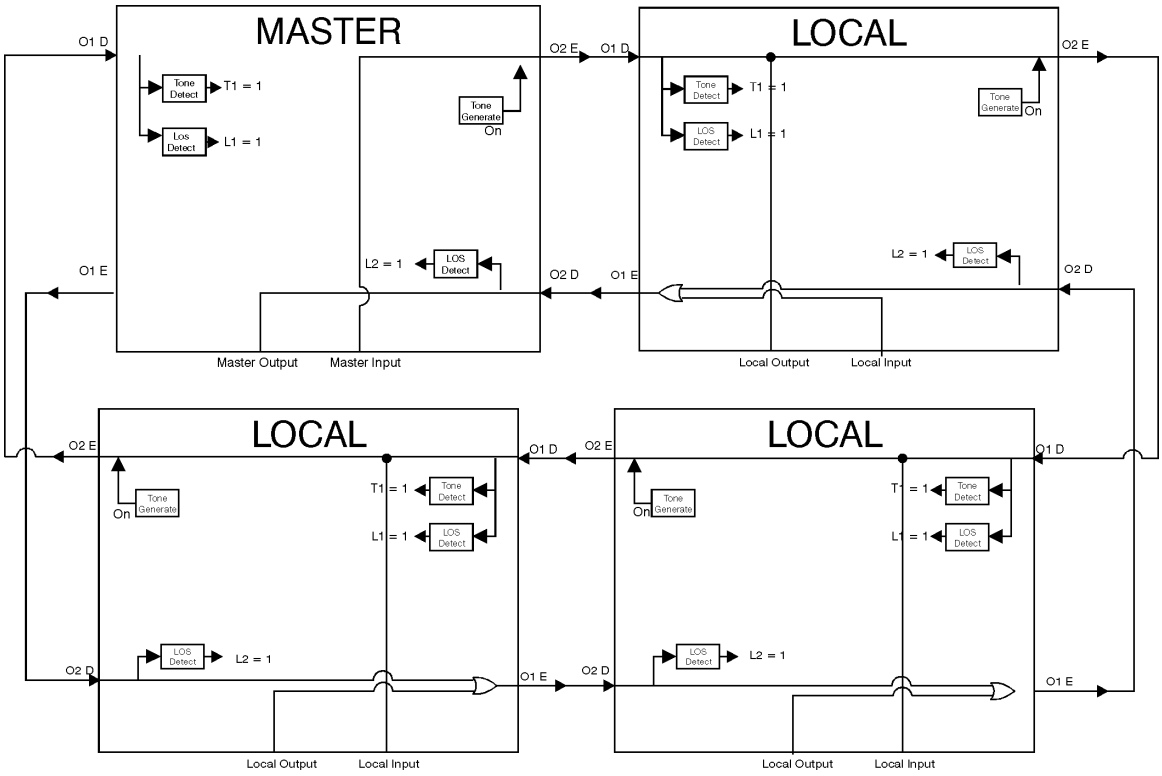

Figure A-3– Fiber Transceiver Signal Routing when Fiber Ring is Intact

Each optical port monitors its light level indicator, and the primary optical port also monitors its pilot tone presence detector. Signal routing is achieved in the following manner; if a break occurs in the polling path fiber, the remote unit downstream from the break will detect a loss of light and a loss of pilot tone. When this happens, the remote unit will disable the pilot tone generator, connected to its O2 output and re-direct its responses from the O1 output to the O2 output. It will also look for polls at its O2 input instead of its O1 input. The next remote down the line from the break will see light at it O1 input but no tone, therefore it too will disable the pilot tone generator connected to is O2 output and re-direct its signal path as described above. This will continue all the way back to the O1 input of the master. When the master detects no tone at its O1 input, the data being received at this input is assumed to be a valid response and the master starts to send polling information out of both its O1 and O2 ports. Note that when the fiber break is repaired, the system reverts to its original configuration. See *Figure A-1.*

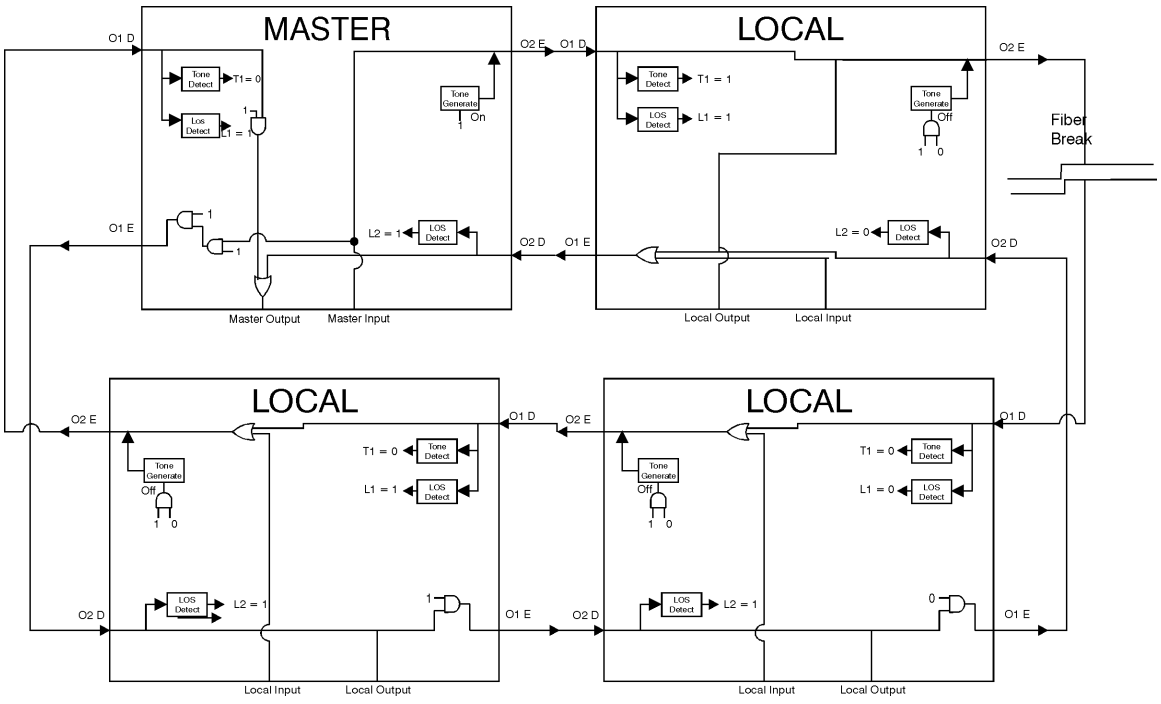

Figure A-4 – Fiber Transceiver Signal Routing in the Event of a Fiber Break

If a break occurs in the response path fiber, the next unit upstream towards the master will detect a loss of light, and it will disable the pilot tone generator connected to its O2 output, but it will not re-transmit signals received at its O1 input through its O2 output. Otherwise, it will behave normally. When the unit downstream detects no tone on its O1 input it will behave as described above.

A.3.2.3 Anti-Streaming Provision:

The fiber transceiver will incorporate an anti-streaming provision. This circuit will ensure that communications failures, which may occur in the field-microprocessor-controllers, do not disable the entire communications link. The anti-streaming circuitry will monitor the length of time that the input RTS (DB-9) is held high. If this time exceeds a user selected (switch selectable) maximum, input from the field-microprocessor-controller is disregarded until such time as the controller is manually brought back on line, and the anti-streaming circuitry is manually reset. The following table shows the interconnections to DB-9 as they relate to the anti-streaming circuitry when the fiber transceiver is master mode.

DB-9 Connection	No Anti-Streaming Fault	Anti-Streaming Fault
DB-9-TXD	O1-TX, O2-TX	NC
DB-9-RXD	O1-RX, O2-RX	O1-RX, O2-RX
DB-9-RTS	“1”	“1”
DB-9-CTS	“1”	“0”
DB-9-DCD	“1”	“0”

Table A-6 DB-9 Anti-Streaming Fault Response

The time allowed before an anti-streaming fault occurs shall be switch selectable and include a minimum time of 4 seconds and a maximum time of infinity (the anti-streaming feature is then disabled). A reset button will also be provided

which will allow the anti-streaming circuitry to be reset once the fault has been cleared.

A.3.2.4 Open Collector Fault Indicator

The fiber transceiver shall provide an open collector output that indicates a fault has occurred at the transceiver. A fault is defined as the loss of optical signal at either optical input, or anti-streaming fault. In normal operation the open collector shall be in high impedance, if a fault occurs the output shall provide a low impedance path to GND #1 capable of sinking 30 mA.

A.3.2.5 Front Panel Indicators:

The fiber transceiver shall have the following front panel indicating Light Emitting Diodes (LED):

LED Designator	Function Monitored	On Condition
Power	Indicates that the unit is powered	Unit is operational
Fault	Indicates that an anti-streaming fault has occurred	Anti-streaming fault has not been reset
O1 TX	Indicates that a “1” is being transmitted out of O1 emitter	“1” is being transmitted
O2 TX	Indicates that a “1” is being transmitted out of O2 emitter	“1” is being transmitted
O1 RX	Indicates that a “1” is being received at the O1 detector	“1” is being received
O2 RX	Indicates that a “1” is being received at the O1 detector	“1” is being received
O1 LOS	Indicates that no optical signal is present at the O1 detector	No optical signal is present
O2 LOS	Indicates that no optical signal is present at the O1 detector	No optical signal is present

Table A-7 Indicator LEDs

A.3.3 Interface Definition:

The following describes each of the bi-directional interfaces associated with the fiber transceiver.

A.3.3.1 DB-9 Connector:

Type: DB-9 (Female)

Max Data Rate: 100 kb/s

The two input configurations listed below are switch selectable. The table describes the interface between the DB-9 connector and SP2:

PIN NO.	EIA-232 (DTE)	EIA-232 (DCE)
1	DCD	RTS
2	RXD	TXD
3	TXD	RXD
4	NC	NC
5	GND	GND
6	NC	NC
7	RTS	CTS
8	CTS	RTS
9	NC	NC

Table A-8 DB-9 Pin Definitions

Note: In EIA-232 (DTE) mode the DCD is an input. In EIA-232 (DCE) mode DCD is an output which is connected to SP2-RTS.

A.3.3.2 Power/Fault Connector:

Type: .200" (Phoenix Style) (Male)

PIN NO.	FUNCTION
1	+VDC
2	GND #1
3	O.C. (fault)
4	GND #1 (fault)

Table A-9 Power Connector Pin Definitions

A.3.3.3 O1 and O2 Optical Interfaces:

The following sections describe the characteristics of the optical port of the fiber transceiver.

A.3.3.3.1 Optical Transmitter Specifications:

Emitter type:	laser	
Operating wavelength:	1310 ± 30 nm	
Connector Type:	FC/PC	
Spectral Width:	60 nm maximum FWHM	
Average Optical Power while transmitting a "1":	-5.75 ± .75 dBm	(See Notes 1 and 2)
Average Optical power while transmitting a "0":	-10.75 ± .75 dBm	(See Notes 1 and 2)
Peak-to-peak Optical power of Pilot Tone P_t:	-7 ± 1.2 dBm	(See Note 3)
Frequency of the Pilot Tone:	455 ± 7 kHz	
Optical Rise/Fall time of the Data Signal T_r:	2 ± 0.5 µs	(See Notes 4 and 5)
Optical Over/Undershoot of the Data Signal V_o/V_t:	6% maximum	(See Notes 4 and 6)

Note 1: Power level measured through three meters of 8 / 125 µm optical fiber.

Note 2: Repeatedly connecting and disconnecting the optical fiber from the fiber transceiver used to measure the power will not alter the measured power by more than 0.4 dB.

Note 3: Peak-to-peak tone level is independent of data power level. Measurement made using HP Lightwave Receiver Model #83411A and HP Oscilloscope Model # 54601A. See *Figure A-5.*

Note 4: *Figure A-6* shows the complete optical waveform used to make the optical rise time and overshoot measurements. Measurement made using HP Lightwave Receiver Model #83411A and HP Oscilloscope Model # 54601A.

Note 5: Optical rise time measured while pilot tone is off. Measurement made using HP Lightwave Receiver Model #83411A and HP Oscilloscope Model # 54601A. See *Figure A-7* this is the 10-90% rise time.

Note 6: Optical overshoot measured while pilot tone is off. Measurement made using HP Lightwave Receiver Model #83411A and HP Oscilloscope Model # 54601A. See *Figure A-8.*

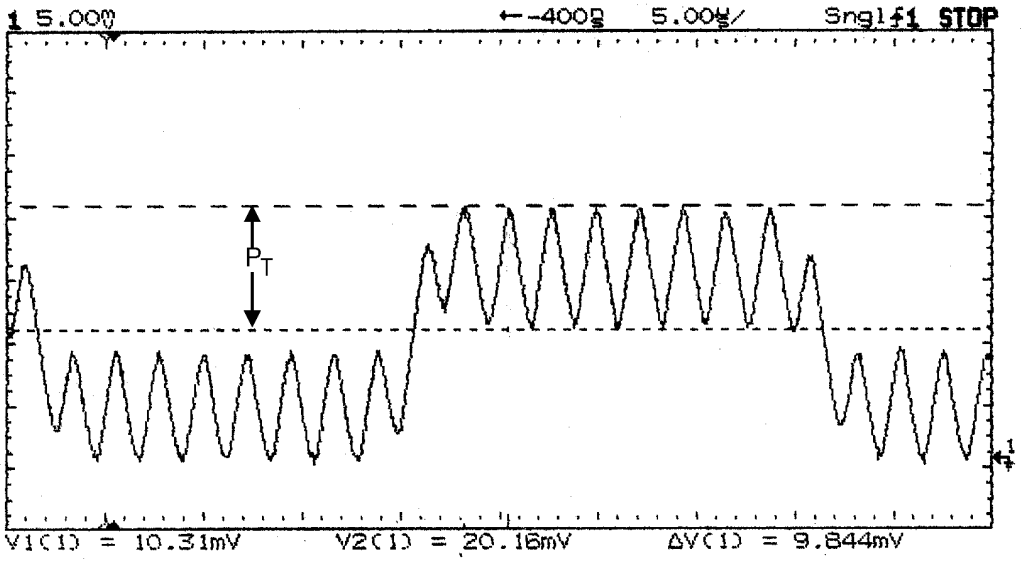

Figure A-5 – Oscilloscope View of the Optical Waveform Showing the Amplitude of the Pilot Tone

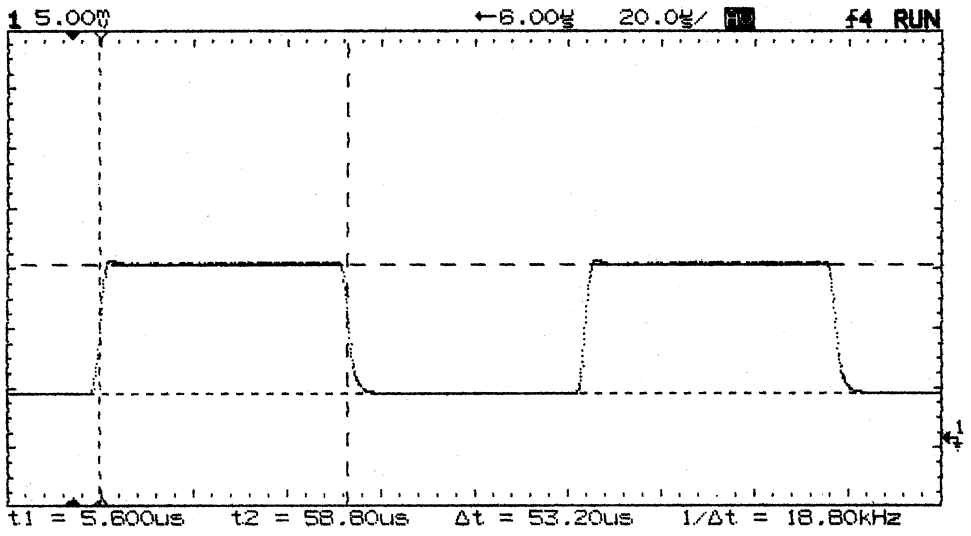

Figure A-6 – Oscilloscope View of the Optical Waveform with the Pilot Tone Turned Off

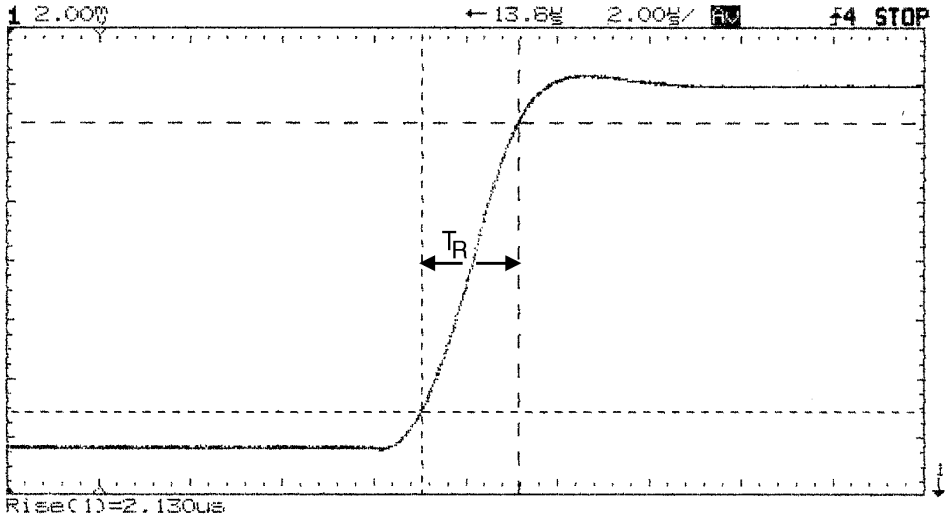

Figure A-7 – Optical Rise Time of the Data Signal

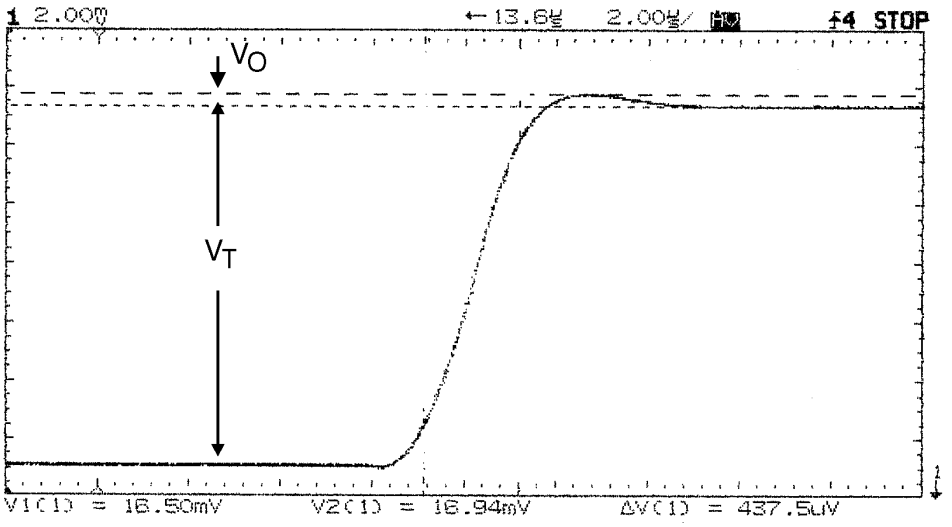

Figure A-8 – Optical Overshoot of the Data Signal

A.3.3.3.2 Optical Receiver Specifications:

Detector Type:	InGaAs	
Operating Spectrum:	1000-1700 nm minimum	
Connector type:	FC / PC	
Optical Data input power when "1" is received:	-4.5 dBm maximum	
Optical Data input power when "0" is received:	-10 dBm maximum	
Optical Average Tone input power level:	-4.5 dBm maximum	
Optical Average Signal Presence input power level:	-4.5 dBm maximum	
"1", "0" Optical power level difference:	6.5 dB maximum	(See Note 1)
"1", "0" Optical power level difference:	3.5 dB minimum	(See Note 1)
Optical Data input power when "1" is received:	<-24.5 dBm minimum	(See Note 2)
Optical Data input power when "0" is received:	<-29.5 dBm minimum	(See Note 2)
Tone level Threshold input power level:	-29.5 dBm maximum	(See Note 3)
Tone level Threshold input power level:	-35.5 dBm minimum	(See Note 3)
Signal Presence threshold input power level:	-29.5 dBm maximum	(See Note 3)
Signal Presence threshold input power level:	-29.5 dBm minimum	(See Note 3)

Note 1: The power difference is measured with the pilot tone off.

Note 2: The incoming data shall be error free while the Signal Presence indicator indicates the presence of an optical signal.

Note 3: The optical power is measured while a "0" is being transmitted.

A.3.3.4 Overall Transceiver Specifications:

The following specifications shall be met under the worst case operating conditions. And are tested through the worst case Input to output port.

Internal Re-transmission Delay:	2 µs maximum
Data Jitter:	2 µs maximum
Data Rate Maximum:	100 kb / s
Data Rate Minimum:	1 bit / s
Mark- Space Ratio at 1 kb/s:	1:1000 maximum
Bit error rate:	1 X 10^{-9} maximum
Optical Dynamic Range:	18 dB minimum
Minimum Optical Loss Required:	0 dB maximum
User Adjustments:	No user adjustments required of full operating range

A.3.4 Power and Grounding Requirements:

A.3.4.1 Available Power Sources:

The fiber transceiver shall operate using the following power sources:

+8 to +16 VDC: @ 300 mA maximum

The peak to peak ripple plus RMS noise shall be greater than 500 mV.

A.3.4.2 Input Power Protection:

The fiber transceiver power input circuitry shall be designed to protect the electronics from damage from a power surge or an under voltage condition without causing damage to electronics. Over and under voltage condition is considered to be a power failure, and therefore, the fiber transceiver does not have to perform to specification during this condition. The fiber transceiver shall automatically recover from an over or under voltage condition when the prime power has returned to values defined by this specification. Guidelines of IEEE Standard 1100-1992 for grounding sensitive electronic equipment shall be utilized.

A.3.4.3 Grounding Provisions:

Grounding provisions shall be included in the design to prevent damage from lightning caused by metallic connections to chassis ground.

The fiber transceiver shall have an insulating compound applied per MIL-I-46058C to avoid shorting and corrosion.

A.3.5 Physical Specifications:

The fiber transceiver shall be enclosed in a metal housing capable of withstanding 300 pounds of pressure, without visible damage.

The fiber transceiver shall have the following maximum overall dimensions:

Length: 8.5”

Width: 5.5”

Height: 1.25”

The weight of the fiber transceiver shall not exceed four pounds. Connectors shall be located on the fiber transceiver for convenient cable attachments. Indicators, test jacks and other maintenance aids shall be easily accessible by maintenance personnel when the fiber transceiver is installed.

Construction and materials selection for the fiber transceiver shall prevent fungus growth and cathodic action. Flame retardant materials shall be utilized in the construction of electronics.

All connectors shall be marked. All replaceable components shall be marked and all markings shall conform to supplied documentation. The fiber transceiver external markings shall include the product name, model number, part number, serial number, manufacturer's name and manufacturer's address.

A.3.6 Environmental Specifications:

The fiber transceiver shall conform to performance specification when operated in the following environment:

Temperature: -34° C to 74° C

Humidity: 5 - 98% RH, non-condensing

No cooling airflow shall be required. Units shall be shipped with protective covers over optical connectors.

A.3.7 Reliability:

The fiber transceiver shall have a minimum Mean Time between Communications Failure (MTBF) of 43,000 hours when operated as a pair. The

MTBF shall be computed per MIL-HDBK-217 Revision F, assuming Ground Benign conditions.

A.3.8 Electromagnetic and Radio Frequency Interference:

The fiber transceiver shall comply with FCC Class A, requirements. Bellcore TR-NWT-001089 electromagnetic compatibility requirements shall be met.

A.3.9 Safety:

The fiber transceiver shall be free of sharp corners. Power input requirements (voltage and current) shall be marked on the fiber transceiver case. Power connections shall be insolated to prevent inadvertent contact by maintenance personnel. Any safety handling related instructions shall be plainly marked on the fiber transceiver case. Bellcore TR-NWT-001089 safety and National Electrical Safety Code requirements apply to the fiber transceiver.

A.3.10 Testing and Factory Set-up:

Each fiber transceiver device shall be tested prior to installation in a factory functional test. Each fiber transceiver shall have been tested for a sufficient time period and with appropriate environmental stress screening to eliminate the possibility of infant mortality of electronic components and marginal mechanical connections of electrical devices supporting required product reliability. Products which have not been previously field-tested in a similar environment are unacceptable.

A.3.11 Quality Assurance:

The fiber transceiver devices shall be manufactured and tested under Quality Assurance procedures as recommended by Bellcore, Electronic Industries Association, MIL-Q-9858, or compliant with International Standards Organization, ISO-9000 Quality Assurance Specification.

A.3.12 Measurement and Payment:

The fiber optic transceiver shall be measured as each unit furnished, installed, tested, and accepted by the Engineer. Work performed and materials furnished as specified shall be paid for at the unit price bid for each fiber optic transceiver. Payment shall include all equipment described under this item and all test results.

Appendix B

Polling Time Data Tables

Table B-1 Poll Time Data for Nodes Spaced at 1 km With No Fiber Break Data for Figure 5-1

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
1	1.0000	0.0050	0.0050	0.0000	0.0000	0.0000	0.0000
2	1.0000	0.0050	0.0100	0.0300	0.0050	0.0100	0.0100
3	1.0000	0.0050	0.0150	0.0900	0.0100	0.0300	0.0250
4	1.0000	0.0050	0.0200	0.1800	0.0150	0.0600	0.0450
5	1.0000	0.0050	0.0250	0.3000	0.0200	0.1000	0.0700
6	1.0000	0.0050	0.0300	0.4500	0.0250	0.1500	0.1000
7	1.0000	0.0050	0.0350	0.6300	0.0300	0.2100	0.1350
8	1.0000	0.0050	0.0400	0.8400	0.0350	0.2800	0.1750
9	1.0000	0.0050	0.0450	1.0800	0.0400	0.3600	0.2200
10	1.0000	0.0050	0.0500	1.3500	0.0450	0.4500	0.2700
11	1.0000	0.0050	0.0550	1.6500	0.0500	0.5500	0.3250
12	1.0000	0.0050	0.0600	1.9800	0.0550	0.6600	0.3850
13	1.0000	0.0050	0.0650	2.3400	0.0600	0.7800	0.4500
14	1.0000	0.0050	0.0700	2.7300	0.0650	0.9100	0.5200
15	1.0000	0.0050	0.0750	3.1500	0.0700	1.0500	0.5950
16	1.0000	0.0050	0.0800	3.6000	0.0750	1.2000	0.6750
17	1.0000	0.0050	0.0850	4.0800	0.0800	1.3600	0.7600
18	1.0000	0.0050	0.0900	4.5900	0.0850	1.5300	0.8500
19	1.0000	0.0050	0.0950	5.1300	0.0900	1.7100	0.9450
20	1.0000	0.0050	0.1000	5.7000	0.0950	1.9000	1.0450
21	1.0000	0.0050	0.1050	6.3000	0.1000	2.1000	1.1500
22	1.0000	0.0050	0.1100	6.9300	0.1050	2.3100	1.2600
23	1.0000	0.0050	0.1150	7.5900	0.1100	2.5300	1.3750
24	1.0000	0.0050	0.1200	8.2800	0.1150	2.7600	1.4950
25	1.0000	0.0050	0.1250	9.0000	0.1200	3.0000	1.6200
26	1.0000	0.0050	0.1300	9.7500	0.1250	3.2500	1.7500
27	1.0000	0.0050	0.1350	10.5300	0.1300	3.5100	1.8850
28	1.0000	0.0050	0.1400	11.3400	0.1350	3.7800	2.0250
29	1.0000	0.0050	0.1450	12.1800	0.1400	4.0600	2.1700
30	1.0000	0.0050	0.1500	13.0500	0.1450	4.3500	2.3200
31	1.0000	0.0050	0.1550	13.9500	0.1500	4.6500	2.4750
32	1.0000	0.0050	0.1600	14.8800	0.1550	4.9600	2.6350
33	1.0000	0.0050	0.1650	15.8400	0.1600	5.2800	2.8000
34	1.0000	0.0050	0.1700	16.8300	0.1650	5.6100	2.9700
35	1.0000	0.0050	0.1750	17.8500	0.1700	5.9500	3.1450
36	1.0000	0.0050	0.1800	18.9000	0.1750	6.3000	3.3250
37	1.0000	0.0050	0.1850	19.9800	0.1800	6.6600	3.5100
38	1.0000	0.0050	0.1900	21.0900	0.1850	7.0300	3.7000

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
39	1.0000	0.0050	0.1950	22.2300	0.1900	7.4100	3.8950
40	1.0000	0.0050	0.2000	23.4000	0.1950	7.8000	4.0950
41	1.0000	0.0050	0.2050	24.6000	0.2000	8.2000	4.3000
42	1.0000	0.0050	0.2100	25.8300	0.2050	8.6100	4.5100
43	1.0000	0.0050	0.2150	27.0900	0.2100	9.0300	4.7250
44	1.0000	0.0050	0.2200	28.3800	0.2150	9.4600	4.9450
45	1.0000	0.0050	0.2250	29.7000	0.2200	9.9000	5.1700
46	1.0000	0.0050	0.2300	31.0500	0.2250	10.3500	5.4000
47	1.0000	0.0050	0.2350	32.4300	0.2300	10.8100	5.6350
48	1.0000	0.0050	0.2400	33.8400	0.2350	11.2800	5.8750
49	1.0000	0.0050	0.2450	35.2800	0.2400	11.7600	6.1200
50	1.0000	0.0050	0.2500	36.7500	0.2450	12.2500	6.3700
51	1.0000	0.0050	0.2550	38.2500	0.2500	12.7500	6.6250
52	1.0000	0.0050	0.2600	39.7800	0.2550	13.2600	6.8850
53	1.0000	0.0050	0.2650	41.3400	0.2600	13.7800	7.1500
54	1.0000	0.0050	0.2700	42.9300	0.2650	14.3100	7.4200
55	1.0000	0.0050	0.2750	44.5500	0.2700	14.8500	7.6950
56	1.0000	0.0050	0.2800	46.2000	0.2750	15.4000	7.9750
57	1.0000	0.0050	0.2850	47.8800	0.2800	15.9600	8.2600
58	1.0000	0.0050	0.2900	49.5900	0.2850	16.5300	8.5500
59	1.0000	0.0050	0.2950	51.3300	0.2900	17.1100	8.8450
60	1.0000	0.0050	0.3000	53.1000	0.2950	17.7000	9.1450
61	1.0000	0.0050	0.3050	54.9000	0.3000	18.3000	9.4500
62	1.0000	0.0050	0.3100	56.7300	0.3050	18.9100	9.7600
63	1.0000	0.0050	0.3150	58.5900	0.3100	19.5300	10.0750
64	1.0000	0.0050	0.3200	60.4800	0.3150	20.1600	10.3950
65	1.0000	0.0050	0.3250	62.4000	0.3200	20.8000	10.7200
66	1.0000	0.0050	0.3300	64.3500	0.3250	21.4500	11.0500
67	1.0000	0.0050	0.3350	66.3300	0.3300	22.1100	11.3850
68	1.0000	0.0050	0.3400	68.3400	0.3350	22.7800	11.7250
69	1.0000	0.0050	0.3450	70.3800	0.3400	23.4600	12.0700
70	1.0000	0.0050	0.3500	72.4500	0.3450	24.1500	12.4200
71	1.0000	0.0050	0.3550	74.5500	0.3500	24.8500	12.7750
72	1.0000	0.0050	0.3600	76.6800	0.3550	25.5600	13.1350
73	1.0000	0.0050	0.3650	78.8400	0.3600	26.2800	13.5000
74	1.0000	0.0050	0.3700	81.0300	0.3650	27.0100	13.8700
75	1.0000	0.0050	0.3750	83.2500	0.3700	27.7500	14.2450
76	1.0000	0.0050	0.3800	85.5000	0.3750	28.5000	14.6250
77	1.0000	0.0050	0.3850	87.7800	0.3800	29.2600	15.0100
78	1.0000	0.0050	0.3900	90.0900	0.3850	30.0300	15.4000
79	1.0000	0.0050	0.3950	92.4300	0.3900	30.8100	15.7950
80	1.0000	0.0050	0.4000	94.8000	0.3950	31.6000	16.1950
81	1.0000	0.0050	0.4050	97.2000	0.4000	32.4000	16.6000
82	1.0000	0.0050	0.4100	99.6300	0.4050	33.2100	17.0100
83	1.0000	0.0050	0.4150	102.0900	0.4100	34.0300	17.4250

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
84	1.0000	0.0050	0.4200	104.5800	0.4150	34.8600	17.8450
85	1.0000	0.0050	0.4250	107.1000	0.4200	35.7000	18.2700
86	1.0000	0.0050	0.4300	109.6500	0.4250	36.5500	18.7000
87	1.0000	0.0050	0.4350	112.2300	0.4300	37.4100	19.1350
88	1.0000	0.0050	0.4400	114.8400	0.4350	38.2800	19.5750
89	1.0000	0.0050	0.4450	117.4800	0.4400	39.1600	20.0200
90	1.0000	0.0050	0.4500	120.1500	0.4450	40.0500	20.4700
91	1.0000	0.0050	0.4550	122.8500	0.4500	40.9500	20.9250
92	1.0000	0.0050	0.4600	125.5800	0.4550	41.8600	21.3850
93	1.0000	0.0050	0.4650	128.3400	0.4600	42.7800	21.8500
94	1.0000	0.0050	0.4700	131.1300	0.4650	43.7100	22.3200
95	1.0000	0.0050	0.4750	133.9500	0.4700	44.6500	22.7950
96	1.0000	0.0050	0.4800	136.8000	0.4750	45.6000	23.2750
97	1.0000	0.0050	0.4850	139.6800	0.4800	46.5600	23.7600
98	1.0000	0.0050	0.4900	142.5900	0.4850	47.5300	24.2500
99	1.0000	0.0050	0.4950	145.5300	0.4900	48.5100	24.7450
100	1.0000	0.0050	0.5000	148.5000	0.4950	49.5000	25.2450
101	1.0000	0.0050	0.5050	151.5000	0.5000	50.5000	25.7500
102	1.0000	0.0050	0.5100	154.5300	0.5050	51.5100	26.2600
103	1.0000	0.0050	0.5150	157.5900	0.5100	52.5300	26.7750
104	1.0000	0.0050	0.5200	160.6800	0.5150	53.5600	27.2950
105	1.0000	0.0050	0.5250	163.8000	0.5200	54.6000	27.8200
106	1.0000	0.0050	0.5300	166.9500	0.5250	55.6500	28.3500
107	1.0000	0.0050	0.5350	170.1300	0.5300	56.7100	28.8850
108	1.0000	0.0050	0.5400	173.3400	0.5350	57.7800	29.4250
109	1.0000	0.0050	0.5450	176.5800	0.5400	58.8600	29.9700
110	1.0000	0.0050	0.5500	179.8500	0.5450	59.9500	30.5200
111	1.0000	0.0050	0.5550	183.1500	0.5500	61.0500	31.0750
112	1.0000	0.0050	0.5600	186.4800	0.5550	62.1600	31.6350
113	1.0000	0.0050	0.5650	189.8400	0.5600	63.2800	32.2000
114	1.0000	0.0050	0.5700	193.2300	0.5650	64.4100	32.7700
115	1.0000	0.0050	0.5750	196.6500	0.5700	65.5500	33.3450
116	1.0000	0.0050	0.5800	200.1000	0.5750	66.7000	33.9250
117	1.0000	0.0050	0.5850	203.5800	0.5800	67.8600	34.5100
118	1.0000	0.0050	0.5900	207.0900	0.5850	69.0300	35.1000
119	1.0000	0.0050	0.5950	210.6300	0.5900	70.2100	35.6950
120	1.0000	0.0050	0.6000	214.2000	0.5950	71.4000	36.2950
121	1.0000	0.0050	0.6050	217.8000	0.6000	72.6000	36.9000
122	1.0000	0.0050	0.6100	221.4300	0.6050	73.8100	37.5100
123	1.0000	0.0050	0.6150	225.0900	0.6100	75.0300	38.1250
124	1.0000	0.0050	0.6200	228.7800	0.6150	76.2600	38.7450
125	1.0000	0.0050	0.6250	232.5000	0.6200	77.5000	39.3700
126	1.0000	0.0050	0.6300	236.2500	0.6250	78.7500	40.0000
127	1.0000	0.0050	0.6350	240.0300	0.6300	80.0100	40.6350
128	1.0000	0.0050	0.6400	243.8400	0.6350	81.2800	41.2750

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
129	1.0000	0.0050	0.6450	247.6800	0.6400	82.5600	41.9200
130	1.0000	0.0050	0.6500	251.5500	0.6450	83.8500	42.5700
131	1.0000	0.0050	0.6550	255.4500	0.6500	85.1500	43.2250
132	1.0000	0.0050	0.6600	259.3800	0.6550	86.4600	43.8850
133	1.0000	0.0050	0.6650	263.3400	0.6600	87.7800	44.5500
134	1.0000	0.0050	0.6700	267.3300	0.6650	89.1100	45.2200
135	1.0000	0.0050	0.6750	271.3500	0.6700	90.4500	45.8950
136	1.0000	0.0050	0.6800	275.4000	0.6750	91.8000	46.5750
137	1.0000	0.0050	0.6850	279.4800	0.6800	93.1600	47.2600
138	1.0000	0.0050	0.6900	283.5900	0.6850	94.5300	47.9500
139	1.0000	0.0050	0.6950	287.7300	0.6900	95.9100	48.6450
140	1.0000	0.0050	0.7000	291.9000	0.6950	97.3000	49.3450
141	1.0000	0.0050	0.7050	296.1000	0.7000	98.7000	50.0500
142	1.0000	0.0050	0.7100	300.3300	0.7050	100.1100	50.7600
143	1.0000	0.0050	0.7150	304.5900	0.7100	101.5300	51.4750
144	1.0000	0.0050	0.7200	308.8800	0.7150	102.9600	52.1950
145	1.0000	0.0050	0.7250	313.2000	0.7200	104.4000	52.9200
146	1.0000	0.0050	0.7300	317.5500	0.7250	105.8500	53.6500
147	1.0000	0.0050	0.7350	321.9300	0.7300	107.3100	54.3850
148	1.0000	0.0050	0.7400	326.3400	0.7350	108.7800	55.1250
149	1.0000	0.0050	0.7450	330.7800	0.7400	110.2600	55.8700
150	1.0000	0.0050	0.7500	335.2500	0.7450	111.7500	56.6200
151	1.0000	0.0050	0.7550	339.7500	0.7500	113.2500	57.3750
152	1.0000	0.0050	0.7600	344.2800	0.7550	114.7600	58.1350
153	1.0000	0.0050	0.7650	348.8400	0.7600	116.2800	58.9000
154	1.0000	0.0050	0.7700	353.4300	0.7650	117.8100	59.6700
155	1.0000	0.0050	0.7750	358.0500	0.7700	119.3500	60.4450
156	1.0000	0.0050	0.7800	362.7000	0.7750	120.9000	61.2250
157	1.0000	0.0050	0.7850	367.3800	0.7800	122.4600	62.0100
158	1.0000	0.0050	0.7900	372.0900	0.7850	124.0300	62.8000
159	1.0000	0.0050	0.7950	376.8300	0.7900	125.6100	63.5950
160	1.0000	0.0050	0.8000	381.6000	0.7950	127.2000	64.3950
161	1.0000	0.0050	0.8050	386.4000	0.8000	128.8000	65.2000
162	1.0000	0.0050	0.8100	391.2300	0.8050	130.4100	66.0100
163	1.0000	0.0050	0.8150	396.0900	0.8100	132.0300	66.8250
164	1.0000	0.0050	0.8200	400.9800	0.8150	133.6600	67.6450
165	1.0000	0.0050	0.8250	405.9000	0.8200	135.3000	68.4700
166	1.0000	0.0050	0.8300	410.8500	0.8250	136.9500	69.3000
167	1.0000	0.0050	0.8350	415.8300	0.8300	138.6100	70.1350
168	1.0000	0.0050	0.8400	420.8400	0.8350	140.2800	70.9750
169	1.0000	0.0050	0.8450	425.8800	0.8400	141.9600	71.8200
170	1.0000	0.0050	0.8500	430.9500	0.8450	143.6500	72.6700
171	1.0000	0.0050	0.8550	436.0500	0.8500	145.3500	73.5250
172	1.0000	0.0050	0.8600	441.1800	0.8550	147.0600	74.3850
173	1.0000	0.0050	0.8650	446.3400	0.8600	148.7800	75.2500

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
174	1.0000	0.0050	0.8700	451.5300	0.8650	150.5100	76.1200
175	1.0000	0.0050	0.8750	456.7500	0.8700	152.2500	76.9950
176	1.0000	0.0050	0.8800	462.0000	0.8750	154.0000	77.8750
177	1.0000	0.0050	0.8850	467.2800	0.8800	155.7600	78.7600
178	1.0000	0.0050	0.8900	472.5900	0.8850	157.5300	79.6500
179	1.0000	0.0050	0.8950	477.9300	0.8900	159.3100	80.5450
180	1.0000	0.0050	0.9000	483.3000	0.8950	161.1000	81.4450
181	1.0000	0.0050	0.9050	488.7000	0.9000	162.9000	82.3500
182	1.0000	0.0050	0.9100	494.1300	0.9050	164.7100	83.2600
183	1.0000	0.0050	0.9150	499.5900	0.9100	166.5300	84.1750
184	1.0000	0.0050	0.9200	505.0800	0.9150	168.3600	85.0950
185	1.0000	0.0050	0.9250	510.6000	0.9200	170.2000	86.0200
186	1.0000	0.0050	0.9300	516.1500	0.9250	172.0500	86.9500
187	1.0000	0.0050	0.9350	521.7300	0.9300	173.9100	87.8850
188	1.0000	0.0050	0.9400	527.3400	0.9350	175.7800	88.8250
189	1.0000	0.0050	0.9450	532.9800	0.9400	177.6600	89.7700
190	1.0000	0.0050	0.9500	538.6500	0.9450	179.5500	90.7200
191	1.0000	0.0050	0.9550	544.3500	0.9500	181.4500	91.6750
192	1.0000	0.0050	0.9600	550.0800	0.9550	183.3600	92.6350
193	1.0000	0.0050	0.9650	555.8400	0.9600	185.2800	93.6000
194	1.0000	0.0050	0.9700	561.6300	0.9650	187.2100	94.5700
195	1.0000	0.0050	0.9750	567.4500	0.9700	189.1500	95.5450
196	1.0000	0.0050	0.9800	573.3000	0.9750	191.1000	96.5250
197	1.0000	0.0050	0.9850	579.1800	0.9800	193.0600	97.5100
198	1.0000	0.0050	0.9900	585.0900	0.9850	195.0300	98.5000
199	1.0000	0.0050	0.9950	591.0300	0.9900	197.0100	99.4950
200	1.0000	0.0050	1.0000	597.0000	0.9950	199.0000	100.4950

Table B-2 Poll Time Data for Nodes Spaced at 2 km With No Fiber Break data for Figure 5-2

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
1	2.0000	0.0100	0.0100	0.0000	0.0000	0.0000	0.0000
2	2.0000	0.0100	0.0200	0.0600	0.0100	0.0200	0.0200
3	2.0000	0.0100	0.0300	0.1800	0.0200	0.0600	0.0500
4	2.0000	0.0100	0.0400	0.3600	0.0300	0.1200	0.0900
5	2.0000	0.0100	0.0500	0.6000	0.0400	0.2000	0.1400
6	2.0000	0.0100	0.0600	0.9000	0.0500	0.3000	0.2000
7	2.0000	0.0100	0.0700	1.2600	0.0600	0.4200	0.2700
8	2.0000	0.0100	0.0800	1.6800	0.0700	0.5600	0.3500
9	2.0000	0.0100	0.0900	2.1600	0.0800	0.7200	0.4400
10	2.0000	0.0100	0.1000	2.7000	0.0900	0.9000	0.5400
11	2.0000	0.0100	0.1100	3.3000	0.1000	1.1000	0.6500
12	2.0000	0.0100	0.1200	3.9600	0.1100	1.3200	0.7700
13	2.0000	0.0100	0.1300	4.6800	0.1200	1.5600	0.9000
14	2.0000	0.0100	0.1400	5.4600	0.1300	1.8200	1.0400
15	2.0000	0.0100	0.1500	6.3000	0.1400	2.1000	1.1900
16	2.0000	0.0100	0.1600	7.2000	0.1500	2.4000	1.3500
17	2.0000	0.0100	0.1700	8.1600	0.1600	2.7200	1.5200
18	2.0000	0.0100	0.1800	9.1800	0.1700	3.0600	1.7000
19	2.0000	0.0100	0.1900	10.2600	0.1800	3.4200	1.8900
20	2.0000	0.0100	0.2000	11.4000	0.1900	3.8000	2.0900
21	2.0000	0.0100	0.2100	12.6000	0.2000	4.2000	2.3000
22	2.0000	0.0100	0.2200	13.8600	0.2100	4.6200	2.5200
23	2.0000	0.0100	0.2300	15.1800	0.2200	5.0600	2.7500
24	2.0000	0.0100	0.2400	16.5600	0.2300	5.5200	2.9900
25	2.0000	0.0100	0.2500	18.0000	0.2400	6.0000	3.2400
26	2.0000	0.0100	0.2600	19.5000	0.2500	6.5000	3.5000
27	2.0000	0.0100	0.2700	21.0600	0.2600	7.0200	3.7700
28	2.0000	0.0100	0.2800	22.6800	0.2700	7.5600	4.0500
29	2.0000	0.0100	0.2900	24.3600	0.2800	8.1200	4.3400
30	2.0000	0.0100	0.3000	26.1000	0.2900	8.7000	4.6400
31	2.0000	0.0100	0.3100	27.9000	0.3000	9.3000	4.9500
32	2.0000	0.0100	0.3200	29.7600	0.3100	9.9200	5.2700
33	2.0000	0.0100	0.3300	31.6800	0.3200	10.5600	5.6000
34	2.0000	0.0100	0.3400	33.6600	0.3300	11.2200	5.9400
35	2.0000	0.0100	0.3500	35.7000	0.3400	11.9000	6.2900
36	2.0000	0.0100	0.3600	37.8000	0.3500	12.6000	6.6500
37	2.0000	0.0100	0.3700	39.9600	0.3600	13.3200	7.0200
38	2.0000	0.0100	0.3800	42.1800	0.3700	14.0600	7.4000

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
39	2.0000	0.0100	0.3900	44.4600	0.3800	14.8200	7.7900
40	2.0000	0.0100	0.4000	46.8000	0.3900	15.6000	8.1900
41	2.0000	0.0100	0.4100	49.2000	0.4000	16.4000	8.6000
42	2.0000	0.0100	0.4200	51.6600	0.4100	17.2200	9.0200
43	2.0000	0.0100	0.4300	54.1800	0.4200	18.0600	9.4500
44	2.0000	0.0100	0.4400	56.7600	0.4300	18.9200	9.8900
45	2.0000	0.0100	0.4500	59.4000	0.4400	19.8000	10.3400
46	2.0000	0.0100	0.4600	62.1000	0.4500	20.7000	10.8000
47	2.0000	0.0100	0.4700	64.8600	0.4600	21.6200	11.2700
48	2.0000	0.0100	0.4800	67.6800	0.4700	22.5600	11.7500
49	2.0000	0.0100	0.4900	70.5600	0.4800	23.5200	12.2400
50	2.0000	0.0100	0.5000	73.5000	0.4900	24.5000	12.7400
51	2.0000	0.0100	0.5100	76.5000	0.5000	25.5000	13.2500
52	2.0000	0.0100	0.5200	79.5600	0.5100	26.5200	13.7700
53	2.0000	0.0100	0.5300	82.6800	0.5200	27.5600	14.3000
54	2.0000	0.0100	0.5400	85.8600	0.5300	28.6200	14.8400
55	2.0000	0.0100	0.5500	89.1000	0.5400	29.7000	15.3900
56	2.0000	0.0100	0.5600	92.4000	0.5500	30.8000	15.9500
57	2.0000	0.0100	0.5700	95.7600	0.5600	31.9200	16.5200
58	2.0000	0.0100	0.5800	99.1800	0.5700	33.0600	17.1000
59	2.0000	0.0100	0.5900	102.660	0.5800	34.2200	17.6900
60	2.0000	0.0100	0.6000	106.200	0.5900	35.4000	18.2900
61	2.0000	0.0100	0.6100	109.800	0.6000	36.6000	18.9000
62	2.0000	0.0100	0.6200	113.460	0.6100	37.8200	19.5200
63	2.0000	0.0100	0.6300	117.180	0.6200	39.0600	20.1500
64	2.0000	0.0100	0.6400	120.960	0.6300	40.3200	20.7900
65	2.0000	0.0100	0.6500	124.800	0.6400	41.6000	21.4400
66	2.0000	0.0100	0.6600	128.700	0.6500	42.9000	22.1000
67	2.0000	0.0100	0.6700	132.660	0.6600	44.2200	22.7700
68	2.0000	0.0100	0.6800	136.680	0.6700	45.5600	23.4500
69	2.0000	0.0100	0.6900	140.760	0.6800	46.9200	24.1400
70	2.0000	0.0100	0.7000	144.900	0.6900	48.3000	24.8400
71	2.0000	0.0100	0.7100	149.100	0.7000	49.7000	25.5500
72	2.0000	0.0100	0.7200	153.360	0.7100	51.1200	26.2700
73	2.0000	0.0100	0.7300	157.680	0.7200	52.5600	27.0000
74	2.0000	0.0100	0.7400	162.060	0.7300	54.0200	27.7400
75	2.0000	0.0100	0.7500	166.500	0.7400	55.5000	28.4900
76	2.0000	0.0100	0.7600	171.000	0.7500	57.0000	29.2500
77	2.0000	0.0100	0.7700	175.560	0.7600	58.5200	30.0200
78	2.0000	0.0100	0.7800	180.180	0.7700	60.0600	30.8000
79	2.0000	0.0100	0.7900	184.860	0.7800	61.6200	31.5900
80	2.0000	0.0100	0.8000	189.600	0.7900	63.2000	32.3900
81	2.0000	0.0100	0.8100	194.400	0.8000	64.8000	33.2000
82	2.0000	0.0100	0.8200	199.2600	0.8100	66.4200	34.0200

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
83	2.0000	0.0100	0.8300	204.1800	0.8200	68.0600	34.8500
84	2.0000	0.0100	0.8400	209.1600	0.8300	69.7200	35.6900
85	2.0000	0.0100	0.8500	214.2000	0.8400	71.4000	36.5400
86	2.0000	0.0100	0.8600	219.3000	0.8500	73.1000	37.4000
87	2.0000	0.0100	0.8700	224.4600	0.8600	74.8200	38.2700
88	2.0000	0.0100	0.8800	229.6800	0.8700	76.5600	39.1500
89	2.0000	0.0100	0.8900	234.9600	0.8800	78.3200	40.0400
90	2.0000	0.0100	0.9000	240.3000	0.8900	80.1000	40.9400
91	2.0000	0.0100	0.9100	245.7000	0.9000	81.9000	41.8500
92	2.0000	0.0100	0.9200	251.1600	0.9100	83.7200	42.7700
93	2.0000	0.0100	0.9300	256.6800	0.9200	85.5600	43.7000
94	2.0000	0.0100	0.9400	262.2600	0.9300	87.4200	44.6400
95	2.0000	0.0100	0.9500	267.9000	0.9400	89.3000	45.5900
96	2.0000	0.0100	0.9600	273.6000	0.9500	91.2000	46.5500
97	2.0000	0.0100	0.9700	279.3600	0.9600	93.1200	47.5200
98	2.0000	0.0100	0.9800	285.1800	0.9700	95.0600	48.5000
99	2.0000	0.0100	0.9900	291.0600	0.9800	97.0200	49.4900
100	2.0000	0.0100	1.0000	297.0000	0.9900	99.0000	50.4900
101	2.0000	0.0100	1.0100	303.0000	1.0000	101.0000	51.5000
102	2.0000	0.0100	1.0200	309.0600	1.0100	103.0200	52.5200
103	2.0000	0.0100	1.0300	315.1800	1.0200	105.0600	53.5500
104	2.0000	0.0100	1.0400	321.3600	1.0300	107.1200	54.5900
105	2.0000	0.0100	1.0500	327.6000	1.0400	109.2000	55.6400
106	2.0000	0.0100	1.0600	333.9000	1.0500	111.3000	56.7000
107	2.0000	0.0100	1.0700	340.2600	1.0600	113.4200	57.7700
108	2.0000	0.0100	1.0800	346.6800	1.0700	115.5600	58.8500
109	2.0000	0.0100	1.0900	353.1600	1.0800	117.7200	59.9400
110	2.0000	0.0100	1.1000	359.7000	1.0900	119.9000	61.0400
111	2.0000	0.0100	1.1100	366.3000	1.1000	122.1000	62.1500
112	2.0000	0.0100	1.1200	372.9600	1.1100	124.3200	63.2700
113	2.0000	0.0100	1.1300	379.6800	1.1200	126.5600	64.4000
114	2.0000	0.0100	1.1400	386.4600	1.1300	128.8200	65.5400
115	2.0000	0.0100	1.1500	393.3000	1.1400	131.1000	66.6900
116	2.0000	0.0100	1.1600	400.2000	1.1500	133.4000	67.8500
117	2.0000	0.0100	1.1700	407.1600	1.1600	135.7200	69.0200
118	2.0000	0.0100	1.1800	414.1800	1.1700	138.0600	70.2000
119	2.0000	0.0100	1.1900	421.2600	1.1800	140.4200	71.3900
120	2.0000	0.0100	1.2000	428.4000	1.1900	142.8000	72.5900
121	2.0000	0.0100	1.2100	435.6000	1.2000	145.2000	73.8000
122	2.0000	0.0100	1.2200	442.8600	1.2100	147.6200	75.0200
123	2.0000	0.0100	1.2300	450.1800	1.2200	150.0600	76.2500
124	2.0000	0.0100	1.2400	457.5600	1.2300	152.5200	77.4900
125	2.0000	0.0100	1.2500	465.0000	1.2400	155.0000	78.7400
126	2.0000	0.0100	1.2600	472.5000	1.2500	157.5000	80.0000

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
127	2.0000	0.0100	1.2700	480.0600	1.2600	160.0200	81.2700
128	2.0000	0.0100	1.2800	487.6800	1.2700	162.5600	82.5500
129	2.0000	0.0100	1.2900	495.3600	1.2800	165.1200	83.8400
130	2.0000	0.0100	1.3000	503.1000	1.2900	167.7000	85.1400
131	2.0000	0.0100	1.3100	510.9000	1.3000	170.3000	86.4500
132	2.0000	0.0100	1.3200	518.7600	1.3100	172.9200	87.7700
133	2.0000	0.0100	1.3300	526.6800	1.3200	175.5600	89.1000
134	2.0000	0.0100	1.3400	534.6600	1.3300	178.2200	90.4400
135	2.0000	0.0100	1.3500	542.7000	1.3400	180.9000	91.7900
136	2.0000	0.0100	1.3600	550.8000	1.3500	183.6000	93.1500
137	2.0000	0.0100	1.3700	558.9600	1.3600	186.3200	94.5200
138	2.0000	0.0100	1.3800	567.1800	1.3700	189.0600	95.9000
139	2.0000	0.0100	1.3900	575.4600	1.3800	191.8200	97.2900
140	2.0000	0.0100	1.4000	583.8000	1.3900	194.6000	98.6900
141	2.0000	0.0100	1.4100	592.2000	1.4000	197.4000	100.1000
142	2.0000	0.0100	1.4200	600.6600	1.4100	200.2200	101.5200
143	2.0000	0.0100	1.4300	609.1800	1.4200	203.0600	102.9500
144	2.0000	0.0100	1.4400	617.7600	1.4300	205.9200	104.3900
145	2.0000	0.0100	1.4500	626.4000	1.4400	208.8000	105.8400
146	2.0000	0.0100	1.4600	635.1000	1.4500	211.7000	107.3000
147	2.0000	0.0100	1.4700	643.8600	1.4600	214.6200	108.7700
148	2.0000	0.0100	1.4800	652.6800	1.4700	217.5600	110.2500
149	2.0000	0.0100	1.4900	661.5600	1.4800	220.5200	111.7400
150	2.0000	0.0100	1.5000	670.5000	1.4900	223.5000	113.2400
151	2.0000	0.0100	1.5100	679.5000	1.5000	226.5000	114.7500
152	2.0000	0.0100	1.5200	688.5600	1.5100	229.5200	116.2700
153	2.0000	0.0100	1.5300	697.6800	1.5200	232.5600	117.8000
154	2.0000	0.0100	1.5400	706.8600	1.5300	235.6200	119.3400
155	2.0000	0.0100	1.5500	716.1000	1.5400	238.7000	120.8900
156	2.0000	0.0100	1.5600	725.4000	1.5500	241.8000	122.4500
157	2.0000	0.0100	1.5700	734.7600	1.5600	244.9200	124.0200
158	2.0000	0.0100	1.5800	744.1800	1.5700	248.0600	125.6000
159	2.0000	0.0100	1.5900	753.6600	1.5800	251.2200	127.1900
160	2.0000	0.0100	1.6000	763.2000	1.5900	254.4000	128.7900
161	2.0000	0.0100	1.6100	772.8000	1.6000	257.6000	130.4000
162	2.0000	0.0100	1.6200	782.4600	1.6100	260.8200	132.0200
163	2.0000	0.0100	1.6300	792.1800	1.6200	264.0600	133.6500
164	2.0000	0.0100	1.6400	801.9600	1.6300	267.3200	135.2900
165	2.0000	0.0100	1.6500	811.8000	1.6400	270.6000	136.9400
166	2.0000	0.0100	1.6600	821.7000	1.6500	273.9000	138.6000
167	2.0000	0.0100	1.6700	831.6600	1.6600	277.2200	140.2700
168	2.0000	0.0100	1.6800	841.6800	1.6700	280.5600	141.9500
169	2.0000	0.0100	1.6900	851.7600	1.6800	283.9200	143.6400
170	2.0000	0.0100	1.7000	861.9000	1.6900	287.3000	145.3400

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
171	2.0000	0.0100	1.7100	872.1000	1.7000	290.7000	147.0500
172	2.0000	0.0100	1.7200	882.3600	1.7100	294.1200	148.7700
173	2.0000	0.0100	1.7300	892.6800	1.7200	297.5600	150.5000
174	2.0000	0.0100	1.7400	903.0600	1.7300	301.0200	152.2400
175	2.0000	0.0100	1.7500	913.5000	1.7400	304.5000	153.9900
176	2.0000	0.0100	1.7600	924.0000	1.7500	308.0000	155.7500
177	2.0000	0.0100	1.7700	934.5600	1.7600	311.5200	157.5200
178	2.0000	0.0100	1.7800	945.1800	1.7700	315.0600	159.3000
179	2.0000	0.0100	1.7900	955.8600	1.7800	318.6200	161.0900
180	2.0000	0.0100	1.8000	966.6000	1.7900	322.2000	162.8900
181	2.0000	0.0100	1.8100	977.4000	1.8000	325.8000	164.7000
182	2.0000	0.0100	1.8200	988.2600	1.8100	329.4200	166.5200
183	2.0000	0.0100	1.8300	999.1800	1.8200	333.0600	168.3500
184	2.0000	0.0100	1.8400	1010.1600	1.8300	336.7200	170.1900
185	2.0000	0.0100	1.8500	1021.2000	1.8400	340.4000	172.0400
186	2.0000	0.0100	1.8600	1032.3000	1.8500	344.1000	173.9000
187	2.0000	0.0100	1.8700	1043.4600	1.8600	347.8200	175.7700
188	2.0000	0.0100	1.8800	1054.6800	1.8700	351.5600	177.6500
189	2.0000	0.0100	1.8900	1065.9600	1.8800	355.3200	179.5400
190	2.0000	0.0100	1.9000	1077.3000	1.8900	359.1000	181.4400
191	2.0000	0.0100	1.9100	1088.7000	1.9000	362.9000	183.3500
192	2.0000	0.0100	1.9200	1100.1600	1.9100	366.7200	185.2700
193	2.0000	0.0100	1.9300	1111.6800	1.9200	370.5600	187.2000
194	2.0000	0.0100	1.9400	1123.2600	1.9300	374.4200	189.1400
195	2.0000	0.0100	1.9500	1134.9000	1.9400	378.3000	191.0900
196	2.0000	0.0100	1.9600	1146.6000	1.9500	382.2000	193.0500
197	2.0000	0.0100	1.9700	1158.3600	1.9600	386.1200	195.0200
198	2.0000	0.0100	1.9800	1170.1800	1.9700	390.0600	197.0000
199	2.0000	0.0100	1.9900	1182.0600	1.9800	394.0200	198.9900
200	2.0000	0.0100	2.0000	1194.0000	1.9900	398.0000	200.9900

Table B-3 Poll Time Data for Nodes Randomly Space 0-2 km With No Fiber Break

Data for Figure 5-3

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
1	1.9003	0.0095	0.0095	0.0000	0.0000	0.0000	0.0000
2	0.6801	0.0034	0.0129	0.0387	0.0034	0.0068	0.0068
3	1.0060	0.0050	0.0179	0.1076	0.0084	0.0237	0.0203
4	0.8747	0.0044	0.0223	0.2007	0.0128	0.0493	0.0374
5	1.1890	0.0059	0.0283	0.3390	0.0187	0.0868	0.0621
6	0.7832	0.0039	0.0322	0.4825	0.0227	0.1321	0.0887
7	0.6125	0.0031	0.0352	0.6341	0.0257	0.1836	0.1175
8	0.9360	0.0047	0.0399	0.8381	0.0304	0.2444	0.1526
9	1.6161	0.0081	0.0480	1.1517	0.0385	0.3213	0.1992
10	1.7766	0.0089	0.0569	1.5356	0.0474	0.4161	0.2554
11	0.0602	0.0003	0.0572	1.7152	0.0477	0.5114	0.3034
12	1.4769	0.0074	0.0646	2.1304	0.0551	0.6215	0.3658
13	1.9586	0.0098	0.0744	2.6766	0.0648	0.7512	0.4405
14	0.2013	0.0010	0.0754	2.9389	0.0659	0.8830	0.5073
15	0.0331	0.0002	0.0755	3.1720	0.0660	1.0150	0.5735
16	0.9093	0.0045	0.0801	3.6031	0.0706	1.1561	0.6486
17	0.7783	0.0039	0.0840	4.0301	0.0745	1.3051	0.7270
18	1.4854	0.0074	0.0914	4.6608	0.0819	1.4688	0.8163
19	0.4795	0.0024	0.0938	5.0644	0.0843	1.6374	0.9030
20	1.3517	0.0068	0.1005	5.7310	0.0910	1.8195	1.0008
21	1.5156	0.0076	0.1081	6.4873	0.0986	2.0167	1.1070
22	0.8744	0.0044	0.1125	7.0871	0.1030	2.2227	1.2143
23	0.5489	0.0027	0.1152	7.6057	0.1057	2.4342	1.3228
24	1.4818	0.0074	0.1226	8.4626	0.1131	2.6605	1.4434
25	0.7836	0.0039	0.1266	9.1127	0.1171	2.8946	1.5644
26	1.2408	0.0062	0.1328	9.9576	0.1233	3.1411	1.6938
27	0.7314	0.0037	0.1364	10.6412	0.1269	3.3950	1.8244
28	1.2107	0.0061	0.1425	11.5408	0.1330	3.6609	1.9634
29	1.3588	0.0068	0.1493	12.5390	0.1398	3.9405	2.1100
30	1.1192	0.0056	0.1549	13.4736	0.1454	4.2312	2.2610
31	1.7379	0.0087	0.1636	14.7203	0.1541	4.5393	2.4237
32	0.8442	0.0042	0.1678	15.6035	0.1583	4.8559	2.5862
33	0.0956	0.0005	0.1683	16.1528	0.1588	5.1734	2.7455
34	1.2891	0.0064	0.1747	17.2956	0.1652	5.5038	2.9171
35	1.2894	0.0064	0.1812	18.4774	0.1716	5.8471	3.0952
36	1.8041	0.0090	0.1902	19.9680	0.1807	6.2085	3.2849
37	0.0357	0.0002	0.1903	20.5577	0.1808	6.5701	3.4659
38	1.1638	0.0058	0.1962	21.7747	0.1867	6.9435	3.6584

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
39	1.4942	0.0075	0.2036	23.2149	0.1941	7.3318	3.8600
40	1.4762	0.0074	0.2110	24.6893	0.2015	7.7348	4.0689
41	1.4357	0.0072	0.2182	26.1838	0.2087	8.1522	4.2848
42	0.4054	0.0020	0.2202	27.0877	0.2107	8.5736	4.4975
43	0.4948	0.0025	0.2227	28.0601	0.2132	9.0000	4.7132
44	0.6382	0.0032	0.2259	29.1398	0.2164	9.4328	4.9328
45	1.0790	0.0054	0.2313	30.5296	0.2218	9.8764	5.1600
46	1.1915	0.0060	0.2372	32.0278	0.2277	10.3319	5.3937
47	0.0146	0.0001	0.2373	32.7495	0.2278	10.7875	5.6216
48	0.8054	0.0040	0.2413	34.0293	0.2318	11.2512	5.8574
49	1.6459	0.0082	0.2496	35.9384	0.2401	11.7313	6.1057
50	0.5992	0.0030	0.2526	37.1275	0.2431	12.2174	6.3518
51	1.3189	0.0066	0.2592	38.8744	0.2497	12.7168	6.6080
52	0.3271	0.0016	0.2608	39.9021	0.2513	13.2194	6.8610
53	1.1648	0.0058	0.2666	41.5930	0.2571	13.7336	7.1239
54	1.9189	0.0096	0.2762	43.9184	0.2667	14.2670	7.4002
55	0.2652	0.0013	0.2775	44.9618	0.2680	14.8031	7.6696
56	1.6692	0.0083	0.2859	47.1715	0.2764	15.3559	7.9543
57	1.1677	0.0058	0.2917	49.0101	0.2822	15.9203	8.2424
58	1.3230	0.0066	0.2983	51.0164	0.2888	16.4980	8.5379
59	1.3708	0.0069	0.3052	53.1040	0.2957	17.0894	8.8404
60	1.3205	0.0066	0.3118	55.1883	0.3023	17.6940	9.1493
61	1.1478	0.0057	0.3175	57.1567	0.3080	18.3101	9.4631
62	0.0368	0.0002	0.3177	58.1430	0.3082	18.9265	9.7715
63	1.8348	0.0092	0.3269	60.8025	0.3174	19.5613	10.0980
64	1.0575	0.0053	0.3322	62.7825	0.3227	20.2067	10.4260
65	1.7481	0.0087	0.3409	65.4572	0.3314	20.8695	10.7662
66	1.0751	0.0054	0.3463	67.5282	0.3368	21.5431	11.1084
67	1.3910	0.0070	0.3533	69.9441	0.3438	22.2306	11.4591
68	1.2061	0.0060	0.3593	72.2161	0.3498	22.9302	11.8149
69	0.0878	0.0004	0.3597	73.3835	0.3502	23.6306	12.1655
70	0.1041	0.0005	0.3602	74.5703	0.3507	24.3321	12.5168
71	1.6608	0.0083	0.3685	77.3949	0.3590	25.0502	12.8841
72	1.0046	0.0050	0.3736	79.5704	0.3641	25.7783	13.2532
73	0.2575	0.0013	0.3749	80.9692	0.3654	26.5090	13.6199
74	0.0897	0.0004	0.3753	82.1920	0.3658	27.2407	13.9861
75	0.9941	0.0050	0.3803	84.4214	0.3708	27.9822	14.3619
76	1.2869	0.0064	0.3867	87.0099	0.3772	28.7366	14.7455
77	1.9991	0.0100	0.3967	90.4490	0.3872	29.5110	15.1427
78	1.2289	0.0061	0.4029	93.0585	0.3933	30.2977	15.5422
79	1.7043	0.0085	0.4114	96.2610	0.4019	31.1015	15.9526
80	1.9394	0.0097	0.4211	99.7933	0.4116	31.9246	16.3739
81	1.1216	0.0056	0.4267	102.4023	0.4172	32.7590	16.7967
82	1.6367	0.0082	0.4349	105.6710	0.4254	33.6097	17.2302
83	1.5613	0.0078	0.4427	108.8960	0.4332	34.4760	17.6712

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
84	1.7555	0.0088	0.4514	112.4095	0.4419	35.3599	18.1219
85	0.6666	0.0033	0.4548	114.6038	0.4453	36.2504	18.5705
86	0.5886	0.0029	0.4577	116.7186	0.4482	37.1469	19.0217
87	0.5478	0.0027	0.4605	118.7985	0.4510	38.0488	19.4754
88	1.6746	0.0084	0.4688	122.3652	0.4593	38.9675	19.9431
89	0.4561	0.0023	0.4711	124.3738	0.4616	39.8907	20.4070
90	0.2787	0.0014	0.4725	126.1592	0.4630	40.8167	20.8713
91	0.1339	0.0007	0.4732	127.7575	0.4637	41.7440	21.3357
92	1.1113	0.0056	0.4787	130.6940	0.4692	42.6825	21.8105
93	1.4394	0.0072	0.4859	134.1166	0.4764	43.6354	22.2941
94	1.4208	0.0071	0.4930	137.5564	0.4835	44.6024	22.7847
95	1.6623	0.0083	0.5013	141.3794	0.4918	45.5861	23.2849
96	1.2282	0.0061	0.5075	144.6335	0.4980	46.5821	23.7890
97	1.5393	0.0077	0.5152	148.3725	0.5057	47.5934	24.3024
98	1.6888	0.0084	0.5236	152.3753	0.5141	48.6217	24.8250
99	1.5706	0.0079	0.5315	156.2550	0.5220	49.6657	25.3548
100	1.5585	0.0078	0.5393	160.1638	0.5298	50.7252	25.8924
101	0.2617	0.0013	0.5406	162.1741	0.5311	51.7873	26.4248
102	0.0881	0.0004	0.5410	163.9293	0.5315	52.8504	26.9567
103	1.6084	0.0080	0.5491	168.0132	0.5396	53.9295	27.5043
104	0.4884	0.0024	0.5515	170.4150	0.5420	55.0135	28.0488
105	1.4733	0.0074	0.5589	174.3678	0.5494	56.1123	28.6055
106	0.5080	0.0025	0.5614	176.8446	0.5519	57.2161	29.1599
107	0.3805	0.0019	0.5633	179.1338	0.5538	58.3237	29.7157
108	1.3276	0.0066	0.5700	182.9545	0.5605	59.4446	30.2828
109	0.7138	0.0036	0.5735	185.8207	0.5640	60.5726	30.8503
110	0.9886	0.0049	0.5785	189.1576	0.5690	61.7106	31.4242
111	1.2745	0.0064	0.5848	192.9959	0.5753	62.8612	32.0060
112	0.9547	0.0048	0.5896	196.3400	0.5801	64.0215	32.5908
113	1.1804	0.0059	0.5955	200.0920	0.5860	65.1935	33.1827
114	0.9198	0.0046	0.6001	203.4376	0.5906	66.3747	33.7780
115	1.1737	0.0059	0.6060	207.2449	0.5965	67.5677	34.3803
116	0.1685	0.0008	0.6068	209.3536	0.5973	68.7623	34.9785
117	0.3889	0.0019	0.6088	211.8507	0.5993	69.9608	35.5797
118	0.8694	0.0043	0.6131	215.2029	0.6036	71.1680	36.1876
119	0.4011	0.0020	0.6151	217.7522	0.6056	72.3793	36.7953
120	0.5266	0.0026	0.6178	220.5375	0.6083	73.5958	37.4061
121	0.2228	0.0011	0.6189	222.7918	0.6094	74.8145	38.0166
122	1.9331	0.0097	0.6285	228.1569	0.6190	76.0526	38.6453
123	1.5738	0.0079	0.6364	232.9225	0.6269	77.3064	39.2801
124	1.3473	0.0067	0.6431	237.3175	0.6336	78.5736	39.9205
125	1.5879	0.0079	0.6511	242.2003	0.6416	79.8568	40.5700
126	1.5103	0.0076	0.6586	246.9854	0.6491	81.1550	41.2266
127	0.8065	0.0040	0.6627	250.4856	0.6532	82.4614	41.8838
128	0.5867	0.0029	0.6656	253.5912	0.6561	83.7735	42.5429

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
129	0.0619	0.0003	0.6659	255.7069	0.6564	85.0864	43.1996
130	0.7250	0.0036	0.6695	259.1074	0.6600	86.4064	43.8632
131	1.3526	0.0068	0.6763	263.7535	0.6668	87.7400	44.5368
132	0.7898	0.0039	0.6802	267.3344	0.6707	89.0815	45.2115
133	1.0023	0.0050	0.6853	271.3597	0.6758	90.4330	45.8922
134	1.7319	0.0087	0.6939	276.8706	0.6844	91.8018	46.5853
135	1.5919	0.0080	0.7019	282.1521	0.6924	93.1865	47.2856
136	1.0731	0.0054	0.7072	286.4307	0.6977	94.5820	47.9887
137	1.4471	0.0072	0.7145	291.5045	0.7050	95.9919	48.7009
138	0.6901	0.0035	0.7179	295.0660	0.7084	97.4088	49.4128
139	0.9192	0.0046	0.7225	299.1226	0.7130	98.8348	50.1304
140	1.3047	0.0065	0.7290	304.0103	0.7195	100.2739	50.8565
141	1.3918	0.0070	0.7360	309.1203	0.7265	101.7269	51.5899
142	1.0359	0.0052	0.7412	313.5191	0.7317	103.1902	52.3268
143	1.7109	0.0086	0.7497	319.3869	0.7402	104.6707	53.0756
144	1.2952	0.0065	0.7562	324.4144	0.7467	106.1641	53.8288
145	1.0448	0.0052	0.7614	328.9397	0.7519	107.6680	54.5859
146	0.9999	0.0050	0.7664	333.3989	0.7569	109.1819	55.3479
147	1.3992	0.0070	0.7734	338.7625	0.7639	110.7097	56.1188
148	0.4806	0.0024	0.7758	342.1424	0.7663	112.2424	56.8875
149	0.7363	0.0037	0.7795	346.1045	0.7700	113.7824	57.6612
150	1.0041	0.0050	0.7845	350.6871	0.7750	115.3325	58.4413
151	1.3533	0.0068	0.7913	356.0857	0.7818	116.8961	59.2298
152	0.7443	0.0037	0.7950	360.1454	0.7855	118.4671	60.0191
153	1.3438	0.0067	0.8017	365.5943	0.7922	120.0516	60.8180
154	0.1210	0.0006	0.8023	368.2771	0.7928	121.6373	61.6115
155	1.5583	0.0078	0.8101	374.2838	0.8006	123.2386	62.4199
156	0.3342	0.0017	0.8118	377.4913	0.8023	124.8432	63.2239
157	0.6435	0.0032	0.8150	381.4324	0.8055	126.4542	64.0326
158	1.1704	0.0059	0.8209	386.6338	0.8114	128.0770	64.8499
159	1.7552	0.0088	0.8297	393.2563	0.8202	129.7173	65.6788
160	1.9075	0.0095	0.8392	400.2947	0.8297	131.3767	66.5180
161	0.7077	0.0035	0.8427	404.5107	0.8332	133.0431	67.3548
162	0.4406	0.0022	0.8449	408.1029	0.8354	134.7140	68.1924
163	1.6125	0.0081	0.8530	414.5562	0.8435	136.4010	69.0440
164	1.1274	0.0056	0.8586	419.8717	0.8491	138.0993	69.8988
165	0.7686	0.0038	0.8625	424.3384	0.8530	139.8052	70.7556
166	0.9394	0.0047	0.8672	429.2508	0.8577	141.5206	71.6179
167	0.5606	0.0028	0.8700	433.2483	0.8605	143.2415	72.4812
168	0.3215	0.0016	0.8716	436.6636	0.8621	144.9657	73.3449
169	0.4029	0.0020	0.8736	440.2937	0.8641	146.6939	74.2110
170	0.1403	0.0007	0.8743	443.2703	0.8648	148.4235	75.0765
171	0.1040	0.0005	0.8748	446.1584	0.8653	150.1541	75.9424
172	0.7830	0.0039	0.8787	450.7913	0.8692	151.8926	76.8155
173	1.0123	0.0051	0.8838	456.0394	0.8743	153.6412	77.6949

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
174	0.2187	0.0011	0.8849	459.2584	0.8754	155.3919	78.5714
175	0.6186	0.0031	0.8880	463.5276	0.8785	157.1489	79.4529
176	1.5400	0.0077	0.8957	470.2342	0.8862	158.9213	80.3468
177	1.2742	0.0064	0.9021	476.2852	0.8926	160.7064	81.2457
178	1.4436	0.0072	0.9093	482.8241	0.8998	162.5059	82.1527
179	1.9648	0.0098	0.9191	490.7981	0.9096	164.3251	83.0722
180	0.0346	0.0002	0.9193	493.6484	0.9098	166.1447	83.9821
181	0.3359	0.0017	0.9210	497.3132	0.9114	167.9676	84.8952
182	0.0410	0.0002	0.9212	500.1874	0.9117	169.7909	85.8071
183	1.4972	0.0075	0.9286	507.0381	0.9191	171.6291	86.7337
184	1.3445	0.0067	0.9354	513.5148	0.9259	173.4809	87.6663
185	0.5466	0.0027	0.9381	517.8295	0.9286	175.3381	88.5976
186	0.8928	0.0045	0.9426	523.1212	0.9331	177.2042	89.5351
187	1.9912	0.0100	0.9525	531.5043	0.9430	179.0902	90.4881
188	1.6353	0.0082	0.9607	538.9488	0.9512	180.9926	91.4475
189	0.9903	0.0050	0.9656	544.6234	0.9561	182.9049	92.4086
190	1.4073	0.0070	0.9727	551.5101	0.9632	184.8312	93.3788
191	0.7993	0.0040	0.9767	556.7061	0.9672	186.7656	94.3500
192	0.9671	0.0048	0.9815	562.4070	0.9720	188.7096	95.3268
193	0.9781	0.0049	0.9864	568.1685	0.9769	190.6634	96.3086
194	1.6132	0.0081	0.9945	575.7979	0.9850	192.6334	97.3016
195	0.9171	0.0046	0.9991	581.4501	0.9896	194.6125	98.2958
196	1.5249	0.0076	1.0067	588.9076	0.9972	196.6068	99.3006
197	0.3036	0.0015	1.0082	592.8203	0.9987	198.6042	100.3008
198	1.5172	0.0076	1.0158	600.3283	1.0063	200.6168	101.3147
199	0.4254	0.0021	1.0179	604.6390	1.0084	202.6336	102.3252
200	1.6494	0.0082	1.0262	612.6160	1.0167	204.6669	103.3501

Table B-4 Poll Time Data for Nodes Distance Between Master and First Remote = 2 km; All others 1 m Data for Figure 5-4

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
1	1.0000	0.0050	0.0050	0.0000	0.0000	0.0000	0.0000
2	2000.00	10.0000	10.0050	30.0150	10.0000	20.0000	20.0000
3	1.0000	0.0050	10.0100	60.0600	10.0050	40.0100	30.0100
4	1.0000	0.0050	10.0150	90.1350	10.0100	60.0300	40.0250
5	1.0000	0.0050	10.0200	120.2400	10.0150	80.0600	50.0450
6	1.0000	0.0050	10.0250	150.3750	10.0200	100.1000	60.0700
7	1.0000	0.0050	10.0300	180.5400	10.0250	120.1500	70.1000
8	1.0000	0.0050	10.0350	210.7350	10.0300	140.2100	80.1350
9	1.0000	0.0050	10.0400	240.9600	10.0350	160.2800	90.1750
10	1.0000	0.0050	10.0450	271.2150	10.0400	180.3600	100.2200
11	1.0000	0.0050	10.0500	301.5000	10.0450	200.4500	110.2700
12	1.0000	0.0050	10.0550	331.8150	10.0500	220.5500	120.3250
13	1.0000	0.0050	10.0600	362.1600	10.0550	240.6600	130.3850
14	1.0000	0.0050	10.0650	392.5350	10.0600	260.7800	140.4500
15	1.0000	0.0050	10.0700	422.9400	10.0650	280.9100	150.5200
16	1.0000	0.0050	10.0750	453.3750	10.0700	301.0500	160.5950
17	1.0000	0.0050	10.0800	483.8400	10.0750	321.2000	170.6750
18	1.0000	0.0050	10.0850	514.3350	10.0800	341.3600	180.7600
19	1.0000	0.0050	10.0900	544.8600	10.0850	361.5300	190.8500
20	1.0000	0.0050	10.0950	575.4150	10.0900	381.7100	200.9450
21	1.0000	0.0050	10.1000	606.0000	10.0950	401.9000	211.0450
22	1.0000	0.0050	10.1050	636.6150	10.1000	422.1000	221.1500
23	1.0000	0.0050	10.1100	667.2600	10.1050	442.3100	231.2600
24	1.0000	0.0050	10.1150	697.9350	10.1100	462.5300	241.3750
25	1.0000	0.0050	10.1200	728.6400	10.1150	482.7600	251.4950
26	1.0000	0.0050	10.1250	759.3750	10.1200	503.0000	261.6200
27	1.0000	0.0050	10.1300	790.1400	10.1250	523.2500	271.7500
28	1.0000	0.0050	10.1350	820.9350	10.1300	543.5100	281.8850
29	1.0000	0.0050	10.1400	851.7600	10.1350	563.7800	292.0250
30	1.0000	0.0050	10.1450	882.6150	10.1400	584.0600	302.1700
31	1.0000	0.0050	10.1500	913.5000	10.1450	604.3500	312.3200
32	1.0000	0.0050	10.1550	944.4150	10.1500	624.6500	322.4750
33	1.0000	0.0050	10.1600	975.3600	10.1550	644.9600	332.6350
34	1.0000	0.0050	10.1650	1006.3350	10.1600	665.2800	342.8000
35	1.0000	0.0050	10.1700	1037.3400	10.1650	685.6100	352.9700
36	1.0000	0.0050	10.1750	1068.3750	10.1700	705.9500	363.1450
37	1.0000	0.0050	10.1800	1099.4400	10.1750	726.3000	373.3250
38	1.0000	0.0050	10.1850	1130.5350	10.1800	746.6600	383.5100

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
39	1.0000	0.0050	10.1900	1161.6600	10.1850	767.0300	393.7000
40	1.0000	0.0050	10.1950	1192.8150	10.1900	787.4100	403.8950
41	1.0000	0.0050	10.2000	1224.0000	10.1950	807.8000	414.0950
42	1.0000	0.0050	10.2050	1255.2150	10.2000	828.2000	424.3000
43	1.0000	0.0050	10.2100	1286.4600	10.2050	848.6100	434.5100
44	1.0000	0.0050	10.2150	1317.7350	10.2100	869.0300	444.7250
45	1.0000	0.0050	10.2200	1349.0400	10.2150	889.4600	454.9450
46	1.0000	0.0050	10.2250	1380.3750	10.2200	909.9000	465.1700
47	1.0000	0.0050	10.2300	1411.7400	10.2250	930.3500	475.4000
48	1.0000	0.0050	10.2350	1443.1350	10.2300	950.8100	485.6350
49	1.0000	0.0050	10.2400	1474.5600	10.2350	971.2800	495.8750
50	1.0000	0.0050	10.2450	1506.0150	10.2400	991.7600	506.1200
51	1.0000	0.0050	10.2500	1537.5000	10.2450	1012.2500	516.3700
52	1.0000	0.0050	10.2550	1569.0150	10.2500	1032.7500	526.6250
53	1.0000	0.0050	10.2600	1600.5600	10.2550	1053.2600	536.8850
54	1.0000	0.0050	10.2650	1632.1350	10.2600	1073.7800	547.1500
55	1.0000	0.0050	10.2700	1663.7400	10.2650	1094.3100	557.4200
56	1.0000	0.0050	10.2750	1695.3750	10.2700	1114.8500	567.6950
57	1.0000	0.0050	10.2800	1727.0400	10.2750	1135.4000	577.9750
58	1.0000	0.0050	10.2850	1758.7350	10.2800	1155.9600	588.2600
59	1.0000	0.0050	10.2900	1790.4600	10.2850	1176.5300	598.5500
60	1.0000	0.0050	10.2950	1822.2150	10.2900	1197.1100	608.8450
61	1.0000	0.0050	10.3000	1854.0000	10.2950	1217.7000	619.1450
62	1.0000	0.0050	10.3050	1885.8150	10.3000	1238.3000	629.4500
63	1.0000	0.0050	10.3100	1917.6600	10.3050	1258.9100	639.7600
64	1.0000	0.0050	10.3150	1949.5350	10.3100	1279.5300	650.0750
65	1.0000	0.0050	10.3200	1981.4400	10.3150	1300.1600	660.3950
66	1.0000	0.0050	10.3250	2013.3750	10.3200	1320.8000	670.7200
67	1.0000	0.0050	10.3300	2045.3400	10.3250	1341.4500	681.0500
68	1.0000	0.0050	10.3350	2077.3350	10.3300	1362.1100	691.3850
69	1.0000	0.0050	10.3400	2109.3600	10.3350	1382.7800	701.7250
70	1.0000	0.0050	10.3450	2141.4150	10.3400	1403.4600	712.0700
71	1.0000	0.0050	10.3500	2173.5000	10.3450	1424.1500	722.4200
72	1.0000	0.0050	10.3550	2205.6150	10.3500	1444.8500	732.7750
73	1.0000	0.0050	10.3600	2237.7600	10.3550	1465.5600	743.1350
74	1.0000	0.0050	10.3650	2269.9350	10.3600	1486.2800	753.5000
75	1.0000	0.0050	10.3700	2302.1400	10.3650	1507.0100	763.8700
76	1.0000	0.0050	10.3750	2334.3750	10.3700	1527.7500	774.2450
77	1.0000	0.0050	10.3800	2366.6400	10.3750	1548.5000	784.6250
78	1.0000	0.0050	10.3850	2398.9350	10.3800	1569.2600	795.0100
79	1.0000	0.0050	10.3900	2431.2600	10.3850	1590.0300	805.4000
80	1.0000	0.0050	10.3950	2463.6150	10.3900	1610.8100	815.7950
81	1.0000	0.0050	10.4000	2496.0000	10.3950	1631.6000	826.1950
82	1.0000	0.0050	10.4050	2528.4150	10.4000	1652.4000	836.6000
83	1.0000	0.0050	10.4100	2560.8600	10.4050	1673.2100	847.0100

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
84	1.0000	0.0050	10.4150	2593.3350	10.4100	1694.0300	857.4250
85	1.0000	0.0050	10.4200	2625.8400	10.4150	1714.8600	867.8450
86	1.0000	0.0050	10.4250	2658.3750	10.4200	1735.7000	878.2700
87	1.0000	0.0050	10.4300	2690.9400	10.4250	1756.5500	888.7000
88	1.0000	0.0050	10.4350	2723.5350	10.4300	1777.4100	899.1350
89	1.0000	0.0050	10.4400	2756.1600	10.4350	1798.2800	909.5750
90	1.0000	0.0050	10.4450	2788.8150	10.4400	1819.1600	920.0200
91	1.0000	0.0050	10.4500	2821.5000	10.4450	1840.0500	930.4700
92	1.0000	0.0050	10.4550	2854.2150	10.4500	1860.9500	940.9250
93	1.0000	0.0050	10.4600	2886.9600	10.4550	1881.8600	951.3850
94	1.0000	0.0050	10.4650	2919.7350	10.4600	1902.7800	961.8500
95	1.0000	0.0050	10.4700	2952.5400	10.4650	1923.7100	972.3200
96	1.0000	0.0050	10.4750	2985.3750	10.4700	1944.6500	982.7950
97	1.0000	0.0050	10.4800	3018.2400	10.4750	1965.6000	993.2750
98	1.0000	0.0050	10.4850	3051.1350	10.4800	1986.5600	1003.7600
99	1.0000	0.0050	10.4900	3084.0600	10.4850	2007.5300	1014.2500
100	1.0000	0.0050	10.4950	3117.0150	10.4900	2028.5100	1024.7450
101	1.0000	0.0050	10.5000	3150.0000	10.4950	2049.5000	1035.2450
102	1.0000	0.0050	10.5050	3183.0150	10.5000	2070.5000	1045.7500
103	1.0000	0.0050	10.5100	3216.0600	10.5050	2091.5100	1056.2600
104	1.0000	0.0050	10.5150	3249.1350	10.5100	2112.5300	1066.7750
105	1.0000	0.0050	10.5200	3282.2400	10.5150	2133.5600	1077.2950
106	1.0000	0.0050	10.5250	3315.3750	10.5200	2154.6000	1087.8200
107	1.0000	0.0050	10.5300	3348.5400	10.5250	2175.6500	1098.3500
108	1.0000	0.0050	10.5350	3381.7350	10.5300	2196.7100	1108.8850
109	1.0000	0.0050	10.5400	3414.9600	10.5350	2217.7800	1119.4250
110	1.0000	0.0050	10.5450	3448.2150	10.5400	2238.8600	1129.9700
111	1.0000	0.0050	10.5500	3481.5000	10.5450	2259.9500	1140.5200
112	1.0000	0.0050	10.5550	3514.8150	10.5500	2281.0500	1151.0750
113	1.0000	0.0050	10.5600	3548.1600	10.5550	2302.1600	1161.6350
114	1.0000	0.0050	10.5650	3581.5350	10.5600	2323.2800	1172.2000
115	1.0000	0.0050	10.5700	3614.9400	10.5650	2344.4100	1182.7700
116	1.0000	0.0050	10.5750	3648.3750	10.5700	2365.5500	1193.3450
117	1.0000	0.0050	10.5800	3681.8400	10.5750	2386.7000	1203.9250
118	1.0000	0.0050	10.5850	3715.3350	10.5800	2407.8600	1214.5100
119	1.0000	0.0050	10.5900	3748.8600	10.5850	2429.0300	1225.1000
120	1.0000	0.0050	10.5950	3782.4150	10.5900	2450.2100	1235.6950
121	1.0000	0.0050	10.6000	3816.0000	10.5950	2471.4000	1246.2950
122	1.0000	0.0050	10.6050	3849.6150	10.6000	2492.6000	1256.9000
123	1.0000	0.0050	10.6100	3883.2600	10.6050	2513.8100	1267.5100
124	1.0000	0.0050	10.6150	3916.9350	10.6100	2535.0300	1278.1250
125	1.0000	0.0050	10.6200	3950.6400	10.6150	2556.2600	1288.7450
126	1.0000	0.0050	10.6250	3984.3750	10.6200	2577.5000	1299.3700
127	1.0000	0.0050	10.6300	4018.1400	10.6250	2598.7500	1310.0000
128	1.0000	0.0050	10.6350	4051.9350	10.6300	2620.0100	1320.6350

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
129	1.0000	0.0050	10.6400	4085.7600	10.6350	2641.2800	1331.2750
130	1.0000	0.0050	10.6450	4119.6150	10.6400	2662.5600	1341.9200
131	1.0000	0.0050	10.6500	4153.5000	10.6450	2683.8500	1352.5700
132	1.0000	0.0050	10.6550	4187.4150	10.6500	2705.1500	1363.2250
133	1.0000	0.0050	10.6600	4221.3600	10.6550	2726.4600	1373.8850
134	1.0000	0.0050	10.6650	4255.3350	10.6600	2747.7800	1384.5500
135	1.0000	0.0050	10.6700	4289.3400	10.6650	2769.1100	1395.2200
136	1.0000	0.0050	10.6750	4323.3750	10.6700	2790.4500	1405.8950
137	1.0000	0.0050	10.6800	4357.4400	10.6750	2811.8000	1416.5750
138	1.0000	0.0050	10.6850	4391.5350	10.6800	2833.1600	1427.2600
139	1.0000	0.0050	10.6900	4425.6600	10.6850	2854.5300	1437.9500
140	1.0000	0.0050	10.6950	4459.8150	10.6900	2875.9100	1448.6450
141	1.0000	0.0050	10.7000	4494.0000	10.6950	2897.3000	1459.3450
142	1.0000	0.0050	10.7050	4528.2150	10.7000	2918.7000	1470.0500
143	1.0000	0.0050	10.7100	4562.4600	10.7050	2940.1100	1480.7600
144	1.0000	0.0050	10.7150	4596.7350	10.7100	2961.5300	1491.4750
145	1.0000	0.0050	10.7200	4631.0400	10.7150	2982.9600	1502.1950
146	1.0000	0.0050	10.7250	4665.3750	10.7200	3004.4000	1512.9200
147	1.0000	0.0050	10.7300	4699.7400	10.7250	3025.8500	1523.6500
148	1.0000	0.0050	10.7350	4734.1350	10.7300	3047.3100	1534.3850
149	1.0000	0.0050	10.7400	4768.5600	10.7350	3068.7800	1545.1250
150	1.0000	0.0050	10.7450	4803.0150	10.7400	3090.2600	1555.8700
151	1.0000	0.0050	10.7500	4837.5000	10.7450	3111.7500	1566.6200
152	1.0000	0.0050	10.7550	4872.0150	10.7500	3133.2500	1577.3750
153	1.0000	0.0050	10.7600	4906.5600	10.7550	3154.7600	1588.1350
154	1.0000	0.0050	10.7650	4941.1350	10.7600	3176.2800	1598.9000
155	1.0000	0.0050	10.7700	4975.7400	10.7650	3197.8100	1609.6700
156	1.0000	0.0050	10.7750	5010.3750	10.7700	3219.3500	1620.4450
157	1.0000	0.0050	10.7800	5045.0400	10.7750	3240.9000	1631.2250
158	1.0000	0.0050	10.7850	5079.7350	10.7800	3262.4600	1642.0100
159	1.0000	0.0050	10.7900	5114.4600	10.7850	3284.0300	1652.8000
160	1.0000	0.0050	10.7950	5149.2150	10.7900	3305.6100	1663.5950
161	1.0000	0.0050	10.8000	5184.0000	10.7950	3327.2000	1674.3950
162	1.0000	0.0050	10.8050	5218.8150	10.8000	3348.8000	1685.2000
163	1.0000	0.0050	10.8100	5253.6600	10.8050	3370.4100	1696.0100
164	1.0000	0.0050	10.8150	5288.5350	10.8100	3392.0300	1706.8250
165	1.0000	0.0050	10.8200	5323.4400	10.8150	3413.6600	1717.6450
166	1.0000	0.0050	10.8250	5358.3750	10.8200	3435.3000	1728.4700
167	1.0000	0.0050	10.8300	5393.3400	10.8250	3456.9500	1739.3000
168	1.0000	0.0050	10.8350	5428.3350	10.8300	3478.6100	1750.1350
169	1.0000	0.0050	10.8400	5463.3600	10.8350	3500.2800	1760.9750
170	1.0000	0.0050	10.8450	5498.4150	10.8400	3521.9600	1771.8200
171	1.0000	0.0050	10.8500	5533.5000	10.8450	3543.6500	1782.6700
172	1.0000	0.0050	10.8550	5568.6150	10.8500	3565.3500	1793.5250
173	1.0000	0.0050	10.8600	5603.7600	10.8550	3587.0600	1804.3850

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
174	1.0000	0.0050	10.8650	5638.9350	10.8600	3608.7800	1815.2500
175	1.0000	0.0050	10.8700	5674.1400	10.8650	3630.5100	1826.1200
176	1.0000	0.0050	10.8750	5709.3750	10.8700	3652.2500	1836.9950
177	1.0000	0.0050	10.8800	5744.6400	10.8750	3674.0000	1847.8750
178	1.0000	0.0050	10.8850	5779.9350	10.8800	3695.7600	1858.7600
179	1.0000	0.0050	10.8900	5815.2600	10.8850	3717.5300	1869.6500
180	1.0000	0.0050	10.8950	5850.6150	10.8900	3739.3100	1880.5450
181	1.0000	0.0050	10.9000	5886.0000	10.8950	3761.1000	1891.4450
182	1.0000	0.0050	10.9050	5921.4150	10.9000	3782.9000	1902.3500
183	1.0000	0.0050	10.9100	5956.8600	10.9050	3804.7100	1913.2600
184	1.0000	0.0050	10.9150	5992.3350	10.9100	3826.5300	1924.1750
185	1.0000	0.0050	10.9200	6027.8400	10.9150	3848.3600	1935.0950
186	1.0000	0.0050	10.9250	6063.3750	10.9200	3870.2000	1946.0200
187	1.0000	0.0050	10.9300	6098.9400	10.9250	3892.0500	1956.9500
188	1.0000	0.0050	10.9350	6134.5350	10.9300	3913.9100	1967.8850
189	1.0000	0.0050	10.9400	6170.1600	10.9350	3935.7800	1978.8250
190	1.0000	0.0050	10.9450	6205.8150	10.9400	3957.6600	1989.7700
191	1.0000	0.0050	10.9500	6241.5000	10.9450	3979.5500	2000.7200
192	1.0000	0.0050	10.9550	6277.2150	10.9500	4001.4500	2011.6750
193	1.0000	0.0050	10.9600	6312.9600	10.9550	4023.3600	2022.6350
194	1.0000	0.0050	10.9650	6348.7350	10.9600	4045.2800	2033.6000
195	1.0000	0.0050	10.9700	6384.5400	10.9650	4067.2100	2044.5700
196	1.0000	0.0050	10.9750	6420.3750	10.9700	4089.1500	2055.5450
197	1.0000	0.0050	10.9800	6456.2400	10.9750	4111.1000	2066.5250
198	1.0000	0.0050	10.9850	6492.1350	10.9800	4133.0600	2077.5100
199	1.0000	0.0050	10.9900	6528.0600	10.9850	4155.0300	2088.5000
200	1.0000	0.0050	10.9950	6564.0150	10.9900	4177.0100	2099.4950

Table B-5 Poll Time Data for Nodes Distance Between Master and Last Remote = 2 km; All others 1 m Data for Figure 5-5

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
1	2000.00	10.0000	10.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	0.0050	10.0050	30.0150	0.0050	0.0100	0.0100
3	1.0000	0.0050	10.0100	60.0600	0.0100	0.0300	0.0250
4	1.0000	0.0050	10.0150	90.1350	0.0150	0.0600	0.0450
5	1.0000	0.0050	10.0200	120.2400	0.0200	0.1000	0.0700
6	1.0000	0.0050	10.0250	150.3750	0.0250	0.1500	0.1000
7	1.0000	0.0050	10.0300	180.5400	0.0300	0.2100	0.1350
8	1.0000	0.0050	10.0350	210.7350	0.0350	0.2800	0.1750
9	1.0000	0.0050	10.0400	240.9600	0.0400	0.3600	0.2200
10	1.0000	0.0050	10.0450	271.2150	0.0450	0.4500	0.2700
11	1.0000	0.0050	10.0500	301.5000	0.0500	0.5500	0.3250
12	1.0000	0.0050	10.0550	331.8150	0.0550	0.6600	0.3850
13	1.0000	0.0050	10.0600	362.1600	0.0600	0.7800	0.4500
14	1.0000	0.0050	10.0650	392.5350	0.0650	0.9100	0.5200
15	1.0000	0.0050	10.0700	422.9400	0.0700	1.0500	0.5950
16	1.0000	0.0050	10.0750	453.3750	0.0750	1.2000	0.6750
17	1.0000	0.0050	10.0800	483.8400	0.0800	1.3600	0.7600
18	1.0000	0.0050	10.0850	514.3350	0.0850	1.5300	0.8500
19	1.0000	0.0050	10.0900	544.8600	0.0900	1.7100	0.9450
20	1.0000	0.0050	10.0950	575.4150	0.0950	1.9000	1.0450
21	1.0000	0.0050	10.1000	606.0000	0.1000	2.1000	1.1500
22	1.0000	0.0050	10.1050	636.6150	0.1050	2.3100	1.2600
23	1.0000	0.0050	10.1100	667.2600	0.1100	2.5300	1.3750
24	1.0000	0.0050	10.1150	697.9350	0.1150	2.7600	1.4950
25	1.0000	0.0050	10.1200	728.6400	0.1200	3.0000	1.6200
26	1.0000	0.0050	10.1250	759.3750	0.1250	3.2500	1.7500
27	1.0000	0.0050	10.1300	790.1400	0.1300	3.5100	1.8850
28	1.0000	0.0050	10.1350	820.9350	0.1350	3.7800	2.0250
29	1.0000	0.0050	10.1400	851.7600	0.1400	4.0600	2.1700
30	1.0000	0.0050	10.1450	882.6150	0.1450	4.3500	2.3200
31	1.0000	0.0050	10.1500	913.5000	0.1500	4.6500	2.4750
32	1.0000	0.0050	10.1550	944.4150	0.1550	4.9600	2.6350
33	1.0000	0.0050	10.1600	975.3600	0.1600	5.2800	2.8000
34	1.0000	0.0050	10.1650	1006.3350	0.1650	5.6100	2.9700
35	1.0000	0.0050	10.1700	1037.3400	0.1700	5.9500	3.1450
36	1.0000	0.0050	10.1750	1068.3750	0.1750	6.3000	3.3250
37	1.0000	0.0050	10.1800	1099.4400	0.1800	6.6600	3.5100
38	1.0000	0.0050	10.1850	1130.5350	0.1850	7.0300	3.7000

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
39	1.0000	0.0050	10.1900	1161.6600	0.1900	7.4100	3.8950
40	1.0000	0.0050	10.1950	1192.8150	0.1950	7.8000	4.0950
41	1.0000	0.0050	10.2000	1224.0000	0.2000	8.2000	4.3000
42	1.0000	0.0050	10.2050	1255.2150	0.2050	8.6100	4.5100
43	1.0000	0.0050	10.2100	1286.4600	0.2100	9.0300	4.7250
44	1.0000	0.0050	10.2150	1317.7350	0.2150	9.4600	4.9450
45	1.0000	0.0050	10.2200	1349.0400	0.2200	9.9000	5.1700
46	1.0000	0.0050	10.2250	1380.3750	0.2250	10.3500	5.4000
47	1.0000	0.0050	10.2300	1411.7400	0.2300	10.8100	5.6350
48	1.0000	0.0050	10.2350	1443.1350	0.2350	11.2800	5.8750
49	1.0000	0.0050	10.2400	1474.5600	0.2400	11.7600	6.1200
50	1.0000	0.0050	10.2450	1506.0150	0.2450	12.2500	6.3700
51	1.0000	0.0050	10.2500	1537.5000	0.2500	12.7500	6.6250
52	1.0000	0.0050	10.2550	1569.0150	0.2550	13.2600	6.8850
53	1.0000	0.0050	10.2600	1600.5600	0.2600	13.7800	7.1500
54	1.0000	0.0050	10.2650	1632.1350	0.2650	14.3100	7.4200
55	1.0000	0.0050	10.2700	1663.7400	0.2700	14.8500	7.6950
56	1.0000	0.0050	10.2750	1695.3750	0.2750	15.4000	7.9750
57	1.0000	0.0050	10.2800	1727.0400	0.2800	15.9600	8.2600
58	1.0000	0.0050	10.2850	1758.7350	0.2850	16.5300	8.5500
59	1.0000	0.0050	10.2900	1790.4600	0.2900	17.1100	8.8450
60	1.0000	0.0050	10.2950	1822.2150	0.2950	17.7000	9.1450
61	1.0000	0.0050	10.3000	1854.0000	0.3000	18.3000	9.4500
62	1.0000	0.0050	10.3050	1885.8150	0.3050	18.9100	9.7600
63	1.0000	0.0050	10.3100	1917.6600	0.3100	19.5300	10.0750
64	1.0000	0.0050	10.3150	1949.5350	0.3150	20.1600	10.3950
65	1.0000	0.0050	10.3200	1981.4400	0.3200	20.8000	10.7200
66	1.0000	0.0050	10.3250	2013.3750	0.3250	21.4500	11.0500
67	1.0000	0.0050	10.3300	2045.3400	0.3300	22.1100	11.3850
68	1.0000	0.0050	10.3350	2077.3350	0.3350	22.7800	11.7250
69	1.0000	0.0050	10.3400	2109.3600	0.3400	23.4600	12.0700
70	1.0000	0.0050	10.3450	2141.4150	0.3450	24.1500	12.4200
71	1.0000	0.0050	10.3500	2173.5000	0.3500	24.8500	12.7750
72	1.0000	0.0050	10.3550	2205.6150	0.3550	25.5600	13.1350
73	1.0000	0.0050	10.3600	2237.7600	0.3600	26.2800	13.5000
74	1.0000	0.0050	10.3650	2269.9350	0.3650	27.0100	13.8700
75	1.0000	0.0050	10.3700	2302.1400	0.3700	27.7500	14.2450
76	1.0000	0.0050	10.3750	2334.3750	0.3750	28.5000	14.6250
77	1.0000	0.0050	10.3800	2366.6400	0.3800	29.2600	15.0100
78	1.0000	0.0050	10.3850	2398.9350	0.3850	30.0300	15.4000
79	1.0000	0.0050	10.3900	2431.2600	0.3900	30.8100	15.7950
80	1.0000	0.0050	10.3950	2463.6150	0.3950	31.6000	16.1950
81	1.0000	0.0050	10.4000	2496.0000	0.4000	32.4000	16.6000
82	1.0000	0.0050	10.4050	2528.4150	0.4050	33.2100	17.0100
83	1.0000	0.0050	10.4100	2560.8600	0.4100	34.0300	17.4250

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
84	1.0000	0.0050	10.4150	2593.3350	0.4150	34.8600	17.8450
85	1.0000	0.0050	10.4200	2625.8400	0.4200	35.7000	18.2700
86	1.0000	0.0050	10.4250	2658.3750	0.4250	36.5500	18.7000
87	1.0000	0.0050	10.4300	2690.9400	0.4300	37.4100	19.1350
88	1.0000	0.0050	10.4350	2723.5350	0.4350	38.2800	19.5750
89	1.0000	0.0050	10.4400	2756.1600	0.4400	39.1600	20.0200
90	1.0000	0.0050	10.4450	2788.8150	0.4450	40.0500	20.4700
91	1.0000	0.0050	10.4500	2821.5000	0.4500	40.9500	20.9250
92	1.0000	0.0050	10.4550	2854.2150	0.4550	41.8600	21.3850
93	1.0000	0.0050	10.4600	2886.9600	0.4600	42.7800	21.8500
94	1.0000	0.0050	10.4650	2919.7350	0.4650	43.7100	22.3200
95	1.0000	0.0050	10.4700	2952.5400	0.4700	44.6500	22.7950
96	1.0000	0.0050	10.4750	2985.3750	0.4750	45.6000	23.2750
97	1.0000	0.0050	10.4800	3018.2400	0.4800	46.5600	23.7600
98	1.0000	0.0050	10.4850	3051.1350	0.4850	47.5300	24.2500
99	1.0000	0.0050	10.4900	3084.0600	0.4900	48.5100	24.7450
100	1.0000	0.0050	10.4950	3117.0150	0.4950	49.5000	25.2450
101	1.0000	0.0050	10.5000	3150.0000	0.5000	50.5000	25.7500
102	1.0000	0.0050	10.5050	3183.0150	0.5050	51.5100	26.2600
103	1.0000	0.0050	10.5100	3216.0600	0.5100	52.5300	26.7750
104	1.0000	0.0050	10.5150	3249.1350	0.5150	53.5600	27.2950
105	1.0000	0.0050	10.5200	3282.2400	0.5200	54.6000	27.8200
106	1.0000	0.0050	10.5250	3315.3750	0.5250	55.6500	28.3500
107	1.0000	0.0050	10.5300	3348.5400	0.5300	56.7100	28.8850
108	1.0000	0.0050	10.5350	3381.7350	0.5350	57.7800	29.4250
109	1.0000	0.0050	10.5400	3414.9600	0.5400	58.8600	29.9700
110	1.0000	0.0050	10.5450	3448.2150	0.5450	59.9500	30.5200
111	1.0000	0.0050	10.5500	3481.5000	0.5500	61.0500	31.0750
112	1.0000	0.0050	10.5550	3514.8150	0.5550	62.1600	31.6350
113	1.0000	0.0050	10.5600	3548.1600	0.5600	63.2800	32.2000
114	1.0000	0.0050	10.5650	3581.5350	0.5650	64.4100	32.7700
115	1.0000	0.0050	10.5700	3614.9400	0.5700	65.5500	33.3450
116	1.0000	0.0050	10.5750	3648.3750	0.5750	66.7000	33.9250
117	1.0000	0.0050	10.5800	3681.8400	0.5800	67.8600	34.5100
118	1.0000	0.0050	10.5850	3715.3350	0.5850	69.0300	35.1000
119	1.0000	0.0050	10.5900	3748.8600	0.5900	70.2100	35.6950
120	1.0000	0.0050	10.5950	3782.4150	0.5950	71.4000	36.2950
121	1.0000	0.0050	10.6000	3816.0000	0.6000	72.6000	36.9000
122	1.0000	0.0050	10.6050	3849.6150	0.6050	73.8100	37.5100
123	1.0000	0.0050	10.6100	3883.2600	0.6100	75.0300	38.1250
124	1.0000	0.0050	10.6150	3916.9350	0.6150	76.2600	38.7450
125	1.0000	0.0050	10.6200	3950.6400	0.6200	77.5000	39.3700
126	1.0000	0.0050	10.6250	3984.3750	0.6250	78.7500	40.0000
127	1.0000	0.0050	10.6300	4018.1400	0.6300	80.0100	40.6350
128	1.0000	0.0050	10.6350	4051.9350	0.6350	81.2800	41.2750

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
129	1.0000	0.0050	10.6400	4085.7600	0.6400	82.5600	41.9200
130	1.0000	0.0050	10.6450	4119.6150	0.6450	83.8500	42.5700
131	1.0000	0.0050	10.6500	4153.5000	0.6500	85.1500	43.2250
132	1.0000	0.0050	10.6550	4187.4150	0.6550	86.4600	43.8850
133	1.0000	0.0050	10.6600	4221.3600	0.6600	87.7800	44.5500
134	1.0000	0.0050	10.6650	4255.3350	0.6650	89.1100	45.2200
135	1.0000	0.0050	10.6700	4289.3400	0.6700	90.4500	45.8950
136	1.0000	0.0050	10.6750	4323.3750	0.6750	91.8000	46.5750
137	1.0000	0.0050	10.6800	4357.4400	0.6800	93.1600	47.2600
138	1.0000	0.0050	10.6850	4391.5350	0.6850	94.5300	47.9500
139	1.0000	0.0050	10.6900	4425.6600	0.6900	95.9100	48.6450
140	1.0000	0.0050	10.6950	4459.8150	0.6950	97.3000	49.3450
141	1.0000	0.0050	10.7000	4494.0000	0.7000	98.7000	50.0500
142	1.0000	0.0050	10.7050	4528.2150	0.7050	100.1100	50.7600
143	1.0000	0.0050	10.7100	4562.4600	0.7100	101.5300	51.4750
144	1.0000	0.0050	10.7150	4596.7350	0.7150	102.9600	52.1950
145	1.0000	0.0050	10.7200	4631.0400	0.7200	104.4000	52.9200
146	1.0000	0.0050	10.7250	4665.3750	0.7250	105.8500	53.6500
147	1.0000	0.0050	10.7300	4699.7400	0.7300	107.3100	54.3850
148	1.0000	0.0050	10.7350	4734.1350	0.7350	108.7800	55.1250
149	1.0000	0.0050	10.7400	4768.5600	0.7400	110.2600	55.8700
150	1.0000	0.0050	10.7450	4803.0150	0.7450	111.7500	56.6200
151	1.0000	0.0050	10.7500	4837.5000	0.7500	113.2500	57.3750
152	1.0000	0.0050	10.7550	4872.0150	0.7550	114.7600	58.1350
153	1.0000	0.0050	10.7600	4906.5600	0.7600	116.2800	58.9000
154	1.0000	0.0050	10.7650	4941.1350	0.7650	117.8100	59.6700
155	1.0000	0.0050	10.7700	4975.7400	0.7700	119.3500	60.4450
156	1.0000	0.0050	10.7750	5010.3750	0.7750	120.9000	61.2250
157	1.0000	0.0050	10.7800	5045.0400	0.7800	122.4600	62.0100
158	1.0000	0.0050	10.7850	5079.7350	0.7850	124.0300	62.8000
159	1.0000	0.0050	10.7900	5114.4600	0.7900	125.6100	63.5950
160	1.0000	0.0050	10.7950	5149.2150	0.7950	127.2000	64.3950
161	1.0000	0.0050	10.8000	5184.0000	0.8000	128.8000	65.2000
162	1.0000	0.0050	10.8050	5218.8150	0.8050	130.4100	66.0100
163	1.0000	0.0050	10.8100	5253.6600	0.8100	132.0300	66.8250
164	1.0000	0.0050	10.8150	5288.5350	0.8150	133.6600	67.6450
165	1.0000	0.0050	10.8200	5323.4400	0.8200	135.3000	68.4700
166	1.0000	0.0050	10.8250	5358.3750	0.8250	136.9500	69.3000
167	1.0000	0.0050	10.8300	5393.3400	0.8300	138.6100	70.1350
168	1.0000	0.0050	10.8350	5428.3350	0.8350	140.2800	70.9750
169	1.0000	0.0050	10.8400	5463.3600	0.8400	141.9600	71.8200
170	1.0000	0.0050	10.8450	5498.4150	0.8450	143.6500	72.6700
171	1.0000	0.0050	10.8500	5533.5000	0.8500	145.3500	73.5250
172	1.0000	0.0050	10.8550	5568.6150	0.8550	147.0600	74.3850
173	1.0000	0.0050	10.8600	5603.7600	0.8600	148.7800	75.2500

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
174	1.0000	0.0050	10.8650	5638.9350	0.8650	150.5100	76.1200
175	1.0000	0.0050	10.8700	5674.1400	0.8700	152.2500	76.9950
176	1.0000	0.0050	10.8750	5709.3750	0.8750	154.0000	77.8750
177	1.0000	0.0050	10.8800	5744.6400	0.8800	155.7600	78.7600
178	1.0000	0.0050	10.8850	5779.9350	0.8850	157.5300	79.6500
179	1.0000	0.0050	10.8900	5815.2600	0.8900	159.3100	80.5450
180	1.0000	0.0050	10.8950	5850.6150	0.8950	161.1000	81.4450
181	1.0000	0.0050	10.9000	5886.0000	0.9000	162.9000	82.3500
182	1.0000	0.0050	10.9050	5921.4150	0.9050	164.7100	83.2600
183	1.0000	0.0050	10.9100	5956.8600	0.9100	166.5300	84.1750
184	1.0000	0.0050	10.9150	5992.3350	0.9150	168.3600	85.0950
185	1.0000	0.0050	10.9200	6027.8400	0.9200	170.2000	86.0200
186	1.0000	0.0050	10.9250	6063.3750	0.9250	172.0500	86.9500
187	1.0000	0.0050	10.9300	6098.9400	0.9300	173.9100	87.8850
188	1.0000	0.0050	10.9350	6134.5350	0.9350	175.7800	88.8250
189	1.0000	0.0050	10.9400	6170.1600	0.9400	177.6600	89.7700
190	1.0000	0.0050	10.9450	6205.8150	0.9450	179.5500	90.7200
191	1.0000	0.0050	10.9500	6241.5000	0.9500	181.4500	91.6750
192	1.0000	0.0050	10.9550	6277.2150	0.9550	183.3600	92.6350
193	1.0000	0.0050	10.9600	6312.9600	0.9600	185.2800	93.6000
194	1.0000	0.0050	10.9650	6348.7350	0.9650	187.2100	94.5700
195	1.0000	0.0050	10.9700	6384.5400	0.9700	189.1500	95.5450
196	1.0000	0.0050	10.9750	6420.3750	0.9750	191.1000	96.5250
197	1.0000	0.0050	10.9800	6456.2400	0.9800	193.0600	97.5100
198	1.0000	0.0050	10.9850	6492.1350	0.9850	195.0300	98.5000
199	1.0000	0.0050	10.9900	6528.0600	0.9900	197.0100	99.4950
200	1.0000	0.0050	10.9950	6564.0150	0.9950	199.0000	100.4950

Table B-6 Poll Time Data for Nodes Spaced at 1 km With a Fiber Break Data for Figure 5-6

Nodes	Distance (km) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (ms)	Total Time (us) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	5.0000	10.0000	0.0300	5.0000	0.0100	0.0100
3	1.0000	5.0000	20.0000	0.1200	10.0000	0.0300	0.0250
4	1.0000	5.0000	30.0000	0.2700	15.0000	0.0600	0.0450
5	1.0000	5.0000	40.0000	0.4800	20.0000	0.1000	0.0700
6	1.0000	5.0000	50.0000	0.7500	25.0000	0.1500	0.1000
7	1.0000	5.0000	60.0000	1.0800	30.0000	0.2100	0.1350
8	1.0000	5.0000	70.0000	1.4700	35.0000	0.2800	0.1750
9	1.0000	5.0000	80.0000	1.9200	40.0000	0.3600	0.2200
10	1.0000	5.0000	90.0000	2.4300	45.0000	0.4500	0.2700
11	1.0000	5.0000	100.0000	3.0000	50.0000	0.5500	0.3250
12	1.0000	5.0000	110.0000	3.6300	55.0000	0.6600	0.3850
13	1.0000	5.0000	120.0000	4.3200	60.0000	0.7800	0.4500
14	1.0000	5.0000	130.0000	5.0700	65.0000	0.9100	0.5200
15	1.0000	5.0000	140.0000	5.8800	70.0000	1.0500	0.5950
16	1.0000	5.0000	150.0000	6.7500	75.0000	1.2000	0.6750
17	1.0000	5.0000	160.0000	7.6800	80.0000	1.3600	0.7600
18	1.0000	5.0000	170.0000	8.6700	85.0000	1.5300	0.8500
19	1.0000	5.0000	180.0000	9.7200	90.0000	1.7100	0.9450
20	1.0000	5.0000	190.0000	10.8300	95.0000	1.9000	1.0450
21	1.0000	5.0000	200.0000	12.0000	100.0000	2.1000	1.1500
22	1.0000	5.0000	210.0000	13.2300	105.0000	2.3100	1.2600
23	1.0000	5.0000	220.0000	14.5200	110.0000	2.5300	1.3750
24	1.0000	5.0000	230.0000	15.8700	115.0000	2.7600	1.4950
25	1.0000	5.0000	240.0000	17.2800	120.0000	3.0000	1.6200
26	1.0000	5.0000	250.0000	18.7500	125.0000	3.2500	1.7500
27	1.0000	5.0000	260.0000	20.2800	130.0000	3.5100	1.8850
28	1.0000	5.0000	270.0000	21.8700	135.0000	3.7800	2.0250
29	1.0000	5.0000	280.0000	23.5200	140.0000	4.0600	2.1700
30	1.0000	5.0000	290.0000	25.2300	145.0000	4.3500	2.3200
31	1.0000	5.0000	300.0000	27.0000	150.0000	4.6500	2.4750
32	1.0000	5.0000	310.0000	28.8300	155.0000	4.9600	2.6350
33	1.0000	5.0000	320.0000	30.7200	160.0000	5.2800	2.8000
34	1.0000	5.0000	330.0000	32.6700	165.0000	5.6100	2.9700
35	1.0000	5.0000	340.0000	34.6800	170.0000	5.9500	3.1450
36	1.0000	5.0000	350.0000	36.7500	175.0000	6.3000	3.3250
37	1.0000	5.0000	360.0000	38.8800	180.0000	6.6600	3.5100
38	1.0000	5.0000	370.0000	41.0700	185.0000	7.0300	3.7000

Nodes	Distance (km) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (ms)	Total Time (us) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
39	1.0000	5.0000	380.0000	43.3200	190.0000	7.4100	3.8950
40	1.0000	5.0000	390.0000	45.6300	195.0000	7.8000	4.0950
41	1.0000	5.0000	400.0000	48.0000	200.0000	8.2000	4.3000
42	1.0000	5.0000	410.0000	50.4300	205.0000	8.6100	4.5100
43	1.0000	5.0000	420.0000	52.9200	210.0000	9.0300	4.7250
44	1.0000	5.0000	430.0000	55.4700	215.0000	9.4600	4.9450
45	1.0000	5.0000	440.0000	58.0800	220.0000	9.9000	5.1700
46	1.0000	5.0000	450.0000	60.7500	225.0000	10.3500	5.4000
47	1.0000	5.0000	460.0000	63.4800	230.0000	10.8100	5.6350
48	1.0000	5.0000	470.0000	66.2700	235.0000	11.2800	5.8750
49	1.0000	5.0000	480.0000	69.1200	240.0000	11.7600	6.1200
50	1.0000	5.0000	490.0000	72.0300	245.0000	12.2500	6.3700
51	1.0000	5.0000	500.0000	75.0000	250.0000	12.7500	6.6250
52	1.0000	5.0000	510.0000	78.0300	255.0000	13.2600	6.8850
53	1.0000	5.0000	520.0000	81.1200	260.0000	13.7800	7.1500
54	1.0000	5.0000	530.0000	84.2700	265.0000	14.3100	7.4200
55	1.0000	5.0000	540.0000	87.4800	270.0000	14.8500	7.6950
56	1.0000	5.0000	550.0000	90.7500	275.0000	15.4000	7.9750
57	1.0000	5.0000	560.0000	94.0800	280.0000	15.9600	8.2600
58	1.0000	5.0000	570.0000	97.4700	285.0000	16.5300	8.5500
59	1.0000	5.0000	580.0000	100.9200	290.0000	17.1100	8.8450
60	1.0000	5.0000	590.0000	104.4300	295.0000	17.7000	9.1450
61	1.0000	5.0000	600.0000	108.0000	300.0000	18.3000	9.4500
62	1.0000	5.0000	610.0000	111.6300	305.0000	18.9100	9.7600
63	1.0000	5.0000	620.0000	115.3200	310.0000	19.5300	10.0750
64	1.0000	5.0000	630.0000	119.0700	315.0000	20.1600	10.3950
65	1.0000	5.0000	640.0000	122.8800	320.0000	20.8000	10.7200
66	1.0000	5.0000	650.0000	126.7500	325.0000	21.4500	11.0500
67	1.0000	5.0000	660.0000	130.6800	330.0000	22.1100	11.3850
68	1.0000	5.0000	670.0000	134.6700	335.0000	22.7800	11.7250
69	1.0000	5.0000	680.0000	138.7200	340.0000	23.4600	12.0700
70	1.0000	5.0000	690.0000	142.8300	345.0000	24.1500	12.4200
71	1.0000	5.0000	700.0000	147.0000	350.0000	24.8500	12.7750
72	1.0000	5.0000	710.0000	151.2300	355.0000	25.5600	13.1350
73	1.0000	5.0000	720.0000	155.5200	360.0000	26.2800	13.5000
74	1.0000	5.0000	730.0000	159.8700	365.0000	27.0100	13.8700
75	1.0000	5.0000	740.0000	164.2800	370.0000	27.7500	14.2450
76	1.0000	5.0000	750.0000	168.7500	375.0000	28.5000	14.6250
77	1.0000	5.0000	760.0000	173.2800	380.0000	29.2600	15.0100
78	1.0000	5.0000	770.0000	177.8700	385.0000	30.0300	15.4000
79	1.0000	5.0000	780.0000	182.5200	390.0000	30.8100	15.7950
80	1.0000	5.0000	790.0000	187.2300	395.0000	31.6000	16.1950
81	1.0000	5.0000	800.0000	192.0000	400.0000	32.4000	16.6000
82	1.0000	5.0000	810.0000	196.8300	405.0000	33.2100	17.0100
83	1.0000	5.0000	820.0000	201.7200	410.0000	34.0300	17.4250

Nodes	Distance (km) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (ms)	Total Time (us) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
84	1.0000	5.0000	830.0000	206.6700	415.0000	34.8600	17.8450
85	1.0000	5.0000	840.0000	211.6800	420.0000	35.7000	18.2700
86	1.0000	5.0000	850.0000	216.7500	425.0000	36.5500	18.7000
87	1.0000	5.0000	860.0000	221.8800	430.0000	37.4100	19.1350
88	1.0000	5.0000	870.0000	227.0700	435.0000	38.2800	19.5750
89	1.0000	5.0000	880.0000	232.3200	440.0000	39.1600	20.0200
90	1.0000	5.0000	890.0000	237.6300	445.0000	40.0500	20.4700
91	1.0000	5.0000	900.0000	243.0000	450.0000	40.9500	20.9250
92	1.0000	5.0000	910.0000	248.4300	455.0000	41.8600	21.3850
93	1.0000	5.0000	920.0000	253.9200	460.0000	42.7800	21.8500
94	1.0000	5.0000	930.0000	259.4700	465.0000	43.7100	22.3200
95	1.0000	5.0000	940.0000	265.0800	470.0000	44.6500	22.7950
96	1.0000	5.0000	950.0000	270.7500	475.0000	45.6000	23.2750
97	1.0000	5.0000	960.0000	276.4800	480.0000	46.5600	23.7600
98	1.0000	5.0000	970.0000	282.2700	485.0000	47.5300	24.2500
99	1.0000	5.0000	980.0000	288.1200	490.0000	48.5100	24.7450
100	1.0000	5.0000	990.0000	294.0300	495.0000	49.5000	25.2450
101	1.0000	5.0000	1000.0000	300.0000	500.0000	50.5000	25.7500
102	1.0000	5.0000	1010.0000	306.0300	505.0000	51.5100	26.2600
103	1.0000	5.0000	1020.0000	312.1200	510.0000	52.5300	26.7750
104	1.0000	5.0000	1030.0000	318.2700	515.0000	53.5600	27.2950
105	1.0000	5.0000	1040.0000	324.4800	520.0000	54.6000	27.8200
106	1.0000	5.0000	1050.0000	330.7500	525.0000	55.6500	28.3500
107	1.0000	5.0000	1060.0000	337.0800	530.0000	56.7100	28.8850
108	1.0000	5.0000	1070.0000	343.4700	535.0000	57.7800	29.4250
109	1.0000	5.0000	1080.0000	349.9200	540.0000	58.8600	29.9700
110	1.0000	5.0000	1090.0000	356.4300	545.0000	59.9500	30.5200
111	1.0000	5.0000	1100.0000	363.0000	550.0000	61.0500	31.0750
112	1.0000	5.0000	1110.0000	369.6300	555.0000	62.1600	31.6350
113	1.0000	5.0000	1120.0000	376.3200	560.0000	63.2800	32.2000
114	1.0000	5.0000	1130.0000	383.0700	565.0000	64.4100	32.7700
115	1.0000	5.0000	1140.0000	389.8800	570.0000	65.5500	33.3450
116	1.0000	5.0000	1150.0000	396.7500	575.0000	66.7000	33.9250
117	1.0000	5.0000	1160.0000	403.6800	580.0000	67.8600	34.5100
118	1.0000	5.0000	1170.0000	410.6700	585.0000	69.0300	35.1000
119	1.0000	5.0000	1180.0000	417.7200	590.0000	70.2100	35.6950
120	1.0000	5.0000	1190.0000	424.8300	595.0000	71.4000	36.2950
121	1.0000	5.0000	1200.0000	432.0000	600.0000	72.6000	36.9000
122	1.0000	5.0000	1210.0000	439.2300	605.0000	73.8100	37.5100
123	1.0000	5.0000	1220.0000	446.5200	610.0000	75.0300	38.1250
124	1.0000	5.0000	1230.0000	453.8700	615.0000	76.2600	38.7450
125	1.0000	5.0000	1240.0000	461.2800	620.0000	77.5000	39.3700
126	1.0000	5.0000	1250.0000	468.7500	625.0000	78.7500	40.0000
127	1.0000	5.0000	1260.0000	476.2800	630.0000	80.0100	40.6350
128	1.0000	5.0000	1270.0000	483.8700	635.0000	81.2800	41.2750

Nodes	Distance (km) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (ms)	Total Time (us) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
129	1.0000	5.0000	1280.0000	491.5200	640.0000	82.5600	41.9200
130	1.0000	5.0000	1290.0000	499.2300	645.0000	83.8500	42.5700
131	1.0000	5.0000	1300.0000	507.0000	650.0000	85.1500	43.2250
132	1.0000	5.0000	1310.0000	514.8300	655.0000	86.4600	43.8850
133	1.0000	5.0000	1320.0000	522.7200	660.0000	87.7800	44.5500
134	1.0000	5.0000	1330.0000	530.6700	665.0000	89.1100	45.2200
135	1.0000	5.0000	1340.0000	538.6800	670.0000	90.4500	45.8950
136	1.0000	5.0000	1350.0000	546.7500	675.0000	91.8000	46.5750
137	1.0000	5.0000	1360.0000	554.8800	680.0000	93.1600	47.2600
138	1.0000	5.0000	1370.0000	563.0700	685.0000	94.5300	47.9500
139	1.0000	5.0000	1380.0000	571.3200	690.0000	95.9100	48.6450
140	1.0000	5.0000	1390.0000	579.6300	695.0000	97.3000	49.3450
141	1.0000	5.0000	1400.0000	588.0000	700.0000	98.7000	50.0500
142	1.0000	5.0000	1410.0000	596.4300	705.0000	100.1100	50.7600
143	1.0000	5.0000	1420.0000	604.9200	710.0000	101.5300	51.4750
144	1.0000	5.0000	1430.0000	613.4700	715.0000	102.9600	52.1950
145	1.0000	5.0000	1440.0000	622.0800	720.0000	104.4000	52.9200
146	1.0000	5.0000	1450.0000	630.7500	725.0000	105.8500	53.6500
147	1.0000	5.0000	1460.0000	639.4800	730.0000	107.3100	54.3850
148	1.0000	5.0000	1470.0000	648.2700	735.0000	108.7800	55.1250
149	1.0000	5.0000	1480.0000	657.1200	740.0000	110.2600	55.8700
150	1.0000	5.0000	1490.0000	666.0300	745.0000	111.7500	56.6200
151	1.0000	5.0000	1500.0000	675.0000	750.0000	113.2500	57.3750
152	1.0000	5.0000	1510.0000	684.0300	755.0000	114.7600	58.1350
153	1.0000	5.0000	1520.0000	693.1200	760.0000	116.2800	58.9000
154	1.0000	5.0000	1530.0000	702.2700	765.0000	117.8100	59.6700
155	1.0000	5.0000	1540.0000	711.4800	770.0000	119.3500	60.4450
156	1.0000	5.0000	1550.0000	720.7500	775.0000	120.9000	61.2250
157	1.0000	5.0000	1560.0000	730.0800	780.0000	122.4600	62.0100
158	1.0000	5.0000	1570.0000	739.4700	785.0000	124.0300	62.8000
159	1.0000	5.0000	1580.0000	748.9200	790.0000	125.6100	63.5950
160	1.0000	5.0000	1590.0000	758.4300	795.0000	127.2000	64.3950
161	1.0000	5.0000	1600.0000	768.0000	800.0000	128.8000	65.2000
162	1.0000	5.0000	1610.0000	777.6300	805.0000	130.4100	66.0100
163	1.0000	5.0000	1620.0000	787.3200	810.0000	132.0300	66.8250
164	1.0000	5.0000	1630.0000	797.0700	815.0000	133.6600	67.6450
165	1.0000	5.0000	1640.0000	806.8800	820.0000	135.3000	68.4700
166	1.0000	5.0000	1650.0000	816.7500	825.0000	136.9500	69.3000
167	1.0000	5.0000	1660.0000	826.6800	830.0000	138.6100	70.1350
168	1.0000	5.0000	1670.0000	836.6700	835.0000	140.2800	70.9750
169	1.0000	5.0000	1680.0000	846.7200	840.0000	141.9600	71.8200
170	1.0000	5.0000	1690.0000	856.8300	845.0000	143.6500	72.6700
171	1.0000	5.0000	1700.0000	867.0000	850.0000	145.3500	73.5250
172	1.0000	5.0000	1710.0000	877.2300	855.0000	147.0600	74.3850
173	1.0000	5.0000	1720.0000	887.5200	860.0000	148.7800	75.2500

Nodes	Distance (km) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (ms)	Total Time (us) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
174	1.0000	5.0000	1730.0000	897.8700	865.0000	150.5100	76.1200
175	1.0000	5.0000	1740.0000	908.2800	870.0000	152.2500	76.9950
176	1.0000	5.0000	1750.0000	918.7500	875.0000	154.0000	77.8750
177	1.0000	5.0000	1760.0000	929.2800	880.0000	155.7600	78.7600
178	1.0000	5.0000	1770.0000	939.8700	885.0000	157.5300	79.6500
179	1.0000	5.0000	1780.0000	950.5200	890.0000	159.3100	80.5450
180	1.0000	5.0000	1790.0000	961.2300	895.0000	161.1000	81.4450
181	1.0000	5.0000	1800.0000	972.0000	900.0000	162.9000	82.3500
182	1.0000	5.0000	1810.0000	982.8300	905.0000	164.7100	83.2600
183	1.0000	5.0000	1820.0000	993.7200	910.0000	166.5300	84.1750
184	1.0000	5.0000	1830.0000	1004.6700	915.0000	168.3600	85.0950
185	1.0000	5.0000	1840.0000	1015.6800	920.0000	170.2000	86.0200
186	1.0000	5.0000	1850.0000	1026.7500	925.0000	172.0500	86.9500
187	1.0000	5.0000	1860.0000	1037.8800	930.0000	173.9100	87.8850
188	1.0000	5.0000	1870.0000	1049.0700	935.0000	175.7800	88.8250
189	1.0000	5.0000	1880.0000	1060.3200	940.0000	177.6600	89.7700
190	1.0000	5.0000	1890.0000	1071.6300	945.0000	179.5500	90.7200
191	1.0000	5.0000	1900.0000	1083.0000	950.0000	181.4500	91.6750
192	1.0000	5.0000	1910.0000	1094.4300	955.0000	183.3600	92.6350
193	1.0000	5.0000	1920.0000	1105.9200	960.0000	185.2800	93.6000
194	1.0000	5.0000	1930.0000	1117.4700	965.0000	187.2100	94.5700
195	1.0000	5.0000	1940.0000	1129.0800	970.0000	189.1500	95.5450
196	1.0000	5.0000	1950.0000	1140.7500	975.0000	191.1000	96.5250
197	1.0000	5.0000	1960.0000	1152.4800	980.0000	193.0600	97.5100
198	1.0000	5.0000	1970.0000	1164.2700	985.0000	195.0300	98.5000
199	1.0000	5.0000	1980.0000	1176.1200	990.0000	197.0100	99.4950
200	1.0000	5.0000	1990.0000	1188.0300	995.0000	199.0000	100.4950

Table B-7 Poll Time Data for Nodes Spaced at 2 km With a Fiber Break Data for Figure 5-7

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	2.0000	0.0100	0.0200	0.0600	0.0100	0.0200	0.0200
3	2.0000	0.0100	0.0400	0.2400	0.0200	0.0600	0.0500
4	2.0000	0.0100	0.0600	0.5400	0.0300	0.1200	0.0900
5	2.0000	0.0100	0.0800	0.9600	0.0400	0.2000	0.1400
6	2.0000	0.0100	0.1000	1.5000	0.0500	0.3000	0.2000
7	2.0000	0.0100	0.1200	2.1600	0.0600	0.4200	0.2700
8	2.0000	0.0100	0.1400	2.9400	0.0700	0.5600	0.3500
9	2.0000	0.0100	0.1600	3.8400	0.0800	0.7200	0.4400
10	2.0000	0.0100	0.1800	4.8600	0.0900	0.9000	0.5400
11	2.0000	0.0100	0.2000	6.0000	0.1000	1.1000	0.6500
12	2.0000	0.0100	0.2200	7.2600	0.1100	1.3200	0.7700
13	2.0000	0.0100	0.2400	8.6400	0.1200	1.5600	0.9000
14	2.0000	0.0100	0.2600	10.1400	0.1300	1.8200	1.0400
15	2.0000	0.0100	0.2800	11.7600	0.1400	2.1000	1.1900
16	2.0000	0.0100	0.3000	13.5000	0.1500	2.4000	1.3500
17	2.0000	0.0100	0.3200	15.3600	0.1600	2.7200	1.5200
18	2.0000	0.0100	0.3400	17.3400	0.1700	3.0600	1.7000
19	2.0000	0.0100	0.3600	19.4400	0.1800	3.4200	1.8900
20	2.0000	0.0100	0.3800	21.6600	0.1900	3.8000	2.0900
21	2.0000	0.0100	0.4000	24.0000	0.2000	4.2000	2.3000
22	2.0000	0.0100	0.4200	26.4600	0.2100	4.6200	2.5200
23	2.0000	0.0100	0.4400	29.0400	0.2200	5.0600	2.7500
24	2.0000	0.0100	0.4600	31.7400	0.2300	5.5200	2.9900
25	2.0000	0.0100	0.4800	34.5600	0.2400	6.0000	3.2400
26	2.0000	0.0100	0.5000	37.5000	0.2500	6.5000	3.5000
27	2.0000	0.0100	0.5200	40.5600	0.2600	7.0200	3.7700
28	2.0000	0.0100	0.5400	43.7400	0.2700	7.5600	4.0500
29	2.0000	0.0100	0.5600	47.0400	0.2800	8.1200	4.3400
30	2.0000	0.0100	0.5800	50.4600	0.2900	8.7000	4.6400
31	2.0000	0.0100	0.6000	54.0000	0.3000	9.3000	4.9500
32	2.0000	0.0100	0.6200	57.6600	0.3100	9.9200	5.2700
33	2.0000	0.0100	0.6400	61.4400	0.3200	10.5600	5.6000
34	2.0000	0.0100	0.6600	65.3400	0.3300	11.2200	5.9400
35	2.0000	0.0100	0.6800	69.3600	0.3400	11.9000	6.2900
36	2.0000	0.0100	0.7000	73.5000	0.3500	12.6000	6.6500
37	2.0000	0.0100	0.7200	77.7600	0.3600	13.3200	7.0200
38	2.0000	0.0100	0.7400	82.1400	0.3700	14.0600	7.4000

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
39	2.0000	0.0100	0.7600	86.6400	0.3800	14.8200	7.7900
40	2.0000	0.0100	0.7800	91.2600	0.3900	15.6000	8.1900
41	2.0000	0.0100	0.8000	96.0000	0.4000	16.4000	8.6000
42	2.0000	0.0100	0.8200	100.8600	0.4100	17.2200	9.0200
43	2.0000	0.0100	0.8400	105.8400	0.4200	18.0600	9.4500
44	2.0000	0.0100	0.8600	110.9400	0.4300	18.9200	9.8900
45	2.0000	0.0100	0.8800	116.1600	0.4400	19.8000	10.3400
46	2.0000	0.0100	0.9000	121.5000	0.4500	20.7000	10.8000
47	2.0000	0.0100	0.9200	126.9600	0.4600	21.6200	11.2700
48	2.0000	0.0100	0.9400	132.5400	0.4700	22.5600	11.7500
49	2.0000	0.0100	0.9600	138.2400	0.4800	23.5200	12.2400
50	2.0000	0.0100	0.9800	144.0600	0.4900	24.5000	12.7400
51	2.0000	0.0100	1.0000	150.0000	0.5000	25.5000	13.2500
52	2.0000	0.0100	1.0200	156.0600	0.5100	26.5200	13.7700
53	2.0000	0.0100	1.0400	162.2400	0.5200	27.5600	14.3000
54	2.0000	0.0100	1.0600	168.5400	0.5300	28.6200	14.8400
55	2.0000	0.0100	1.0800	174.9600	0.5400	29.7000	15.3900
56	2.0000	0.0100	1.1000	181.5000	0.5500	30.8000	15.9500
57	2.0000	0.0100	1.1200	188.1600	0.5600	31.9200	16.5200
58	2.0000	0.0100	1.1400	194.9400	0.5700	33.0600	17.1000
59	2.0000	0.0100	1.1600	201.8400	0.5800	34.2200	17.6900
60	2.0000	0.0100	1.1800	208.8600	0.5900	35.4000	18.2900
61	2.0000	0.0100	1.2000	216.0000	0.6000	36.6000	18.9000
62	2.0000	0.0100	1.2200	223.2600	0.6100	37.8200	19.5200
63	2.0000	0.0100	1.2400	230.6400	0.6200	39.0600	20.1500
64	2.0000	0.0100	1.2600	238.1400	0.6300	40.3200	20.7900
65	2.0000	0.0100	1.2800	245.7600	0.6400	41.6000	21.4400
66	2.0000	0.0100	1.3000	253.5000	0.6500	42.9000	22.1000
67	2.0000	0.0100	1.3200	261.3600	0.6600	44.2200	22.7700
68	2.0000	0.0100	1.3400	269.3400	0.6700	45.5600	23.4500
69	2.0000	0.0100	1.3600	277.4400	0.6800	46.9200	24.1400
70	2.0000	0.0100	1.3800	285.6600	0.6900	48.3000	24.8400
71	2.0000	0.0100	1.4000	294.0000	0.7000	49.7000	25.5500
72	2.0000	0.0100	1.4200	302.4600	0.7100	51.1200	26.2700
73	2.0000	0.0100	1.4400	311.0400	0.7200	52.5600	27.0000
74	2.0000	0.0100	1.4600	319.7400	0.7300	54.0200	27.7400
75	2.0000	0.0100	1.4800	328.5600	0.7400	55.5000	28.4900
76	2.0000	0.0100	1.5000	337.5000	0.7500	57.0000	29.2500
77	2.0000	0.0100	1.5200	346.5600	0.7600	58.5200	30.0200
78	2.0000	0.0100	1.5400	355.7400	0.7700	60.0600	30.8000
79	2.0000	0.0100	1.5600	365.0400	0.7800	61.6200	31.5900
80	2.0000	0.0100	1.5800	374.4600	0.7900	63.2000	32.3900
81	2.0000	0.0100	1.6000	384.0000	0.8000	64.8000	33.2000
82	2.0000	0.0100	1.6200	393.6600	0.8100	66.4200	34.0200
83	2.0000	0.0100	1.6400	403.4400	0.8200	68.0600	34.8500

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
84	2.0000	0.0100	1.6600	413.3400	0.8300	69.7200	35.6900
85	2.0000	0.0100	1.6800	423.3600	0.8400	71.4000	36.5400
86	2.0000	0.0100	1.7000	433.5000	0.8500	73.1000	37.4000
87	2.0000	0.0100	1.7200	443.7600	0.8600	74.8200	38.2700
88	2.0000	0.0100	1.7400	454.1400	0.8700	76.5600	39.1500
89	2.0000	0.0100	1.7600	464.6400	0.8800	78.3200	40.0400
90	2.0000	0.0100	1.7800	475.2600	0.8900	80.1000	40.9400
91	2.0000	0.0100	1.8000	486.0000	0.9000	81.9000	41.8500
92	2.0000	0.0100	1.8200	496.8600	0.9100	83.7200	42.7700
93	2.0000	0.0100	1.8400	507.8400	0.9200	85.5600	43.7000
94	2.0000	0.0100	1.8600	518.9400	0.9300	87.4200	44.6400
95	2.0000	0.0100	1.8800	530.1600	0.9400	89.3000	45.5900
96	2.0000	0.0100	1.9000	541.5000	0.9500	91.2000	46.5500
97	2.0000	0.0100	1.9200	552.9600	0.9600	93.1200	47.5200
98	2.0000	0.0100	1.9400	564.5400	0.9700	95.0600	48.5000
99	2.0000	0.0100	1.9600	576.2400	0.9800	97.0200	49.4900
100	2.0000	0.0100	1.9800	588.0600	0.9900	99.0000	50.4900
101	2.0000	0.0100	2.0000	600.0000	1.0000	101.0000	51.5000
102	2.0000	0.0100	2.0200	612.0600	1.0100	103.0200	52.5200
103	2.0000	0.0100	2.0400	624.2400	1.0200	105.0600	53.5500
104	2.0000	0.0100	2.0600	636.5400	1.0300	107.1200	54.5900
105	2.0000	0.0100	2.0800	648.9600	1.0400	109.2000	55.6400
106	2.0000	0.0100	2.1000	661.5000	1.0500	111.3000	56.7000
107	2.0000	0.0100	2.1200	674.1600	1.0600	113.4200	57.7700
108	2.0000	0.0100	2.1400	686.9400	1.0700	115.5600	58.8500
109	2.0000	0.0100	2.1600	699.8400	1.0800	117.7200	59.9400
110	2.0000	0.0100	2.1800	712.8600	1.0900	119.9000	61.0400
111	2.0000	0.0100	2.2000	726.0000	1.1000	122.1000	62.1500
112	2.0000	0.0100	2.2200	739.2600	1.1100	124.3200	63.2700
113	2.0000	0.0100	2.2400	752.6400	1.1200	126.5600	64.4000
114	2.0000	0.0100	2.2600	766.1400	1.1300	128.8200	65.5400
115	2.0000	0.0100	2.2800	779.7600	1.1400	131.1000	66.6900
116	2.0000	0.0100	2.3000	793.5000	1.1500	133.4000	67.8500
117	2.0000	0.0100	2.3200	807.3600	1.1600	135.7200	69.0200
118	2.0000	0.0100	2.3400	821.3400	1.1700	138.0600	70.2000
119	2.0000	0.0100	2.3600	835.4400	1.1800	140.4200	71.3900
120	2.0000	0.0100	2.3800	849.6600	1.1900	142.8000	72.5900
121	2.0000	0.0100	2.4000	864.0000	1.2000	145.2000	73.8000
122	2.0000	0.0100	2.4200	878.4600	1.2100	147.6200	75.0200
123	2.0000	0.0100	2.4400	893.0400	1.2200	150.0600	76.2500
124	2.0000	0.0100	2.4600	907.7400	1.2300	152.5200	77.4900
125	2.0000	0.0100	2.4800	922.5600	1.2400	155.0000	78.7400
126	2.0000	0.0100	2.5000	937.5000	1.2500	157.5000	80.0000
127	2.0000	0.0100	2.5200	952.5600	1.2600	160.0200	81.2700
128	2.0000	0.0100	2.5400	967.7400	1.2700	162.5600	82.5500

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
129	2.0000	0.0100	2.5600	983.0400	1.2800	165.1200	83.8400
130	2.0000	0.0100	2.5800	998.4600	1.2900	167.7000	85.1400
131	2.0000	0.0100	2.6000	1014.0000	1.3000	170.3000	86.4500
132	2.0000	0.0100	2.6200	1029.6600	1.3100	172.9200	87.7700
133	2.0000	0.0100	2.6400	1045.4400	1.3200	175.5600	89.1000
134	2.0000	0.0100	2.6600	1061.3400	1.3300	178.2200	90.4400
135	2.0000	0.0100	2.6800	1077.3600	1.3400	180.9000	91.7900
136	2.0000	0.0100	2.7000	1093.5000	1.3500	183.6000	93.1500
137	2.0000	0.0100	2.7200	1109.7600	1.3600	186.3200	94.5200
138	2.0000	0.0100	2.7400	1126.1400	1.3700	189.0600	95.9000
139	2.0000	0.0100	2.7600	1142.6400	1.3800	191.8200	97.2900
140	2.0000	0.0100	2.7800	1159.2600	1.3900	194.6000	98.6900
141	2.0000	0.0100	2.8000	1176.0000	1.4000	197.4000	100.1000
142	2.0000	0.0100	2.8200	1192.8600	1.4100	200.2200	101.5200
143	2.0000	0.0100	2.8400	1209.8400	1.4200	203.0600	102.9500
144	2.0000	0.0100	2.8600	1226.9400	1.4300	205.9200	104.3900
145	2.0000	0.0100	2.8800	1244.1600	1.4400	208.8000	105.8400
146	2.0000	0.0100	2.9000	1261.5000	1.4500	211.7000	107.3000
147	2.0000	0.0100	2.9200	1278.9600	1.4600	214.6200	108.7700
148	2.0000	0.0100	2.9400	1296.5400	1.4700	217.5600	110.2500
149	2.0000	0.0100	2.9600	1314.2400	1.4800	220.5200	111.7400
150	2.0000	0.0100	2.9800	1332.0600	1.4900	223.5000	113.2400
151	2.0000	0.0100	3.0000	1350.0000	1.5000	226.5000	114.7500
152	2.0000	0.0100	3.0200	1368.0600	1.5100	229.5200	116.2700
153	2.0000	0.0100	3.0400	1386.2400	1.5200	232.5600	117.8000
154	2.0000	0.0100	3.0600	1404.5400	1.5300	235.6200	119.3400
155	2.0000	0.0100	3.0800	1422.9600	1.5400	238.7000	120.8900
156	2.0000	0.0100	3.1000	1441.5000	1.5500	241.8000	122.4500
157	2.0000	0.0100	3.1200	1460.1600	1.5600	244.9200	124.0200
158	2.0000	0.0100	3.1400	1478.9400	1.5700	248.0600	125.6000
159	2.0000	0.0100	3.1600	1497.8400	1.5800	251.2200	127.1900
160	2.0000	0.0100	3.1800	1516.8600	1.5900	254.4000	128.7900
161	2.0000	0.0100	3.2000	1536.0000	1.6000	257.6000	130.4000
162	2.0000	0.0100	3.2200	1555.2600	1.6100	260.8200	132.0200
163	2.0000	0.0100	3.2400	1574.6400	1.6200	264.0600	133.6500
164	2.0000	0.0100	3.2600	1594.1400	1.6300	267.3200	135.2900
165	2.0000	0.0100	3.2800	1613.7600	1.6400	270.6000	136.9400
166	2.0000	0.0100	3.3000	1633.5000	1.6500	273.9000	138.6000
167	2.0000	0.0100	3.3200	1653.3600	1.6600	277.2200	140.2700
168	2.0000	0.0100	3.3400	1673.3400	1.6700	280.5600	141.9500
169	2.0000	0.0100	3.3600	1693.4400	1.6800	283.9200	143.6400
170	2.0000	0.0100	3.3800	1713.6600	1.6900	287.3000	145.3400
171	2.0000	0.0100	3.4000	1734.0000	1.7000	290.7000	147.0500
172	2.0000	0.0100	3.4200	1754.4600	1.7100	294.1200	148.7700
173	2.0000	0.0100	3.4400	1775.0400	1.7200	297.5600	150.5000

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node N	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
174	2.0000	0.0100	3.4600	1795.7400	1.7300	301.0200	152.2400
175	2.0000	0.0100	3.4800	1816.5600	1.7400	304.5000	153.9900
176	2.0000	0.0100	3.5000	1837.5000	1.7500	308.0000	155.7500
177	2.0000	0.0100	3.5200	1858.5600	1.7600	311.5200	157.5200
178	2.0000	0.0100	3.5400	1879.7400	1.7700	315.0600	159.3000
179	2.0000	0.0100	3.5600	1901.0400	1.7800	318.6200	161.0900
180	2.0000	0.0100	3.5800	1922.4600	1.7900	322.2000	162.8900
181	2.0000	0.0100	3.6000	1944.0000	1.8000	325.8000	164.7000
182	2.0000	0.0100	3.6200	1965.6600	1.8100	329.4200	166.5200
183	2.0000	0.0100	3.6400	1987.4400	1.8200	333.0600	168.3500
184	2.0000	0.0100	3.6600	2009.3400	1.8300	336.7200	170.1900
185	2.0000	0.0100	3.6800	2031.3600	1.8400	340.4000	172.0400
186	2.0000	0.0100	3.7000	2053.5000	1.8500	344.1000	173.9000
187	2.0000	0.0100	3.7200	2075.7600	1.8600	347.8200	175.7700
188	2.0000	0.0100	3.7400	2098.1400	1.8700	351.5600	177.6500
189	2.0000	0.0100	3.7600	2120.6400	1.8800	355.3200	179.5400
190	2.0000	0.0100	3.7800	2143.2600	1.8900	359.1000	181.4400
191	2.0000	0.0100	3.8000	2166.0000	1.9000	362.9000	183.3500
192	2.0000	0.0100	3.8200	2188.8600	1.9100	366.7200	185.2700
193	2.0000	0.0100	3.8400	2211.8400	1.9200	370.5600	187.2000
194	2.0000	0.0100	3.8600	2234.9400	1.9300	374.4200	189.1400
195	2.0000	0.0100	3.8800	2258.1600	1.9400	378.3000	191.0900
196	2.0000	0.0100	3.9000	2281.5000	1.9500	382.2000	193.0500
197	2.0000	0.0100	3.9200	2304.9600	1.9600	386.1200	195.0200
198	2.0000	0.0100	3.9400	2328.5400	1.9700	390.0600	197.0000
199	2.0000	0.0100	3.9600	2352.2400	1.9800	394.0200	198.9900
200	2.0000	0.0100	3.9800	2376.0600	1.9900	398.0000	200.9900

Table B-8 Poll Time Data for Nodes Randomly Space 0-2 km With a Fiber Break Data for Figure 5-8

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.6801	0.0034	0.0068	0.0204	0.0034	0.0068	0.0068
3	1.0060	0.0050	0.0169	0.1012	0.0084	0.0237	0.0203
4	0.8747	0.0044	0.0256	0.2305	0.0128	0.0493	0.0374
5	1.1890	0.0059	0.0375	0.4500	0.0187	0.0868	0.0621
6	0.7832	0.0039	0.0453	0.6800	0.0227	0.1321	0.0887
7	0.6125	0.0031	0.0515	0.9262	0.0257	0.1836	0.1175
8	0.9360	0.0047	0.0608	1.2771	0.0304	0.2444	0.1526
9	1.6161	0.0081	0.0770	1.8474	0.0385	0.3213	0.1992
10	1.7766	0.0089	0.0947	2.5580	0.0474	0.4161	0.2554
11	0.0602	0.0003	0.0953	2.8603	0.0477	0.5114	0.3034
12	1.4769	0.0074	0.1101	3.6337	0.0551	0.6215	0.3658
13	1.9586	0.0098	0.1297	4.6692	0.0648	0.7512	0.4405
14	0.2013	0.0010	0.1317	5.1368	0.0659	0.8830	0.5073
15	0.0331	0.0002	0.1320	5.5458	0.0660	1.0150	0.5735
16	0.9093	0.0045	0.1411	6.3512	0.0706	1.1561	0.6486
17	0.7783	0.0039	0.1489	7.1481	0.0745	1.3051	0.7270
18	1.4854	0.0074	0.1638	8.3524	0.0819	1.4688	0.8163
19	0.4795	0.0024	0.1686	9.1027	0.0843	1.6374	0.9030
20	1.3517	0.0068	0.1821	10.3789	0.0910	1.8195	1.0008
21	1.5156	0.0076	0.1972	11.8345	0.0986	2.0167	1.1070
22	0.8744	0.0044	0.2060	12.9770	0.1030	2.2227	1.2143
23	0.5489	0.0027	0.2115	13.9573	0.1057	2.4342	1.3228
24	1.4818	0.0074	0.2263	15.6141	0.1131	2.6605	1.4434
25	0.7836	0.0039	0.2341	16.8571	0.1171	2.8946	1.5644
26	1.2408	0.0062	0.2465	18.4901	0.1233	3.1411	1.6938
27	0.7314	0.0037	0.2538	19.8002	0.1269	3.3950	1.8244
28	1.2107	0.0061	0.2660	21.5424	0.1330	3.6609	1.9634
29	1.3588	0.0068	0.2795	23.4817	0.1398	3.9405	2.1100
30	1.1192	0.0056	0.2907	25.2940	0.1454	4.2312	2.2610
31	1.7379	0.0087	0.3081	27.7303	0.1541	4.5393	2.4237
32	0.8442	0.0042	0.3166	29.4398	0.1583	4.8559	2.5862
33	0.0956	0.0005	0.3175	30.4813	0.1588	5.1734	2.7455
34	1.2891	0.0064	0.3304	32.7100	0.1652	5.5038	2.9171
35	1.2894	0.0064	0.3433	35.0164	0.1716	5.8471	3.0952
36	1.8041	0.0090	0.3613	37.9406	0.1807	6.2085	3.2849
37	0.0357	0.0002	0.3617	39.0632	0.1808	6.5701	3.4659
38	1.1638	0.0058	0.3733	41.4401	0.1867	6.9435	3.6584

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
39	1.4942	0.0075	0.3883	44.2634	0.1941	7.3318	3.8600
40	1.4762	0.0074	0.4030	47.1554	0.2015	7.7348	4.0689
41	1.4357	0.0072	0.4174	50.0874	0.2087	8.1522	4.2848
42	0.4054	0.0020	0.4214	51.8381	0.2107	8.5736	4.4975
43	0.4948	0.0025	0.4264	53.7259	0.2132	9.0000	4.7132
44	0.6382	0.0032	0.4328	55.8283	0.2164	9.4328	4.9328
45	1.0790	0.0054	0.4436	58.5509	0.2218	9.8764	5.1600
46	1.1915	0.0060	0.4555	61.4902	0.2277	10.3319	5.3937
47	0.0146	0.0001	0.4556	62.8767	0.2278	10.7875	5.6216
48	0.8054	0.0040	0.4637	65.3793	0.2318	11.2512	5.8574
49	1.6459	0.0082	0.4801	69.1405	0.2401	11.7313	6.1057
50	0.5992	0.0030	0.4861	71.4617	0.2431	12.2174	6.3518
51	1.3189	0.0066	0.4993	74.8983	0.2497	12.7168	6.6080
52	0.3271	0.0016	0.5026	76.8968	0.2513	13.2194	6.8610
53	1.1648	0.0058	0.5142	80.2217	0.2571	13.7336	7.1239
54	1.9189	0.0096	0.5334	84.8154	0.2667	14.2670	7.4002
55	0.2652	0.0013	0.5361	86.8453	0.2680	14.8031	7.6696
56	1.6692	0.0083	0.5528	91.2077	0.2764	15.3559	7.9543
57	1.1677	0.0058	0.5645	94.8277	0.2822	15.9203	8.2424
58	1.3230	0.0066	0.5777	98.7834	0.2888	16.4980	8.5379
59	1.3708	0.0069	0.5914	102.9016	0.2957	17.0894	8.8404
60	1.3205	0.0066	0.6046	107.0131	0.3023	17.6940	9.1493
61	1.1478	0.0057	0.6161	110.8930	0.3080	18.3101	9.4631
62	0.0368	0.0002	0.6164	112.8085	0.3082	18.9265	9.7715
63	1.8348	0.0092	0.6348	118.0705	0.3174	19.5613	10.0980
64	1.0575	0.0053	0.6454	121.9736	0.3227	20.2067	10.4260
65	1.7481	0.0087	0.6628	127.2659	0.3314	20.8695	10.7662
66	1.0751	0.0054	0.6736	131.3509	0.3368	21.5431	11.1084
67	1.3910	0.0070	0.6875	136.1258	0.3438	22.2306	11.4591
68	1.2061	0.0060	0.6996	140.6126	0.3498	22.9302	11.8149
69	0.0878	0.0004	0.7004	142.8904	0.3502	23.6306	12.1655
70	0.1041	0.0005	0.7015	145.2071	0.3507	24.3321	12.5168
71	1.6608	0.0083	0.7181	150.7993	0.3590	25.0502	12.8841
72	1.0046	0.0050	0.7281	155.0933	0.3641	25.7783	13.2532
73	0.2575	0.0013	0.7307	157.8339	0.3654	26.5090	13.6199
74	0.0897	0.0004	0.7316	160.2224	0.3658	27.2407	13.9861
75	0.9941	0.0050	0.7416	164.6242	0.3708	27.9822	14.3619
76	1.2869	0.0064	0.7544	169.7443	0.3772	28.7366	14.7455
77	1.9991	0.0100	0.7744	176.5654	0.3872	29.5110	15.1427
78	1.2289	0.0061	0.7867	181.7273	0.3933	30.2977	15.5422
79	1.7043	0.0085	0.8037	188.0754	0.4019	31.1015	15.9526
80	1.9394	0.0097	0.8231	195.0829	0.4116	31.9246	16.3739
81	1.1216	0.0056	0.8344	200.2441	0.4172	32.7590	16.7967
82	1.6367	0.0082	0.8507	206.7243	0.4254	33.6097	17.2302
83	1.5613	0.0078	0.8663	213.1173	0.4332	34.4760	17.6712

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
84	1.7555	0.0088	0.8839	220.0873	0.4419	35.3599	18.1219
85	0.6666	0.0033	0.8906	224.4189	0.4453	36.2504	18.5705
86	0.5886	0.0029	0.8964	228.5915	0.4482	37.1469	19.0217
87	0.5478	0.0027	0.9019	232.6942	0.4510	38.0488	19.4754
88	1.6746	0.0084	0.9187	239.7708	0.4593	38.9675	19.9431
89	0.4561	0.0023	0.9232	243.7309	0.4616	39.8907	20.4070
90	0.2787	0.0014	0.9260	247.2447	0.4630	40.8167	20.8713
91	0.1339	0.0007	0.9273	250.3843	0.4637	41.7440	21.3357
92	1.1113	0.0056	0.9385	256.2003	0.4692	42.6825	21.8105
93	1.4394	0.0072	0.9529	262.9885	0.4764	43.6354	22.2941
94	1.4208	0.0071	0.9671	269.8110	0.4835	44.6024	22.7847
95	1.6623	0.0083	0.9837	277.4000	0.4918	45.5861	23.2849
96	1.2282	0.0061	0.9960	283.8514	0.4980	46.5821	23.7890
97	1.5393	0.0077	1.0114	291.2723	0.5057	47.5934	24.3024
98	1.6888	0.0084	1.0283	299.2209	0.5141	48.6217	24.8250
99	1.5706	0.0079	1.0440	306.9232	0.5220	49.6657	25.3548
100	1.5585	0.0078	1.0595	314.6837	0.5298	50.7252	25.8924
101	0.2617	0.0013	1.0622	318.6474	0.5311	51.7873	26.4248
102	0.0881	0.0004	1.0630	322.1008	0.5315	52.8504	26.9567
103	1.6084	0.0080	1.0791	330.2116	0.5396	53.9295	27.5043
104	0.4884	0.0024	1.0840	334.9582	0.5420	55.0135	28.0488
105	1.4733	0.0074	1.0987	342.8069	0.5494	56.1123	28.6055
106	0.5080	0.0025	1.1038	347.7034	0.5519	57.2161	29.1599
107	0.3805	0.0019	1.1076	352.2248	0.5538	58.3237	29.7157
108	1.3276	0.0066	1.1209	359.8091	0.5605	59.4446	30.2828
109	0.7138	0.0036	1.1280	365.4846	0.5640	60.5726	30.8503
110	0.9886	0.0049	1.1379	372.1013	0.5690	61.7106	31.4242
111	1.2745	0.0064	1.1507	379.7210	0.5753	62.8612	32.0060
112	0.9547	0.0048	1.1602	386.3522	0.5801	64.0215	32.5908
113	1.1804	0.0059	1.1720	393.7991	0.5860	65.1935	33.1827
114	0.9198	0.0046	1.1812	400.4333	0.5906	66.3747	33.7780
115	1.1737	0.0059	1.1930	407.9909	0.5965	67.5677	34.3803
116	0.1685	0.0008	1.1946	412.1512	0.5973	68.7623	34.9785
117	0.3889	0.0019	1.1985	417.0885	0.5993	69.9608	35.5797
118	0.8694	0.0043	1.2072	423.7358	0.6036	71.1680	36.1876
119	0.4011	0.0020	1.2112	428.7775	0.6056	72.3793	36.7953
120	0.5266	0.0026	1.2165	434.2910	0.6083	73.5958	37.4061
121	0.2228	0.0011	1.2187	438.7427	0.6094	74.8145	38.0166
122	1.9331	0.0097	1.2381	449.4158	0.6190	76.0526	38.6453
123	1.5738	0.0079	1.2538	458.8901	0.6269	77.3064	39.2801
124	1.3473	0.0067	1.2673	467.6230	0.6336	78.5736	39.9205
125	1.5879	0.0079	1.2831	477.3316	0.6416	79.8568	40.5700
126	1.5103	0.0076	1.2983	486.8448	0.6491	81.1550	41.2266
127	0.8065	0.0040	1.3063	493.7881	0.6532	82.4614	41.8838
128	0.5867	0.0029	1.3122	499.9424	0.6561	83.7735	42.5429

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
129	0.0619	0.0003	1.3128	504.1168	0.6564	85.0864	43.1996
130	0.7250	0.0036	1.3201	510.8609	0.6600	86.4064	43.8632
131	1.3526	0.0068	1.3336	520.0961	0.6668	87.7400	44.5368
132	0.7898	0.0039	1.3415	527.2007	0.6707	89.0815	45.2115
133	1.0023	0.0050	1.3515	535.1943	0.6758	90.4330	45.8922
134	1.7319	0.0087	1.3688	546.1592	0.6844	91.8018	46.5853
135	1.5919	0.0080	1.3847	556.6652	0.6924	93.1865	47.2856
136	1.0731	0.0054	1.3955	565.1655	0.6977	94.5820	47.9887
137	1.4471	0.0072	1.4099	575.2559	0.7050	95.9919	48.7009
138	0.6901	0.0035	1.4168	582.3220	0.7084	97.4088	49.4128
139	0.9192	0.0046	1.4260	590.3781	0.7130	98.8348	50.1304
140	1.3047	0.0065	1.4391	600.0966	0.7195	100.2739	50.8565
141	1.3918	0.0070	1.4530	610.2595	0.7265	101.7269	51.5899
142	1.0359	0.0052	1.4634	619.0002	0.7317	103.1902	52.3268
143	1.7109	0.0086	1.4805	630.6787	0.7402	104.6707	53.0756
144	1.2952	0.0065	1.4934	640.6766	0.7467	106.1641	53.8288
145	1.0448	0.0052	1.5039	649.6703	0.7519	107.6680	54.5859
146	0.9999	0.0050	1.5139	658.5317	0.7569	109.1819	55.3479
147	1.3992	0.0070	1.5279	669.2019	0.7639	110.7097	56.1188
148	0.4806	0.0024	1.5327	675.9047	0.7663	112.2424	56.8875
149	0.7363	0.0037	1.5400	683.7718	0.7700	113.7824	57.6612
150	1.0041	0.0050	1.5501	692.8800	0.7750	115.3325	58.4413
151	1.3533	0.0068	1.5636	703.6202	0.7818	116.8961	59.2298
152	0.7443	0.0037	1.5710	711.6826	0.7855	118.4671	60.0191
153	1.3438	0.0067	1.5845	722.5233	0.7922	120.0516	60.8180
154	0.1210	0.0006	1.5857	727.8320	0.7928	121.6373	61.6115
155	1.5583	0.0078	1.6013	739.7883	0.8006	123.2386	62.4199
156	0.3342	0.0017	1.6046	746.1463	0.8023	124.8432	63.2239
157	0.6435	0.0032	1.6111	753.9716	0.8055	126.4542	64.0326
158	1.1704	0.0059	1.6228	764.3174	0.8114	128.0770	64.8499
159	1.7552	0.0088	1.6403	777.5054	0.8202	129.7173	65.6788
160	1.9075	0.0095	1.6594	791.5252	0.8297	131.3767	66.5180
161	0.7077	0.0035	1.6665	799.9001	0.8332	133.0431	67.3548
162	0.4406	0.0022	1.6709	807.0276	0.8354	134.7140	68.1924
163	1.6125	0.0081	1.6870	819.8772	0.8435	136.4010	69.0440
164	1.1274	0.0056	1.6983	830.4511	0.8491	138.0993	69.8988
165	0.7686	0.0038	1.7060	839.3275	0.8530	139.8052	70.7556
166	0.9394	0.0047	1.7153	849.0953	0.8577	141.5206	71.6179
167	0.5606	0.0028	1.7210	857.0333	0.8605	143.2415	72.4812
168	0.3215	0.0016	1.7242	863.8069	0.8621	144.9657	73.3449
169	0.4029	0.0020	1.7282	871.0102	0.8641	146.6939	74.2110
170	0.1403	0.0007	1.7296	876.9063	0.8648	148.4235	75.0765
171	0.1040	0.0005	1.7306	882.6255	0.8653	150.1541	75.9424
172	0.7830	0.0039	1.7385	891.8344	0.8692	151.8926	76.8155
173	1.0123	0.0051	1.7486	902.2734	0.8743	153.6412	77.6949

Nodes	Distance (km) Node (n,n-1)	Time (ms) Node (n,n-1)	Total Time (ms) Time around ring	Token ring Poll Time (ms)	Total Time (ms) Time to node n	Tone Method Poll Time (ms)	Improved Tone Method Poll Time (ms)
174	0.2187	0.0011	1.7508	908.6544	0.8754	155.3919	78.5714
175	0.6186	0.0031	1.7570	917.1359	0.8785	157.1489	79.4529
176	1.5400	0.0077	1.7724	930.4920	0.8862	158.9213	80.3468
177	1.2742	0.0064	1.7851	942.5370	0.8926	160.7064	81.2457
178	1.4436	0.0072	1.7995	955.5579	0.8998	162.5059	82.1527
179	1.9648	0.0098	1.8192	971.4488	0.9096	164.3251	83.0722
180	0.0346	0.0002	1.8195	977.0923	0.9098	166.1447	83.9821
181	0.3359	0.0017	1.8229	984.3650	0.9114	167.9676	84.8952
182	0.0410	0.0002	1.8233	990.0563	0.9117	169.7909	85.8071
183	1.4972	0.0075	1.8383	1003.7007	0.9191	171.6291	86.7337
184	1.3445	0.0067	1.8517	1016.5972	0.9259	173.4809	87.6663
185	0.5466	0.0027	1.8572	1025.1696	0.9286	175.3381	88.5976
186	0.8928	0.0045	1.8661	1035.6960	0.9331	177.2042	89.5351
187	1.9912	0.0100	1.8860	1052.4052	0.9430	179.0902	90.4881
188	1.6353	0.0082	1.9024	1067.2372	0.9512	180.9926	91.4475
189	0.9903	0.0050	1.9123	1078.5294	0.9561	182.9049	92.4086
190	1.4073	0.0070	1.9264	1092.2458	0.9632	184.8312	93.3788
191	0.7993	0.0040	1.9344	1102.5808	0.9672	186.7656	94.3500
192	0.9671	0.0048	1.9440	1113.9254	0.9720	188.7096	95.3268
193	0.9781	0.0049	1.9538	1125.3916	0.9769	190.6634	96.3086
194	1.6132	0.0081	1.9699	1140.5933	0.9850	192.6334	97.3016
195	0.9171	0.0046	1.9791	1151.8407	0.9896	194.6125	98.2958
196	1.5249	0.0076	1.9944	1166.6988	0.9972	196.6068	99.3006
197	0.3036	0.0015	1.9974	1174.4670	0.9987	198.6042	100.3008
198	1.5172	0.0076	2.0126	1189.4260	1.0063	200.6168	101.3147
199	0.4254	0.0021	2.0168	1197.9904	1.0084	202.6336	102.3252
200	1.6494	0.0082	2.0333	1213.8875	1.0167	204.6669	103.3501

Table B-9 Poll Time Data for Nodes Distance Between Master and First Remote = 2 km; All others 1 m Data for Figure 5-9

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	2000.00	10.0000	20.0000	60.0000	10.0000	20.0000	20.0000
3	1.0000	0.0050	20.0100	120.0600	10.0050	40.0100	30.0100
4	1.0000	0.0050	20.0200	180.1800	10.0100	60.0300	40.0250
5	1.0000	0.0050	20.0300	240.3600	10.0150	80.0600	50.0450
6	1.0000	0.0050	20.0400	300.6000	10.0200	100.1000	60.0700
7	1.0000	0.0050	20.0500	360.9000	10.0250	120.1500	70.1000
8	1.0000	0.0050	20.0600	421.2600	10.0300	140.2100	80.1350
9	1.0000	0.0050	20.0700	481.6800	10.0350	160.2800	90.1750
10	1.0000	0.0050	20.0800	542.1600	10.0400	180.3600	100.2200
11	1.0000	0.0050	20.0900	602.7000	10.0450	200.4500	110.2700
12	1.0000	0.0050	20.1000	663.3000	10.0500	220.5500	120.3250
13	1.0000	0.0050	20.1100	723.9600	10.0550	240.6600	130.3850
14	1.0000	0.0050	20.1200	784.6800	10.0600	260.7800	140.4500
15	1.0000	0.0050	20.1300	845.4600	10.0650	280.9100	150.5200
16	1.0000	0.0050	20.1400	906.3000	10.0700	301.0500	160.5950
17	1.0000	0.0050	20.1500	967.2000	10.0750	321.2000	170.6750
18	1.0000	0.0050	20.1600	1028.1600	10.0800	341.3600	180.7600
19	1.0000	0.0050	20.1700	1089.1800	10.0850	361.5300	190.8500
20	1.0000	0.0050	20.1800	1150.2600	10.0900	381.7100	200.9450
21	1.0000	0.0050	20.1900	1211.4000	10.0950	401.9000	211.0450
22	1.0000	0.0050	20.2000	1272.6000	10.1000	422.1000	221.1500
23	1.0000	0.0050	20.2100	1333.8600	10.1050	442.3100	231.2600
24	1.0000	0.0050	20.2200	1395.1800	10.1100	462.5300	241.3750
25	1.0000	0.0050	20.2300	1456.5600	10.1150	482.7600	251.4950
26	1.0000	0.0050	20.2400	1518.0000	10.1200	503.0000	261.6200
27	1.0000	0.0050	20.2500	1579.5000	10.1250	523.2500	271.7500
28	1.0000	0.0050	20.2600	1641.0600	10.1300	543.5100	281.8850
29	1.0000	0.0050	20.2700	1702.6800	10.1350	563.7800	292.0250
30	1.0000	0.0050	20.2800	1764.3600	10.1400	584.0600	302.1700
31	1.0000	0.0050	20.2900	1826.1000	10.1450	604.3500	312.3200
32	1.0000	0.0050	20.3000	1887.9000	10.1500	624.6500	322.4750
33	1.0000	0.0050	20.3100	1949.7600	10.1550	644.9600	332.6350
34	1.0000	0.0050	20.3200	2011.6800	10.1600	665.2800	342.8000
35	1.0000	0.0050	20.3300	2073.6600	10.1650	685.6100	352.9700
36	1.0000	0.0050	20.3400	2135.7000	10.1700	705.9500	363.1450
37	1.0000	0.0050	20.3500	2197.8000	10.1750	726.3000	373.3250
38	1.0000	0.0050	20.3600	2259.9600	10.1800	746.6600	383.5100

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
39	1.0000	0.0050	20.3700	2322.1800	10.1850	767.0300	393.7000
40	1.0000	0.0050	20.3800	2384.4600	10.1900	787.4100	403.8950
41	1.0000	0.0050	20.3900	2446.8000	10.1950	807.8000	414.0950
42	1.0000	0.0050	20.4000	2509.2000	10.2000	828.2000	424.3000
43	1.0000	0.0050	20.4100	2571.6600	10.2050	848.6100	434.5100
44	1.0000	0.0050	20.4200	2634.1800	10.2100	869.0300	444.7250
45	1.0000	0.0050	20.4300	2696.7600	10.2150	889.4600	454.9450
46	1.0000	0.0050	20.4400	2759.4000	10.2200	909.9000	465.1700
47	1.0000	0.0050	20.4500	2822.1000	10.2250	930.3500	475.4000
48	1.0000	0.0050	20.4600	2884.8600	10.2300	950.8100	485.6350
49	1.0000	0.0050	20.4700	2947.6800	10.2350	971.2800	495.8750
50	1.0000	0.0050	20.4800	3010.5600	10.2400	991.7600	506.1200
51	1.0000	0.0050	20.4900	3073.5000	10.2450	1012.2500	516.3700
52	1.0000	0.0050	20.5000	3136.5000	10.2500	1032.7500	526.6250
53	1.0000	0.0050	20.5100	3199.5600	10.2550	1053.2600	536.8850
54	1.0000	0.0050	20.5200	3262.6800	10.2600	1073.7800	547.1500
55	1.0000	0.0050	20.5300	3325.8600	10.2650	1094.3100	557.4200
56	1.0000	0.0050	20.5400	3389.1000	10.2700	1114.8500	567.6950
57	1.0000	0.0050	20.5500	3452.4000	10.2750	1135.4000	577.9750
58	1.0000	0.0050	20.5600	3515.7600	10.2800	1155.9600	588.2600
59	1.0000	0.0050	20.5700	3579.1800	10.2850	1176.5300	598.5500
60	1.0000	0.0050	20.5800	3642.6600	10.2900	1197.1100	608.8450
61	1.0000	0.0050	20.5900	3706.2000	10.2950	1217.7000	619.1450
62	1.0000	0.0050	20.6000	3769.8000	10.3000	1238.3000	629.4500
63	1.0000	0.0050	20.6100	3833.4600	10.3050	1258.9100	639.7600
64	1.0000	0.0050	20.6200	3897.1800	10.3100	1279.5300	650.0750
65	1.0000	0.0050	20.6300	3960.9600	10.3150	1300.1600	660.3950
66	1.0000	0.0050	20.6400	4024.8000	10.3200	1320.8000	670.7200
67	1.0000	0.0050	20.6500	4088.7000	10.3250	1341.4500	681.0500
68	1.0000	0.0050	20.6600	4152.6600	10.3300	1362.1100	691.3850
69	1.0000	0.0050	20.6700	4216.6800	10.3350	1382.7800	701.7250
70	1.0000	0.0050	20.6800	4280.7600	10.3400	1403.4600	712.0700
71	1.0000	0.0050	20.6900	4344.9000	10.3450	1424.1500	722.4200
72	1.0000	0.0050	20.7000	4409.1000	10.3500	1444.8500	732.7750
73	1.0000	0.0050	20.7100	4473.3600	10.3550	1465.5600	743.1350
74	1.0000	0.0050	20.7200	4537.6800	10.3600	1486.2800	753.5000
75	1.0000	0.0050	20.7300	4602.0600	10.3650	1507.0100	763.8700
76	1.0000	0.0050	20.7400	4666.5000	10.3700	1527.7500	774.2450
77	1.0000	0.0050	20.7500	4731.0000	10.3750	1548.5000	784.6250
78	1.0000	0.0050	20.7600	4795.5600	10.3800	1569.2600	795.0100
79	1.0000	0.0050	20.7700	4860.1800	10.3850	1590.0300	805.4000
80	1.0000	0.0050	20.7800	4924.8600	10.3900	1610.8100	815.7950
81	1.0000	0.0050	20.7900	4989.6000	10.3950	1631.6000	826.1950
82	1.0000	0.0050	20.8000	5054.4000	10.4000	1652.4000	836.6000
83	1.0000	0.0050	20.8100	5119.2600	10.4050	1673.2100	847.0100

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
84	1.0000	0.0050	20.8200	5184.1800	10.4100	1694.0300	857.4250
85	1.0000	0.0050	20.8300	5249.1600	10.4150	1714.8600	867.8450
86	1.0000	0.0050	20.8400	5314.2000	10.4200	1735.7000	878.2700
87	1.0000	0.0050	20.8500	5379.3000	10.4250	1756.5500	888.7000
88	1.0000	0.0050	20.8600	5444.4600	10.4300	1777.4100	899.1350
89	1.0000	0.0050	20.8700	5509.6800	10.4350	1798.2800	909.5750
90	1.0000	0.0050	20.8800	5574.9600	10.4400	1819.1600	920.0200
91	1.0000	0.0050	20.8900	5640.3000	10.4450	1840.0500	930.4700
92	1.0000	0.0050	20.9000	5705.7000	10.4500	1860.9500	940.9250
93	1.0000	0.0050	20.9100	5771.1600	10.4550	1881.8600	951.3850
94	1.0000	0.0050	20.9200	5836.6800	10.4600	1902.7800	961.8500
95	1.0000	0.0050	20.9300	5902.2600	10.4650	1923.7100	972.3200
96	1.0000	0.0050	20.9400	5967.9000	10.4700	1944.6500	982.7950
97	1.0000	0.0050	20.9500	6033.6000	10.4750	1965.6000	993.2750
98	1.0000	0.0050	20.9600	6099.3600	10.4800	1986.5600	1003.7600
99	1.0000	0.0050	20.9700	6165.1800	10.4850	2007.5300	1014.2500
100	1.0000	0.0050	20.9800	6231.0600	10.4900	2028.5100	1024.7450
101	1.0000	0.0050	20.9900	6297.0000	10.4950	2049.5000	1035.2450
102	1.0000	0.0050	21.0000	6363.0000	10.5000	2070.5000	1045.7500
103	1.0000	0.0050	21.0100	6429.0600	10.5050	2091.5100	1056.2600
104	1.0000	0.0050	21.0200	6495.1800	10.5100	2112.5300	1066.7750
105	1.0000	0.0050	21.0300	6561.3600	10.5150	2133.5600	1077.2950
106	1.0000	0.0050	21.0400	6627.6000	10.5200	2154.6000	1087.8200
107	1.0000	0.0050	21.0500	6693.9000	10.5250	2175.6500	1098.3500
108	1.0000	0.0050	21.0600	6760.2600	10.5300	2196.7100	1108.8850
109	1.0000	0.0050	21.0700	6826.6800	10.5350	2217.7800	1119.4250
110	1.0000	0.0050	21.0800	6893.1600	10.5400	2238.8600	1129.9700
111	1.0000	0.0050	21.0900	6959.7000	10.5450	2259.9500	1140.5200
112	1.0000	0.0050	21.1000	7026.3000	10.5500	2281.0500	1151.0750
113	1.0000	0.0050	21.1100	7092.9600	10.5550	2302.1600	1161.6350
114	1.0000	0.0050	21.1200	7159.6800	10.5600	2323.2800	1172.2000
115	1.0000	0.0050	21.1300	7226.4600	10.5650	2344.4100	1182.7700
116	1.0000	0.0050	21.1400	7293.3000	10.5700	2365.5500	1193.3450
117	1.0000	0.0050	21.1500	7360.2000	10.5750	2386.7000	1203.9250
118	1.0000	0.0050	21.1600	7427.1600	10.5800	2407.8600	1214.5100
119	1.0000	0.0050	21.1700	7494.1800	10.5850	2429.0300	1225.1000
120	1.0000	0.0050	21.1800	7561.2600	10.5900	2450.2100	1235.6950
121	1.0000	0.0050	21.1900	7628.4000	10.5950	2471.4000	1246.2950
122	1.0000	0.0050	21.2000	7695.6000	10.6000	2492.6000	1256.9000
123	1.0000	0.0050	21.2100	7762.8600	10.6050	2513.8100	1267.5100
124	1.0000	0.0050	21.2200	7830.1800	10.6100	2535.0300	1278.1250
125	1.0000	0.0050	21.2300	7897.5600	10.6150	2556.2600	1288.7450
126	1.0000	0.0050	21.2400	7965.0000	10.6200	2577.5000	1299.3700
127	1.0000	0.0050	21.2500	8032.5000	10.6250	2598.7500	1310.0000
128	1.0000	0.0050	21.2600	8100.0600	10.6300	2620.0100	1320.6350

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
129	1.0000	0.0050	21.2700	8167.6800	10.6350	2641.2800	1331.2750
130	1.0000	0.0050	21.2800	8235.3600	10.6400	2662.5600	1341.9200
131	1.0000	0.0050	21.2900	8303.1000	10.6450	2683.8500	1352.5700
132	1.0000	0.0050	21.3000	8370.9000	10.6500	2705.1500	1363.2250
133	1.0000	0.0050	21.3100	8438.7600	10.6550	2726.4600	1373.8850
134	1.0000	0.0050	21.3200	8506.6800	10.6600	2747.7800	1384.5500
135	1.0000	0.0050	21.3300	8574.6600	10.6650	2769.1100	1395.2200
136	1.0000	0.0050	21.3400	8642.7000	10.6700	2790.4500	1405.8950
137	1.0000	0.0050	21.3500	8710.8000	10.6750	2811.8000	1416.5750
138	1.0000	0.0050	21.3600	8778.9600	10.6800	2833.1600	1427.2600
139	1.0000	0.0050	21.3700	8847.1800	10.6850	2854.5300	1437.9500
140	1.0000	0.0050	21.3800	8915.4600	10.6900	2875.9100	1448.6450
141	1.0000	0.0050	21.3900	8983.8000	10.6950	2897.3000	1459.3450
142	1.0000	0.0050	21.4000	9052.2000	10.7000	2918.7000	1470.0500
143	1.0000	0.0050	21.4100	9120.6600	10.7050	2940.1100	1480.7600
144	1.0000	0.0050	21.4200	9189.1800	10.7100	2961.5300	1491.4750
145	1.0000	0.0050	21.4300	9257.7600	10.7150	2982.9600	1502.1950
146	1.0000	0.0050	21.4400	9326.4000	10.7200	3004.4000	1512.9200
147	1.0000	0.0050	21.4500	9395.1000	10.7250	3025.8500	1523.6500
148	1.0000	0.0050	21.4600	9463.8600	10.7300	3047.3100	1534.3850
149	1.0000	0.0050	21.4700	9532.6800	10.7350	3068.7800	1545.1250
150	1.0000	0.0050	21.4800	9601.5600	10.7400	3090.2600	1555.8700
151	1.0000	0.0050	21.4900	9670.5000	10.7450	3111.7500	1566.6200
152	1.0000	0.0050	21.5000	9739.5000	10.7500	3133.2500	1577.3750
153	1.0000	0.0050	21.5100	9808.5600	10.7550	3154.7600	1588.1350
154	1.0000	0.0050	21.5200	9877.6800	10.7600	3176.2800	1598.9000
155	1.0000	0.0050	21.5300	9946.8600	10.7650	3197.8100	1609.6700
156	1.0000	0.0050	21.5400	10016.1000	10.7700	3219.3500	1620.4450
157	1.0000	0.0050	21.5500	10085.4000	10.7750	3240.9000	1631.2250
158	1.0000	0.0050	21.5600	10154.7600	10.7800	3262.4600	1642.0100
159	1.0000	0.0050	21.5700	10224.1800	10.7850	3284.0300	1652.8000
160	1.0000	0.0050	21.5800	10293.6600	10.7900	3305.6100	1663.5950
161	1.0000	0.0050	21.5900	10363.2000	10.7950	3327.2000	1674.3950
162	1.0000	0.0050	21.6000	10432.8000	10.8000	3348.8000	1685.2000
163	1.0000	0.0050	21.6100	10502.4600	10.8050	3370.4100	1696.0100
164	1.0000	0.0050	21.6200	10572.1800	10.8100	3392.0300	1706.8250
165	1.0000	0.0050	21.6300	10641.9600	10.8150	3413.6600	1717.6450
166	1.0000	0.0050	21.6400	10711.8000	10.8200	3435.3000	1728.4700
167	1.0000	0.0050	21.6500	10781.7000	10.8250	3456.9500	1739.3000
168	1.0000	0.0050	21.6600	10851.6600	10.8300	3478.6100	1750.1350
169	1.0000	0.0050	21.6700	10921.6800	10.8350	3500.2800	1760.9750
170	1.0000	0.0050	21.6800	10991.7600	10.8400	3521.9600	1771.8200
171	1.0000	0.0050	21.6900	11061.9000	10.8450	3543.6500	1782.6700
172	1.0000	0.0050	21.7000	11132.1000	10.8500	3565.3500	1793.5250
173	1.0000	0.0050	21.7100	11202.3600	10.8550	3587.0600	1804.3850

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
174	1.0000	0.0050	21.7200	11272.6800	10.8600	3608.7800	1815.2500
175	1.0000	0.0050	21.7300	11343.0600	10.8650	3630.5100	1826.1200
176	1.0000	0.0050	21.7400	11413.5000	10.8700	3652.2500	1836.9950
177	1.0000	0.0050	21.7500	11484.0000	10.8750	3674.0000	1847.8750
178	1.0000	0.0050	21.7600	11554.5600	10.8800	3695.7600	1858.7600
179	1.0000	0.0050	21.7700	11625.1800	10.8850	3717.5300	1869.6500
180	1.0000	0.0050	21.7800	11695.8600	10.8900	3739.3100	1880.5450
181	1.0000	0.0050	21.7900	11766.6000	10.8950	3761.1000	1891.4450
182	1.0000	0.0050	21.8000	11837.4000	10.9000	3782.9000	1902.3500
183	1.0000	0.0050	21.8100	11908.2600	10.9050	3804.7100	1913.2600
184	1.0000	0.0050	21.8200	11979.1800	10.9100	3826.5300	1924.1750
185	1.0000	0.0050	21.8300	12050.1600	10.9150	3848.3600	1935.0950
186	1.0000	0.0050	21.8400	12121.2000	10.9200	3870.2000	1946.0200
187	1.0000	0.0050	21.8500	12192.3000	10.9250	3892.0500	1956.9500
188	1.0000	0.0050	21.8600	12263.4600	10.9300	3913.9100	1967.8850
189	1.0000	0.0050	21.8700	12334.6800	10.9350	3935.7800	1978.8250
190	1.0000	0.0050	21.8800	12405.9600	10.9400	3957.6600	1989.7700
191	1.0000	0.0050	21.8900	12477.3000	10.9450	3979.5500	2000.7200
192	1.0000	0.0050	21.9000	12548.7000	10.9500	4001.4500	2011.6750
193	1.0000	0.0050	21.9100	12620.1600	10.9550	4023.3600	2022.6350
194	1.0000	0.0050	21.9200	12691.6800	10.9600	4045.2800	2033.6000
195	1.0000	0.0050	21.9300	12763.2600	10.9650	4067.2100	2044.5700
196	1.0000	0.0050	21.9400	12834.9000	10.9700	4089.1500	2055.5450
197	1.0000	0.0050	21.9500	12906.6000	10.9750	4111.1000	2066.5250
198	1.0000	0.0050	21.9600	12978.3600	10.9800	4133.0600	2077.5100
199	1.0000	0.0050	21.9700	13050.1800	10.9850	4155.0300	2088.5000
200	1.0000	0.0050	21.9800	13122.0600	10.9900	4177.0100	2099.4950

Table B-10 Poll Time Data for Nodes Distance Between Master and Last Remote = 2 km; All others 1 m Data for Figure 5-10

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	1.0000	0.0050	0.0100	0.0300	0.0050	0.0100	0.0100
3	1.0000	0.0050	0.0200	0.1200	0.0100	0.0300	0.0250
4	1.0000	0.0050	0.0300	0.2700	0.0150	0.0600	0.0450
5	1.0000	0.0050	0.0400	0.4800	0.0200	0.1000	0.0700
6	1.0000	0.0050	0.0500	0.7500	0.0250	0.1500	0.1000
7	1.0000	0.0050	0.0600	1.0800	0.0300	0.2100	0.1350
8	1.0000	0.0050	0.0700	1.4700	0.0350	0.2800	0.1750
9	1.0000	0.0050	0.0800	1.9200	0.0400	0.3600	0.2200
10	1.0000	0.0050	0.0900	2.4300	0.0450	0.4500	0.2700
11	1.0000	0.0050	0.1000	3.0000	0.0500	0.5500	0.3250
12	1.0000	0.0050	0.1100	3.6300	0.0550	0.6600	0.3850
13	1.0000	0.0050	0.1200	4.3200	0.0600	0.7800	0.4500
14	1.0000	0.0050	0.1300	5.0700	0.0650	0.9100	0.5200
15	1.0000	0.0050	0.1400	5.8800	0.0700	1.0500	0.5950
16	1.0000	0.0050	0.1500	6.7500	0.0750	1.2000	0.6750
17	1.0000	0.0050	0.1600	7.6800	0.0800	1.3600	0.7600
18	1.0000	0.0050	0.1700	8.6700	0.0850	1.5300	0.8500
19	1.0000	0.0050	0.1800	9.7200	0.0900	1.7100	0.9450
20	1.0000	0.0050	0.1900	10.8300	0.0950	1.9000	1.0450
21	1.0000	0.0050	0.2000	12.0000	0.1000	2.1000	1.1500
22	1.0000	0.0050	0.2100	13.2300	0.1050	2.3100	1.2600
23	1.0000	0.0050	0.2200	14.5200	0.1100	2.5300	1.3750
24	1.0000	0.0050	0.2300	15.8700	0.1150	2.7600	1.4950
25	1.0000	0.0050	0.2400	17.2800	0.1200	3.0000	1.6200
26	1.0000	0.0050	0.2500	18.7500	0.1250	3.2500	1.7500
27	1.0000	0.0050	0.2600	20.2800	0.1300	3.5100	1.8850
28	1.0000	0.0050	0.2700	21.8700	0.1350	3.7800	2.0250
29	1.0000	0.0050	0.2800	23.5200	0.1400	4.0600	2.1700
30	1.0000	0.0050	0.2900	25.2300	0.1450	4.3500	2.3200
31	1.0000	0.0050	0.3000	27.0000	0.1500	4.6500	2.4750
32	1.0000	0.0050	0.3100	28.8300	0.1550	4.9600	2.6350
33	1.0000	0.0050	0.3200	30.7200	0.1600	5.2800	2.8000
34	1.0000	0.0050	0.3300	32.6700	0.1650	5.6100	2.9700
35	1.0000	0.0050	0.3400	34.6800	0.1700	5.9500	3.1450
36	1.0000	0.0050	0.3500	36.7500	0.1750	6.3000	3.3250
37	1.0000	0.0050	0.3600	38.8800	0.1800	6.6600	3.5100
38	1.0000	0.0050	0.3700	41.0700	0.1850	7.0300	3.7000

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
39	1.0000	0.0050	0.3800	43.3200	0.1900	7.4100	3.8950
40	1.0000	0.0050	0.3900	45.6300	0.1950	7.8000	4.0950
41	1.0000	0.0050	0.4000	48.0000	0.2000	8.2000	4.3000
42	1.0000	0.0050	0.4100	50.4300	0.2050	8.6100	4.5100
43	1.0000	0.0050	0.4200	52.9200	0.2100	9.0300	4.7250
44	1.0000	0.0050	0.4300	55.4700	0.2150	9.4600	4.9450
45	1.0000	0.0050	0.4400	58.0800	0.2200	9.9000	5.1700
46	1.0000	0.0050	0.4500	60.7500	0.2250	10.3500	5.4000
47	1.0000	0.0050	0.4600	63.4800	0.2300	10.8100	5.6350
48	1.0000	0.0050	0.4700	66.2700	0.2350	11.2800	5.8750
49	1.0000	0.0050	0.4800	69.1200	0.2400	11.7600	6.1200
50	1.0000	0.0050	0.4900	72.0300	0.2450	12.2500	6.3700
51	1.0000	0.0050	0.5000	75.0000	0.2500	12.7500	6.6250
52	1.0000	0.0050	0.5100	78.0300	0.2550	13.2600	6.8850
53	1.0000	0.0050	0.5200	81.1200	0.2600	13.7800	7.1500
54	1.0000	0.0050	0.5300	84.2700	0.2650	14.3100	7.4200
55	1.0000	0.0050	0.5400	87.4800	0.2700	14.8500	7.6950
56	1.0000	0.0050	0.5500	90.7500	0.2750	15.4000	7.9750
57	1.0000	0.0050	0.5600	94.0800	0.2800	15.9600	8.2600
58	1.0000	0.0050	0.5700	97.4700	0.2850	16.5300	8.5500
59	1.0000	0.0050	0.5800	100.9200	0.2900	17.1100	8.8450
60	1.0000	0.0050	0.5900	104.4300	0.2950	17.7000	9.1450
61	1.0000	0.0050	0.6000	108.0000	0.3000	18.3000	9.4500
62	1.0000	0.0050	0.6100	111.6300	0.3050	18.9100	9.7600
63	1.0000	0.0050	0.6200	115.3200	0.3100	19.5300	10.0750
64	1.0000	0.0050	0.6300	119.0700	0.3150	20.1600	10.3950
65	1.0000	0.0050	0.6400	122.8800	0.3200	20.8000	10.7200
66	1.0000	0.0050	0.6500	126.7500	0.3250	21.4500	11.0500
67	1.0000	0.0050	0.6600	130.6800	0.3300	22.1100	11.3850
68	1.0000	0.0050	0.6700	134.6700	0.3350	22.7800	11.7250
69	1.0000	0.0050	0.6800	138.7200	0.3400	23.4600	12.0700
70	1.0000	0.0050	0.6900	142.8300	0.3450	24.1500	12.4200
71	1.0000	0.0050	0.7000	147.0000	0.3500	24.8500	12.7750
72	1.0000	0.0050	0.7100	151.2300	0.3550	25.5600	13.1350
73	1.0000	0.0050	0.7200	155.5200	0.3600	26.2800	13.5000
74	1.0000	0.0050	0.7300	159.8700	0.3650	27.0100	13.8700
75	1.0000	0.0050	0.7400	164.2800	0.3700	27.7500	14.2450
76	1.0000	0.0050	0.7500	168.7500	0.3750	28.5000	14.6250
77	1.0000	0.0050	0.7600	173.2800	0.3800	29.2600	15.0100
78	1.0000	0.0050	0.7700	177.8700	0.3850	30.0300	15.4000
79	1.0000	0.0050	0.7800	182.5200	0.3900	30.8100	15.7950
80	1.0000	0.0050	0.7900	187.2300	0.3950	31.6000	16.1950
81	1.0000	0.0050	0.8000	192.0000	0.4000	32.4000	16.6000
82	1.0000	0.0050	0.8100	196.8300	0.4050	33.2100	17.0100
83	1.0000	0.0050	0.8200	201.7200	0.4100	34.0300	17.4250

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
84	1.0000	0.0050	0.8300	206.6700	0.4150	34.8600	17.8450
85	1.0000	0.0050	0.8400	211.6800	0.4200	35.7000	18.2700
86	1.0000	0.0050	0.8500	216.7500	0.4250	36.5500	18.7000
87	1.0000	0.0050	0.8600	221.8800	0.4300	37.4100	19.1350
88	1.0000	0.0050	0.8700	227.0700	0.4350	38.2800	19.5750
89	1.0000	0.0050	0.8800	232.3200	0.4400	39.1600	20.0200
90	1.0000	0.0050	0.8900	237.6300	0.4450	40.0500	20.4700
91	1.0000	0.0050	0.9000	243.0000	0.4500	40.9500	20.9250
92	1.0000	0.0050	0.9100	248.4300	0.4550	41.8600	21.3850
93	1.0000	0.0050	0.9200	253.9200	0.4600	42.7800	21.8500
94	1.0000	0.0050	0.9300	259.4700	0.4650	43.7100	22.3200
95	1.0000	0.0050	0.9400	265.0800	0.4700	44.6500	22.7950
96	1.0000	0.0050	0.9500	270.7500	0.4750	45.6000	23.2750
97	1.0000	0.0050	0.9600	276.4800	0.4800	46.5600	23.7600
98	1.0000	0.0050	0.9700	282.2700	0.4850	47.5300	24.2500
99	1.0000	0.0050	0.9800	288.1200	0.4900	48.5100	24.7450
100	1.0000	0.0050	0.9900	294.0300	0.4950	49.5000	25.2450
101	1.0000	0.0050	1.0000	300.0000	0.5000	50.5000	25.7500
102	1.0000	0.0050	1.0100	306.0300	0.5050	51.5100	26.2600
103	1.0000	0.0050	1.0200	312.1200	0.5100	52.5300	26.7750
104	1.0000	0.0050	1.0300	318.2700	0.5150	53.5600	27.2950
105	1.0000	0.0050	1.0400	324.4800	0.5200	54.6000	27.8200
106	1.0000	0.0050	1.0500	330.7500	0.5250	55.6500	28.3500
107	1.0000	0.0050	1.0600	337.0800	0.5300	56.7100	28.8850
108	1.0000	0.0050	1.0700	343.4700	0.5350	57.7800	29.4250
109	1.0000	0.0050	1.0800	349.9200	0.5400	58.8600	29.9700
110	1.0000	0.0050	1.0900	356.4300	0.5450	59.9500	30.5200
111	1.0000	0.0050	1.1000	363.0000	0.5500	61.0500	31.0750
112	1.0000	0.0050	1.1100	369.6300	0.5550	62.1600	31.6350
113	1.0000	0.0050	1.1200	376.3200	0.5600	63.2800	32.2000
114	1.0000	0.0050	1.1300	383.0700	0.5650	64.4100	32.7700
115	1.0000	0.0050	1.1400	389.8800	0.5700	65.5500	33.3450
116	1.0000	0.0050	1.1500	396.7500	0.5750	66.7000	33.9250
117	1.0000	0.0050	1.1600	403.6800	0.5800	67.8600	34.5100
118	1.0000	0.0050	1.1700	410.6700	0.5850	69.0300	35.1000
119	1.0000	0.0050	1.1800	417.7200	0.5900	70.2100	35.6950
120	1.0000	0.0050	1.1900	424.8300	0.5950	71.4000	36.2950
121	1.0000	0.0050	1.2000	432.0000	0.6000	72.6000	36.9000
122	1.0000	0.0050	1.2100	439.2300	0.6050	73.8100	37.5100
123	1.0000	0.0050	1.2200	446.5200	0.6100	75.0300	38.1250
124	1.0000	0.0050	1.2300	453.8700	0.6150	76.2600	38.7450
125	1.0000	0.0050	1.2400	461.2800	0.6200	77.5000	39.3700
126	1.0000	0.0050	1.2500	468.7500	0.6250	78.7500	40.0000
127	1.0000	0.0050	1.2600	476.2800	0.6300	80.0100	40.6350
128	1.0000	0.0050	1.2700	483.8700	0.6350	81.2800	41.2750

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
129	1.0000	0.0050	1.2800	491.5200	0.6400	82.5600	41.9200
130	1.0000	0.0050	1.2900	499.2300	0.6450	83.8500	42.5700
131	1.0000	0.0050	1.3000	507.0000	0.6500	85.1500	43.2250
132	1.0000	0.0050	1.3100	514.8300	0.6550	86.4600	43.8850
133	1.0000	0.0050	1.3200	522.7200	0.6600	87.7800	44.5500
134	1.0000	0.0050	1.3300	530.6700	0.6650	89.1100	45.2200
135	1.0000	0.0050	1.3400	538.6800	0.6700	90.4500	45.8950
136	1.0000	0.0050	1.3500	546.7500	0.6750	91.8000	46.5750
137	1.0000	0.0050	1.3600	554.8800	0.6800	93.1600	47.2600
138	1.0000	0.0050	1.3700	563.0700	0.6850	94.5300	47.9500
139	1.0000	0.0050	1.3800	571.3200	0.6900	95.9100	48.6450
140	1.0000	0.0050	1.3900	579.6300	0.6950	97.3000	49.3450
141	1.0000	0.0050	1.4000	588.0000	0.7000	98.7000	50.0500
142	1.0000	0.0050	1.4100	596.4300	0.7050	100.1100	50.7600
143	1.0000	0.0050	1.4200	604.9200	0.7100	101.5300	51.4750
144	1.0000	0.0050	1.4300	613.4700	0.7150	102.9600	52.1950
145	1.0000	0.0050	1.4400	622.0800	0.7200	104.4000	52.9200
146	1.0000	0.0050	1.4500	630.7500	0.7250	105.8500	53.6500
147	1.0000	0.0050	1.4600	639.4800	0.7300	107.3100	54.3850
148	1.0000	0.0050	1.4700	648.2700	0.7350	108.7800	55.1250
149	1.0000	0.0050	1.4800	657.1200	0.7400	110.2600	55.8700
150	1.0000	0.0050	1.4900	666.0300	0.7450	111.7500	56.6200
151	1.0000	0.0050	1.5000	675.0000	0.7500	113.2500	57.3750
152	1.0000	0.0050	1.5100	684.0300	0.7550	114.7600	58.1350
153	1.0000	0.0050	1.5200	693.1200	0.7600	116.2800	58.9000
154	1.0000	0.0050	1.5300	702.2700	0.7650	117.8100	59.6700
155	1.0000	0.0050	1.5400	711.4800	0.7700	119.3500	60.4450
156	1.0000	0.0050	1.5500	720.7500	0.7750	120.9000	61.2250
157	1.0000	0.0050	1.5600	730.0800	0.7800	122.4600	62.0100
158	1.0000	0.0050	1.5700	739.4700	0.7850	124.0300	62.8000
159	1.0000	0.0050	1.5800	748.9200	0.7900	125.6100	63.5950
160	1.0000	0.0050	1.5900	758.4300	0.7950	127.2000	64.3950
161	1.0000	0.0050	1.6000	768.0000	0.8000	128.8000	65.2000
162	1.0000	0.0050	1.6100	777.6300	0.8050	130.4100	66.0100
163	1.0000	0.0050	1.6200	787.3200	0.8100	132.0300	66.8250
164	1.0000	0.0050	1.6300	797.0700	0.8150	133.6600	67.6450
165	1.0000	0.0050	1.6400	806.8800	0.8200	135.3000	68.4700
166	1.0000	0.0050	1.6500	816.7500	0.8250	136.9500	69.3000
167	1.0000	0.0050	1.6600	826.6800	0.8300	138.6100	70.1350
168	1.0000	0.0050	1.6700	836.6700	0.8350	140.2800	70.9750
169	1.0000	0.0050	1.6800	846.7200	0.8400	141.9600	71.8200
170	1.0000	0.0050	1.6900	856.8300	0.8450	143.6500	72.6700
171	1.0000	0.0050	1.7000	867.0000	0.8500	145.3500	73.5250
172	1.0000	0.0050	1.7100	877.2300	0.8550	147.0600	74.3850
173	1.0000	0.0050	1.7200	887.5200	0.8600	148.7800	75.2500

Nodes	Distance (m) Node (n,n-1)	Time (us) Node (n,n-1)	Total Time (us) Time around ring	Token ring Poll Time (us)	Total Time (us) Time to node n	Tone Method Poll Time (us)	Improved Tone Method Poll Time (us)
174	1.0000	0.0050	1.7300	897.8700	0.8650	150.5100	76.1200
175	1.0000	0.0050	1.7400	908.2800	0.8700	152.2500	76.9950
176	1.0000	0.0050	1.7500	918.7500	0.8750	154.0000	77.8750
177	1.0000	0.0050	1.7600	929.2800	0.8800	155.7600	78.7600
178	1.0000	0.0050	1.7700	939.8700	0.8850	157.5300	79.6500
179	1.0000	0.0050	1.7800	950.5200	0.8900	159.3100	80.5450
180	1.0000	0.0050	1.7900	961.2300	0.8950	161.1000	81.4450
181	1.0000	0.0050	1.8000	972.0000	0.9000	162.9000	82.3500
182	1.0000	0.0050	1.8100	982.8300	0.9050	164.7100	83.2600
183	1.0000	0.0050	1.8200	993.7200	0.9100	166.5300	84.1750
184	1.0000	0.0050	1.8300	1004.6700	0.9150	168.3600	85.0950
185	1.0000	0.0050	1.8400	1015.6800	0.9200	170.2000	86.0200
186	1.0000	0.0050	1.8500	1026.7500	0.9250	172.0500	86.9500
187	1.0000	0.0050	1.8600	1037.8800	0.9300	173.9100	87.8850
188	1.0000	0.0050	1.8700	1049.0700	0.9350	175.7800	88.8250
189	1.0000	0.0050	1.8800	1060.3200	0.9400	177.6600	89.7700
190	1.0000	0.0050	1.8900	1071.6300	0.9450	179.5500	90.7200
191	1.0000	0.0050	1.9000	1083.0000	0.9500	181.4500	91.6750
192	1.0000	0.0050	1.9100	1094.4300	0.9550	183.3600	92.6350
193	1.0000	0.0050	1.9200	1105.9200	0.9600	185.2800	93.6000
194	1.0000	0.0050	1.9300	1117.4700	0.9650	187.2100	94.5700
195	1.0000	0.0050	1.9400	1129.0800	0.9700	189.1500	95.5450
196	1.0000	0.0050	1.9500	1140.7500	0.9750	191.1000	96.5250
197	1.0000	0.0050	1.9600	1152.4800	0.9800	193.0600	97.5100
198	1.0000	0.0050	1.9700	1164.2700	0.9850	195.0300	98.5000
199	1.0000	0.0050	1.9800	1176.1200	0.9900	197.0100	99.4950
200	1.0000	0.0050	1.9900	1188.0300	0.9950	199.0000	100.4950

Table B-11 Maximum Number of Nodes That can be Connected in an Asynchronous Network Data for Jitter Specification in the 1 us range Data for Figure 5-11

Data Rate Kbit/s	J = 1us Max. Nodes	J = 2us Max. Nodes	J = 3us Max. Nodes	J = 4us Max. Nodes
20.0000	400.0000	100.0000	44.4444	25.0000
20.8081	369.5353	92.3838	41.0595	23.0960
21.6162	342.4229	85.6057	38.0470	21.4014
22.4242	318.1885	79.5471	35.3543	19.8868
23.2323	296.4386	74.1096	32.9376	18.5274
24.0404	276.8449	69.2112	30.7605	17.3028
24.8485	259.1315	64.7829	28.7924	16.1957
25.6566	243.0653	60.7663	27.0073	15.1916
26.4646	228.4482	57.1121	25.3831	14.2780
27.2727	215.1111	53.7778	23.9012	13.4444
28.0808	202.9088	50.7272	22.5454	12.6818
28.8889	191.7160	47.9290	21.3018	11.9822
29.6970	181.4244	45.3561	20.1583	11.3390
30.5051	171.9398	42.9850	19.1044	10.7462
31.3131	163.1800	40.7950	18.1311	10.1988
32.1212	155.0730	38.7682	17.2303	9.6921
32.9293	147.5554	36.8889	16.3950	9.2222
33.7374	140.5716	35.1429	15.6191	8.7857
34.5455	134.0720	33.5180	14.8969	8.3795
35.3535	128.0131	32.0033	14.2237	8.0008
36.1616	122.3557	30.5889	13.5951	7.6472
36.9697	117.0653	29.2663	13.0073	7.3166
37.7778	112.1107	28.0277	12.4567	7.0069
38.5859	107.4642	26.8660	11.9405	6.7165
39.3939	103.1006	25.7751	11.4556	6.4438
40.2020	98.9975	24.7494	10.9997	6.1873
41.0101	95.1346	23.7836	10.5705	5.9459
41.8182	91.4934	22.8733	10.1659	5.7183
42.6263	88.0573	22.0143	9.7841	5.5036
43.4343	84.8112	21.2028	9.4235	5.3007
44.2424	81.7414	20.4354	9.0824	5.1088
45.0505	78.8353	19.7088	8.7595	4.9272
45.8586	76.0814	19.0204	8.4535	4.7551
46.6667	73.4694	18.3673	8.1633	4.5918
47.4747	70.9896	17.7474	7.8877	4.4368
48.2828	68.6333	17.1583	7.6259	4.2896
49.0909	66.3923	16.5981	7.3769	4.1495
49.8990	64.2594	16.0648	7.1399	4.0162

Data Rate Kbit/s	J = 1us Max. Nodes	J = 2us Max. Nodes	J = 3us Max. Nodes	J = 4us Max. Nodes
50.7071	62.2276	15.5569	6.9142	3.8892
51.5152	60.2907	15.0727	6.6990	3.7682
52.3232	58.4428	14.6107	6.4936	3.6527
53.1313	56.6786	14.1696	6.2976	3.5424
53.9394	54.9931	13.7483	6.1103	3.4371
54.7475	53.3816	13.3454	5.9313	3.3364
55.5556	51.8400	12.9600	5.7600	3.2400
56.3636	50.3642	12.5911	5.5960	3.1478
57.1717	48.9505	12.2376	5.4389	3.0594
57.9798	47.5956	11.8989	5.2884	2.9747
58.7879	46.2961	11.5740	5.1440	2.8935
59.5960	45.0491	11.2623	5.0055	2.8156
60.4040	43.8519	10.9630	4.8724	2.7407
61.2121	42.7017	10.6754	4.7446	2.6689
62.0202	41.5962	10.3990	4.6218	2.5998
62.8283	40.5331	10.1333	4.5037	2.5333
63.6364	39.5102	9.8776	4.3900	2.4694
64.4444	38.5256	9.6314	4.2806	2.4078
65.2525	37.5773	9.3943	4.1753	2.3486
66.0606	36.6636	9.1659	4.0737	2.2915
66.8687	35.7828	8.9457	3.9759	2.2364
67.6768	34.9334	8.7333	3.8815	2.1833
68.4848	34.1139	8.5285	3.7904	2.1321
69.2929	33.3229	8.3307	3.7025	2.0827
70.1010	32.5590	8.1398	3.6177	2.0349
70.9091	31.8212	7.9553	3.5357	1.9888
71.7172	31.1081	7.7770	3.4565	1.9443
72.5253	30.4188	7.6047	3.3799	1.9012
73.3333	29.7521	7.4380	3.3058	1.8595
74.1414	29.1071	7.2768	3.2341	1.8192
74.9495	28.4828	7.1207	3.1648	1.7802
75.7576	27.8784	6.9696	3.0976	1.7424
76.5657	27.2930	6.8233	3.0326	1.7058
77.3737	26.7259	6.6815	2.9695	1.6704
78.1818	26.1763	6.5441	2.9085	1.6360
78.9899	25.6435	6.4109	2.8493	1.6027
79.7980	25.1267	6.2817	2.7919	1.5704
80.6061	24.6255	6.1564	2.7362	1.5391
81.4141	24.1391	6.0348	2.6821	1.5087
82.2222	23.6669	5.9167	2.6297	1.4792
83.0303	23.2085	5.8021	2.5787	1.4505
83.8384	22.7632	5.6908	2.5292	1.4227
84.6465	22.3307	5.5827	2.4812	1.3957
85.4545	21.9104	5.4776	2.4345	1.3694
86.2626	21.5018	5.3754	2.3891	1.3439
87.0707	21.1045	5.2761	2.3449	1.3190

Data Rate Kbit/s	J = 1us Max. Nodes	J = 2us Max. Nodes	J = 3us Max. Nodes	J = 4us Max. Nodes
87.8788	20.7182	5.1795	2.3020	1.2949
88.6869	20.3424	5.0856	2.2603	1.2714
89.4949	19.9767	4.9942	2.2196	1.2485
90.3030	19.6207	4.9052	2.1801	1.2263
91.1111	19.2742	4.8186	2.1416	1.2046
91.9192	18.9368	4.7342	2.1041	1.1836
92.7273	18.6082	4.6521	2.0676	1.1630
93.5354	18.2881	4.5720	2.0320	1.1430
94.3434	17.9761	4.4940	1.9973	1.1235
95.1515	17.6721	4.4180	1.9636	1.1045
95.9596	17.3757	4.3439	1.9306	1.0860
96.7677	17.0867	4.2717	1.8985	1.0679
97.5758	16.8049	4.2012	1.8672	1.0503
98.3838	16.5300	4.1325	1.8367	1.0331
99.1919	16.2618	4.0654	1.8069	1.0164
100.0000	16.0000	4.0000	1.7778	1.0000

Table B-12 Maximum Number of Nodes That can be Connected in an Asynchronous Network Data for Jitter Specification in the .5 us range Data for Figure 5-12

Data Rate Mbit/s	J = 300ps Max. Nodes	J = 400ps Max. Nodes	J = 500ps Max. Nodes
80.0000	277.7778	156.2500	100.0000
80.2010	276.3872	155.4678	99.4994
80.4020	275.0069	154.6914	99.0025
80.6030	273.6370	153.9208	98.5093
80.8040	272.2774	153.1560	98.0199
81.0050	270.9278	152.3969	97.5340
81.2060	269.5882	151.6434	97.0518
81.4070	268.2586	150.8954	96.5731
81.6080	266.9387	150.1530	96.0979
81.8090	265.6286	149.4161	95.6263
82.0101	264.3281	148.6846	95.1581
82.2111	263.0371	147.9584	94.6934
82.4121	261.7556	147.2375	94.2320
82.6131	260.4834	146.5219	93.7740
82.8141	259.2204	145.8115	93.3194
83.0151	257.9666	145.1062	92.8680
83.2161	256.7219	144.4061	92.4199
83.4171	255.4862	143.7110	91.9750
83.6181	254.2594	143.0209	91.5334
83.8191	253.0414	142.3358	91.0949
84.0201	251.8321	141.6556	90.6596
84.2211	250.6315	140.9802	90.2273
84.4221	249.4394	140.3097	89.7982
84.6231	248.2558	139.6439	89.3721
84.8241	247.0807	138.9829	88.9490
85.0251	245.9138	138.3265	88.5290
85.2261	244.7552	137.6748	88.1119
85.4271	243.6048	137.0277	87.6977
85.6281	242.4624	136.3851	87.2865
85.8291	241.3281	135.7471	86.8781
86.0302	240.2017	135.1135	86.4726
86.2312	239.0832	134.4843	86.0700
86.4322	237.9725	133.8595	85.6701
86.6332	236.8695	133.2391	85.2730
86.8342	235.7741	132.6229	84.8787
87.0352	234.6864	132.0111	84.4871
87.2362	233.6061	131.4034	84.0982
87.4372	232.5333	130.8000	83.7120

Data Rate Mbit/s	J = 300ps Max. Nodes	J = 400ps Max. Nodes	J = 500ps Max. Nodes
87.6382	231.4678	130.2007	83.3284
87.8392	230.4097	129.6055	82.9475
88.0402	229.3588	129.0143	82.5692
88.2412	228.3151	128.4272	82.1934
88.4422	227.2785	127.8441	81.8202
88.6432	226.2489	127.2650	81.4496
88.8442	225.2263	126.6898	81.0815
89.0452	224.2106	126.1185	80.7158
89.2462	223.2018	125.5510	80.3526
89.4472	222.1998	124.9874	79.9919
89.6482	221.2045	124.4275	79.6336
89.8492	220.2159	123.8714	79.2777
90.0503	219.2339	123.3190	78.9242
90.2513	218.2584	122.7703	78.5730
90.4523	217.2894	122.2253	78.2242
90.6533	216.3269	121.6839	77.8777
90.8543	215.3708	121.1461	77.5335
91.0553	214.4210	120.6118	77.1915
91.2563	213.4774	120.0810	76.8519
91.4573	212.5401	119.5538	76.5144
91.6583	211.6089	119.0300	76.1792
91.8593	210.6838	118.5097	75.8462
92.0603	209.7648	117.9927	75.5153
92.2613	208.8518	117.4792	75.1867
92.4623	207.9448	116.9689	74.8601
92.6633	207.0436	116.4620	74.5357
92.8643	206.1483	115.9584	74.2134
93.0653	205.2587	115.4580	73.8931
93.2663	204.3750	114.9609	73.5750
93.4673	203.4969	114.4670	73.2589
93.6683	202.6244	113.9762	72.9448
93.8693	201.7576	113.4886	72.6327
94.0704	200.8963	113.0042	72.3227
94.2714	200.0405	112.5228	72.0146
94.4724	199.1902	112.0445	71.7085
94.6734	198.3453	111.5692	71.4043
94.8744	197.5057	111.0970	71.1021
95.0754	196.6715	110.6277	70.8017
95.2764	195.8425	110.1614	70.5033
95.4774	195.0188	109.6981	70.2068
95.6784	194.2002	109.2376	69.9121
95.8794	193.3868	108.7801	69.6193
96.0804	192.5785	108.3254	69.3283
96.2814	191.7753	107.8736	69.0391
96.4824	190.9770	107.4246	68.7517
96.6834	190.1838	106.9784	68.4662

Data Rate Mbit/s	J = 300ps Max. Nodes	J = 400ps Max. Nodes	J = 500ps Max. Nodes
96.8844	189.3955	106.5349	68.1824
97.0854	188.6120	106.0943	67.9003
97.2864	187.8334	105.6563	67.6200
97.4874	187.0597	105.2211	67.3415
97.6884	186.2907	104.7885	67.0646
97.8894	185.5264	104.3586	66.7895
98.0905	184.7668	103.9313	66.5161
98.2915	184.0119	103.5067	66.2443
98.4925	183.2616	103.0847	65.9742
98.6935	182.5159	102.6652	65.7057
98.8945	181.7747	102.2483	65.4389
99.0955	181.0380	101.8339	65.1737
99.2965	180.3058	101.4220	64.9101
99.4975	179.5780	101.0127	64.6481
99.6985	178.8547	100.6058	64.3877
99.8995	178.1357	100.2013	64.1288
100.1005	177.4210	99.7993	63.8716
100.3015	176.7106	99.3997	63.6158
100.5025	176.0044	99.0025	63.3616
100.7035	175.3025	98.6077	63.1089
100.9045	174.6048	98.2152	62.8577
101.1055	173.9112	97.8251	62.6080
101.3065	173.2218	97.4373	62.3599
101.5075	172.5365	97.0518	62.1131
101.7085	171.8552	96.6685	61.8679
101.9095	171.1779	96.2876	61.6240
102.1106	170.5046	95.9089	61.3817
102.3116	169.8353	95.5324	61.1407
102.5126	169.1700	95.1581	60.9012
102.7136	168.5085	94.7860	60.6631
102.9146	167.8509	94.4161	60.4263
103.1156	167.1972	94.0484	60.1910
103.3166	166.5472	93.6828	59.9570
103.5176	165.9011	93.3194	59.7244
103.7186	165.2587	92.9580	59.4931
103.9196	164.6200	92.5987	59.2632
104.1206	163.9850	92.2416	59.0346
104.3216	163.3537	91.8864	58.8073
104.5226	162.7260	91.5334	58.5814
104.7236	162.1019	91.1823	58.3567
104.9246	161.4814	90.8333	58.1333
105.1256	160.8645	90.4863	57.9112
105.3266	160.2511	90.1413	57.6904
105.5276	159.6412	89.7982	57.4708
105.7286	159.0348	89.4571	57.2525
105.9296	158.4318	89.1179	57.0355

Data Rate Mbit/s	J = 300ps Max. Nodes	J = 400ps Max. Nodes	J = 500ps Max. Nodes
106.1307	157.8323	88.7807	56.8196
106.3317	157.2361	88.4453	56.6050
106.5327	156.6433	88.1119	56.3916
106.7337	156.0539	87.7803	56.1794
106.9347	155.4678	87.4506	55.9684
107.1357	154.8850	87.1228	55.7586
107.3367	154.3054	86.7968	55.5499
107.5377	153.7291	86.4726	55.3425
107.7387	153.1560	86.1503	55.1362
107.9397	152.5861	85.8297	54.9310
108.1407	152.0194	85.5109	54.7270
108.3417	151.4559	85.1939	54.5241
108.5427	150.8954	84.8787	54.3224
108.7437	150.3381	84.5652	54.1217
108.9447	149.7839	84.2534	53.9222
109.1457	149.2327	83.9434	53.7238
109.3467	148.6846	83.6351	53.5264
109.5477	148.1394	83.3284	53.3302
109.7487	147.5973	83.0235	53.1350
109.9497	147.0581	82.7202	52.9409
110.1508	146.5219	82.4186	52.7479
110.3518	145.9886	82.1186	52.5559
110.5528	145.4582	81.8202	52.3650
110.7538	144.9307	81.5235	52.1751
110.9548	144.4061	81.2284	51.9862
111.1558	143.8843	80.9349	51.7983
111.3568	143.3653	80.6430	51.6115
111.5578	142.8492	80.3526	51.4257
111.7588	142.3358	80.0639	51.2409
111.9598	141.8252	79.7766	51.0571
112.1608	141.3173	79.4910	50.8742
112.3618	140.8121	79.2068	50.6924
112.5628	140.3097	78.9242	50.5115
112.7638	139.8099	78.6431	50.3316
112.9648	139.3128	78.3634	50.1526
113.1658	138.8183	78.0853	49.9746
113.3668	138.3265	77.8087	49.7975
113.5678	137.8373	77.5335	49.6214
113.7688	137.3507	77.2598	49.4462
113.9698	136.8666	76.9875	49.2720
114.1709	136.3851	76.7166	49.0986
114.3719	135.9062	76.4472	48.9262
114.5729	135.4297	76.1792	48.7547
114.7739	134.9558	75.9126	48.5841
114.9749	134.4843	75.6474	48.4143
115.1759	134.0153	75.3836	48.2455

Data Rate Mbit/s	J = 300ps Max. Nodes	J = 400ps Max. Nodes	J = 500ps Max. Nodes
115.3769	133.5488	75.1212	48.0776
115.5779	133.0846	74.8601	47.9105
115.7789	132.6229	74.6004	47.7443
115.9799	132.1636	74.3421	47.5789
116.1809	131.7067	74.0850	47.4144
116.3819	131.2522	73.8293	47.2508
116.5829	130.8000	73.5750	47.0880
116.7839	130.3501	73.3219	46.9260
116.9849	129.9025	73.0702	46.7649
117.1859	129.4573	72.8197	46.6046
117.3869	129.0143	72.5706	46.4452
117.5879	128.5736	72.3227	46.2865
117.7889	128.1352	72.0760	46.1287
117.9899	127.6990	71.8307	45.9716
118.1910	127.2650	71.5866	45.8154
118.3920	126.8332	71.3437	45.6600
118.5930	126.4037	71.1021	45.5053
118.7940	125.9763	70.8616	45.3515
118.9950	125.5510	70.6224	45.1984
119.1960	125.1279	70.3845	45.0461
119.3970	124.7070	70.1477	44.8945
119.5980	124.2881	69.9121	44.7437
119.7990	123.8714	69.6777	44.5937
120.0000	123.4568	69.4444	44.4444

Resume

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Employment:

Senior Development Engineer August 1989 - Present

Force, Incorporated, 825 Park Street, Christiansburg, Virginia 24073 (www.forceinc.com)

Major Responsibilities:

- Directly responsible for 1.8 million dollars in sales year to date
- Responsible for several product lines, which account for over 25% of company revenue
- Product line responsibility includes: design, sales, production and testing
- Directly supervised three technicians, indirectly supervised production lines
- Produced cost and feasibility estimates of various electronic systems.

Products Designed:

- Low cost RS-485 fiber optic bus transceiver
- Fiber optic RS-232 self healing redundant ring transceiver
- Developed front end circuitry to extend dynamic range of Fiber optic receivers
- Bi-directional video conferencing system
- 6 channel fiber optic AM sonar link
- DC - 120 MHZ analog fiber optic RGB link with AGC
- Fiber based OOK transmission system using 200-400 MHZ carriers
- Qualified a fiber upgrade to the HAWK missile system
- 16 channel 50 kHz A-to-D converter and fiber transmission system
- High speed (to 1.2 Gb/s) fiber optical data links
- Near studio quality fiber optic FM video links
- CATV fiber optic link

Process Improvements:

- Set up high speed pick and place machine and integrated into production
- Developed internal part numbering system to ease design
- Designed a new flexible product enclosure to reduce production costs
- Automated tests procedures to speed testing, increase test accuracy, create data base of test results, reduce technician training

Customer Support:

- Attended trade shows to meet customers and evaluate market needs
- Developed and delivered on-site training programs
- Met with customers to discuss product requirements
- Visited customer installations to verify product operation
- Debugged customer installation/ product problems

Professional Service:

- Member of SMPTE committee charged with writing the standard for serial digital fiber optic interfaces.

Electronics Engineer March 1988 - August 1989

Force, Incorporated, 825 Park Street, Christiansburg, Virginia 24073 (www.forceinc.com)

- Designed analog and digital circuits to meet military specifications.
- Developed hardware/software for micro controller based instrumentation equipment, including torque meters, and pyrometers.

Consultant January 1997 - Present

- Reviewed designs for a wireless repeating smoke detector

(Client: Scott Markwell; *Safenight Technology*; Roanoke VA)

- Reviewed designs and created PCB artwork for automated Aquarium Controller

(Client: J.J. Martin; Computer Science, *University of New Orleans*, LA.)

Electrical Engineer (Co-op) 1983-1984

General Electric, Mobile Communications Division, Lynchburg, Virginia

- Developed an automated test system for radio frequency part (800 MHz) of one of G.E.'s mobile radios.

Education:

- Graduate, **Dale Carnegie** course, February 1997. Christiansburg, VA.
- 29 hours of graduate coursework toward **MSEE**. *Virginia Tech*, Blacksburg VA.
- **BSEE**, July 1985, *Virginia Tech*, Blacksburg VA. GPA of 3.4 on 4.0 scale.

Skills:

- Computer Programming
- (Pascal, FORTRAN 77, C, BASIC, VISUAL BASIC, PDP-11 and other Assemblers)
- Fluent in German