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[54] NORMALIZED PROPORTIONAL SYNCHRONOUS BANDWIDTH ALLOCATION IN A TOKEN RING NETWORK BY SETTING A MAXIMUM MESSAGE TRANSMISSION TIME

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[21] Appl. No.: **949,043**

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[51] Int. Cl.[6] **G06F 15/00**

[52] U.S. Cl. **370/85.5**; 370/85.4; 370/85.12; 370/85.15; 340/825.05; 395/800; 364/222.2; 364/229.3; 364/241.8; 364/DIG. 1

[58] Field of Search 395/800; 370/85.5, 85.4, 370/85.12, 85.15; 340/825.05

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"Some Properties of timed token medium access protocols"; IEEE Transaction, Aug. 1990, by Adriano Valenzano et al.

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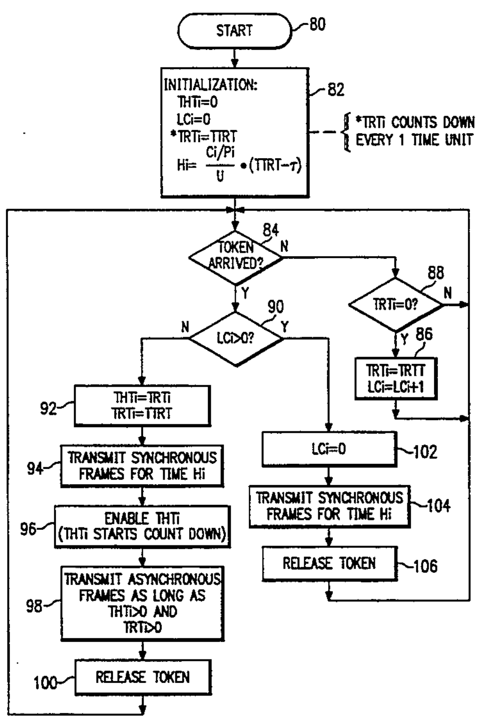
[57] **ABSTRACT**

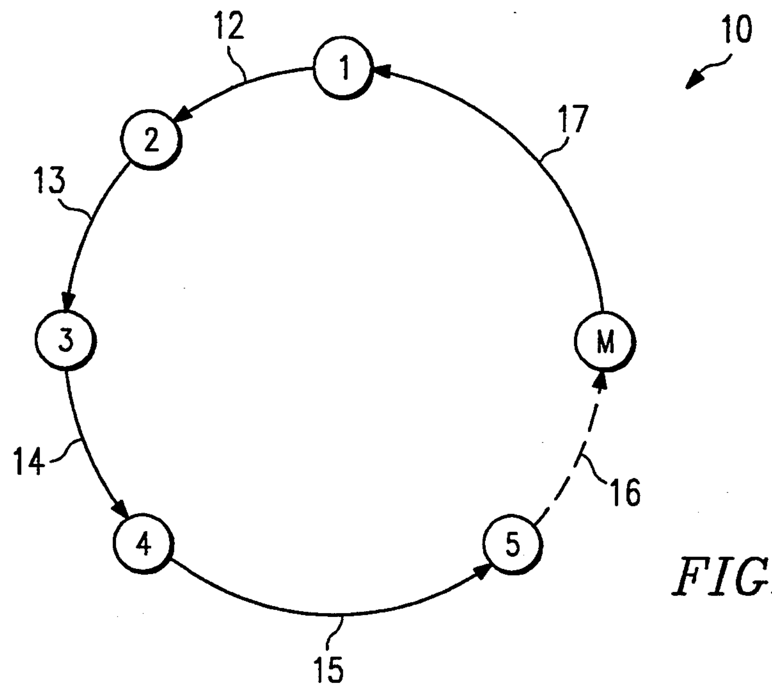
A method for real time message transmission in a token ring network is provided. The method initializes each node in the network, including setting a maximum message transmission time H_i such that

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \text{ where } U = \sum_{i=1}^{n} \frac{C_i}{P_i},\ C_i$$

is the transmission time of a message in a message stream, P_i is the period length of the message stream, TTRT is the target token rotation time, and τ is the portion of TTRT that is unavailable to transmit messages. The messages are then transmitted when a token arrives at a node for the duration of H_i. Using this method with the timed token protocol, the synchronous messages are guaranteed to be transmitted before their deadlines if the utilization of synchronous messages is no more than 33% of available utilization.

9 Claims, 3 Drawing Sheets




10
12
1
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13
17
3
M
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FIG. 1

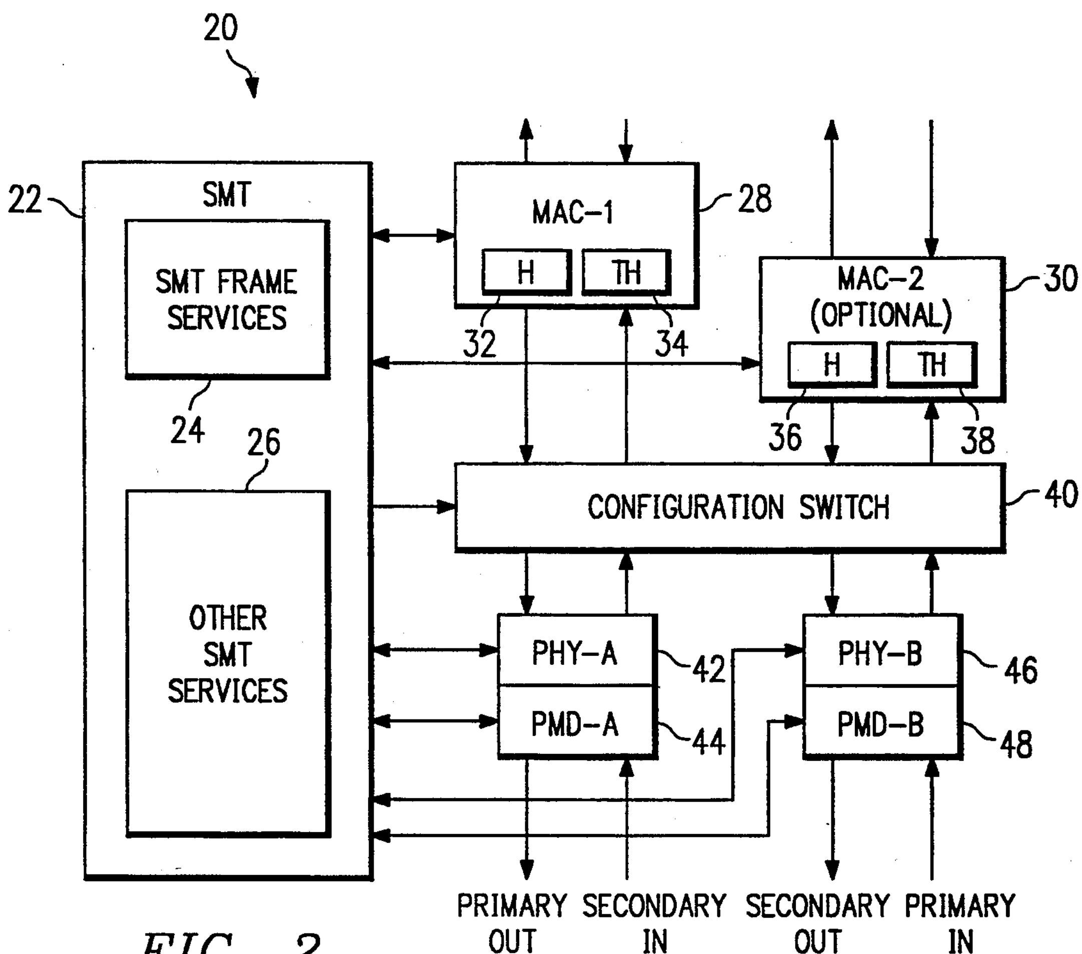

20
22
SMT
SMT FRAME SERVICES
24
26
OTHER SMT SERVICES
MAC-1
H
TH
28
32
34
MAC-2 (OPTIONAL)
H
TH
30
36
38
CONFIGURATION SWITCH
40
PHY-A
42
PMD-A
44
PHY-B
46
PMD-B
48
PRIMARY OUT
SECONDARY IN
SECONDARY OUT
PRIMARY IN

FIG. 2

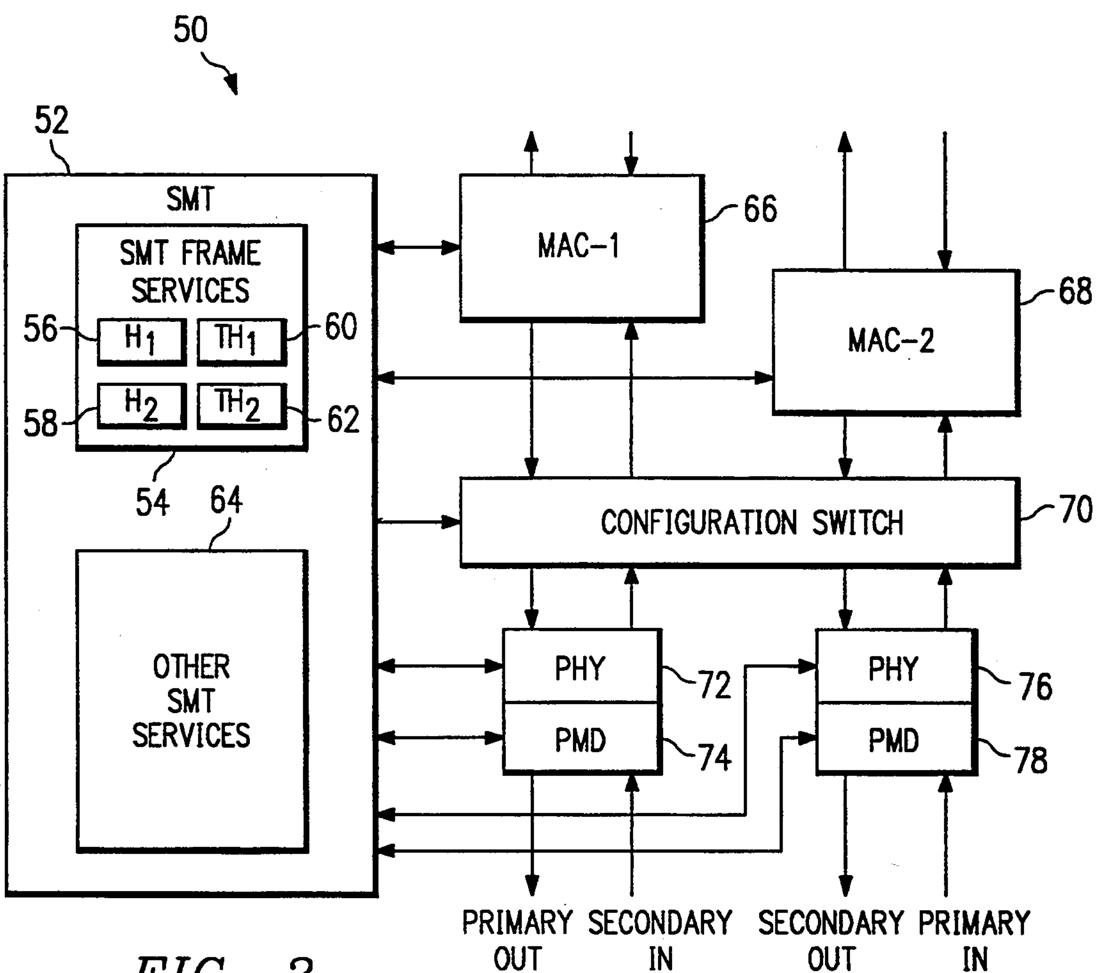
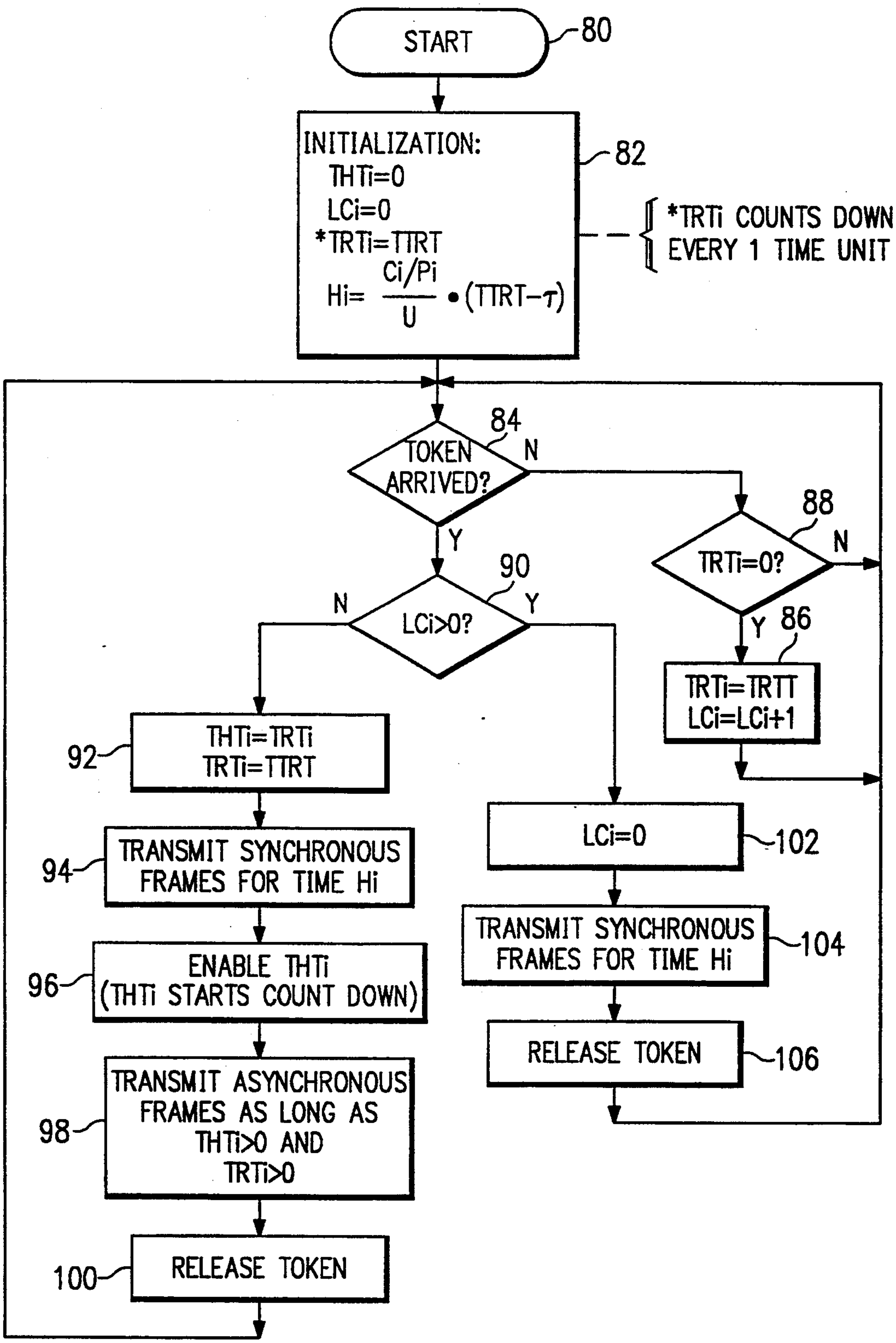

50
52
SMT
SMT FRAME SERVICES
56
H_1
TH_1
60
58
H_2
TH_2
62
54
64
OTHER SMT SERVICES
MAC-1
66
MAC-2
68
CONFIGURATION SWITCH
70
PHY
72
PMD
74
PHY
76
PMD
78
PRIMARY OUT
SECONDARY IN
SECONDARY OUT
PRIMARY IN

FIG. 3



START
80
INITIALIZATION:
THTi=0
LCi=0
*TRTi=TTRT
Hi= Ci/Pi / U • (TTRT−τ)
82
*TRTi COUNTS DOWN EVERY 1 TIME UNIT
TOKEN ARRIVED?
84
N
Y
TRTi=0?
88
N
Y
86
TRTi=TRTT
LCi=LCi+1
LCi>0?
90
N
Y
THTi=TRTi
TRTi=TTRT
92
TRANSMIT SYNCHRONOUS FRAMES FOR TIME Hi
94
ENABLE THTi
(THTi STARTS COUNT DOWN)
96
TRANSMIT ASYNCHRONOUS FRAMES AS LONG AS THTi>0 AND TRTi>0
98
RELEASE TOKEN
100
LCi=0
102
TRANSMIT SYNCHRONOUS FRAMES FOR TIME Hi
104
RELEASE TOKEN
106

FIG. 4

NORMALIZED PROPORTIONAL SYNCHRONOUS BANDWIDTH ALLOCATION IN A TOKEN RING NETWORK BY SETTING A MAXIMUM MESSAGE TRANSMISSION TIME

CROSS-REFERENCE TO RELATED APPLICATION

This patent application is related to U.S. Pat. No. 5,313,466 entitled "Local Synchronous Bandwidth Allocation in a Token Ring Network" by Wei Zhao et al. issued on May 17, 1994, filed concurrently with the present application.

TECHNICAL FIELD OF THE INVENTION

This invention relates in general to the field of distributed processing, and more particularly the present invention relates to a method for normalized proportional synchronous bandwidth allocation in a token ring network that utilizes timed token protocol carrying real time traffic.

BACKGROUND OF THE INVENTION

Distributed digital computers and microprocessors have been used for embedded real time applications such as space vehicle systems, image processing and transmission, and integration of expert systems into avionics and industrial process control. Such distributed systems have stringent timing requirements because they often operate in real time. Timing failures in these systems are impermissible since such failures may produce catastrophic results.

The key to success in using a distributed system for these applications is the timely execution of computation tasking more than one microprocessor node as well as the communication of computed results and information among the nodes. End-to-end deadline guarantees are not possible without a communication network that supports the timely delivery of inter-task messages. Therefore, it is important that messages can be guaranteed to be transmitted to their destinations before their deadlines.

A particular protocol for real time communication between distributed nodes have recently received recognition as the ANSI standard for such systems. The protocol is the FDDI (Fiber Distributed Data Interface) token ring media access control, the details of which are available by consulting *FDDI Token Ring Media Access Control (MAC). ANSI Standard X*3.139, 1987. This protocol is suitable for real time applications not only because of its use in high capacity networks, but also due to the fact that it has the important property of bounded access time. Bounded access time is necessary for real time communications. The timed token protocol has been incorporated into many network standards, including the Fiber Distributed Data Interface (FDDI), IEEE 802.4, the High-Speed Data Bus and the High-Speed Ring Bus (HSDB/HSRB), and the Survivable Adaptable Fiber Optic Embedded Network (SAFENET). Many embedded real time applications use them as backbone networks. For example, the FDDI has been selected as a backbone network for NASA's Space Station Freedom.

With the timed token protocol, messages are grouped into two separate classes: synchronous and asynchronous. Synchronous messages arrive in the system at regular intervals and may be associated with deadline constraints. Timed token protocol is primarily concerned with the control of the token rotation time, which is defined as the time between two consecutive visits of the token to a particular node. At network initialization time, a protocol parameter called Target Token Rotation Time (TTRT) is determined which indicates the expected token rotation time. Each station is assigned a fraction of the TTRT, known as synchronous bandwidth, which is the maximum time for which a node is permitted to transmit its synchronous messages every time it receives the token. Once a node receives the token, it transmits its synchronous message, if any, for a time no more than its allocated synchronous bandwidth. It can then transmit its asynchronous messages only if the time elapsed since the previous token departure from the same node is less than the value of TTRT, i.e., only if the token arrived earlier than expected.

Guaranteeing a message deadline implies transmitting the message before its deadline. With a token passing protocol, a node can transmit its messages only when it captures the token. This implies that if a message deadline is to be guaranteed, the token should visit the node where the message is waiting before the expiration of the message's deadline. That is, in order to guarantee message deadlines in a token ring network, it is necessary to bound the time between two consecutive visits of the token to a node or the token rotation time. However, merely setting a limit for the token rotation time does not guarantee meeting message deadlines. A node with inadequate synchronous bandwidth may be unable to complete the transmission of a synchronous message before its deadline. On the other hand, allocating excess amounts of synchronous bandwidth to the nodes could increase the token rotation time, which may also cause message deadlines to be missed. Thus, guaranteeing message deadlines is also dependent on the appropriate allocation of synchronous bandwidth to the nodes in the distributed system.

It is widely recognized in the art of real time distributed systems that the allocation of synchronous bandwidth is an open problem with no known solution. Accordingly, it is desirable to provide a method for synchronous bandwidth allocation in a real time distributed system which guarantees message deadlines are met. Such a bandwidth allocation method should be especially compatible with the timed token protocol in order to adhere to industry standard requirements.

SUMMARY OF THE INVENTION

In accordance with the present invention, normalized proportional synchronous bandwidth allocation is provided which substantially eliminate or reduce disadvantages and problems associated with prior schemes.

In one aspect of the present invention, a method for real time message transmission in a token ring network is provided. The method initializes each node in the network, including setting a synchronous bandwidth which is the maximum message transmission time H_i for node i, such that

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \text{ where } U = \sum_{i=1}^{n} \frac{C_i}{P_i}, C_i$$

is the transmission time of a message in a message stream, P_i is the period length of the message stream, TTRT is the target token rotation time, and τ is the portion of TTRT that is unavailable to transmit messages. The synchronous messages are then transmitted when a token arrives at a node for the duration of H_i.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference may be made to the accompanying drawings, in which:

FIG. 1 is a simplified diagram of a token ring network;

FIG. 2 is a simplified block diagram of a station architecture;

FIG. 3 is a simplified block diagram of an alternative architecture; and

FIG. 4 is a simplified flow chart of a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawings, FIG. 1 illustrates a preferred embodiment of a distributed ring network, indicated generally at 10 and constructed according to the teaching of the present invention. Network 10 topology includes nodes or stations 1-m connected by point-to-point links 12–17 forming a ring. A token typically consisting of a predetermined bit pattern circulates around ring network 10 and visits each node 1-m. Only the node which has possession of the token may transmit messages.

FIGS. 2 and 3 provide the physical hardware architecture of node i typically employed in timed token ring 10. Referring to FIG. 2, a simplified block diagram of the architecture of a FDDI (fiber distributed data interface) dual attachment station 20 is shown. The architecture shown is recommended by the FDDI ANSI standards, which may be consulted for details not described herein. Station management (SMT) 22 is a component responsible for the local portion of the network management application process. SMT 22 provides the control required for the proper internal configuration and operation of a node or station in an FDDI timed token ring. It further controls and coordinates the various activities between the various network layers in the computer network. SMT 22 includes SMT frame services 24 and other SMT management services 26.

SMT 22 is connected to media access control (MAC) 28 and 30, one of which may be an optional component. MAC 28 and 30 forms the lower sublayer of the data link layer and are responsible for access to the medium, addressing, data checking and data framing. MAC 28 and 30 communicate with SMT 22 to determine if any frame, synchronous or asynchronous, is to be transmitted. They also inform SMT 22 any change in the transmission status.

MAC 28 and 30 each includes registers, H 32, TH 34, and H 36, and TH 38, respectively, which are of interest to the instant invention. H registers 32 and 36 are used to record the synchronous bandwidth allocated to MAC 28 and 30, respectively. Each time MAC 28 and/or 30 begins the transmission of synchronous frames, the contents of corresponding H registers 32 and 36 are loaded into TH registers 34 and 38, respectively. Subsequently, TH registers 34 and 38 counts down until zero upon which it interrupts MAC 28 and 30, respectively, to stop synchronous flame transmission.

Physical layer protocol (PHY) 42 and 46 form the upper sublayer of the physical layer, and is responsible for the encoding or coding, clocking and framing for transmission. Physical medium dependent (PMD) 44 and 48 are coupled to PHY 42 and 46, respectively, and form the lower sublayer of the physical layer. PMD 44 and 48 are responsible for interfacing with the fiber optic transmission medium, handling the optical signal requirements, bit error rates, and other functions.

In operation, SMT 22 and higher level layers are responsible for queuing up synchronous and asynchronous frames for transmission. SMT 22 communicates to MAC 28 and 30 the availability of the frames and requests the capture of the token. Once a token is captured, MAC 28 and 30 transmits the queued frames in accordance with the rules of the timed token protocol. The connection of MAC 28 and 30 with PHY 42 and 46 are controlled through a configuration switch 40, which is in turn controlled by SMT 22. The frames transmitted by MAC 28 and 30 are routed to the appropriate PHY 42 and 46 through configuration switch 40.

Referring to FIG. 3, an alternative architecture 50 of an FDDI dual attachment station is shown. Architecture 50 is substantially similar to that shown in FIG. 2, with some minor differences. SMT 52, which includes SMT frame services 54 and other management components 62, also includes H1, H2 registers 54 and 56, and TH1 and TH2 registers 58 and 60. H1 and TH1 registers 54 and 58 control the synchronous frame transmission of MAC-1 64, and similarly, H2 and TH2 registers 56 and 60 control MAC-2 66. Registers H1, H2, TH1, and TH2 54-60 function and operate as described above in connection with architecture 20 shown in FIG. 2. The other components' organization and functions, such as configuration switch 68, PHY 70 and 74 and PMD 72 and 76 also remain the same as that of architecture 20.

Messages generated in network 10 at run time may be classified as either synchronous or asynchronous. We assume that there are n streams of synchronous messages, $S_1, S_2, \ldots, S_n$ in the system which form a synchronous message set M:

$$M=\{S_1, S_2, \ldots, S_n\} \tag{1}$$

Although details of the messages in network 10 can be found in *FDDI Token Ring Media Access Control (MAC).* ANSI Standard X3.139, 1987, some selected characteristics of messages are set forth below:

1. Synchronous messages are periodic, i.e., messages in a synchronous message stream have a constant inter-arrival time. The period length of stream $S_i(i=1,2,\ldots,n)$ is denoted as P_i.

2. The deadline of a synchronous message is the end of the period in which it arrives. That is, if a message in stream S_i arrives at time t, then its deadline is at time $t+P_i$.

3. Messages are independent in that message arrivals do not depend on the initiation or the completion of transmission requests for other messages.

4. The length of each message in stream S_i is C_i which is the maximum amount of time needed to transmit this message.

The utilization factor of a synchronous message set, U(M), is defined as the fraction of time spent by the network in the transmission of the synchronous messages. That is,

$$U(M) = \sum_{i=1}^{n} \frac{C_i}{P_i} \tag{2}$$

where n is the number of synchronous message streams.

Several timed token MAC protocol parameters and variables are defined for its operation and is related to the embodiment of the instant invention. Target Token Rotation Time (TTRT) is the expected value of the token rotation time defined at network initialization time. TTRT is generally selected to be sufficiently small to support the response time requirements of the messages at all the nodes **1**-m in the network. Since the time elapsed between two consecutive visits of the token at a node can be as much as (2·TTRT), a node may not be able to transmit any message during this interval. In order to meet message deadlines it is necessary to select TTRT such that, for $1 \leqq i \leqq n$,

$$TTRT \leqq P_i/2 \tag{3}$$

where P_i may therefore be represented as a linear function of TTRT. That is,

$$P_i = m_i \cdot TTRT - \delta_i \tag{4}$$

where

$$m_i = \left\lceil \frac{P_i}{TTRT} \right\rceil \geqq 2 \text{ and } \delta_i = \left\lceil \frac{P_i}{TTRT} \right\rceil \cdot TTRT - P_i.$$

Note that if $m_i=2$, for example, then $\delta_i=0$ and if $m_i \geqq 3$ then $0 \leqq \delta_i < TTRT$.

The synchronous bandwidth of node i,(H_i), is the maximum time for which a node **1**-m is permitted to transmit synchronous messages each time the station receives the token. Note that each node **1**-m may be assigned a different H_i value.

The token rotation timer of node i,(TRT_i), is a counter which is initialized to TTRT, and counts down until it is equal to zero or until the token is received and the time elapsed since the previous token departure is less than TTRT. In either situation, the TRT_i is reinitialized to TTRT. After being reset, it continues the subsequent counting down cycles in the same manner.

The Token Holding Timer of node i,(TH_i), is a counter which is used to control the amount of time for which the node i can transmit asynchronous messages. The Late Counter of node i, (LC_i), is used to record the number of times that TRT_i has expired since the last token arrival at node i.

A synchronous bandwidth allocation scheme is defined as a process which, when given as input the values of all C_i and P_i in the message set and the value of TTRT, assigns synchronous bandwidths H_i to node i in the network. Therefore, if function f represents an allocation scheme. Then,

$$f(C_1, C_2, \ldots C_n, P_1, P_2, \ldots P_n, TTRT) = (H_1, H_2, \ldots H_n) \tag{5}$$

The synchronous bandwidths allocated to the nodes **1**-m by any scheme must satisfy two constraints in order to ensure that the real time messages can be transmitted before their deadlines and that the timed token protocol requirements are satisfied. The first constraint is the protocol constraint. Theoretically, the total available time to transmit synchronous messages, during one complete traversal of the token around the ring **10**, can be as much as TTRT. However, factors such as ring latency Θ and other protocol/network dependent overheads reduce the total available time to transmit the synchronous messages. The ring latency Θ is defined as the token walk time around the ring **10** when none of the nodes **1**-m in the network disturb it. The portion of TTRT unavailable for transmitting synchronous messages is denoted by the parameter τ. That is, $\tau = \Theta + \Delta$ where Δ represents the protocol dependent overheads. Furthermore, the ratio τ to TTRT to be α. The usable ring utilization available for synchronous messages would therefore be $(1-\alpha)$.

Thus, the protocol constraint on the allocation of synchronous bandwidths is that the sum total of the synchronous bandwidths allocated to all nodes **1**-m in the ring **10** should not be greater than the available portion of TTRT so theft:

$$\sum_{i=1}^{n} H_i \leqq TTRT - \tau. \tag{6}$$

The second constraint is the deadline constraint. The allocation of the synchronous bandwidths to the nodes **1**-m should be such that the synchronous messages are always guaranteed to be transmitted before their deadlines, i.e., before the end of the period in which they arrive. In other words, if X_i is the minimum amount of time available for node i to transmit its synchronous messages in a time interval $(t, t+P_i)$, then

$$X_i \geqq C_i \tag{7}$$

Note that X_i will be a function of H_i and the number of token visits to node i in time interval $(t, t+P_i)$.

A message set is defined to be guaranteed by a bandwidth allocation scheme if both the protocol and the deadline constraints are satisfied. Once a message set is guaranteed, messages will be transmitted before their deadlines, as long as the network operates normally.

Known synchronous bandwidth allocation schemes, such as the full length allocation scheme, proportional allocation scheme, and equal partition allocation scheme, may not satisfy the protocol and/or deadline constraints even if the real time traffic is very light. Please refer to the table below for a summary and comparison of the various allocation schemes. The instant invention provides a normalized proportional allocation scheme which satisfies both constraints under the condition that the synchronous real time traffic is no more than 33%. The synchronous bandwidth is allocated according to the normalized load of the synchronous message on a node, i.e.,

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \tag{8}$$

where

$$U = \sum_{i=1}^{n} C_i/P_i.$$

It can be shown that the Worst Case Achievable Utilization factor of the normalized proportional allocation scheme is $\frac{1}{3}(1-\alpha)$ where $\alpha = \tau/TTRT$. To do so, it first must be shown that:

1. For any message set M, the protocol constraint will be satisfied if

$$\sum_{i=1}^{n} \frac{C_i}{P_i} = U \leqq 1.$$

2. For any message set M with utilization factor $U(M) \leqq \frac{1}{3}(1-\alpha)$, the deadline constraint will always be satisfied.

3. For any given $\epsilon > 0$, there exists a message set M with utilization factor $[\frac{1}{3}(1-\alpha) < U(M) \leqq \frac{1}{3}(1-\alpha)+\epsilon]$ so that the deadline constraint cannot be satisfied for this set of messages when the synchronous bandwidths are allocated using the normalized proportional scheme.

For any message set M with

$$\sum_{i=1}^{n} \frac{C_i}{P_i} = U \leqq 1, \tag{9}$$

$$\sum_{i=1}^{n} H_i = \sum_{i=1}^{n} \frac{C_i/P_i}{U} \cdot (TTRT - \tau) = TTRT - \tau.$$

Hence, the protocol constraint

$$\sum_{i=1}^{n} H_i \leqq TTRT - \tau. \tag{10}$$

is satisfied.

For proving the second statement, consider a message set whose utilization factor $U(M) \leqq \frac{1}{3}(1-\alpha)$. It can be shown that:

$$U \leqq \frac{1}{3}(1-\alpha) \leqq \frac{\left\lfloor \frac{P_i}{TTRT} - 1 \right\rfloor}{P_i/TTRT}(1-\alpha) \leqq \frac{\left\lfloor \frac{P_i}{TTRT} - 1 \right\rfloor}{P_i}(TTRT-\tau). \tag{11}$$

Multiplying with C_i/U on both sides, the result is:

$$C_i \leqq \frac{\frac{\left\lfloor \frac{P_i}{TTRT} - 1 \right\rfloor}{P_i} \cdot (TTRT-\tau) \cdot C_i}{U}. \tag{12}$$

For $1 \leqq i \leqq n$, it becomes:

$$C_i \leqq \left\lfloor \frac{P_i}{TTRT} - 1 \right\rfloor \cdot \frac{C_i}{P_i U} \cdot (TTRT-\tau). \tag{13}$$

Substituting

$$\frac{C_i/P_i}{U} \cdot (TTRT-\tau) = H_i,$$

the equation becomes:

$$C_i \leqq \left\lfloor \frac{P_i}{TTRT} - 1 \right\rfloor \cdot H_i. \tag{14}$$

Therefore, since the total amount of time available for node i to transmit the synchronous message is bound by

$$\left\lfloor \frac{P_i}{TTRT} - 1 \right\rfloor \cdot H_i$$

any node i can transmit its synchronous message before the deadline.

For a proof of statement 3, let

$$\epsilon' = \min\left(\frac{1-\alpha}{3}, \epsilon\right), \tag{15}$$

for any given $\epsilon > 0$, where $\alpha = \tau/TTRT$. Let $TTRT = \frac{1}{2}$. Consider the following message set:

$$C_1 = \epsilon', \quad P_1 = 1, \tag{16}$$
$$C_2 = \epsilon', \quad P_2 = \frac{3}{2} - \epsilon',$$
$$C_3 = 1 - 3\epsilon' - \alpha, \quad P_3 = 3.$$

Note that Equation (15) guarantees that $C_3 > 0$. . All other $C_i = 0$ for $i > 3$.

The utilization of this message set is

$$\begin{aligned} U &= \frac{C_1}{P_1} + \frac{C_2}{P_2} + \frac{C_3}{P_3} \\ &= \epsilon' + \frac{\epsilon'}{(3/2) - \epsilon'} + \frac{1}{3} - \epsilon' - \frac{1}{3}\alpha \\ &= \frac{1}{3}(1-\alpha) + \frac{\epsilon'}{(3/2) - \epsilon'}. \end{aligned} \tag{17}$$

Since $\frac{3}{2} - \epsilon' > 1$ and $\epsilon' \leqq \epsilon$,

$$U < \frac{1}{3}(1-\alpha) + \epsilon' \leqq \frac{1}{3}(1-\alpha) + \epsilon. \tag{18}$$

Consider the synchronous bandwidth allocated to node 2:

$$\begin{aligned} H_2 &= \frac{C_2}{P_2 \cdot U} \cdot (TTRT - \tau) = \\ &\frac{C_2}{P_2 \cdot U} \cdot TTRT \cdot (1-\alpha) \\ &= C_2 \cdot \frac{\frac{1}{2}(1-\alpha)}{\left(\frac{3}{2} - \epsilon'\right)\left(\frac{1}{3}(1-\alpha) + \frac{\epsilon'}{\frac{3}{2} - \epsilon}\right)} = \\ &C_2 \cdot \frac{\frac{1}{2}(1-\alpha)}{\frac{1}{2}(1-\alpha) - \frac{1}{3}\epsilon'(1-\alpha) + \epsilon'} \\ &= C_2 \cdot \frac{1}{1 - \frac{2}{3}\epsilon' + \frac{2\epsilon'}{(1-\alpha)}} = \\ &C_2 \cdot \frac{1}{1 + \frac{2\epsilon'}{(1-\alpha)}\left(1 - \frac{1-\alpha}{3}\right)}. \end{aligned} \tag{19}$$

Since $0 < \epsilon \leqq \frac{1}{3}$ and $0 \leqq \alpha < 1$, the denominator of Equation (19) is greater than 1. Hence.

$$H_2 < C_2 \tag{20}$$

To show that $\delta_2 > H_2$,

$$\begin{aligned} \delta_2 &= \left\lceil \frac{P_2}{TTRT} \right\rceil \cdot TTRT - P_2 \\ &= \left\lceil \frac{3/2 - \epsilon'}{1/2} \right\rceil \cdot \frac{1}{2} - \left(\frac{3}{2} - \epsilon'\right) = \\ &\lceil 3 - 2\epsilon' \rceil \cdot \frac{1}{2} - \frac{3}{2} + \epsilon' \\ &= \frac{3}{2} - \frac{3}{2} + \epsilon'. \end{aligned} \tag{21}$$

-continued

$$= \epsilon' = C_2 > H_2.$$

In the worst case, the amount of time for node 2 to transmit its synchronous message in a time interval $(t, t+P_2)$ is given by:

$$X_2 = \left\lfloor \frac{P_2}{TTRT} - 1 \right\rfloor \cdot H_2 = \left\lfloor \frac{(3/2) - \epsilon'}{1/2} - 1 \right\rfloor \cdot H_2 = 1 \cdot H_2 < C_2. \quad (22)$$

Therefore, the deadline constraint (7) is violated and this set of messages cannot be guaranteed. For a more detailed discussion of the proofs, please refer to "Guaranteeing Synchronous Message Deadlines with the Timed Token Protocol" by Gopal Agrawal, Biao Chen, Wei Zhao and Sadegh Davari, *IEEE International Conference on Distributed Computing Systems,* dated June 1992.

Therefore, the worst case achievable utilization used as the metric to evaluate the normalized proportional synchronous bandwidth allocation scheme shows that the scheme has a high worst case achievable utilization (WCAU) of

$$\frac{1-\alpha}{3}.$$

This WCAU value is independent of the number of nodes in the system or the message lengths and periods.

Guaranteeing message deadlines is a key issue in distributed real time applications. The property of the bounded token rotation time of the timed token protocol provided a necessary condition to ensure that the message deadlines are satisfied. However, the synchronous bandwidth allocated to each node in the network was also shown to be a decisive factor in guaranteeing time-critical messages.

Referring to FIG. 4, a flowchart 80 demonstrating the operation of the instant invention is shown. Applying the normalized proportional synchronous bandwidth allocation scheme at network 10 initialization, the parameters are initialized at each node i=1-m so that $THT_i 0$, $LC_i=0$, $TRT_i=TTRT$, and

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \quad (23)$$

as shown in block 82. Recall that THT_i is the token holding timer for node i; TRT_i is the token rotation timer for node i; LC_i is the late counter for node i; and H_i is the synchronous bandwidth allocated to node i. Subsequently, the TRT_i counter is enable to count down at every time unit. A check is made as to whether a token has arrived, as shown in block 84. If a token has not arrived, a determination is made as to whether TRT_i has reached zero as shown in block 88. If TRT_i has not reached zero, execution returns to block 84. If TRT_i has reached zero, TRT_i is reset to TTRT, and LC_i is incremented by one, as shown in block 86. TRT_i then begins the counting down process again with LC_i being incremented by one at every expiration of TRT_i. Normally, if LC_i exceeds one, the ring recovery process is initiated.

A token is considered to arrive early at node i if $LC_i=0$ at the time of its arrival. The token is late if $LC_i>0$. Therefore, if a token has arrived (as determined in block 84), a determination of the status of LC_i is made in block 90. If LC_i is not greater than zero, the parameters are set $THT_i=TRT_i$, $TRT_i=TTRT$, and TRT_i continues to count down as before. If there are any synchronous frames, they are transmitted for a maximum time of H_i, as shown in block 94. After transmitting the synchronous frames, the node i enables counter THT_i to start counting down, as shown in block 96. The node may then transmit asynchronous frames as long as $THT_i>0$ and $TRT_i>0$, as shown in block 98. Subsequently, the token is released, as shown in block 100.

When the token arrives late at node i, LC_i is greater than zero, and LC_i is reset to zero as shown in block 102. Note that TRT_i is not reset to TTRT as in the case when the token is early. In block 104, node i transmits synchronous frames, if any, for a maximum time of H_i. No asynchronous frame is transmitted. The token is then released in block 108. Whether the token arrived early or late, the execution returns to block 84 to check for capture of any subsequent tokens.

In summary, four synchronous bandwidth allocation schemes and their analysis results are shown in the following table:

TABLE

Summary of the synchronous bandwidth allocation schemes.

Name	Formula of H_i	W.C.A.U.	Comments
Full length	$H_i = C_i$	0	Uses local information only, i.e., C_i.
Proportional	$H_i = \frac{C_i}{P_i} \cdot (TTRT - \tau)$	0	Uses local information only, i.e., $\frac{C_i}{P_i}$.
Equal Partition	$H_i = \frac{TTRT - \tau}{n}$	$\frac{1-\alpha}{3n-(1-\alpha)}$	Uses global information only, i.e., the number of nodes n.
Normalized proportional	$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau)$	$\frac{1-\alpha}{3}$	Uses both local and global information, i.e., load on the system (U) and the load offered by local message streams $\left(\frac{C_i}{P_i}\right)$.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A method for real time synchronous message transmission in a token ring network having a plurality of nodes, comprising the steps of:

initializing each node in the network, including setting a maximum message transmission time H_i for each node i,

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \text{ where } U = \sum_{i=1}^{n} \frac{C_i}{P_i}, C_i$$

is a transmission time of a message in a message stream, P_i is a period length of a message stream, TTRT is a target token rotation time, and τ is a portion of TTRT that is unavailable to transmit messages; and

transmitting said message stream for duration of H_i when a token arrives at node i.

2. The method, as set forth in claim 1, wherein said messages transmitted are synchronous messages.

3. The method, as set forth in claim 1, wherein said initializing step further comprises the steps of:

determining a target token rotation time TTRT;

setting a token rotation timer for node i to equal to said target token rotation time TTRT; and

setting a late counter for node i to zero.

4. The method, as set forth in claim 3, further comprising the steps of:

after said initializing step, decrementing said token rotation timer to zero;

incrementing said late counter each time said token rotation timer reaches zero; and

determining whether a token has arrived at node i.

5. The method, as set forth in claim 4, wherein the initializing step further comprises the step of setting a token holding timer to zero.

6. The method, as set forth in claim 5, further comprising the steps of:

determining that said late counter is equal to zero;

setting said token holding timer to said token rotation timer;

setting said token rotation timer to said target token rotation time;

enabling countdown of said token rotation timer;

transmitting synchronous messages for time H_i;

enabling the countdown of said token holding timer;

transmitting asynchronous messages until one of said token rotation timer and said token holding timer reaches zero.

7. In a token ring network connecting a plurality of nodes, said nodes communicating with one another by transmitting messages, and said nodes transmit said messages only when a token is received, a method for allocating a synchronous maximum message transmission time H_i for each node i, the method comprising the steps of:

computing for H_i, such that:

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \text{ where } U = \sum_{i=1}^{n} \frac{C_i}{P_i}, C_i$$

is a transmission time of a message in a message stream, P_i is a predetermined period length of the message stream, TTRT is a predetermined target token rotation time, and τ is a predetermined portion of TTRT that is unavailable to transmit messages;

initializing each node i with respective computed H_i; and

transmitting said messages when said token is captured by node i for duration of respective computed H_i.

8. The method, as set forth in claim 7, wherein said transmitted messages are synchronous messages.

9. Apparatus for allocating a maximum synchronous message transmission time H_i for node i in a token ring network connecting a plurality of nodes, said nodes communicating with one another by transmitting messages, and said nodes transmit said messages only when a token is received, the apparatus comprising:

a processor computing for H_i, such that:

$$H_i = \frac{C_i/P_i}{U} \cdot (TTRT - \tau), \text{ where } U = \sum_{i=1}^{n} \frac{C_i}{P_i}, C_i$$

is a transmission time of a message in a message stream, P_i is a predetermined period length of the message stream, TTRT is a predetermined target token rotation time, and τ is a predetermined portion of TTRT that is unavailable to transmit messages;

means for initializing each said nodes with respective computed H_i; and

means for transmitting said synchronous messages for the duration of respective computed H_i when said token is received at node i.

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