SIMULATION AND ANALYSIS STUDIES TO EXPLORE THE PARAMETERS THAT AFFECT THE PERFORMANCE OF THE FDDI AT GIGABIT SPEED

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ABSTRACT

*This paper explores the parameters that affect the performance of FDDI at gigabit speed, a simple analytical model and simulation model have been used to analyze the performance of FDDI ring network at gigabit speeds. The performance metrics of maximum utilization, throughput, efficiency, maximum access delay, average token rotation time, average frame and queuing delay are considered. Both of these models have been presented and compared. The results show that the proposed simulator model is very closed to the analytical model, and there are several parameters have sensitive effects on the performance characteristics of FDDI network, such as Target Token Rotation Time (*TTRT*), frame length, FDDI fiber length, number of stations. The effects of these parameters have been considered on the study of the performance of FDDI network and obviously are promising enough.*

KEYWORDS: *FDDI ring network; TTRT; efficiency; maximum untilization; total throughput; maximum delay and simulation & analytical models.*

I. INTRODUCTION

The original FDDI and the upward compatible extension of FDDI, referred to as FDDI-II, are being developed as a set of ANSI standards by ASC X3T9.5 committee. There are gigabit per second token ring local area networks which are optical fiber as the transmission medium. Both are candidates for use in campus area networks as well as local area networks, some of the related work can be found in [1-12]. FDDI networks benefit from the many advantages of fiber, including wide bandwidth, low attenuation, immunity to electromagnetic interference, security, light weight, and small size [13,14], also, with the benefit of a collision-free network access procedure, FDDI can achieve up to 99% of its theoretical bandwidth throughout the entire system, independent of network growth. Today, FDDI network products are commercially available and the protocol is one of the most commonly installed high-speed local area network. Practical experiences in existing system have resulted in enhanced FDDI products. The advanced design of concentrators as well as appropriate adapter cards for workstations and personal computers are extend the market of FDDI. Driven by technical development, the basic FDDI standards are continuously evolving [15]. There are many research papers about FDDI protocol [14,16-30], also it is well known that the FDDI uses what is called a timed-token access protocol that allows both synchronous and asynchronous traffic simultaneously. The maximum access delay, the time between successive transmission opportunities, is bounded for both above traffic [31]. It is to be mention here that the long access delays are not desirable and can be avoided by proper setting of the network parameters (such as *TTRT*, number of stations, etc.) and configurations (e.g., FDDI fiber length). The effect of *TTRT* and FDDI fiber length on various performance metrics is investigated by using a simple analytical model and a simulation model.
The remaining of the paper is organized as follow: section 2 explains the FDDI network mechanism, the operation of the TTR presents in section 3, section 4 describes the network architecture, the

simulation and analytical results are introduce in section 5, finally section 6 shows the conclusion of the paper.

II. FDDI NETWORK MECHANISM

The FDDI media access protocol is a Timed Token Rotation (*TTR*) protocol which operates by passing a unique, short, fixed length symbol sequence, called a token, around the ring [1,32,33]. The token allocates the right to transmit data to each station in turn (round robin). In order to transmit, a station must wait until it detects a token passing by. It then captures the token by removing it off the ring. The station

allows to transmit packets for a period determined by the *TTR* algorithm. At the end Token Holding Time (*THT*), the token is forward to the downstream station. If the downstream station has data to transmit, it will capture the token, transmits its data, and then issue a token or else it will repeat the token [31]. The FDDI's MAC protocol is an enhancement of the access method specified for the IEEE802.5 token passing LAN [34], modified to support the higher data rate of FDDI. There are two key differences:

(1) An IEEE802.5 technique of flipping a bit to convert a token to start of frame was considered impractical because of the high data rate of FDDI. In FDDI a station waiting for a token seizes the token by aborting (failing to repeat) the token transmission as soon as the token frame is recognized. After captured token is completely received, the station beings transmitting one or more data frames [35].
(2) With token ring standard (IEEE802.5), a sending station doesn't emit a new token until the trailing edge of its last frame has been transmitted and the source address field of its first frame returned after propagation around the ring. With FDDI, a station that has been transmitting data frames releases a new token as soon as it completes last data frame transmission, even if it has not begun to receive its first frame transmitted [36]. Thus, transmissions from multiple users are allowed to occupy the ring at the same time. This mechanism allows for more efficiently usage of bandwidth and is known as early token release [1,30].

Proper operation of the FDDI ring requires each station, except the transmitting station, to repeat any frame received from its upstream neighbor to its downstream neighbor. It the frame's destination address field matches the station own address or a relevant group address, and there is no error has been detected, the station copies the frame into its frame buffer. If the station has frame ready to be transmitted, it must wait for and capture a token. As soon as the station has completed transmission of its waiting frames, or has exhausted the time allocated for the transmission opportunity, it must release the token to allow another station to transmit. After a frame has propagated around the entire ring, the transmitting station should recognize its own address in the source address field. This station is then responsible for `stripping' the rest of the frame from the ring, which it does by absorbing the remaining fields and transmitting idle symbol onto the ring in their place. However, the fields prior to the source address field will have already been repeated and will be recognized as a remnant by the other stations on the ring. Eventually, the next station to transmit will be responsible for removing the remnant from the ring. If an error had been detected, the transmitting station must capture another token to retransmit the frame[1,33,36,37].

III. TIMED TOKEN ROTATION (TTR) PROTOCOL OPERATION

Suppose there are N stations on the ring which are numbered from 1 to N. The token circulates among all the N stations of the ring in a round robin fashion , the station' access to the ring use then the controlled by the following protocol [30,35,38-41]:

(1) As part of FDDI ring initialization process, each station declares a Target Token Rotation Time (TTRT) which equals one half of the requested transmission delay (Treq) of its synchronous frames. The smallest among them is selected as the ring's TTRT. Each station which supports synchronous traffic is assigned a portion of the TTRT to transmit its synchronous frames. Lets $SAi \geq 0$ denotes the portion of TTRT of station I which assigned to transmit its synchronous frames, the allocation must be such as:

$$T_{ring} + T_p + \sum_{i=1}^{N} SA_i \leq TTRT$$

Where: Tring: propagation Time of one complete cycle of the token around the ring;

Tp : time required to transmit a maximum size frame. Note that: all stations have the same value of TTRT and separately assigned value of SAi by means of (Station Management) SMT protocol, to assure that the preceding equation is satisfied [35].

(2) Each station has two timers, to control how long this station and each type of traffic may use the channel once the station captures the token: Token Rotation Timer (TRT) and Token Holding Timer (THT). During the first token rotation, no frames are allowed to be transmitted and the following parameters are initialized at all stations:

(i) TRTi = TTRT ; (ii) THTi = 0 ; (iii) LCi = 0 .

(3) The TRTi counter always counts down and the THTi counter counts only when the node is transmitting asynchronous frames. When a station's TRT reaches zero before the token arrives at the station, TRT is reset to TTRT and the token is marked "late" by incrementing the station's LC by one. That is, the following actions take place:

(i) TRTi = TTRT ; (ii) LCi = LCi + 1 .

TRTi is then begins the counting down process again with LCi begin incremented by one every expiration of TRTi, Normally, if LCi exceeds on (i.e., LCi = 2), the ring recovery process is initiated [15].

(4) Only the station which has the token is eligible to transmit frames. The frame transmission time is controlled by the timers, but an in progress frame transmission will not be interrupted until its completion. When a station receives the token, its actions will depends on whether the token is early or late. A token is considered to arrive early at station i if LCi = 0, and late if LCi > 0 at the time of its arrival.

(a) When the token arrives early at station 1, the following actions take place:

- (i) THTi = TRT ;
- (ii) TRTi = TTRT ;
- (iii) If the station has synchronous frames, it transmits them for a time period up to SAi (i.e., the synchronous bandwidth at station i) or until all synchronous frames are transmitted, which occurs first;
- (iv) After transmitting synchronous frames (if any) or if there is no synchronous frames to transmit, the station enable THTi (i.e., it starts counting down), and begins transmitting asynchronous frames (if any) until THTi reaches zero or all its asynchronous frames are transmitted, whichever occurs first.

(b) When the token arrives late at station i, the following actions take place:

- (i) LCi = 0 ;
- (ii) TRTi continuous to count down towards expiration (note that, it is not reset to TTRT as in the case when the token is early);
- (iii) Node i can transmit synchronous frames (if any) for a maximum time period up to or until the synchronous frames are transmitted, whichever occurs first ;
- (iv) No asynchronous frames will be transmitted.

(5) Station i passes the token to next station (i+1).

IV. NETWORK ARCHITECTURE

4.A Assumptions

The FDDI ring network is simulated with *N* stations (*20, 40, 60, 80*, and *100*) and various *L* fiber ring lengths (*4Km, 20Km, 50Km, 100Km, 300Km, 400Km,* and *500Km*). All stations are uniformly distributed on the ring, i.e., the station propagation delay is the same for all stations. Each station has a latency of 1µs and the light waves travel along the fiber at a speed of *5.085 µs / Km* [39,42]. The FDDI channel speed (C) is 1Gbps, and the maximum frame size is 4500 bytes including header 28 bytes, and thus, the maximum frame transmission time is *36 µs* (*36Kb / 1Gbps*).

The proposed network consists of *N* stations connected as point-to-point links forming a ring. A special bit pattern called token circulates around the ring providing access control among the active stations. The ring latency is *Tring*, which represents the movement time of the token around the ring without any disturbance of any stations on the networks.

4.B Simulation Model

The simulation model is carried for the FDDI token ring servicing data traffic only (non-real time traffic). A data source is characterized by its message size *M* and its average message interval time (μm), each data source generates fixed message with uniformly distributed interarrival time. If the received message is larger the length of data frame (*Ps*), it is divided into as many frames as needed. In that case, after packetization, the frames belonging to the same message are placed into the transmit queue as a bulk arrival. The average interarrival time (μm) is varied to adjust the total data load on the network. The total data load (*Tl*) over the network can be defined as:

$$Tl = \lambda * N * M \quad bit/sec, \quad \text{-----(1)}$$

Where: *M: represents the message size (bits),*

Λ: is the arrival rate of data message from a data source (message/sec). It is to be mention here the interarrival time of data messages can be defined as $\mu m = 1/\lambda$ *sec, and the data traffic intensity or normalized data throughput (ρ) on the network is defined as [43,44].*

$$P = Tl / C = (\lambda * N * M) / C \quad \text{-----(2)}$$

The data frame delays (D) through the network are measured upon the arrival at the destination and can be defined as [44,45]:

$$D = Qd + TT + Pro \quad sec. \quad \text{-----(3)}$$

Where: *Qd*: *is the queuing delay of the data frame at the source (sec)*;

TT: *is the transmission time of data packet* [$TT = (Ps + h) / C$, *H is the frame Header*];

Pro: *is propagation delay from source to destination is sec.*

4.C Analytical Model

We have followed the same analytical models were used and described in [1,31], in which the FDDI ring latency (*Rl*) can be defined as:

$$Rl = (L * Slw) + (N * Ds) \quad sec. \quad \text{-----(4)}$$

Where: *L* : *is the total FDDI fiber length (km)* ;

Slw: *is the speed of the light waves travel along the fiber and equals to 5.085 µs / Km* ;

N : *is the number of stations* ;

Ds: *is the station delay, i.e.,the delay between receiving a bit and repeating it on the transmission side, it is of the order of 1 µs per station.*

If the value of *TTRT* is *v*, the efficiency (ζ) and the maximum access delay (δ) are [31]:

$$\zeta = [N * (v - Rl)] / [N * (v + Rl)] \quad \text{-----(5)}$$

$$\delta = (N - 1) * v + 2\,Rl \quad \text{-----(6)}$$

The analytical results obtained by substitution in equations (1) to (6).

V. SIMULATION AND ANALYTICAL RESULTS

5.A The Effect of TTRT*(v)* and Total Fiber Length *(L)* on the Efficiency *(ζ)*

The simulation and analytical models are used to compute the efficiency for the following values: *N*=20 stations *M*=10KB, ρ =1, and the data rate (*C*) = 1Gbps.

From Table I and Table II it is clear that the total fiber length (*L*) and the *TTRT* have a significant effect on the efficiency. It is to be mention here that the increasing of *TTRT* resulting in increasing of efficiency for all the various fiber lengths and vice versa. The efficiency is significantly affected by the small values of *TTRT* and long fiber length, but it is not significantly affected by the large values of *TTRT* and any fiber length.

5.B The Effect of Number of Stations on the Throughput and Delay

The simulation and analytical models are used to compute the maximum utilization, the total throughput, the average token rotation time, the average queue delay, the average frame delay, and the maximum access delay for the following values: *M=10KB*, *L=100Km*, **ρ** *=1*, and the data rate *(C) = 1Gbps.*

Table III ,IV, V ,VI, and VII indicate that the average queue delay, the average packet delay, and the maximum access delay significantly affected by the total number of stations, meanwhile the total throughput, and the average token rotation time significantly affected under heavy load, and slightly affected under the light and the medium loads, the maximum utilization is very slightly affected by the loads.

5.C The Effect of Fiber Length on the Max. Utilization, Throughput and Delays

The simulation and analytical models are used to compute the maximum utilization, the total throughput, the average token rotation time, the average queue delay, the average frame delay, and the maximum access delay for the following values: *M=10KB*, *TTRT=4ms*, **ρ** *=1*, and the data rate *(C) = 1Gbps.*

Table VIII indicates that the maximum utilization, the average queue delay, and the average packet delay significantly affected by the fiber length, meanwhile the average token rotation time is slightly affected by the fiber length, and the total throughput is not affected by the fiber length.

VI. CONCLUSION

Obviously that there are some parameters which have significant affect on the performance of the FDDI network, such as the fiber length, number of stations, Target Token Rotation Time (*TTRT*), and frame length (which it is not considered here), all are investigated. The results confirm that the optimization of the performance of the FDDI network can be controlled by the value of *TTRT*, which represents the key network parameter. A large value of *TTRT* improves the efficiency, the maximum utilization, and the total throughput, but it also increases the average token rotation time (*TRT*), the average queue delay, the average frame delay, and the maximum access delay. The proposed simulation model and the analytical model, were used to compute and compare the efficiency, and the maximum access delay. The results are introduced as shown in Table I - Table VIII, and obviously these are promising enough.

TABLE I

TTRT (ms)	**Efficiency**							
	L=4Km		***L=20Km***		***L=50Km***		***L=100Km***	
	Simulation	Analytical	Simulation	Analytical	Simulation	Analytical	Simulation	Analytical
4	99.01	98.94	97.29	99.21	93.98	98.81	87.24	86.17
8	100.00	99.47	99.46	99.60	97.98	99.40	93.08	93.07
16	100.00	99.73	99.36	99.80	98.57	99.70	97.04	96.53
32	100.00	99.87	100.00	99.90	99.29	99.85	98.11	98.26
165	100.00	99.97	100.00	99.98	99.36	99.97	100.00	99.66

TABLE II

TTRT (ms)	**Efficiency**							
	L=200Km		***L=300Km***		***L=400Km***		***L=500Km***	
	Simulation	Analytical	Simulation	Analytical	Simulation	Analytical	Simulation	Analytical
4	74.02	73.13	62.05	60.20	49.08	47.43	36.10	34.82
8	87.19	86.48	81.23	79.91	74.17	73.38	68.56	66.90
16	94.01	93.22	90.03	89.91	87.65	86.61	84.78	83.32
32	97.31	96.60	95.01	94.94	94.16	93.28	92.21	91.63
165	99.17	99.34	99.06	99.02	99.00	98.69	98.00	98.37

TABLE III For TTRT = 4ms

Number of Stations (N)	**Maximum Utilization**	**Total Throughput**	**Average TRT (ms)**	**Average Queue Delay (ms)**	**Average Packet Delay (ms)**	**Maximum Access Delay (ms)**
20	0.87	0.19	0.52	7.78	8.35	77.06
40	0.87	0.38	0.54	14.33	14.93	157.1
60	0.86	0.79	0.55	20.61	21.23	237.14
80	0.86	0.76	0.56	32.10	32.73	317.18
100	0.86	85.73	3.99	748.55	749.19	397.22

TABLE IV For TTRT = 8ms

Number of Stations (N)	**Maximum Utilization**	**Total Throughput**	**Average TRT (ms)**	**Average Queue Delay**	**Average Packet Delay**	**Maximum Access Delay**

				(ms)	(ms)	(ms)
20	0.93	0.19	0.52	7.26	7.84	153.06
40	0.93	0.38	0.54	13.33	13.93	313.10
60	0.93	0.79	0.55	19.14	19.75	473.14
80	0.93	0.76	0.56	29.73	30.36	633.18
100	0.93	92.87	7.99	747.29	747.94	793.22

TABLE V For TTRT = 16ms

Number of Stations (N)	Maximum Utilization	Total Throughput	Average TRT (ms)	Average Queue Delay (ms)	Average Packet Delay (ms)	Maximum Access Delay (ms)
20	0.97	0.19	0.52	7.03	7.60	305.06
40	0.97	0.38	0.54	12.89	13.49	625.10
60	0.97	0.79	0.55	18.49	19.10	945.14
80	0.97	0.76	0.56	28.67	29.30	1265.18
100	0.96	96.45	16.05	746.66	747.31	158522

TABLE VI For TTRT = 32ms

Number of Stations (N)	Maximum Utilization	Total Throughput	Average TRT (ms)	Average Queue Delay (ms)	Average Packet Delay (ms)	Maximum Access Delay (ms)
20	0.98	0.19	0.52	7.01	7.59	609.06
40	0.98	0.38	0.54	12.68	13.28	1249.10
60	0.98	0.80	0.55	18.19	18.80	1889.14
80	0.98	0.76	0.56	28.17	28.80	2529.18
100	0.98	98.22	32.02	736.47	737.12	3169.22

TABLE VII For TTRT = 165ms

Number of Stations (N)	Maximum Utilization	Total Throughput	Average TRT (ms)	Average Queue Delay (ms)	Average Packet Delay (ms)	Maximum Access Delay (ms)
20	1.00	0.20	0.52	7.01	7.59	3136.06
40	1.00	0.38	0.54	12.68	13.28	6436.10
60	1.00	0.81	0.55	18.19	18.80	9736.14
80	1.00	0.77	0.56	27.92	28.55	13036.18
100	1.00	99.65	165.03	742.65	743.20	1633622

TABLE VIII

Fiber Length (Km)	Maximum Utilization	Total Throughput	Average TRT (ms)	Average Queue Delay (ms)	Average Packet Delay (ms)
4	0.99	0.19	0.03	6.64	6.75
20	0.97	0.19	0.11	6.81	7.00
50	0.93	0.19	0.27	7.16	7.50
100	0.87	0.19	0.52	7.78	8.35
200	0.74	0.19	1.03	9.28	10.34
300	0.62	0.19	1.54	11.40	12.94
400	0.49	0.19	2.05	14.20	16.23
500	0.36	0.19	2.06	18.77	21.27

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