Temporal Constraints for Real Time Image Transmission are Satisfied by FDDI Synchronous Transmission Mode

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Abstract
This article presents the temporal constraints for digitalized video transmission and the timing requirements of the synchronous transmission mode of the FDDI token ring protocol. First, we develop a timed model of the FDDI protocol and we establish its timing requirements. Secondly, we verify that the temporal constraints for real time image transmission are fulfilled by the FDDI protocol. If the first image is delayed at the receiver for 2·TTRT, we prove that our technique for the transmission unit constituting ensures that the transmission of images conforms to temporal constraints. Our technique requires only an optimal allocation of the exact bandwidth required by the image transmission. Moreover, image sample blocking enables larger TTRT to be used, and thus, reduces the overhead induced by the token rotation. We also prove that the proposed technique produces a constant delay equal to 2·TTRT plus the physical response time of the network, in spite of the aperiodic delivery of the image samples due to the access method of the FDDI protocol.

1. Introduction

Given the heavy load induced by digitalized image transmission, only the most advanced transmission techniques can be considered. For this reason, we are interested in the FDDI protocol representative of high speed local area networks [FDDI 87, FDDI 88, FDDI 89, AMD 89]. To transmit video movies the network has to propose real time services, so we are interested in the synchronous transmission mode of the FDDI protocol. Our description should highlight the fundamental features of the FDDI protocol, and accordingly it should allow us to demonstrate its adequacy for the transmission of images.

First, to establish our statement with exactness we develop a timed model of the functioning of the FDDI protocol. In a previous paper [Cousin 91], we have proved that the time between successive token arrivals at any given station has an upper limit of twice the Target Token Rotation Time (TTRT) negotiated by the stations during the initialization phase of the protocol minus the token delay measured at the given station during the previous rotation. This limit is tantamount to proving that the token rotates quickly enough to satisfy the standard statement : "The protocol guarantees an average response time (TRT : Token Rotation Timer) not greater than the TTRT, and a maximum TRT not greater than twice TTRT".

Intuitive arguments that timing requirements are satisfied are given in [Iyer 85, Ulm 82]. In [Johnson 87] M.Johnson proves a similar but weaker result to assure that the token rotates quickly enough to prevent initiation of recovery unless there is failure of a physical resource or unless the network management entity within a station initiates the recovery process. A formal proof of the two properties can be found in [Sevcik 87], but the study is applied on a lightly modified FDDI protocol.

Secondly, we examine the temporal constraints required to enable real time image transmission. Then, we prove that the temporal constraints necessary for the real time image transmission can

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be met by the synchronous mode of the FDDI protocol with an optimal allocation of the exact bandwidth required by the image transmission, and a minimal size of the emitting and receiving image buffers inducing a minimal transmission delay equal to 2·TTRT plus the physical response delay of the network. This can be achieved, in spite of the use of both asynchronous transmission technique and sample blocking, enabling efficient bandwidth utilization, which lead to aperiodic delivery of image samples.

2. FDDI

2.1 Introduction

The technique favored by local area networks chooses to share the same medium among all of the stations. This choice has as its first consequence the elimination of the intermediate switching devices and the delays that they entail. Unfortunately, if the congestion at the intermediate devices disappears with them, then access to the medium -the resource shared by all the stations- becomes critical. For this reason, local area networks involve specific methods of access to the medium (MAC: Media Access Control sublayer).

The protocol FDDI uses an access method called Token Ring [Johnson 86, Ross 89]. FDDI stations are connected in a ring where a token passes round. Any station that wants to transmit over the ring has to capture the token. At the end of its transmission, that station must release the token. Every station, therefore, obtains the right to use the medium turn by turn.

We will let N denote the number of stations in the network, assuming one network connection per station. The stations around the ring will be numbered from 0 to N-1 in a clockwise manner.

We denote **Tk(I)[k]** the moment where the token is received at the station k during its I^{th} rotation. So, Tk(I+1)[k]-Tk(I)[k] is the duration of the rotation of the token number I, duration measured at the station k.

To establish our proofs, we notice that any event Tx can be denoted either by Tx(I)[k] or by Tx(I-1)[k+N], because the stations are set around a ring.
(Ring definition) :

$\forall I, \forall k, \forall T_x, T_x(I)[k] = T_x(I-1)[k+N]$.

The FDDI protocol enables transmission in synchronous mode. FDDI uses fundamentally a **technique** of asynchronous transmission (that is to say, the delay in transmission is variable), but this protocol stipulates two **modes** of transmission : the asynchronous mode and the synchronous mode. Support for synchronous transmission is optional, and is not required for interoperability. The synchronous mode guarantees a station a pre-allocated bandwidth and the right to transmit with an average periodicity equal to a value negotiated among all the stations. This periodicity is referred to as the Target Token Rotation Time (TTRT). Furthermore, the protocol guarantees a maximum rotation time of the token that cannot surpass 2·TTRT. The synchronous mode is used for those applications whose bandwidth and response time limits are predictable, permitting them to be preallocated. The asynchronous mode is used for those applications whose bandwidth requirements are less predictable (bursty or potentially unlimited) or whose response time requirements are less critical. Asynchronous bandwidth is instantaneously allocated from the poll of remaining ring bandwidths that are unallocated or unused.

At first glance, then, it seems easy to transmit voice or images by means of the synchronous mode of the FDDI protocol. Nevertheless, if we disregard the rate of transmission, which seems barely reasonable in conveying images in good condition, then we find that variations in network load can lead to variations in the transmission delay of images.

2.2 The TTRT negotiation

During the initialization phase of the FDDI protocol, all the stations connected to the ring negotiate the value of TTRT. The TTRT chosen is the smallest. TTRT has to lie between the two values, TTRTmin and TTRTmax ($TTRTmax \geq TTRT \geq TTRTmin$). The value TTRTmin corresponds to the minimum time for the management and rotation of the token. A TTRT value less than TTRTmin would not even allow the token to reach all of the stations, and thus such a time is unacceptable. A TTRT value greater than TTRTmax is conceivable without major problems except that it creates a partition of the medium that is somewhat prejudicial to equal access because a station holding the token could very well keep it a very long time. Furthermore, a TTRT value greater than TTRTmax slows the detection of errors and in addition the reconfiguration of the ring.

Let us note that the smaller the value of TTRT, then the more important becomes the amount of time dedicated to the management of access to the medium. In fact, the number of rotations of the token per unit of time is inversely proportional to TTRT. Thus the token consumes a great part of the bandwidth. We have every interest in sustaining as great as possible a TTRT within the limits of foreseeable applications [Dykeman 88].

In order to ensure a given flow to a channel sharing a connection with other channels, we can either adjust the frequency of access to the network or adjust the quantity of data sent during each session of access. Thus, in order to have a low frequency of access (i.e. a large TTRT), it is necessary to transmit a great deal of data simultaneously. We have, therefore, a tendency to block together several samples of the image (cf § 3.3).

The problems of data corruption, of synchronization, and of adaptation of the receiver to the flow of data, all oblige the receiving stations to buffer part of the images. Buffering at the level of the sender allows us to send great frames onto the network and thus necessitates only a long TTRT. In fact, the accumulation of these different bufferings is quite acceptable physiologically; a delay of several images occasions a delay of less than a tenth of a second, a negligible delay for a human being. We recall that this delay is applicable to all the images, and thus only the starting of the movie is affected by it. Nevertheless, this buffering does demand a great deal of memory .

2.3 The TRT and the THT

To provide the required service towards the token rotation time the standard specifies a timer in each station called TRT (Token Rotation Timer). It is used to control scheduling during normal operation and to detect and recover from serious error situations. Whenever the TRT expires, is is reinitialized to the TTRT value and the variable "Late_Ct" is set. If the token arrives at the station before the expiration of the timer (early), it is reinitialized to the value TTRT and the variable "Late_Ct" is reset.

Although in the standard the FDDI timing control is assured by both the value of the TRT and the Late_Ct variable, in order to simplify the timing model we use only one parameter. We denote by **TRT(I)[k]** the value of the timer at the station k during the I^{th} token rotation. It can be recursively defined by the token rotation time Tk :

(TRT definition) :

$\forall k,\ TRT(0)[k] = Tk(1)[k] - Tk(0)[k]$, and $\forall I \neq 0$,

if $TRT(I-1)[k] \leq TTRT$ then $TRT(I)[k] = Tk(I+1)[k] - Tk(I)[k]$,

else $TRT(I)[k] = (TRT(I-1)[k] - TTRT) + Tk(I+1)[k] - Tk(I)[k]$.

At the first rotation the TRT value is initialized. Afterwards if the token is early, that is to say if the previous rotation respects the negotiated periodicity TTRT, the next TRT is equal to the token rotation duration. Otherwise, if the token is late, the next TRT is equal to the sum of the token rotation duration and the token delay. This sum enables the delay to be taken into account from one rotation to the next, and thus, enforces the periodicity.

Each station has another timer called by the standard : THT (Token Holding Timer). It contains the maximum duration during which the stations can transmit in asynchronous mode. It is set at each early token reception with the token gain. We denote by **THT(I)[k]** the value of the timer at the station k during the I^{th} token rotation :
(THT definition) :

$$\forall I,\ \text{if } TRT(I)[k] \leq TTRT \text{ then } THT(I)[k] = TTRT - TRT(I)[k] \text{ else } THT(I)[k] = 0.$$

Similarly, **δk(I)[k]** denotes the delay of a late token :

(δk definition) :

$$\forall I,\ \text{if } TRT(I)[k] > TTRT \text{ then } \delta k(I)[k] = TRT(I)[k] - TTRT \text{ else } \delta k(I)[k] = 0.$$

2.4 Synchronous and asynchronous transmission

We denote Tas(I)[k] the asynchronous transmission duration of the station number k during the I^{th} token rotation. We denote Ts(I)[k] the synchronous transmission duration during the I^{th} token rotation. We denote [a,b[the set of natural integer from a inclusive to b exclusive.

The token rotation time Tk is related with the above notations :
(Token rotation duration definition) :

$$\forall I, \forall n,\ Tk(I+1)[n] - Tk(I)[n] = \sum_{k \in [n,n+N[} (Tas(I)[k]+Ts(I)[k]).$$

To achieve correct protocol operation, the standard asserts the following relations :

For any token rotation, the sum of synchronous transmission duration of all stations on the ring is lower than the negotiated TTRT. All the synchronous transmission can be operated during the negotiated TTRT.
(Synchronous transmission duration definition) :

$$\forall I, \forall n,\ \sum_{k \in [n,n+N[} Ts(I)[k] \leq TTRT.$$

During any token rotation, a station can transmit in asynchronous mode for a duration less than the token gain. So, none asynchronous transmission can take place if the token is late.
(Asynchronous transmission duration definition) :

$$\forall I, \forall k,\ Tas(I)[k] \leq THT(I-1)[k].$$

2.5 FDDI timing properties

From the above definitions and relations, we have proved in [Cousin 91] that the time between successive token arrivals at station has an upper limit of twice the Target Token Rotation Time (TTRT) negotiated by the station during the initialization phase of the protocol minus the token delay measured at the station during the previous rotation. This proves that the FDDI operation meets the standard statement : "The protocol guarantees a maximum TRT not greater than twice TTRT".

From the above properties, we can assert that the duration of the token rotation is lower than twice the negotiated Target Token Rotation Time minus the token delay at the previous rotation : *(Token rotation duration property)* :

$$\forall I,\ \forall l,\ Tk(I+1)[l] - Tk(I)[l] \leq 2 \cdot TTRT - \delta k(I-1)[l].$$

We have established a timed model of the FDDI protocol, and we assert that the FDDI operation enables the standard statement to be met. So now, we have to show that the synchronous transmission mode of the FDDI protocol enables real time image transmission to be carried out.

3. Images

3.1 Temporal constraints

Both transmission of digital images and digital voice have temporal constraints that we do not ordinarily encounter in conventional data transfer. These temporal constraints associate samples. A sample is that portion of a signal that is digitalized. For example, a sample could be a group of bits, one byte of coded sound, or a line of an image.

The set of the samples makes a sequence $\{ei\}$. So we can associate to each sample its running number in the sequence. We indicate the moment of production of the sample by the emitter with the notation Te. Likewise, we use the notation **Tv** (visualization) to indicate the moment when the sample can be displayed on the visual equipment. Te and Tv are strictly increasing functions.

The preservation of the quality of the movie during transmission requires that two constraints must be satisfied. First constraint : the delay after the emission of the movie must be humanly tolerable, virtually instantaneous. We refer to the time that one must wait to see the first image of a movie as Tmax. This time is critical if the user intervenes in the unfolding of the movie; that is, if the movie is in any sense interactive. Second constraint: the images should appear on the screen of the receiver at the same speed relative to one another as they are produced by the emitter. If these two constraints are satisfied, then the movie is received with temporal integrity. Two relations suffice to express these constraints:

Tolerable delay constraint : $\forall i,\ Tv(i) < Tmax + Te(i)$.

Temporal integrity constraint : $\forall i,\ \forall j,\ Tv(j) - Tv(i) = Te(j) - Te(i)$.

These temporal constraints exist only if the movie should be visualized on its arrival at the receiver (in real time, no less!). These constraints do not exist if the movie is broadcast in deferred time (for example, if it is pre-recorded for later broadcast), and if it is thus consequently stored on its arrival at the receiver. In such a case, the transmission of the movie can simply be treated as the transmission of a large file.

3.2 Transmission

In fact, in as much as they are located on distinct sites, the receiver of images is completely independent of the sender of images, and it is thus difficult to respect the two previous constraints. Two phenomena intervene in the transmission delay : the technique of transmission and the blocking of samples.

Conventionally, the clock of the receiver of images is slaved to the clock of the emitter by means of a synchronization included in the signal. Since the conventional methods of transmission use **isochronous** (circuit switched) technique, the intervals of time between samples are preserved during their transmission. The synchronization of the receiver with the sender of the images is therefore easily achieved. It suffices to slave the receiver's clock to the flow of the received images. Only a constant delay is added (the propagation delay).

The most current techniques of transmission now use **asynchronous** transmission technique. With this technique, the delay in the transmission of the samples varies: it depends on the access method to the medium, on the resolution of collisions, on the load of the network, etc. Consequently the time separating two samples at their reception may differ from the time separating them at their production. We can no longer count on slaving the clock of the receiver directly on the flow of received images.

The technique of asynchronous transmission permits a better use of support than does isochronous transmission because sporadic flows can be compensated for. Asynchronous transmission works well with dynamic allocation methods of the bandwidth between different links as a function of the load. Nevertheless, in order to be efficient, the overhead introduced by this dynamic management must be compensated for by a better allocation of the traffic. In contrast, isochronous techniques can use a method of static allocation that requires little or no management overhead.

We denote **Tr** the moment of reception of a sample. We denote by **Tt** the response delay of a sample over the network. These moments are described by the relation :
(Tr definition) :

$\forall i,\ Tr(i) = Te(i) + Tt(i).$

3.3 Blocking

The blocking of several samples in one unit of transmission enables the transmission to be improved. The overhead induced by the structure of the transmission unit (starting and ending delimiters, addresses, frame control, and so on) is spread over a large number of samples. As all the samples blocked in the same transmission unit are sent and received at the same moment, this technique produces variation in the transmission delay. Consequently the time separating two samples at their delivery may differ from the time separating them at their production.

The response delay Tt of local area networks like FDDI consists of the access delay **Ta,** the transmission delay **Td**, and the propagation delay **Tp**. The propagation delay depends on the propagation speed and the length of the media. The propagation delay can be regarded as constant. The transmission delay depends on the data rate and the length of the transmission unit. The access delay depends on both the load and the access method used by the protocol. Access delays fluctuate in most LAN. They are related by the relation :
(Tt definition) :

$\forall i,\ Tt(i)= Ta(i)+Td(i)+Tp.$

As the samples, the transmission units makes a strictly increasing sequence {Si}. So we can associate to each unit is number in the sequence. We denote **I(i)** the number of the transmission unit associated to the sample of number i. We denote **deb(I)** the number of the first sample of the unit I. And we denote **fin(I)** the number of the last sample of the unit I.

If two consecutive samples do not belong to the same transmission unit then they belong to two distinct but consecutive units.
(Consecutive units definition) :

$\forall i$, if $I(i+1)\neq I(i)$ then $I(i+1)=I(i)+1$.

Previously, we noted that all the samples blocked in the same transmission unit are sent and received at the same moment, because the samples blocked in a same transmission unit are available at the receiver when the transmission unit is entirely received.
(Unit receiving moment definition) :

$\forall i, \forall j$, if $I(i)=I(j)$ then $Tr(i)=Tr(j)$.

3.4 The usable synchronous bandwidth

Let S (and R respectively) the station number of the sender (the receiver) of samples. If we use the FDDI protocol to send the images, a station begins to send when it receives the token. So Tk(I)[S] is also the moment where the transmission units associated with the token number I are sent. As FDDI protocol uses token ring as the access method, the moments Te, Tk, and Ta are related by :

(Access method definition)

$$\forall i,\ Tk(I(i))[S] = Te(i) + Ta(i).$$

To use the synchronous transmission mode of the FDDI protocol to send a movie, first, we need to know the average synchronous throughput Ds[k] required by each station k to transmit the images in real time, to ensure that we always maintain the following relation :

(Synchronous bandwidth definition) :

$$\sum_{k\in[0,N[} Ds[k] \le D.$$

That is to say, the sum of throughput sent should be lower than the effective throughput D of the network. This avoids overallocation of the medium. The effective throughput is obtained by starting from the nominal throughput minus the throughput used to manage the network, essentially the packaging of the frames and the management of the token. Network management has the responsibility for maintaining this statement. Every station requesting to transmit in synchronous mode calls the network management for a reservation of the average throughput required ([FDDI 88] and [FDDI 87]).

Secondly, once the TTRT is fixed, once we know the average synchronous throughput Ds[k] required by each station k to transmit the images in real time, to achieve correct protocol operation we have to maintain the previously established relation (Synchronous transmission duration definition) : $\forall I, \forall n, \sum_{k\in[n,n+N[} Ts(I)[k] \le TTRT$. To maintain this relation for any rotation, the evident solution is to limit the duration of the synchronous transmission to Ts[k].

(Maximum synchronous transmission definition) :

$$\forall I, \forall n,\ Ts(I)[k] \le Ds[k]\cdot TTRT \div D\ (=Ts[k]).$$

Unfortunately, the load on the network can make the moment at which the token arrives at a station vary greatly, remembering that a station must capture the token before it can transmit. This moment is remembered by the token rotation timer (TRT) local to each station. It may be early or late with respect to the negotiated TTRT period. Logically, in order to maintain the inequality of the synchronous bandwidth relation, each station k should have the right to transmit at most Ds[k]·TRT bits. This quantity is extremely difficult to manage because the TRT varies as a function of the load with each rotation of the token ($0<TRT<2\cdot TTRT$). Moreover, the implementation of FDDI does not permit us to get the value of TRT in time. We risk, then, to exceed the duration Ts(I)[k] attributed to each station k, and thus to violate the inequality of the synchronous transmission duration relation, if we do not adapt the length of a frame to the rotation time of the token.

However, if the token is early ($TRT<TTRT$), this indicates that the network is underloaded, and thus it is permissible to transmit Ds[k]·TTRT bits, but impossible. It is impossible because the image emitter has not yet produced enough samples in such a short time. Our proposition is to send all the produced samples when an early token arrives. In that case, we know that the synchronous bandwidth relation and the synchronous transmission duration relation are obviously enforced by the regular throughput of the image emitter.

Inversely, if the token is late (TTRT<TRT), then the FDDI operations ensure that the delay cannot surpass 2·TTRT, even if all of the stations transmit the entirety of their throughput synchronously. But if we want to respect the synchronous transmission duration relation, the stations are allowed to send at most Ds[k]·TTRT bits at each token rotation. The remaining (TRT - TTRT)·Ds[k] bits are not sent with the first arrived token, but the FDDI operation guarantees that the delay will not be cumulative, so the remaining bits will be sent with the next units. In fact, the protocol is self-regulating because the overload induced by the token diminishes if the time between two passes of the token grows. Furthermore, if one of the stations does not use the entire throughput allocated to a synchronous transmission, then the unused time will be recovered, first of all, to ensure other synchronous transmissions, in recovering the delay, and in re-establishing the negotiated frequency of rotation of the token; secondly and ultimately to authorize asynchronous transmissions.

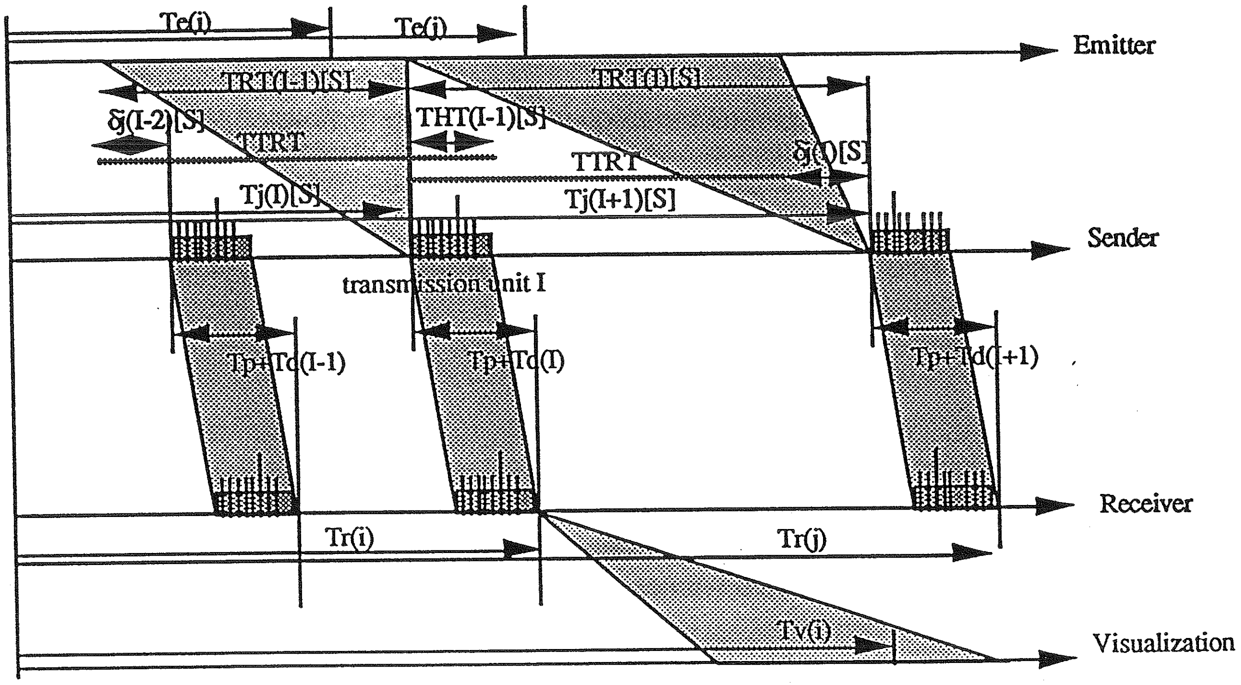

Figure 1 - Constituting of the transmission units

So, we propose building each synchronous transmission unit in such a way (Figure 1). If we denote J(I) the set of sample numbers carried by the transmission unit associated with the I^{th} token, then the relation of correct constituting of the transmission unit property is defined by :
(Correct constituting of transmission unit definition) :

$$\forall I, \forall i \in J(I), Tk(I)[S] - TRT(I-1)[S] \leq Te(i) < Tk(I)[S] - \delta k(I-1)[S].$$

In conclusion, we propose to use the synchronous mode of the FDDI protocol to transmit images of a movie. The average transmission rate Ds[k] necessary for the transmission of the movie should be known, and the application requires the network manager to make an appropriate reservation for the duration of the movie to guard against congestion of the media. The negotiation procedure for the TTRT could then be started, if required. The smaller the value of the required TTRT, the smaller the delay in transmission. However, we have already raised the idea that the efficiency of the FDDI protocol will be accordingly weakened. The calculations that we have undertaken indicate that the ideal value lies in the neighborhood of twenty milliseconds. Independently of the fact that the negotiated value of the TTRT should lie between TTRTmin and TTRTmax to ensure the proper global functioning of the network, our application can accommodate a large range of values for TTRT. If the token is late, the application should be able to transmit at most $Ls[k] = Ds[k] \cdot TTRT$ bits at each rotation of the token. If the token is early, the control of the quantity of data transmitted at each capture of the token does not have to be managed at the level of the FDDI sender, the normal throughput of the emitter of images naturally assuming this role.

3.5 Validation

First of all, we have to prove that the definition of the correct constituting of transmission units enables the maximum synchronous transmission duration requirement, and thus the synchronous bandwidth definition, to be fulfilled.

(Maximum synchronous transmission duration property) :

$$\forall k, \forall I, Ts(I)[k] < Ts[k].$$

Proof :

Assuming that $Ls(I)[k]$ is the number of bits of the transmission unit associated with the I^{th} token, by definition of $Ts(I)[k]$:

$Ts(I)[k] = Ls(I)[k] \div D.$

The number of bits of a transmission unit has an upper limit of the duration between the first and the last sample of the transmission unit multiplied by the effective throughput of the sample.

$\Rightarrow Ts(I)[k] \leq (Te(fin(I))-Te(deb(I))) \cdot Ds[k] \div D.$

Assuming the correct unit constituting definition :

$\Rightarrow Ts(I)[k] \leq ((Tk(I)[S] - \delta k(I-1)[S]) - (Tk(I)[S] - TRT(I-1)[S])) \cdot Ds[k] \div D.$

$\Rightarrow Ts(I)[k] \leq (TRT(I-1)[S] - \delta k(I-1)[S]) \cdot Ds[k] \div D.$

Two cases appear :

1. Either $TRT(I-1)[S]<TTRT$ then $\delta_k(I-1)[S]=0$:

$\Rightarrow Ts(I)[k] \leq TRT (I-1)[S] \cdot Ds[k] \div D.$

Which can have an upper limit, according to the assumption :

$\Rightarrow Ts(I)[k] \leq TTRT \cdot Ds[k] \div D.$

According to the definition of maximum synchronous duration :

$\Rightarrow Ts(I)[k] \leq Ts[k].$ (◊)

2. Or $TRT(I-1)>TTRT$ then by definition $\delta_k(I-1)[S]=TRT(I-1)[S] - TTRT$:

$\Rightarrow Ts(I)[k] \leq TTRT \cdot Ds[k] \div D.$

By definition of $Ts[k]$:

$\Rightarrow Ts(I)[k] \leq Ts[k].$ (◊)

The second temporal constraint can be achieved, first, if the samples are buffered between the receiver and the image visualization equipment. The buffer has to be large enough to contain all the samples produced during $2 \cdot TTRT$ duration. Secondly, we can proved that all the samples are received in time at the receiver (i.e. before being displayed)

(Correct timing visualization property) :

$$\forall i, \; Tv(i) \geq Tr(i).$$

To prove this property, we need to prove the property of correct reception. If the visualization moment of the first sample is delayed by twice the Target Token Rotation Time then the reception moment of the samples is limited by the visualization moment of the first and the last sample of the same transmission unit.

(Correct reception property) :

$$\forall i, Tv(0)=Tr(0)+2 \cdot TTRT \Rightarrow Tv(fin(I(i)))<Tr(i)+2 \cdot TTRT-\delta k(I(i)-1)[S] \leq Tv(deb(I(i)+1))$$

Proof :

According to the correct constituting relation :

$\forall I, \forall i \in J(I), Tk(I)[S] - TRT(I-1)[S] \leq Te(i) < Tk(I)[S] - \delta k(I-1)[S]$.

For $i = fin(I)$: $\forall I, Tk(I)[S] - TRT(I-1)[S] \leq Te(fin(I)) < Tk(I)[S] - \delta k(I-1)[S]$, (1)

and for $i = deb(I')$: $\forall I', Tk(I')[S] - TRT(I'-1)[S] \leq Te(deb(I')) < Tk(I')[S] - \delta k(I'-1)[S]$. (2)

According to the TRT definition : $\forall I, TRT(I)[S] = Tk(I+1)[S] - Tk(I)[S] + \delta k(I-1)[S]$,

which can be rewritten : $\forall I, Tk(I+1)[S] - TRT(I)[S] = Tk(I)[S] - \delta k(I-1)[S]$.

Let $I'=I+1$, then the relations (1) et (2) can be rewritten :

$\forall I, Te(fin(I)) < Tk(I)[S] - \delta k(I-1)[S] \leq Te(deb(I+1))$. (3)

According to the Te definition :

$\forall i, Tv(i) = Te(i) + Tv(0) - Te(0)$.

The relation (3) can be rewritten :

$\Rightarrow \forall I, Tv(fin(I)) < Tk(I) - \delta k(I-1)[S] + Tv(0) - Te(0) \leq Tv(deb(I+1))$.

From the assumption about the visualization moment of the first sample :

$Tv(0) = Tr(0)+2 \cdot TTRT$.

$\Rightarrow \forall I, Tv(fin(I)) < Tk(I) - \delta k(I-1)[S] + Tr(0) + 2 \cdot TTRT - Te(0) \leq Tv(deb(I+1))$.

According to the Tr definition, the access method definition and the Tt definition : $\forall i, Tr(i) = Tk(I(i))[S] + Td(i) + Tp$.

$\Rightarrow \forall i, Tv(fin(I(i))) < Tk(I(i))[S] - \delta k(I(i)-1)[S] + Tk(I(0))[S] + Td(0) + Tp + 2 \cdot TTRT - Te(0) \leq Tv(deb(I(i)+1))$

If we assume that the transmission delay is constant for a fixed data rate: $\forall i, Td(i)=Td$.

$\Rightarrow \forall i, Tv(fin(I(i))) < Tr(I(i)) - \delta k(I(i)-1)[S] + Tk(I(0))[S] + 2 \cdot TTRT - Te(0) \leq Tv(deb(I(i)+1))$.

From the assumption of the sending moment of the first sample : $Te(0) = Tk(I(0))[S]$,

$\Rightarrow \forall i, Tv(fin(I(i))) < Tr(I(i)) - \delta k(I(i)-1)[S] + 2 \cdot TTRT \leq Tv(deb(I(i)+1))$. (◊)

Then, we prove the correct timing visualization property :

$\forall i, Tr(i) \leq Tv(i)$.

Proof :

Recurrent demonstration :

1. For $i=0$, the relation is obvious because according to the visualization moment of the first sample assumption : $Tv(0) = Tr(0) + 2 \cdot TTRT$, then : $Tr(0) < Tv(0)$. (◊)

2. Assuming that the recurrent assumption is true for $i \in [0,n]$, two cases appear :

2.1 Either the samples n and n+1 belong to the same transmission unit : "$I(n)=I(n+1)$".

Then, according to the Tv definition :

$Tv(n+1) = Tv(n) + Tv(n+1) - Tv(n)$.

According to the second temporal constraint :

$Tv(n+1) = Tv(n) + Te(n+1) - Te(n)$.

According to the strictly increasing function Te :

$Tv(n+1) > Tv(n)$.

According to the recurrent assumption :

$Tv(n+1) > Tr(n)$.

According to the initial assumption : if $I(n)=I(n+1)$ then $Tr(n)=Tr(n+1)$.

$Tv(n+1) > Tr(n+1)$. (◊)

2.2 Either the samples n and n+1 do not belong to the same transmission unit : "$I(n) \neq I(n+1)$".

Then, we know that "$I(n+1)=I(n)+1$", because the samples and the transmission units are numbered in an strict increasing manner.

According to the Tr definition, the access method definition and the Tt definition :

$Tr(n+1) = Tk(I(n+1))[S] + Td(n+1) + Tp$.
Which can be rewritten :
$Tr(n+1) = Tk(I(n))[S] + Tk(I(n+1))[S] - Tk(I(n))[S] + Td(n+1) + Tp$.
According to the following assumption : $\forall i, Td(i)=Td$.
$Tr(n+1) = Tr(n) + Tk(I(n+1))[S] - Tk(I(n))[S]$.
From the token rotation duration property :
$Tr(n+1) \leq Tr(I(n)) + 2 \cdot TTRT - \delta k(I(n)-1)[S]$.
According to the correct reception property :
$\forall i, Tv(fin(I(i))) < Tr(I(i)) + 2 \cdot TTRT - \delta k(I(i)-1)[S] \leq Tv(deb(I(i)+1))$.
Then :
$Tr(n+1) \leq Tv(deb(I(n)+1))$.
According to the definition of the deb and fin functions : if $I(n) \neq I(n+1)$ then $fin(I(n))=n$ and $deb(I(n)+1) = n+1$.
We deduce that : $Tr(n+1) \leq Tv(n+1)$ (◊)

The first constraint introduces a delay Tmax, which can be deduced from the previous definitions and relations :
(Tmax lower limit property) :
$Tmax > Tt(0) + 2 \cdot TTRT$.
Proof :
According to the Tolerable delay constraint :
$\forall i, Tmax > Tv(i) - Te(i)$.
Which can be rewritten :
$\forall i, Tmax > Tv(0) + (Tv(i) - Tv(0) - Te(i) + Te(0)) - Te(0)$.
According to the temporal integrity constraint :
$Tmax > Tv(0) - Te(0)$.
According to the visualization moment of the first sample :
$Tmax > Tr(0) + 2 \cdot TTRT - Te(0)$.
According to the Tt definition :
$Tmax > Tt(0) + 2 \cdot TTRT$. (◊)

Accordingly, at the price of a delay equal to 2·TTRT due to the buffering at the level of the receiver of images plus the physical response time of the network, we prove that it is useless to request a rotation time equal to half of the delay required by the application, as that would let it over-determine the maximum rotation time guaranteed to be more than 2·TTRT.

4. Conclusion

In view of this study, we can observe the image transmission has to resolve two problems, namely the preservation of the synchronization between images, and the minimization of the buffer length.

Yet the ring topology in the FDDI protocol both necessitates and allows controlled access to the medium, and favors the management of a method of access favorable to the transmission of images by the creation of two modes of transmission : the synchronous and the asynchronous modes. The synchronous mode of transmission guarantees a station an average throughput and the right to transmit with a periodicity, on the average, equal to a value --the TTRT -- negotiated among all the stations. Moreover, this mode guarantees that the maximum rotation time cannot exceed 2·TTRT.

Accordingly, at the price of a slight buffering delay equal to 2.TTRT, using the synchronous mode of the FDDI protocol, we prove that it is possible to allocate only the exact average throughput to achieved image transmission in real time. This allocation optimizes the use of the medium bandwidth. Dealing with the aperiodic delivery of image samples due network access method, compression and blocking processes, our proposed technique for the transmission unit constituting produced a minimal and constant delay equal to 2.TTRT plus the physical response time of the network and ensures that the transmission of images conforms to its temporal constraints. Moreover, sample blocking enables our application to be adapted to a large range of TTRT, enabling an efficient image transmission process.

We observe that in order to allow the transmission of periodic information with asynchronous techniques, it is necessary to transmit temporal information explicitly; it is further necessary to supply sufficient buffer space in memory at the level of the receiver to accommodate the inevitable variations in transmission delay. These memory buffers imply a systematic delay inhospitable to interactive applications. In short, the great throughput required by the transmission of images obliges one to use a great quantity of rapid access memory. Yet the memory buffers necessary at the level of the receiver in order to allow the use of an asynchronous technique of transmission can be usefully exploited to detect and then to correct loss, corruption, and duplication in all or part of the images of the movie.

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