FDDI and Timing Requirements for Image Transmission

B.Cousin
LaBRI
351 Cours de la Libération
F-33405 Talence cedex
FRANCE

Abstract

This article presents the timing requirements for digitalized video transmission and the synchronous transmission mode of the Fiber Distributed Data Interface (FDDI) protocol. First, we develop a timed model of the FDDI protocol and we prove that it meets its standard requirement. Secondly, we verify that the temporal constraints for real time image transmission are fulfilled by 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. Then, we formally prove 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 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.

In the following sections, we study the new techniques of transmission proposed for High Speed Local Area Networks, and we prove that the timing requirements of the FDDI protocol can be met. Then, we present the criteria characteristic of the transmission of images, and finally, we study the adequacy of services provided by the synchronous transmission mode of the FDDI protocol, particularly with respect to medium rate transmission of images.

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 FDDI protocol has the following property about the upper limit of consecutive delays : The delay at a station is lower than the delay at a previous station plus the sum of both the synchronous and the asynchronous transmission of all the stations between them.

(Lemma 1) :

$$\forall I \geq 1,\ \forall l,\ \forall n \in [l, l+N[,\quad \delta_j(I)[l] \leq \delta_j(I-1)[n] + \sum_{k \in [n,l+N[} (Ts(I)[k] + Tas(I)[k]).$$

With the lemma 1, we prove that the sum of all the asynchronous transmission time between successive token arrivals at station (one rotation) has an upper limit of the Target Token Rotation Time minus the token delay measured at the station during the previous rotation.

(Lemma 2) :

$$\forall I, \forall l,\quad \sum_{k \in [l,l+N[} Tas(I)[k] \leq TTRT - \delta_j(I-1)[l].$$

From the above lemma definitions, we prove 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) :

$$\forall I, \forall l,\ Tj(I+1)[l] - Tj(I)[l] \leq 2*TTRT - \delta_j(I-1)[l].$$

Proof :

According to the definition of Tj :

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

According to the synchronous transmission definition:

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

$$\Rightarrow \forall I, \forall l,\ Tj(I+1)[l] - Tj(I)[l] \leq \sum_{k \in [l,l+N[} Tas(I)[k] + TTRT.$$

Lemma 2 says that :

$$\forall I,\forall l,\quad \sum_{k \in [l,l+N[} (Tas(I)[k]) < TTRT - \delta_j(I-1)[l].$$

So, it is easy to see that :

$$\Rightarrow \forall I, \forall l,\ Tj(I+1)[l] - Tj(I)[l] \leq TTRT + TTRT - \delta_j(I-1)[l].\ (\Diamond)$$

We have established a timed model of the FDDI protocol, and we have proved 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 (See figure 1).

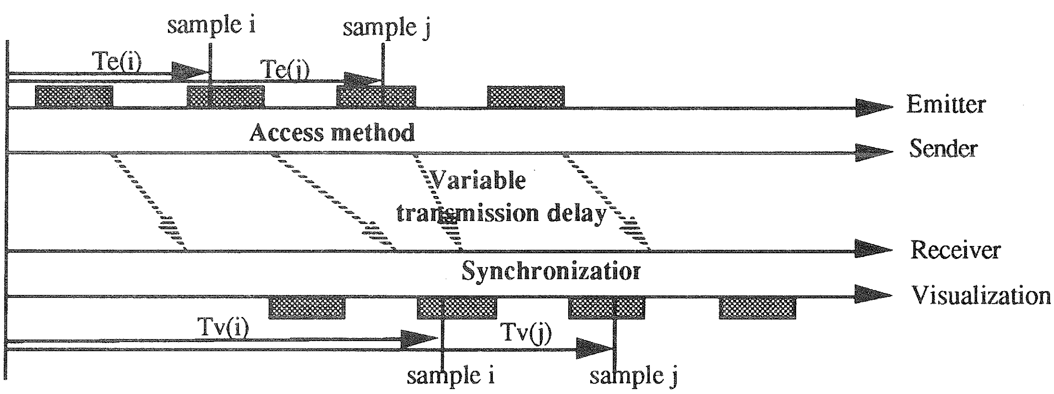

Figure 1 - Temporal constraints

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 (Figure 2). 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.

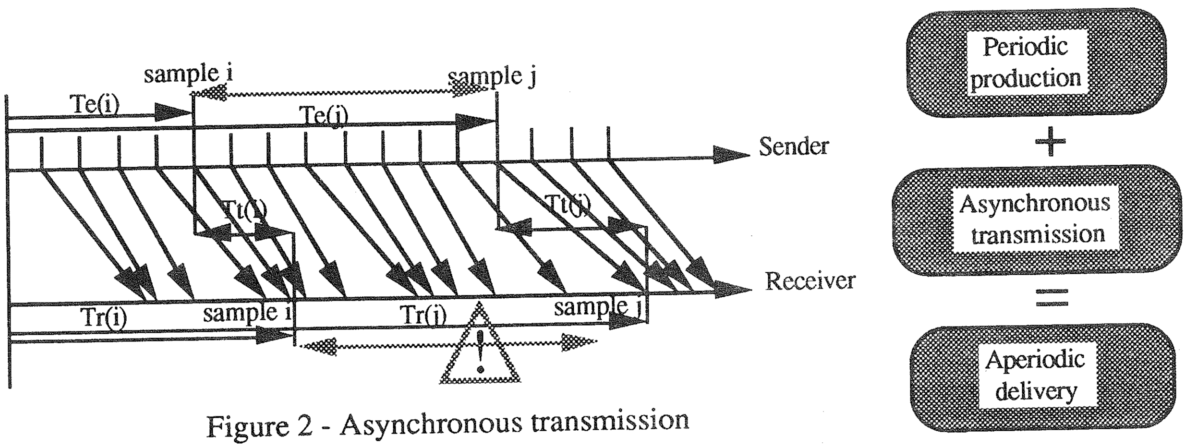

Figure 2 - Asynchronous transmission

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 (Figure 3).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 $Tr(i)=Tr(j)$.

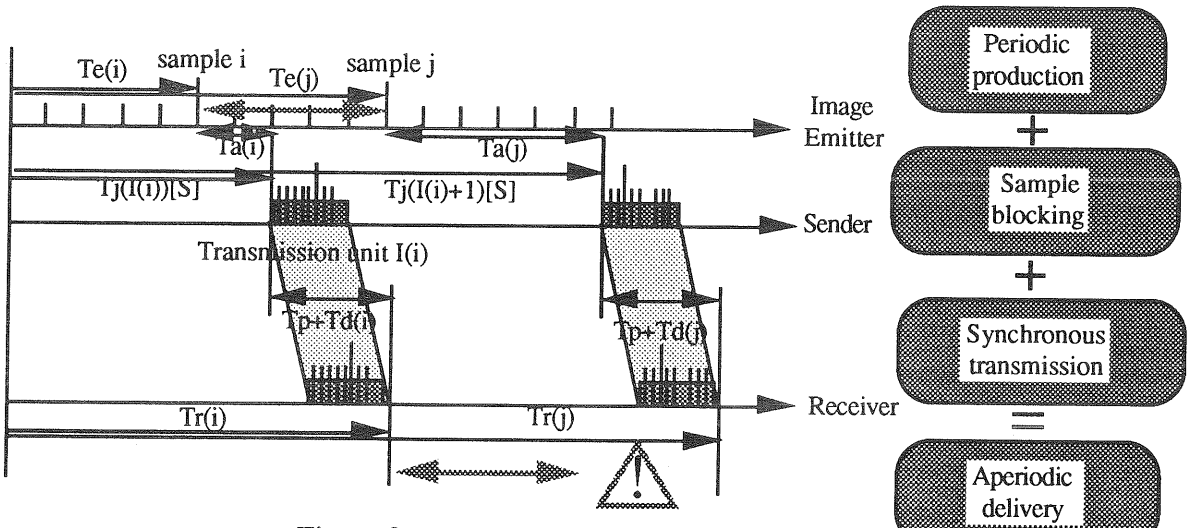

Figure 3 - Blocking

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 Tj(I)[S] is also the moment where the transmission units associated with the I^{th} token rotation are sent. As FDDI protocol uses token ring as the access method, the moments Te, Tj, and Ta are related by :
(Access method definition)
$\forall i$, $Tj(I(i))[S] = Te(i) + Ta(i)$.

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) :

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

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) :

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

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) :
$\forall k$, $Ts[k] = Ds[k].TTRT \div D$.

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. ($0<TRT<2*TTRT$). 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.

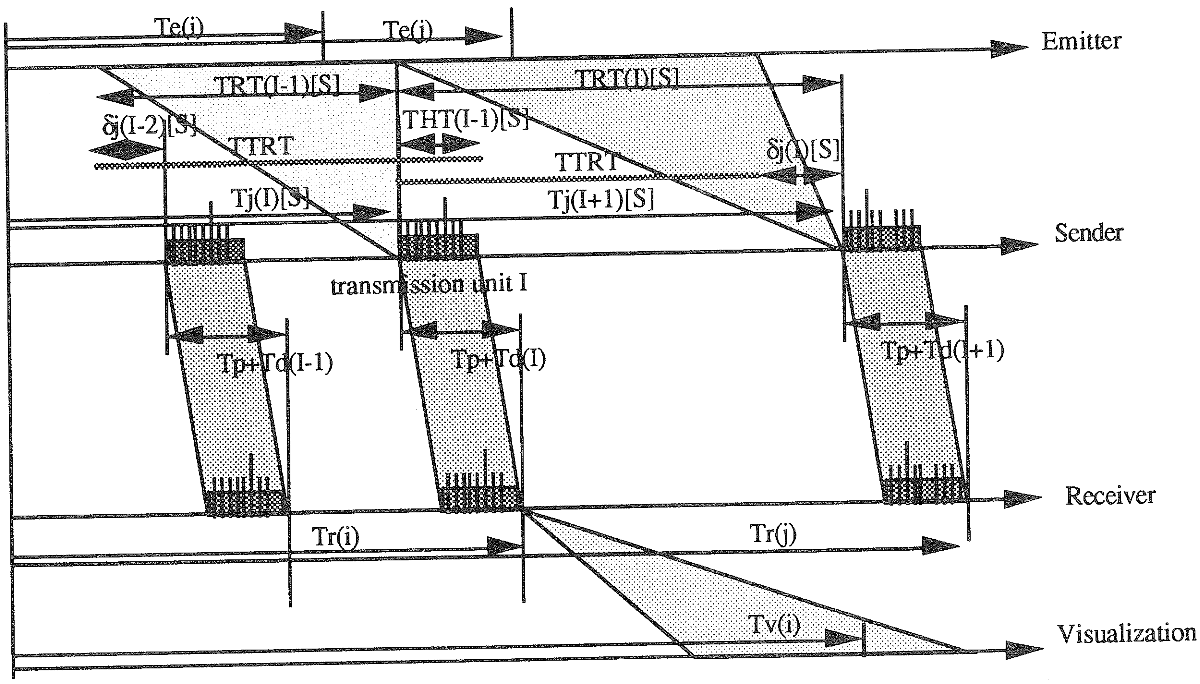

Figure 4 - Constituting of the transmission units

So, we propose building each synchronous transmission unit in such a way (Figure 4). If we denote J(I) the set of sample numbers carried by the transmission unit associated with the I^{th} token rotation, then the relation of correct constituting of the transmission unit property is defined by:
(Correct constituting of transmission unit definition) :

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

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 [Cousin 90]. 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].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 rotation, 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.

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

Assuming the correct unit constituting definition :

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

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

Two cases appear :

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

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

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

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

According to the definition of maximum synchronous duration :

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

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

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

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*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) :

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

Proof :

According to the correct constituting relation :

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

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

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

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

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

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

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

According to the Te definition :

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

The relation (3) can be rewritten :

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

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

$Tv(0) = Tr(0)+2*TTRT$.

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

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

$\Rightarrow \forall i,Tv(fin(I(i)))<Tj(I(i))[S]-\delta j(I(i)-1)[S]+Tj(I(0))[S]+ Td(0)+Tp+2*TTRTTe(0)\leq Tv(deb(I(i)+1))$

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

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

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

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

Then, we prove the correct timing visualization property :

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

Proof :

Recurrent demonstration :

1. For i=0, the relation is obvious because

According to the visualization moment of the first sample assumption : $Tv(0) = Tr(0) + 2*TTRT$,

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) = Tj(I(n+1))[S] + Td(n+1) + Tp.
Which can be rewritten :
Tr(n+1) = Tj(I(n))[S] + Tj(I(n+1))[S] - Tj(I(n))[S] + Td(n+1) + Tp.
According to the following assumption : ∀i, Td(i)=Td.
Tr(n+1) = Tr(n) + Tj(I(n+1))[S] - Tj(I(n))[S].
From the token rotation duration property, the TRT definition and the δj definition :
Tr(n+1) ≤ Tr(I(n)) + 2*TTRT - δj(I(n)-1)[S].
According to the correct reception property :
∀i, Tv(fin(I(i))) < Tr(I(i))+2*TTRT - δj(I(i)-1)[S] ≤ Tv(deb(I(i)+1)).
Then :
Tr(n+1)≤Tv(deb(I(n)+1)).
According to the definition of the deb and fin functions : if I(n)≠I(n+1) then fin(I(n))=n and deb(I(n)+1) = n+1.
We deduce that : Tr(n+1) < 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*TTRT.
Proof :
According to the Tolerable delay constraint :
∀i, Tmax > Tv(i) - Te(i).
Which can be rewritten :
∀i, Tmax > Tv(0) + (Tv(i) - Tv(0) - Te(i) + Te(0)) - Te(0).
According to the first temporal constraint :
Tmax > Tv(0) - Te(0).
According to the visualization moment of the first sample :
Tmax > Tr(0) + 2*TTRT - Te(0).
According to the Tt definition :
Tmax > Tt(0) + 2*TTRT. (◊)

Accordingly, at the price of a delay due to the buffering at the level of the receiver of images equal to 2*TTRT 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.

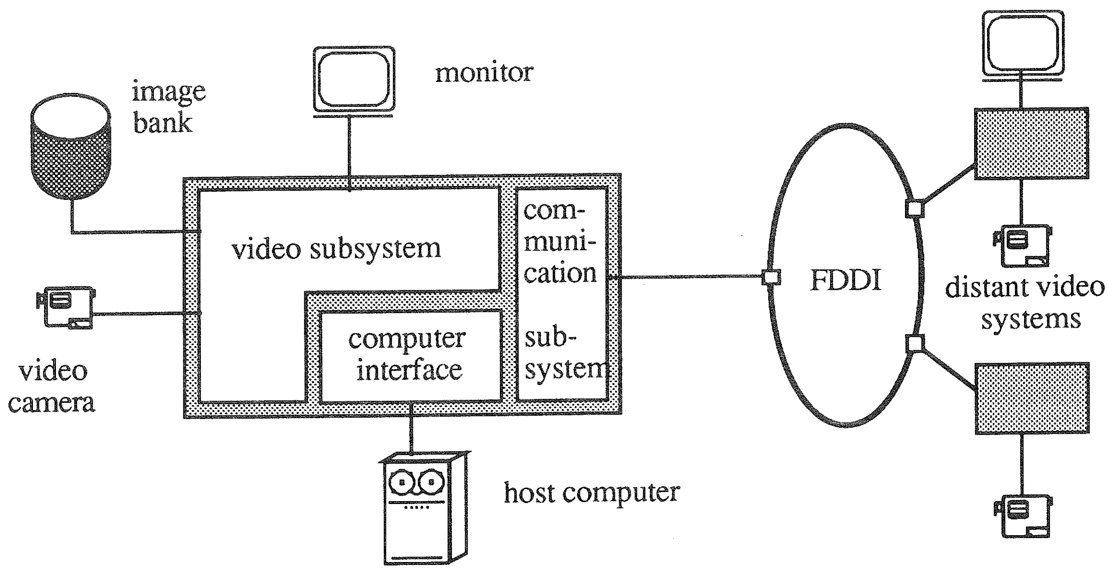

Figure 5 - The architecture of the video system

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 delay equal to 2.TTRT plus the physical response time of the network, 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. 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.

A prototype is under development which will put into practice what we prove. This prototype consists of three subsystems : the video subsystem, the communication subsystem, and the computer interface (Figure 5). The communication subsystem uses the AMD SuperNet components for the FDDI network. Each subsystem is linked to the others by a very high speed bus. This architecture enables both the local (1) and distant (2) image distribution not to be restricted by the bus throughput of the computer. Specific components enabling fast image processing (real time compression, image analysis,...) will be included in the prototype in the near future.

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Appendix

The FDDI protocol has the following property about the upper limit of consecutive delays :

(Lemma 1) : $\forall I \geq 1, \forall l, \forall n \in [l, l+N[, \; \delta_j(I)[l] \leq \delta_j(I-1)[n] + \sum_{k \in [n,l+N[} (Ts(I)[k]+Tas(I)[k]).$

Proof :

1. If $\delta_j(I)[l] = 0$ then the previous relation is obviously true, because durations are always positive or nil (◊).

2. Otherwise if $\delta_j(I)[l] > 0$ then we prove by recurrence :

2.1 According to the definition of δ_j for the first rotation:

$\forall l, \delta_j(1)[l] = TRT(1)[l] - TTRT.$

According to the definition of TRT :

$\forall l, \delta_j(1)[l] = Tj(2)[l] - Tj(1)[l] + \delta_j(0)[l] - TTRT.$

According to the token rotation duration definition :

$$\forall l, \delta_j(1)[l] = \sum_{k \in [l,l+N[} (Ts(1)[k]+Tas(1)[k]) + \delta_j(0)[l] - TTRT.$$

By definition of the FDDI protocol, we know that no transmission can occur during the first rotation ($\forall k \in [0, N[$, $Ts(0)[k]=Tas(0)[k]=0$), so by definition of δ_j : $\forall k$, $\delta_j(0)[k]=0$. We can deduce that :

$$\forall l, \delta_j(1)[l] = \sum_{k \in [l,l+N[} (Ts(1)[k]+Tas(1)[k]) - TTRT.$$

As $n \in [l, l+N[$ the previous relation can be rewritten :

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

By definition of the FDDI protocol, we know that no asynchronous transmission can occur during the following rotation (number 1) ($\forall k \in [0, N[$, Tas(1)[k]=0) so we can deduce that :

$$\forall l,\ \delta_j(1)[l] = \sum_{k \in [l,n[} (Ts(1)[k]+Tas(1)[k]) + \sum_{k \in [n,l+N[} (Ts(1)[k]) - TTRT$$

Moreover by definition of the bandwidth allocation for synchronous transmission, we know that $\sum_{k \in [l,l+N[} (Ts(1)[k]) \leq TTRT$, so we can deduce that :

$$\forall l,\ \delta_j(1)[l] \leq \sum_{k \in [l,n[} (Ts(1)[k]+Tas(1)[k]).(\Diamond)$$

2.2 Assuming that the relation is true for any token rotation before the Ith rotation, for any station $\forall k \in [0,N[$ and $\forall n \in [l,l+N[$. We want to prove it for the next rotation.

2.2.1 Either the token is late at the station l : $\delta_j(I)[l]>0$. According to the definition of the token delay δ_j :

$$\delta_j(I)[l] = \sum_{k \in [l,l+N[} (Ts(I)[k]+Tas(I)[k]) + \delta_j(I-1)[l] - TTRT.$$

As $n \in [l, l+N[$ the previous relation can be rewritten :

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

2.2.1.1 If the token arrives early at the station n during the previous rotation : $\delta_j(I-1)[n]=0$, then by definition an asynchronous transmision can take place during THT(I-1)[n]. That is :

$$Tas(I)[n] \leq THT(I-1)[n].$$

According to the THT definition :

$$Tas(I)[n] \leq TTRT - Tj(I)[n] + Tj(I-1)[n] - \delta_j(I-2)[l].$$

According to the token rotation duration definition :

$$Tas(I)[n] \leq TTRT- \sum_{k \in [n,n+N[} (Ts(I-1)[k]+Tas(I-1)[k])-\delta_j(I-2)[l].$$

As $n \in [l, l+N[$, the previous relation can be rewritten :

$$Tas(I)[n] \leq TTRT - \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]) - \sum_{k \in [l+N,n+N[} (Ts(I-1)[k]+Tas(I-1)[k]) - \delta_j(I-2)[l].$$

Which can be rewritten :

$$Tas(I)[n] \leq TTRT - \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]) - \sum_{k \in [l,n[} (Ts(I)[k] + Tas(I)[k]) - \delta_j(I-2)[l].$$

So :

$$\delta_j(I)[l] \leq Ts(I)[n] - \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]) - \delta_j(I-2)[l] + \sum_{k \in [n+1,l+N[} (Ts(I)[k]+Tas(I)[k]) + \delta_j(I-1)[l].$$

By recurrent assumption over I-1 :

$$\forall l,\ \forall n \in [l, l+N[,\ \delta_j(I-1)[l] \leq \delta_j(I-2)[n] + \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]).$$

So :

$$\delta_j(I)[l] \leq Ts(I)[n] + \sum_{k \in [n+1,l+N[} (Ts(I)[k]+Tas(I)[k]).$$

Which can have an upper limit of, because the durations are positive or nil :

$$\delta_j(I)[l] \leq \sum_{k \in [n,l+N[} (Ts(I)[k]+Tas(I)[k])\ (\Diamond).$$

2.2.1.2 Either the token arrives late at the station n during the previous rotation : $\delta_j(I-1)[n] \geq 0$, then according to the definition of the token delay δ_j :

$$\delta_j(I)[l] = \sum_{k \in [l,l+N[} (Ts(I)[k]+Tas(I)[k]) + \delta_j(I-1)[l] - TTRT.$$

As $n \in [l, l+N[$ the previous relation can be rewritten :

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

According to the definition of the token delay δ_j :

$$\delta_j(I-1)[n] = \sum_{k \in [n,n+N[} (Ts(I-1)[k]+Tas(I-1)[k]) + \delta_j(I-2)[n] - TTRT.$$

As $n \in [l, l+N[$ the previous relation can be rewritten :

$$\delta_j(I-1)[n] = \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]) + \sum_{k \in [l+N,n+N[} (Ts(I-1)[k]+Tas(I-1)[k]) + \delta_j(I-2)[n] - TTRT.$$

Which can be rewrites :

$$\delta_j(I-1)[n] = \sum_{k \in [n,l+N[} (Ts(I-1)[k] + Tas(I-1)[k]) + \sum_{k \in [l,n[} (Ts(I)[k]+Tas(I)[k]) + \delta_j(I-2)[n] - TTRT.$$

So,

$$\delta_j(I)[l] = \sum_{k \in [n,l+N[} (Ts(I)[k]+Tas(I)[k]) + \delta_j(I-1)[l] + \delta_j(I-1)[n] - \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]) - \delta_j(I-2)[n].$$

By recurent assumption over I-1 :

$$\forall l,\ \forall n \in [l, l+N[,\ \delta_j(I-1)[l] \leq \delta_j(I-2)[n] + \sum_{k \in [n,l+N[} (Ts(I-1)[k]+Tas(I-1)[k]).$$

So we can write :

$$\delta_j(I)[l] \leq \sum_{k \in [n,l+N[} (Ts(I)[k]+Tas(I)[k]) + \delta_j(I-1)[n].\ (\Diamond)$$

2.2.2 Either the token is early : $\delta_j(I)[l]=0$, then as all the durations are positive or nil the relation is obviously true. $(\Diamond)$

We prove that the sum of all the asynchronous transmission time between successive token arrivals at station (one rotation) has an upper limit of the Target Token Rotation Time minus the delay measured at the station during the previous rotation.

(Lemme 2) : $\forall l,\ \forall I,\ \sum_{k \in [l,l+N[} Tas(I)[k] \leq TTRT - \delta_j(I-1)[l].$

Proof by recurrence over the pair built by the rotation number and the station number, is as follows :

1. During the first rotation, no asynchronous transmission can take place :

$\forall k$, Tas(0)[k]=0, so $\sum_{k \in [0,N[} Tas(0)[k] = 0.$ (◊)

2. Assuming that the relation is true during the I^{th} rotation at the station l, we want to prove it for the next station l+1.

2.1 Either all the stations during the $I\text{-}1^{th}$ rotation received the token late, then no asynchronous transmission can occur:

If $\forall k \in [l+1, l+1+N[$, $\delta_j(I-1)[k]>0$ then $Tas(I)[k]=0$, from which we can deduce that :

$$\sum_{k \in [l+1,l+1+N[} Tas(I)[k] = 0. \quad (\lozenge)$$

2.2 Either there exists a station k which, during the $I\text{-}1^{th}$ rotation, received the token early :

$\exists\, k \in [l+1, l+1+N[$, with $\delta_j(I-1)[k]=0$.

Let n the higher number of the station which can transmit asynchronously. Then we have :

$\forall\, k \in [n+1, l+1+N[$, $\delta_j(I-1)[k]>0$ and $Tas(I)(k)=0$; and $\delta_j(I-1)[n]=0$. From which we can deduce that :

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

The asynchronous transmission at the station n is limited by the THT :

$Tas(I)[n] \le THT(I-1)[n]$.

According to the definition of THT :

$Tas(I)[n] \le TTRT - Tj(I)[n] + Tj(I-1)[n] - \delta_j(I-2)[n]$.

According to the definition of Tj :

$$Tas(I)[n] \le TTRT - \sum_{k \in [n,n+N[} (Ts(I-1)[k]+Tas(I-1)[k]) - \delta_j(I-2)[n].$$

So, we can rewrite :

$$\sum_{k \in [l+1,l+1+N[} Tas(I)[k] \le \sum_{k \in [l+1,n[} Tas(I)[k] + TTRT - \sum_{k \in [n,n+N[} (Ts(I-1)[k])+Tas(I-1)[k]) - \delta_j(I-2)[n].$$

As $n \in [l+1, l+1+N[$ then $l+1+N \in [n, n+N[$:

$$\sum_{k \in [l+1,l+1+N[} Tas(I)[k] \le TTRT - \sum_{k \in [n,n+N[} Ts(I-1)[k] - \sum_{k \in [n,l+1+N[} Tas(I-1)[k] - \delta_j(I-2)[n].$$

According to the previous property (lemma 1) :

$$\delta_j(I-1)[l+1] \le \delta_j(I-2)[n] + \sum_{k \in [n,l+1+N[} (Ts(I-1)[k]+Tas(I-1)[k]).$$

So, we can rewrite :

$$\sum_{k \in [l+1,l+1+N[} Tas(I)[k] \le TTRT - \sum_{k \in [l+1+N,n+N[} Ts(I-1)[k] - \delta_j(I-1)[l+1].$$

As all the durations are positive or nil, we prove that :

$$\sum_{k \in [l+1,l+1+N[} Tas(I)[k] \le TTRT - \delta_j(I-1)[l+1]. \quad (\lozenge)$$