LIGHTNET : a set of efficient high speed access protocols

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Lightnet: A Set Of Efficient High Speed Access Protocols.

Lightnet: Un ensemble De Protocoles A Haut Débit Efficaces.

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Abstract: This paper introduces a set of new high-speed access protocols working on unidirectional media which can achieve very good throughput and average delay.

Résumé: Ce papier introduit un ensemble de nouveaux protocoles d'accès à haut débit qui s'adapte à une topologie sur bus unidirectionel et permet d'obtenir un très bon délai moyen ainsi qu'un très bon débit.

I.Introduction.

Recently the idea arises that it could be interesting to handle applications such as speech,high-resolution graphics, video, etc, on local area networks. Such applications require high bandwidth. With the development of fiber optic communications, it seems more and more likely that such a requirement can be met. Such a capacity calls for a new generation of communication protocols.

Existing protocols (e.g. Ethernet or the Token passing bus) are obviously not efficient for high speed local area networks: too much time or bandwidth is lost in propagation delays. It can be shown that the maximum channel capacity C_{max} is for such protocols given by:

$$C_{max} = \frac{1}{1 + O(a)} \qquad (1)$$

where a denotes the ratio of the propagation delay by the average transmission duration of a packet. High bandwidth implies a small duration to transmit a packet; a is large and therefore C_{max} is small.

Other multiple access protocol like TDMA performs according to the number of active stations. The maximum channel capacity C_{max} is given by:

$$C_{max} = \frac{N_a}{N_t}, \qquad (2)$$

where N_a denotes the number of active stations and N_t the total number of stations. In standard utilization the number of active stations is whithin 10 percent of the total number of stations.

New protocols (e.g. Fastnet or Expressnet) have been introduced for high speed communication. They achieve a maximum channel capacity C_{max} :

$$C_{max} = \frac{1}{1 + \dfrac{a}{N_a}}. \qquad (3)$$

So these protocols work well when a is small compared to N_a. For exemple for $N_a = 50$ and $a = 20$, we have $C_{max} = 0,71$.

In the following sections we introduce a set of access protocols: Lightnet 1,2,3 [1]. Based on the same general principles, they can tolerate very large values for a and various kind of traffic mixes. We will be also interested in the following properties:

(i) acccess rights are fair for all stations.

(ii) determinism i.e. access delays are bound with a bound only network dependent.

(iii) it is possible to reach 100 % of the channel utilization, independently of the distribution of active stations.

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Lightnet protocols met the three requirements, except the third one for the ring version because of the particularity of this architecture. In the analysis it will be shown that the maximum channel efficiency is: $N_a/(N_a + 1)$.

This paper is divided into five sections. Section II is a brief reminder on Expressnet. Section III introduces Lightnet protocols. In section IV, we approach technical problems met by Lightnet protocols. In section V, we analyze Lightnet protocols with standard hypothesis: symmetric Poisson traffic and infinite number of stations. Results obtained out of analytical models and simulation results are given as well as a comparison between Expressnet and Lightnet 1. Such a comparison seems relevant because Lightnet and Expressnet have the same topology and the same mechamism to avoid collisions. Section VI is a comparison between Lightnet 1, Expressnet and TDMA with unbalanced trafic.

II. Expressnet as a unidirectional broadcast system.

Expressnet is based on a unidirectional broadcast medium consisting of one outbound channel connected to one inbound channel. Figure 1 gives one possible topology for Expressnet. Each station writes on the outbound channel. Packets are read by the addressees on the inbound channel. The main idea behind this protocol is to create **trains of packets** : each station having a pending packet senses the outbound channel to find the end of a train and then transmits immediately. Doing so increases the length of the train; a train can include at most N_u packets. When the more upstream station senses the end of a train on the **inbound channel**, it starts a new train, with the transmission of a packet if one is waiting, with a burst which is long enough to be sensed on the **outbound channel** otherwise. Figure 2 helps to understand how this protocol works.

In fact, due to delays between sensing the begin-of-carrier and aborting transmission, every packet must include a bumper ,see figure 3. This protocol includes also a "cold start" procedure which allows every disconnected stations to reconnect. A station which is disconnected has no longer to generate trains. For details, a complete description of Expressnet is given in [2] .

For this protocol to work it is very important that the propagation delay between the outbound and inbound tap be the same for every stations. It is also very important to be able to react very quickly to a beginning of carrier if you want to keep bumpers a reasonnable length.

If all packets have the same duration:1, a train follows the later after a time units. The used bandwidth is $N_u + a$ and only N_a packets are transmitted. This leads to a maximum channel capacity given by (4).

III.Lightnet a unidirectionnal broadcast system with simple reservation scheme.

The three protocols: Lightnet 1,2,3 are all based on the same general ideas but show few differences in algorithms or in topologies.

We start with Lightnet 1 which works on the same topology as Expressnet (Figure1). Contrary to Expressnet, Lightnet 1 is a synchron protocol. The time is divided into slots which consists of time intervals. This division is simultaneous for all the stations if we set local time of each station so that a same signal propagating on the channel is read on the inbound channel at the same time by each of them.

1. Lightnet 1.

Lightnet 1 is based upon two very simple ideas: the first one is to avoid collisions with packets including bumpers just as in Expressnet, the second one is to use a simple reservation scheme.

Collision avoidance.

A bumper is a consumable part of a packet which does not comprise usefull information. The mechanism which avoids collisions works as in Expressnet, a transmission is started at the beginning of a slot and immediatly aborted if a beginning of carrier is sensed on the outbound channel. The result is then a damage for the bumper of the propagating packet , but the collision is avoided. The set of stations which have unsuccesfully tried to transmit on this slot is a session.

The reservation scheme.

Let us suppose that a station has just read on the inbound channel a packet with a damaged bumper, then the coming slot on the outbound channel will be reserved. This reservation is for the packets, which having unsuccessfully competed, have produced this damaged bumper. These stations will therefore receive access rights according to their relative position on the inbound channel. Two access rights for packets belonging to the same session will be separated by a slots (a denotes an integer and includes propagation delay and the time to detect the damaged bumper). A station must be able to recognize the slot on the inbound channel for which it has competed. That is possible by counting slots on the inbound channel.

A first attempt to transmit can only be tried on a free slot (free means not reserved). If no station more upstream has already written on this slot the packet is successfully transmitted. If a station more upstream has already written on this slot, the bumper of the transmitted packet will be damaged and the station has to wait for its reservation to be retransmitted.

With that mechanism up to a sessions can be opened at the same time and in the same station up to a packets can wait for being retransmitted. Figure 4 helps to understand how this protocol works.

In fact Lightnet implicitly consists in managing a global queues numbered from 0 to a-1. At the current slot t Lightnet modifies queue numbered t modulo a as follows:

- if the queue is empty, pending packets in stations are put in the queue starting by the more upstream station and the first packet in the queue is transmitted (that corresponds to the case of a free slot).

- if not, the first packet of the queue is emitted (that corresponds to the case of a reserved slot). One can notice that every packet in the same queue belongs to the same session.

Some Observations:

Requirement (i) is satisfied. In Expressnet an access right is equivalent to the passing of a locomotive before one station outbound tap. For Lightnet 1, an access right is given by a free slot which visits every station from the must upstream to the must downstream.

Introduction of a kind of "parallelism".

The essential newness of protocols "Lightnet" is parallelism. Many sessions are handled at the same time. In fact it is rather a weak parallelism, on the channel events occur sequentially. The parallelism appears at the level of the stations where up to a packets can be waiting for retransmission at the same time. So an optimal utilization of the channel capacity can be reached even if the traffic is focused on a single station. Actually to reach 100% of the channel capacity it is sufficient that, at every free slot, a station has at least a pending packet. So every traffic gets through up to the channel capacity.Requirement (iii) is satisfied.

Channel access is determinist: property (ii) is satisfied.

A packet is emitted at worst $2aN_a$ slots after this packet has arrived in the station.
Proof:
It is obvious that all the packets of a session are transmitted $a(N_a-1)$ slots after the beginning of this session. A packet will therefore find a free slot a the latest after aN_a slots. A packet has to wait at most aN_a slots to get a free slot and a session is finished at the latest aN_a slots after its beginning.

2. Improvements for heavy load:Lightnet 2.

At heavy load, a free coming slot (i.e. the first free slot coming after busy ones) is likely to produce a session containing a lot of packets. This may be damaging for delays. To lessen this

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effect, Lightnet 2 allows a station to use a free slot only with probability pr; pr is chosen so that $a \times pr$ is large. We can easily see that we still have fair access for every station but we have lost determinism and the possibility to reach 100 % of the channel utilization indepently of the distribution of active stations.

In fact we can preserve determinism and property (iii) if we use the following solution: every station receives an integer between 0 and F which represents the number of free slots every packet from this station has to wait before being sent on the channel. With a random assignment of these numbers to each station, it is possible to suitably distribute pending packets on free slots. This protocol will be referred in the following as Lightnet 2 determinist.

3. Lightnet on a ring: Lightnet 3.

Lightnet 1 and 2 work on the same topology than Expressnet. It is possible to adapt these protocols to a ring. We suppose that the round trip delay is a slots. The principle is the same as in Lightnet 1 for collision avoidance. Contrary to Lightnet 1, where the reservation is read on the inbound channel, in Lightnet 3 stations have to count slot. The reservation scheme works as follows: if a station reads a damaged bumper on slot n then slot $n + a$ is reserved for stations having unsuccessfully competed for slot n. Every station will know that reservation because a round trip delay is a slots long. As usually on a ring, the station which sends a packet is also in charge of destroying it after the packet has performed a round.

IV Technical problems met by Lightnet protocols.

The major problem faced by Expressnet is to react very quickly to the beginning of a carrier read on the outbound channel. This response time determines the length of the bumpers and thus the lost part of the initial bandwidth. Lightnet has the same problem and in addition we are supposed to be able to decide whether or not a bumper has been damaged. Besides we can notice that the detection time has been included in a.

In the following we propose solutions to these problems

According to the previous protocol the effect of a damaged bumper is to put the following slot on the outbound channel in session. To resolve the problem of a very brief response time we suggest the following solution. We add a parallele medium that we call control cable, see the precise topology on figure 5. The two media are supposed to be synchronized with the same slot duration.

A station having a pending packet reacts the following way:

If the packet belongs to a session, a-1 slots after the last attempt to transmit the station senses the control cable, see whether or not the coming slot is free and write on that slot a specific sequence. If this slot is free the station sends the packet on the main channel on the next slot, the fact of having written on the controle cable avoids collision. If this slot was already busy nothing is done on the main channel. The fact of having written on the controle cable produces a collision which will be used as reservation flag.

For the first attempt to transmit a packet a station must find a free slot. For that it must sense a slot collision free on outbound tap of the controle cable. The algorithm is then the same as in the case of a packet belonging to a session.

The response time we had on the data medium to see whether or not a slot is free is now shifted on the control cable. This protocol requires that a station can read a slot, decide if it is free or not and write on it to produce a collision. This assumption does not seem impossible to satisfy, collision can be detected by code violation. Figure 5 helps to understand how this protocol works.

The problem of collision detection can be resolved using a third cable called collision cable. Every stations have an outbound and inbound taps on the data medium and collision cable. The control cable will be connected by outbound taps only. For a station having a pending packet not belonging to a session the protocol is the following: this station waits for a free slot read on the collision cable, then it reads the control cable. If the coming slot is free, the slot is written on that cable and the packet is sent on the data medium on the next slot. Otherwise the coming slot of the collision cable is written and the packet waits for its reservation to be retransmitted.

On the control and collision cables we can reasonably use a bandwidth in the order of 10 Mbits/s thus we can use existing technology.

As we have just shown, it is possible to cope with the major problem of conflict free protocol which is the swiftness to detect a carrier and to abort transmitting.

V Analytical models for performance evaluations.

We suppose that the number of stations is infinite and that the traffic is Poisson and symmetric. All packets have the same duration taken as a slot. The total input load by slot is λ.

Our goal is to derive the mean access delay for a packet (i.e. the time between the arrival of a packet in a station and its successfull transmission).

When a station has a pending packet it tries to transmit on the first free slot. The average access delay can be divided into two parts: the mean time to search for a free slot and the retransmission delay.

The main approximation of our paper is to suppose that all the slots are independent and have the probability μ to be reserved.

1. Evaluation of Lightnet 1.

Theorem 1: The mean access delay $W(\lambda)$ for a random packet is :

$$W(\lambda) = (1 + a \frac{\lambda}{2}) \frac{3 + \lambda - \sqrt{(1-\lambda)^2 + 4(e^{-\lambda}-1)(1-\lambda)}}{1 - \lambda + \sqrt{(1-\lambda)^2 + 4(e^{-\lambda}-1)(1-\lambda)}}.$$

A station with a packet waits k slots with probability $(1-\mu) \mu^{k-1}, k \geq 1$. The average delay to find a free slot is therefore:

$$\frac{1}{1-\mu} - \frac{1}{2}. \tag{4}$$

The half comes from the fact that we consider continuous time.

It remains to evaluate the retransmission delay. The distribution of the number of packets in a random session depends on the distribution of the number of reserved slots which precede and during which stations with pending packets defer transmission. The distribution of the number of packets in a session is given by a mixing of Poisson traffics with rate $k\lambda$ and with the coefficients of ponderation $(1- \mu) \mu^k$. Therefore the mean number of packets in a session is :

$$N = \sum_{k \geq 1} (1-\mu) \mu^{k-1} k\lambda = \frac{\lambda}{1-\mu}. \tag{5}$$

The cumulated delays by session are:

$$D = a \sum_{k \geq 1} (1-\mu) \mu^{k-1} \sum_{n \geq 0} \frac{n(n-1)}{2} \frac{(k\lambda)^n}{n!} e^{-\lambda k}, \tag{6}$$

$$D = a \frac{\lambda^2}{2} (\frac{2\mu}{(1-\mu)^2} + \frac{1}{1-\mu}) = a \frac{\lambda^2}{2} \frac{\mu+1}{(1-\mu)^2}. \tag{7}$$

The mean retransmission delay is :

$$\frac{D}{N} = a \frac{\lambda}{2} (\frac{1+\mu}{1-\mu}). \tag{8}$$

Therefore :

$$W(\lambda) = (\frac{1}{2} + a \frac{\lambda}{2}) (\frac{1+\mu}{1-\mu}). \tag{9}$$

μ is a function of λ. Let S denote the mean number of slots used for the resolution of a random session. The equation of the steady state is :

$$\lambda = \frac{N}{S} .$$ (10)

S is equal to the mean number of packets involved in a session except in the case where this session is empty. Therefore:

$$S = N + \sum_{k \geq 1} (1 - \mu) \, \mu^{k-1} e^{-k\lambda} = \frac{\lambda}{1 - \mu} + \frac{(1 - \mu) e^{-\lambda}}{1 - \mu e^{-\lambda}} .$$ (11)

The resolution of (10) leads to

$$\mu = 1 - \frac{1 - \lambda + \sqrt{(1 - \lambda)^2 + 4(e^{-\lambda} - 1)(1 - \lambda)}}{2} .$$ (12)

Using (9) it comes:

$$W(\lambda) = (1 + a \frac{\lambda}{2}) \frac{3 + \lambda - \sqrt{(1 - \lambda)^2 + 4(e^{-\lambda} - 1)(1 - \lambda)}}{1 - \lambda + \sqrt{(1 - \lambda)^2 + 4(e^{-\lambda} - 1)(1 - \lambda)}} .$$ (13)

□

We have tested this model with 50 stations and $a = 20$. Simulation software has been written in C⁺⁺ under Sphinx which is a performance evaluation tool developed at INRIA for the analysis of local area network [3]. Curves on figure 6 show the accuracy of our model.

2.Evaluation of Expressnet.

Theorem 2:

The mean access delay $W(\lambda)$ for a random packet is:

$$W(\lambda) = \frac{a}{2} \frac{1}{1 - \lambda} + \frac{1}{2} \frac{1}{1 - \lambda^2}$$

With the hypothesis of infinite number of stations and symmetric Poisson traffic ,the mean access delay can be easily derived for Expressnet. Let $E(L)$ denote the mean duration of a train of packets. It is obvious that the used bandwidth is:

$$1 - \frac{a}{E(L)} .$$

The equation of the steady state is:

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$$\lambda = 1 - \frac{a}{E(L)} \quad or \quad E(L) = \frac{a}{1-\lambda}. \tag{14}$$

The mean acccess delay is therefore [4]:

$$W(\lambda) = \frac{E(L)}{2} + \frac{VAR(L)}{2\,E(L)} \tag{15}$$

$VAR(L)$ has been evaluated in [5]

$$W(\lambda) = \frac{a}{2}\,\frac{1}{1-\lambda} + \frac{1}{2}\,\frac{1}{1-\lambda^2} \tag{16}$$

□

3.Comparison between Expressnet at low and heavy load.

Let us introduce:

$$w_{Exp}(\lambda) = \frac{W_{Exp}(\lambda)}{a} \quad , \quad w_{ligh}(\lambda) = \frac{W_{Ligh}(\lambda)}{a}. \tag{17}$$

With large values of a and when λ tends to 0, we have the following expansions:

$$w_{Exp}(\lambda) = \frac{1}{2} + \frac{\lambda}{2} + O(\lambda^2), \tag{18}$$

$$w_{ligh}(\lambda) = \frac{\lambda}{2} + O(\lambda^2). \tag{19}$$

When λ tends to 1, we have the following expansions:

$$w_{Exp}(\lambda) = \frac{1}{2\,(1-\lambda)}, \tag{20}$$

$$w_{Ligh}(\lambda) = \frac{1}{\sqrt{1-e}}\,\frac{1}{\sqrt{1-\lambda}} + O(\lambda^2). \tag{21}$$

This clearly shows that Lightnet 1 behaves much better at low and heavy loads than Expressnet. Contrary to Lightnet 1, whose behaviour in the real case of finite number of stations seems close to the case of our model (infinite number of stations), Expressnet has a different behaviour with the assumption of a finite number of stations, see [3].A complete comparison between Lightnet 1 and Expressnet is given on figure 7 ; results for Expressnet are derived of simulations. One can see that under all circumstances Lightnet 1 has better average delays than Expressnet.

4. Evaluation of Lightnet 2 and 2 determinist.

Theorem 3: The mean access delay $W(\lambda)$ for a random packet is :

$$W(\lambda)= \frac{1}{pr(1-\mu)} - \frac{1}{2} + \frac{\gamma a}{2} \quad with \quad \gamma\, e^{\gamma} = \frac{\lambda}{1-\lambda} \quad and \quad \mu = \frac{\gamma + e^{-\gamma}-1}{\gamma + e^{-\gamma}}.$$

The smoothing of packets arrivals on free slot leads us to use the following model: the arrival on a free slot is a Poisson process with rate γ. The average delay can still be split into the average time to find a free slot and the retransmission time. It comes:

$$W(\lambda)= \frac{1}{pr(1-\mu)} - \frac{1}{2} + \frac{\gamma a}{2}. \tag{22}$$

It remains to calculate γ and μ. With the same notation, we have:

$$N=\gamma \quad and \quad S = \gamma + e^{-\gamma} \tag{23}$$

The equation of equilibrium always gives:

$$\frac{N}{S} = \lambda \quad which\ is\ equivalent\ to \quad \gamma\, e^{\gamma} = \frac{\lambda}{1-\lambda}. \tag{24}$$

We can solve it numerically, for example by iteration:

$$\gamma_{n+1} = \frac{\lambda}{1-\lambda}\, e^{-\gamma_n}, \ \gamma_0 = 0\ if\ \lambda \leq 0.8\ otherwise \quad \gamma_{n+1} = \ln\left(\frac{\lambda}{(1-\lambda)\gamma_n}\right),\quad \gamma_0 = 1 \tag{25}$$

It remains to calculate μ. If n $(n \geq 2)$ is the number packets belonging to the same session, n-1 reserved slots are produced. If $n \leq 1$ no reserved slot is produced. The law of n being Poisson of rate γ, for a free slot there are in average $\gamma + e^{-\gamma}$ -1 reserved slots. Therefore we have the following formula:

$$\mu = \frac{\gamma + e^{-\gamma}-1}{\gamma + e^{-\gamma}}. \tag{26}$$

$\square$

We can find the average delay if we have defined pr, for example

$$pr = \frac{1}{\sqrt{a}} \ , thus \qquad W(\lambda) = (\gamma + e^\gamma) \ \sqrt{a} + \frac{\gamma}{2} \ a - \frac{1}{2} \ . \tag{27}$$

With large values of a and when λ tends to 0, we have the following expansion:

$$w_{ligh}(\lambda) = \frac{\lambda}{2} + O(\lambda^2) \ . \tag{28}$$

Under the same conditions when λ tends to 1, we have the following expansion:

$$w_{ligh}(\lambda) = \frac{1}{\sqrt{1-e}} \ log \ (\frac{1}{1-\lambda}) + O \ (\ log(\ log \ (\frac{1}{1-\lambda}))) \ . \tag{29}$$

We have tested this model with 50 stations and $a = 20$. We have chosen $pr = \sqrt{20}$ for Lightnet 2 and $F = 9$ for Lightnet 2 determinist. Figure 8 clearly shows the improvement in the behaviour of the protocol under heavy load. The matching of our model with simulations of Lightnet 2 and 2 determinist is quite good.

5. Evaluation of Lightnet 3.

Theorem 4:

The mean access $W(\lambda)$ for a random packet is:

$$W(\lambda) = (\frac{1}{2} + a \ \frac{\lambda}{2}) \ (\frac{1+\mu}{1-\mu}),$$

with

$$\lambda = \cfrac{\cfrac{\lambda}{1-\mu}}{1 + \cfrac{\lambda}{1-\mu} + (1-\mu)(\ \cfrac{1}{\lambda\mu} \ log \ (\cfrac{1-\mu e^{-\lambda}}{1-\mu}) + \cfrac{e^{-\lambda}}{1-\mu e^{-\lambda}} \ )} \ .$$

We will still suppose that all the slots are independent and have the probability μ to be reserved. Thus a station with a message waits k slots with probability μ if $k = 0$ and $(1-\mu) \mu^{k-1}$ if $k \geq 1$. The average delay to find a free slot is therefore $1/(1-\mu)-1/2$.

With that model formulas (4) to (10) remain valid. But there is a change in the value of S which is the mean number of slots used for the resolution of a session. If a session comprises k' ($k' \geq 1$) packets the average number of lost slots is equal to $a(1-1/(k'+1))$ slots, if $k' = 0$ a slots are lost. The proof of this assertion is simple. Because of independence of arrivals, the stations involved in the

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session plus the station which creates the free slot used for the beginning of this session are uniformely distributed on the set of connected stations. Among these stations, the average distance (in slot unit) between two consecutive stations is $a/(k'+1)$. Thus, $a(1-1/(k'+1))$ represents the mean number of reserved slots remaining not used during the session. Therefore we obtain the following formulas:

$$S = N + \sum_{k \geq 1} (1-\mu) \mu^{k-1} \left(e^{-k\lambda} + \sum_{k' \geq 1} e^{-k\lambda} \frac{(\lambda k)^{k'}}{k'!} \left(1 - \frac{1}{k'+1}\right) \right), \tag{30}$$

$$S = N + \sum_{k \geq 1} (1-\mu) \mu^{k-1} \left(1 - \sum_{k' \geq 1} e^{-k'\lambda} \frac{(\lambda k)^{k'}}{k'!} \frac{1}{k'+1}\right), \tag{31}$$

$$S = N + \sum_{k \geq 1} (1-\mu) \mu^{k-1} \left(\frac{1 - e^{-k\lambda} - k\lambda e^{-k\lambda}}{\lambda k}\right). \tag{32}$$

We have the identities:

$$\sum_{k \geq 1} (1-\mu) \mu^{k-1} \frac{1}{\lambda k} = \frac{1-\mu}{\lambda \mu} \log(1-\mu), \tag{33}$$

$$\sum_{k \geq 1} (1-\mu) \mu^{k-1} \frac{e^{-k\lambda}}{\lambda k} = \frac{1-\mu}{\lambda \mu} \log(1 - \mu e^{-\lambda}), \tag{34}$$

$$\sum_{k \geq 1} (1-\mu) \mu^{k-1} e^{-k\lambda} = \frac{(1-\mu)e^{-\lambda}}{1 - \mu e^{-\lambda}}. \tag{35}$$

We obtain finally:

$$S = 1 + \frac{\lambda}{1-\mu} + (1-\mu)\left(\frac{1}{\lambda \mu} \log\left(\frac{1 - \mu e^{-\lambda}}{1-\mu}\right) + \frac{e^{-\lambda}}{1 - \mu e^{-\lambda}}\right), \tag{36}$$

Equation 12 leads to:

$$\lambda = \frac{\dfrac{\lambda}{1-\mu}}{1 + \dfrac{\lambda}{1-\mu} + (1-\mu)\left(\dfrac{1}{\lambda \mu} \log\left(\dfrac{1 - \mu e^{-\lambda}}{1-\mu}\right) + \dfrac{e^{-\lambda}}{1 - \mu e^{-\lambda}}\right)}, \tag{37}$$

That can be written as follows:

$$\mu = \lambda + (1-\mu)^2 \left(\frac{1}{\lambda \mu} \log\left(\frac{1 - \mu e^{-\lambda}}{1-\mu}\right) + \frac{e^{-\lambda}}{1 - \mu e^{-\lambda}}\right). \tag{38}$$

This equation can be solved numerically by iteration:

$$\mu_{n+1} = \lambda + (1 - \mu_n)^2 \ (\ \frac{1}{\lambda\mu_n} \ log \ (\frac{1 - \mu_n e^{-\lambda}}{1 - \mu_n}) + \frac{e^{-\lambda}}{1 - \mu_n e^{-\lambda}} \ ) \qquad with \ \mu_0 = 0 \qquad (39)$$

$\square$

Let N_a be the number of active stations. If they are all involved in every session, for every session a slots are lost, then $S = N_a a + a$ and the maximum channel efficiency is:

$$C_{max} = \frac{N_a a}{N_a a + a} = \frac{N_a}{N_a + 1} \ . \qquad (40)$$

Figure 9 gives mean access delay derived from this analysis and results obtained out of simulation of Lightnet 3. The conditions are still $N_a = 50$ stations and $a = 20$. The matching is good and still demonstrates the accuracy of our model.

VI Behaviour of Lightnet with unbalanced traffic

For that part we will just give results of simulation the conditions are $N = 50$ and $a = 20$. We compare Lightnet 1, Expressnet and TDMA. The trafic is composed by the merge of two Poisson traffics. The first traffic is symmetric on stations 1 and 2 with rate λ. The second one is symmetric on stations 3,4,5,....,50 with rate 1-λ. The total input is 100% of the channel capacity. On figure 10 we give the output traffic in percent of the cannel capacity versus the load on stations 1 and 2. For Lightnet 1 allmost all the trafic gets through. Performances of Expressnet and TDMA deteriorate when station 1 and 2 are loaded. One can find a certain likeness in the behaviour of these two protocols. The fact that Expressnet can be considered as a protocol with an implicit token is likely to explain this similarity in behaviours.

VII Conclusion

We have defined a set of perfomant high speed protocols working on unidirectionnal media. Beside Lightnet 1 two other protocols are designed to fit special applications: heavy load or to work on a ring topology. Three analytical models have been developped to evaluate performances of these protocols. Comparisons between analytical results and results obtained out of simulations show the accuracy of models. The models have been tested at the second order and still provide very good matching with results obtained out of simulations. This has not been printed here to keep this paper a reasonable length. A careful comparison between Lightnet 1 and Expressnet shows that the former outperforms the later both for average delay

and for its flexibility to various kinds of trafic mixes under the assumption of uniform packet size. But Expressnet is essentially an asynchronous protocol and to the authors' knowledge, it is one of the best protocol of this class.

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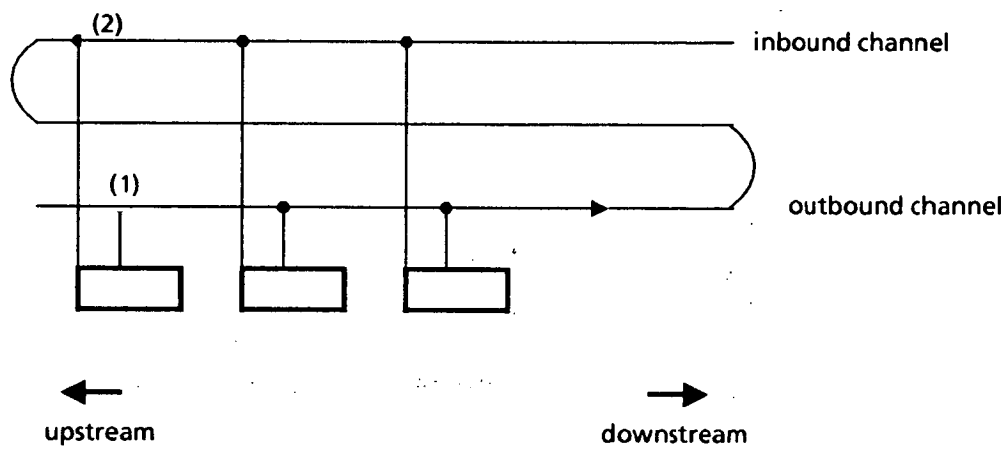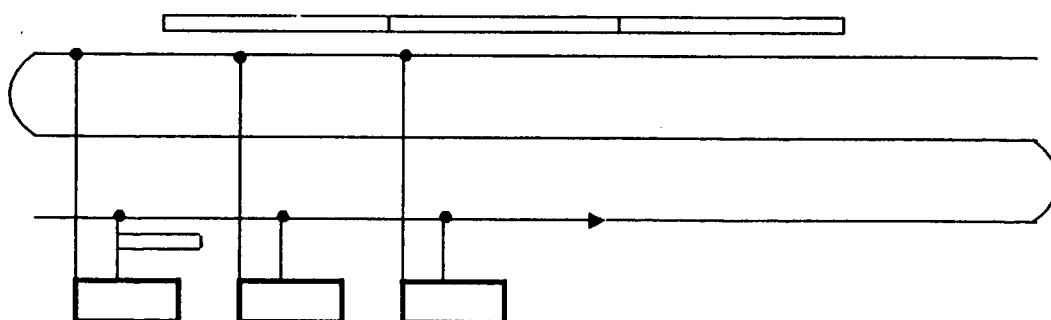
(1) outbound tap of the most upstream station

(2) inbound tap of the most upstream station

Figure 1
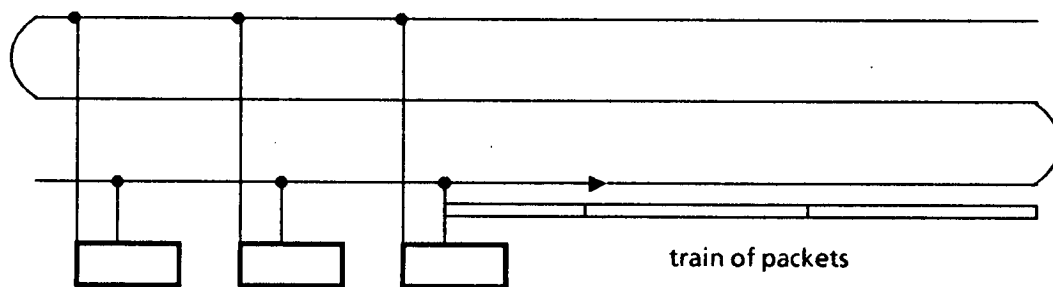
a station adds a packet to the train

the most upstream station senses the end of the train and starts transmitting
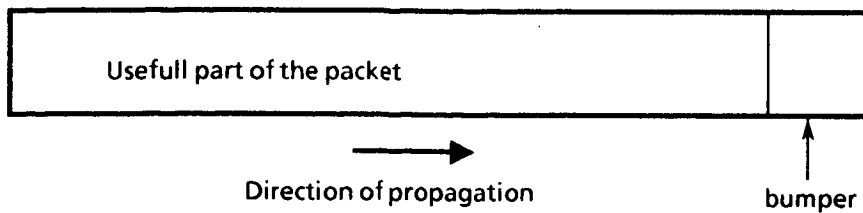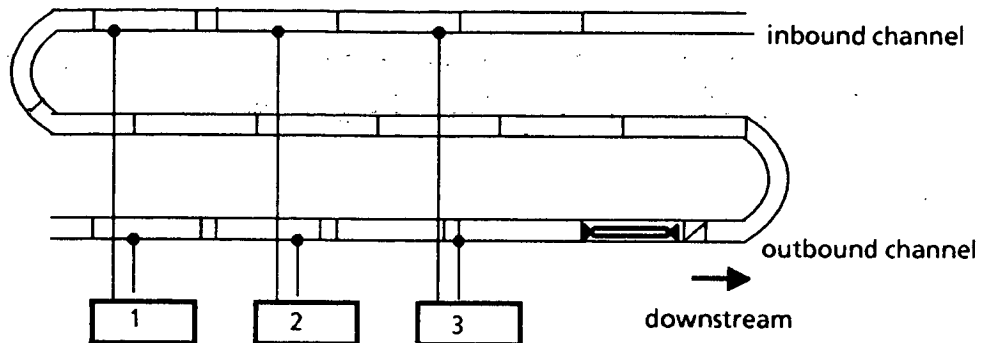
Figure 2

15

Usefull part of the packet

Direction of propagation

bumper

Figure 3: Structure of packets in Expressnet or Lightnet 1,2,3.

inbound channel
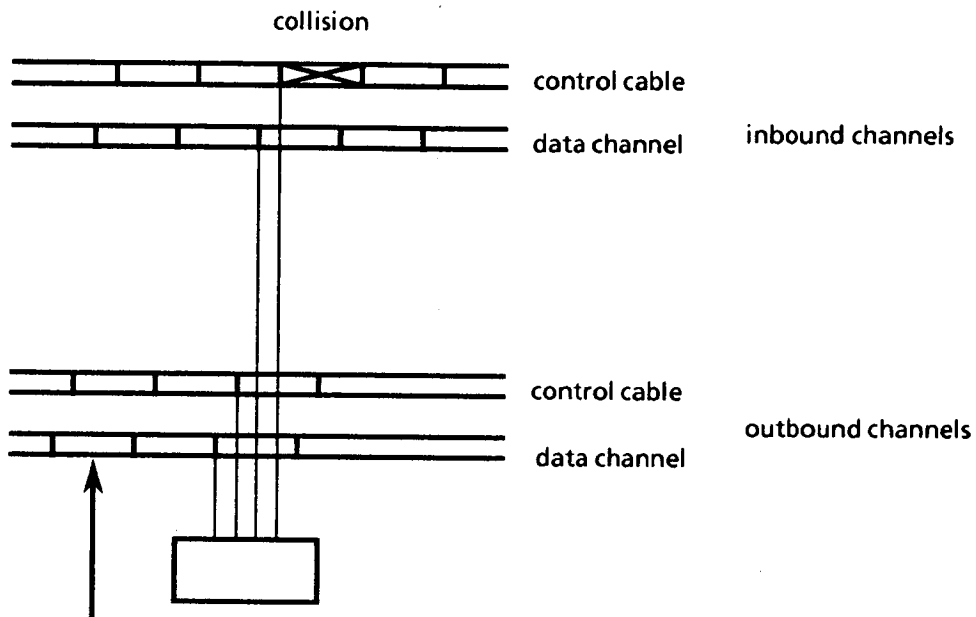
outbound channel

downstream

1 2 3

Station 1 has sent a packet , stations 2 and 3 having pending packets have competed for the same slot producing a damaged bumper. They will receive access rights when this damaged bumper will be sensed on their outbound tap.



slot with a
damaged bumper

downstream

1 2 3
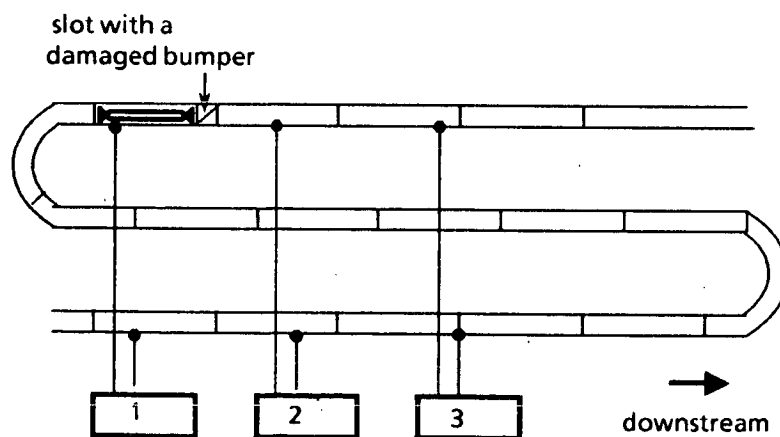
Station 1 which has another pending packet can't send it on the coming slot because it has just sensed a damaged bumper on its outbound tap.
Stations 2 and 3 will receive access rights when the damaged bumper will be sensed on their inbound taps. Actually, station 2 will send its packet as station 3 will have to abort transmission of its packet producing a damaged bumper to reserve an access right.
Station 3 will have to wait another propagation delay to send its packet.

Figure 4: Reservation scheme for Lightnet 1.

collision

control cable

data channel   inbound channels

control cable

outbound channels

data channel

This slot is free if the previous slot on the controle cable is collision free. In our case this slot is collided will be reserved for the stations having competed on the control cable for this slot.

control cable

data channel   inbound channels

busy   free

control cable

outbound channels

data channel
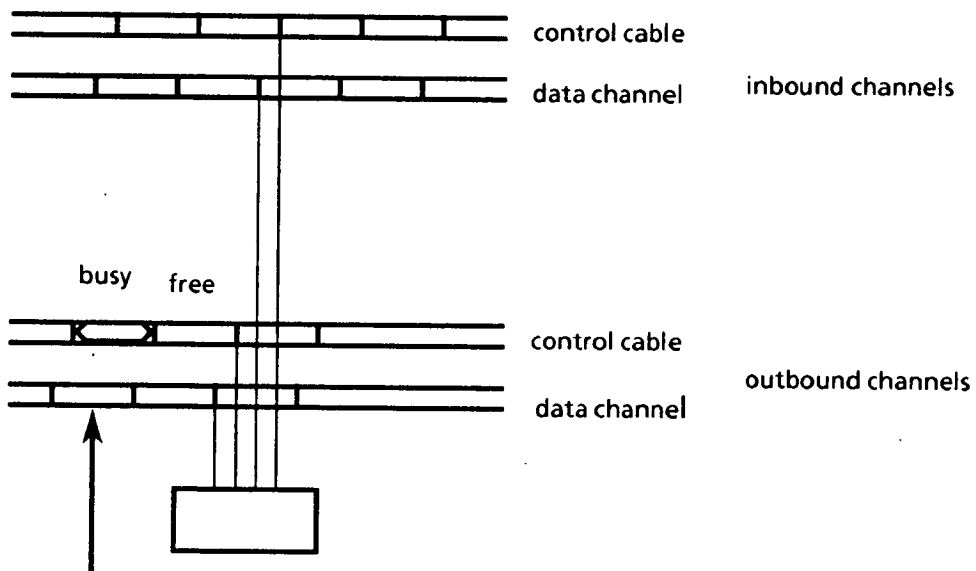
The station can write on this slot if the two following conditions are satisfied:
       its packet has a reservation or the previous slot of the cotrol cable is collision free,
       the coming slot on the control cable is free. (It is the case in this example)
If this slot is written the coming slot on the control cable will be written too.

Figure 5: Lightnet 1 with control cable.
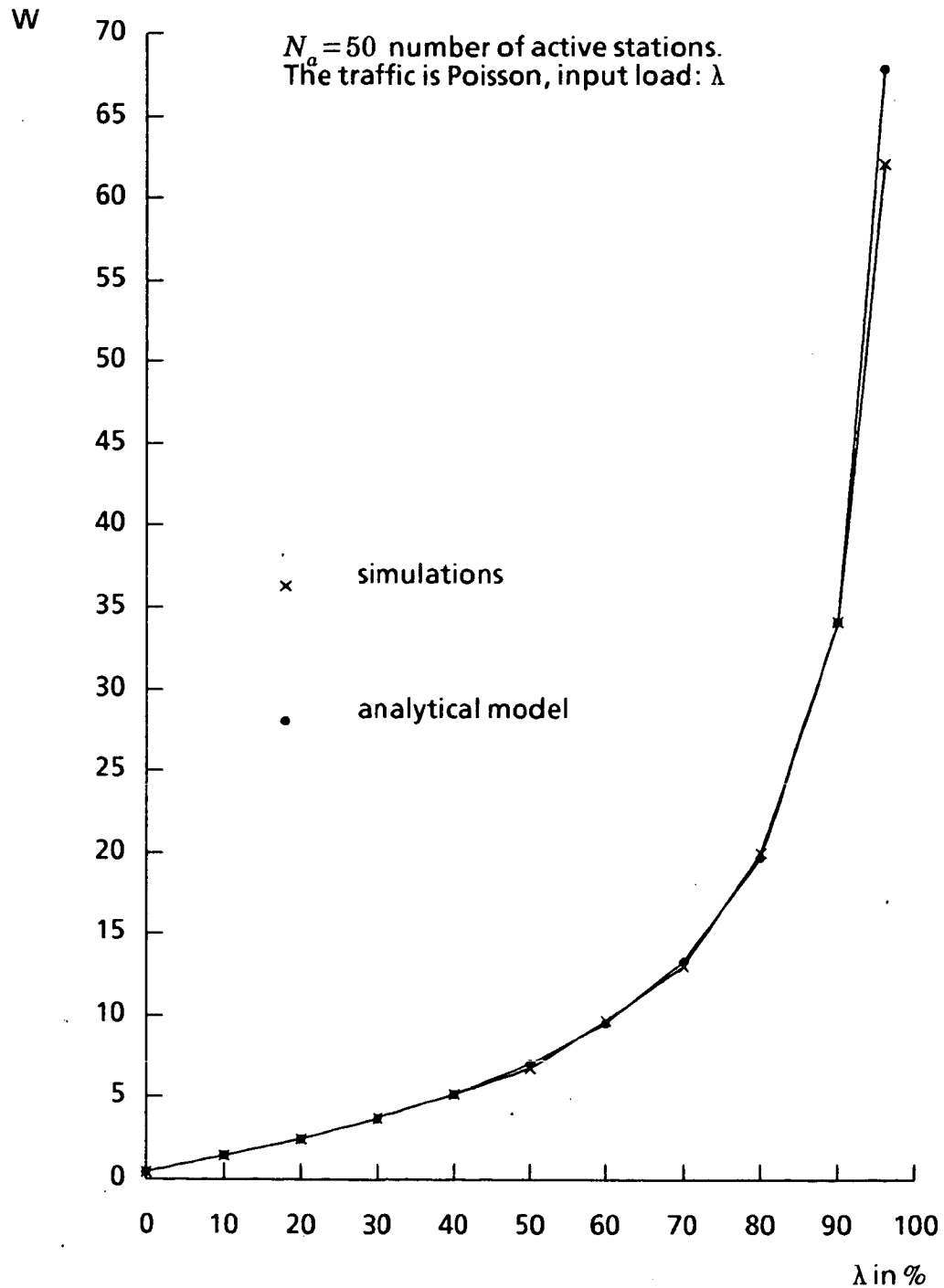
Unit: duration of a slot

Lightnet 1

W

$N_a = 50$ number of active stations.
The traffic is Poisson, input load: λ

× simulations

• analytical model

λ in %

Figure 6: Average access delays versus input load λ in percent of channel capacity.

Unit: duration of a slot

$N_a = 50$ number of active stations.
The traffic is Poisson, input load: λ

W   80

75

70

65

60   ▲   Lightnet 1

55

50   ●   Expressnet

45

40

35

30

25

20

15

10

5

0

0   10   20   30   40   50   60   70   80   90
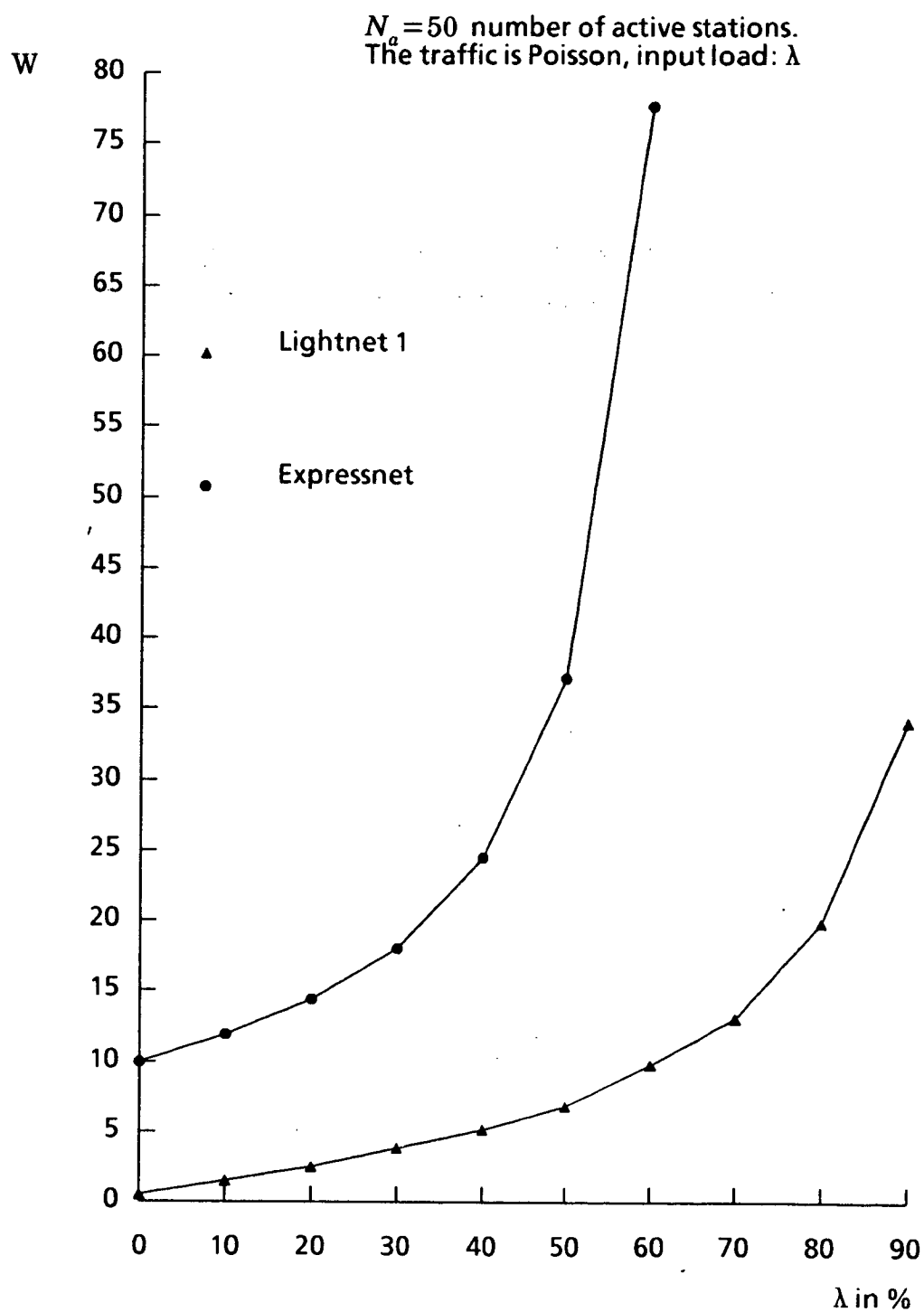
λ in %

Figure 7: Comparison between Expressnet and Lighnet 1. Average delay versus input load λ.

Unit: duration of a slot

Lightnet for heavy load

$N_a = 50$ number of active stations.
The traffic is Poisson, input load: λ

- ■ Lightnet 1 (simulations)
- ▲ Lightnet 2
- × Lightnet 2 determinist
- ● Analytical model for Lightnet 2
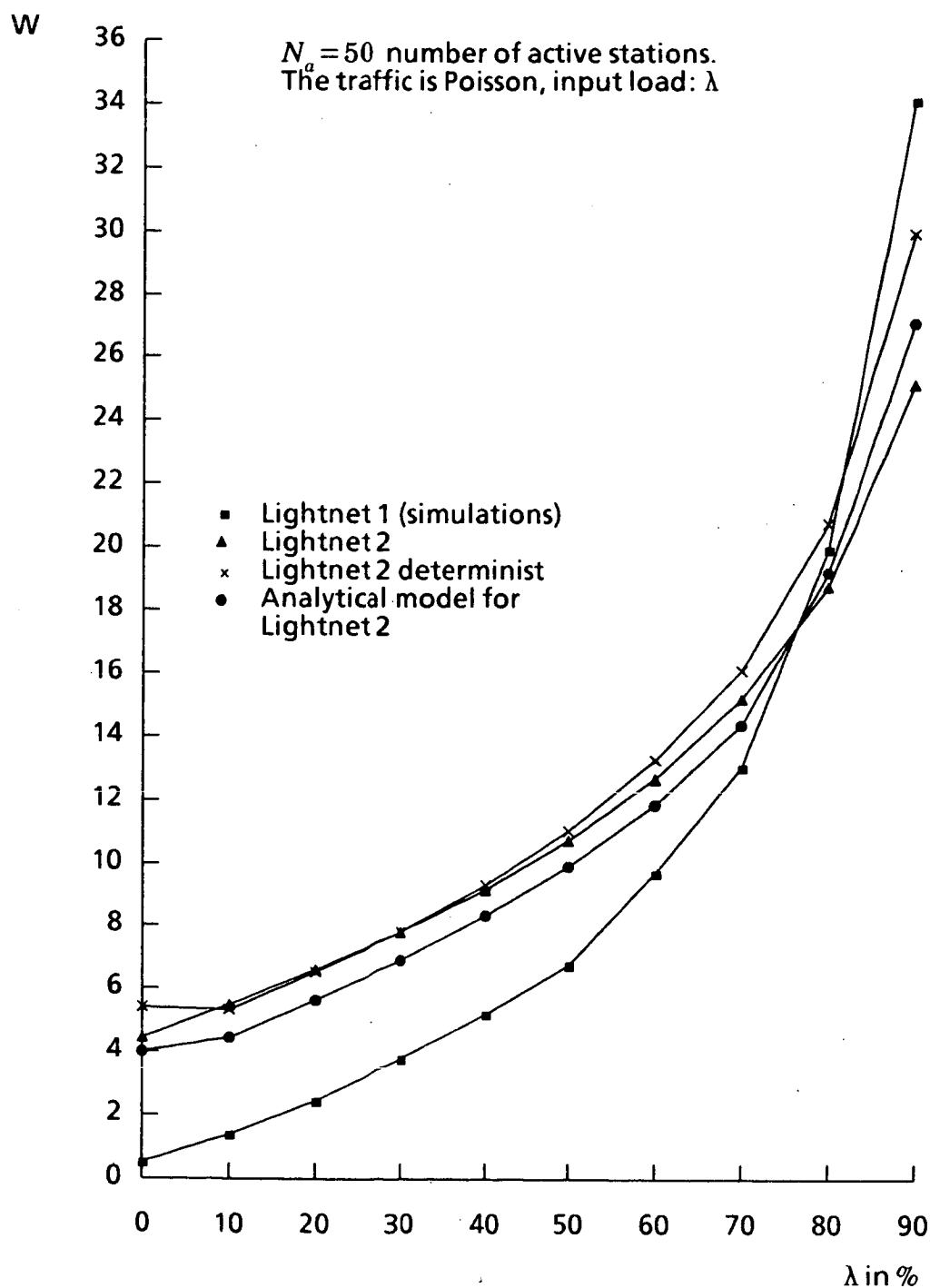
λ in %

Figure 8: Average access delays versus input load λ in percent of channel capacity.

Unit: duration of a slot

Lightnet 3

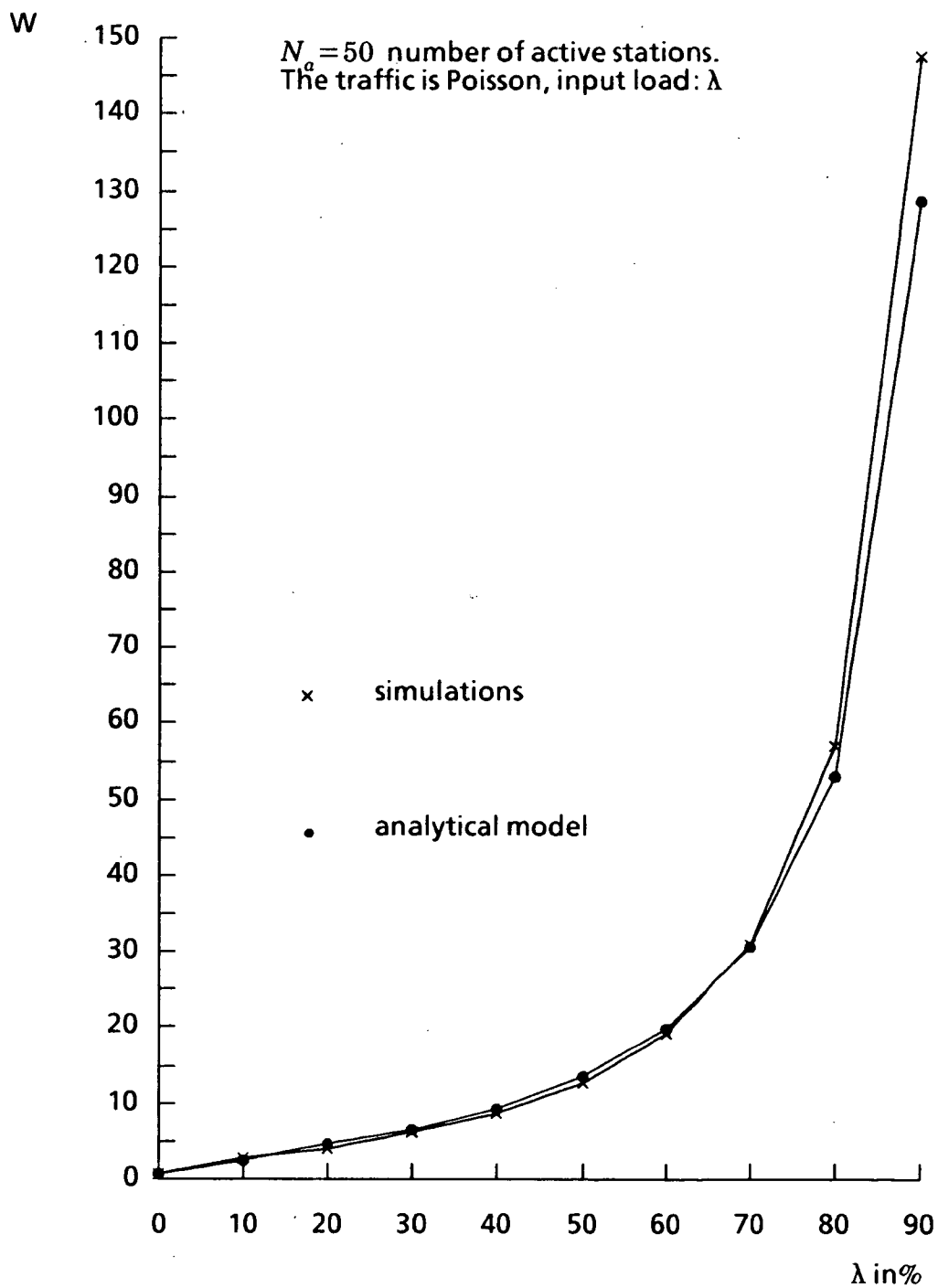Figure 9: Average access delays versus input load λ in percent of channel capacity.
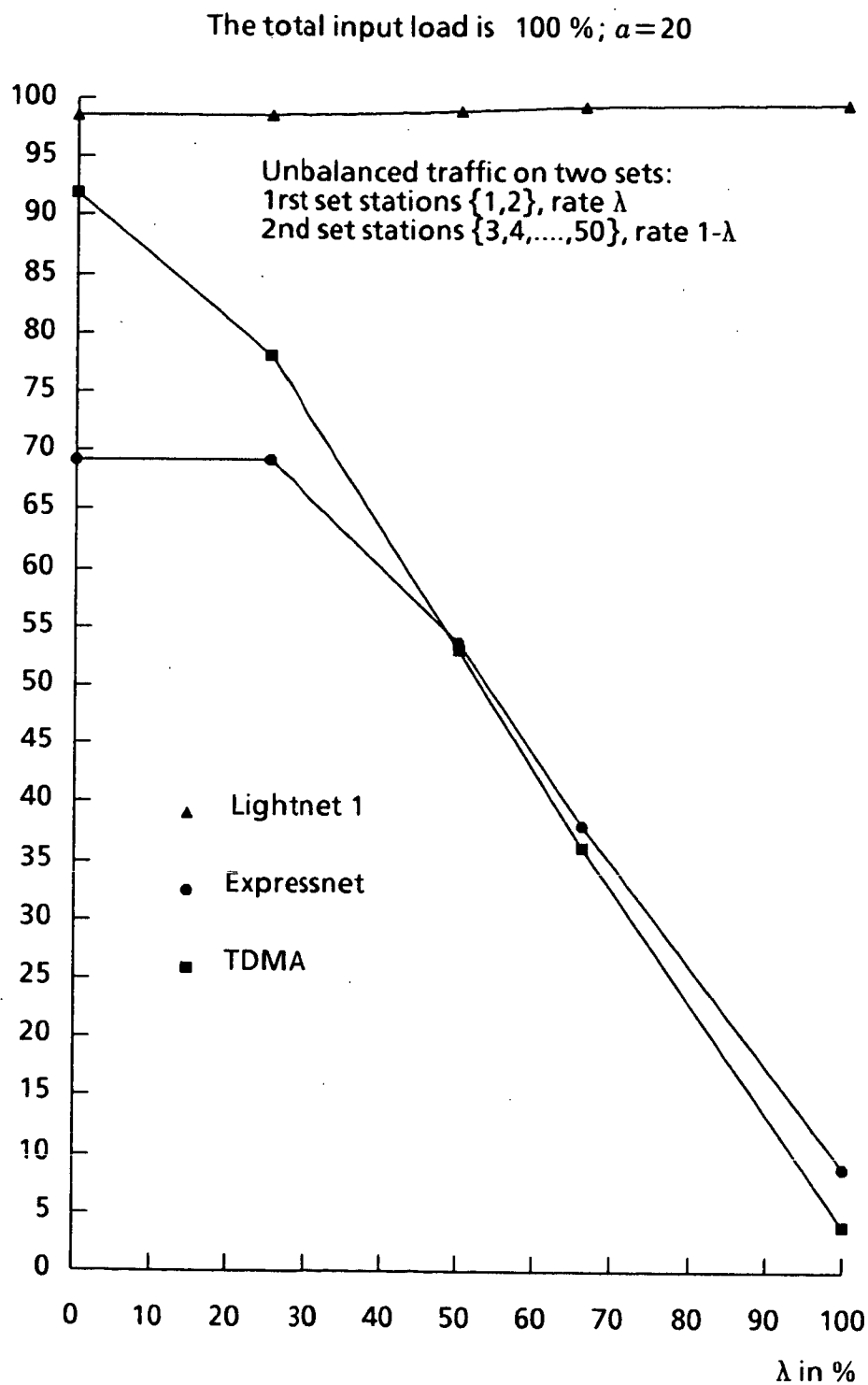
The total input load is 100 %; $a = 20$

Unbalanced traffic on two sets:
1rst set stations {1,2}, rate λ
2nd set stations {3,4,....,50}, rate 1-λ

▲ Lightnet 1

● Expressnet

■ TDMA

λ in %

Figure 10: Percentage of utilized bandwidth versus the input load on stations 1 and 2: λ.