Frequency allocation for high speed-communications

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ALLOCATION DE FREQUENCES POUR LES COMMUNICATIONS A HAUT DEBIT

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Abstract — We propose a high speed communication protocol, based on reservation scheme on broadcast channel. Reservation packets are sent on a fundamental high speed channel while datas obtain access to lower speed parallel channels. An analytical model is used to evaluate the performance.

Résumé — Nous proposons un protocole de communication à haut débit basé sur un processus à réservation par le truchement d'un canal à diffusion. Les paquets de réservation sont envoyés sur un canal principal à haut dèbit, tandis que les données sont transmises sur des canaux parallèles de moindre débit. Nous évaluons les performances du protocole à partir d'un modèle analytique.

1 Introduction

The specialization and the increasing power of computer systems are both calling for a new generation of high speed data communication. Recent developments of high speed chipment seems to allow now the realization of such networks. This short note introduces networks and protocols which allow high speed communication through allocation of frequencies.

One of the major problems of high speed communication (within 1 or 10 Gigabits per second) is the read of data. It is obviously possible to monitor high speed channels with new chipment, when protocols are sufficiently simple; but it is more difficult to pick out, read and store datas from a high speed stream. If you want to read (or write) a record with more than a million of bits, you need, nearby your highspeed protocol chipment, device able to pick out large sequence of bits from high speed stream, and to store them, in high speed memories. The high speed mass read and storage features, to our knowledge, will not be immediately available, and certainly not with an affordable price.

One solution to the problem of a million bits record: to cut it in ten thousand pieces of hundred bits each. But then forget about high speed or reliability. Another solution: to divide the channel into sufficiently slower parallel channels (in the range of 10 or 100 Megabits per second) that allow read and storage with usual device. This partition is technically possible by dividing the large available bandwidth into separate frequencies. But this solution is not good, because now you need to monitor ten or hundred separate channels in parallel and you multiply the cost of your system in the same proportion.

The solution we propose operates on a broadcast channel. Briefly, we suggest to use on the channel several different frequencies, as in the second solution. There will be a high speed frequency, called the *fundamental* frequency, that need high speed chipment but with simple implementation. The other frequencies will operate at lower speed and called *data* frequencies. These last frequencies will be equivalent to parallel slower channels that only need usual chipment to deal with. The station features are

1 a high speed chipment that monitors the fundamental frequency;
2 only one low speed chipment for the read and write on data frequencies;
3 a *frequency agile modem* that can jump from a data frequency to another one.

The main difference with the second solution lies in the fact that you do not need as many low speed chipments as data frequencies, but only one. This last remark shows that our solution needs the same hardware than FTDMA in [1]. But our solution basically differs from FTDMA and leads to more flexible high speed protocols.

Briefly, our solution can operate on various kinds of high speed topologies such that, star, tree network, unidirectional busses and satellite communications (long haul communications), see figure 1 for illustration . The note is divided into two main parts: the presentation of the protocol and an analytical — and simple — evaluation of the performance.

2 The protocol

The protocol is based on a reservation scheme and operates on topologies which allow broacast. On a fundamental frequency reservation packets are sent with a high data rate, so we are in high speed conditions: the propagation delay is large compared with the transmission of reservation packets. The reservation packet includes all information the receiver may need, say the length of the record and the data frequency on which it will be transmitted. The transmitter *a priori* selects its data frequency at random, for each record to transmit. See figure 2 for illustration.

When a station has a record to send, it behaves as following.

First, it sends a reservation packet on the fundamental frequency, according to the high speed protocol.

Second, it schedules the transmission of its record by inserting it in the *global queue* of the waiting records to be transmitted on the selected data frequency.

The global queue of each data frequency is filled according to reservations on the fundamental frequency; thus all stations can monitor the global queues. The simplest way to monitor a global queue is the FIFO (First In, First Out) strategy. We only need a real counter, called the scheduler, for each data frequency. This counter evolves as following. Suppose that, at time t, a reservation requesting this data frequency occurs, then every station updates the counter to the value t, if the current value was below, and then adds to it the length of the record which is just declared. The station, which has sent the reservation, stores the intermediate value of the counter, before adding to it the length of the record to be sent. This intermediate value is the date at which the station will initiate its transmission on the data frequency.

Thus there are as many schedulers to monitor as data frequencies; but there is only one frequency to monitor (say two when you are requested to read a data frequency). Transactions on the fundamental frequency are elementary, the reservation packets do not exceed one hundred bits of information. There are, say, within one hundred schedulers to monitor. Thus the fundamental frequency can be monitored by presently available high speed chipments. Some services, which need few bits per message (*e.g.* voice), can be restricted on the fundamental frequency without any allocation of data frequency

Stations need to be synchron on the data frequencies, but the relative low rate of the data frequencies reduces the problem of time accuracy. On the high speed frequency, you put your favorite high speed broadcast protocol. Our choice is the simplest of all: ALOHA with defered collision detection. Its principles are simple: you send your packet, you wait for the feedback, if it is a success, then you exit, if it is a collision then you wait for a random duration before a new attempt. Other alternative are possible such as Machnet, Minimac [2,3], Expressnet, Fastnet, Lightnet [4,5].

Remark 1 : As a matter of fact, a station cannot simultaneously receive from several data frequencies, since it has *a priori* only *one* frequency agile modem. In general, we consider negligeable the probability for a station to be simultaneously requested for several data frequencies. Of course, one or two stations in the network may need to centralize permanent information from the other stations, like *remote servers*, in such a quantity that it may be worthy to add extra frequency agile modems to their features. However, it remains possible (but very unlikely) that a station, with only one frequency agile modem, be simultaneously requested for several data frequencies. To insure the consistency of the communication process in this very particular case, we can lock the reservation scheme with *acknowledgement* packets on the fundamental frequency.

Remark 2 : Fault tolerance properties of the protocol relies on the monitoring of the global queues in each data frequency, since the reservation protocol on the fundamental frequency (ALOHA) is already very robust and fault tolerant. For brievety, we did not mention the plethora of *error recovery* procedures on data frequencies which can be implemented and mostly rely on a consistent use of the fundamental frequency. One particular case : suppose that the data frequencies have data rates which fit the ©Ethernet standards. In this case, we can replace the global queues scheme on each data frequency by the simpler features of Ethernet (or some other Local Area Network free access protocol) which allow collision and do not necessitate permanent monitoring, and we obtain an almost optimally fault tolerant high speed protocol.

3 THE ANALYTICAL MODEL

Our aim is to *analytically* determine the distribution of the delay of a random message. The delay is certainly the most important user-oriented parameter for evaluating the performance of a communication system.

The system is defined by the bandwidth (in bits per second), b_f, of the fundamental frequency. The bandwidth of a single data frequency is b_d, and there are N different data frequencies. The total bandwidth is then $b_f + Nb_d$. The input load is λ (in packet per second). The length (in bits) of the reservation packets is r and the distribution of the lengths $\mathbf{L}$, of the records to be transmitted on data frequency is given.

At first, we will assume that the protocol on the fundamental frequency is slotted ALOHA. Unslotted ALOHA is easier to implement, but entails lower throughput than the slotted one. However, we will give results for both protocols. A slot corresponds to the length of a reservation packet, thus its duration is r/b_f. We call ρ the duration of the slot. We assume that the random duration at station between the reception of a feedback of collision and a new attempt of transmission is a random variable called $\mathbf{T}$. In the literature, $\mathbf{T}$ is generally assumed to be geometrically distributed, however our paper deals with general distributions.

The last, but not the least, of the parameters that define the system is the propagation delay R which, only for convenience of presentation, is supposed to be the same for every station.

For the analytical model we need R, λ, ρ ($\rho = r/b_f$), and the distribution of $\mathbf{T}$ and $\mathbf{L}$. Significant parameters are $\lambda_f = \lambda\rho$, and $\lambda_d = \frac{\lambda}{N}$.

Any distribution of random variable (*e.g.* $\mathbf{T}$), will be given by their *Laplace-*

Stieljes transform, defined, for any complex number s, by

$$\mathrm{E}[e^{-s\mathbf{T}}] = \int_0^\infty \Pr\{\mathbf{T} \in [x, x+\mathrm{d}x[\} e^{-sx} \ .$$

For convenience of notation, we note

$$T^\star(s) = \mathrm{E}[e^{-s\mathbf{T}}] \ ,$$
$$B^\star(s) = \mathrm{E}[e^{-s\mathbf{L}/b_d}] \ .$$

Similarily we denote by τ the mean value of $\mathbf{T}$ and β , the mean value of $\mathbf{L}/b_d$. These last quantities are homogeneous to time durations and supposed large in comparison with the slot duration ρ.

We denote by $\mathbf{W}$ the delay experienced by a random record. Our aim is to derive its Laplace-Stieljes transform $\mathrm{E}[e^{-s\mathbf{W}}]$. The delay has two components:

$$\mathbf{W} = \mathbf{F} + \mathbf{D} \ ,$$

where $\mathbf{F}$ denotes the delay experienced by the reservation packet, and $\mathbf{D}$, the delay spent in global queue. The main approximation of our paper is to suppose that the reservation delay and waiting time in global queues are mutually independent. This assumption relies on the fact that the number, N, of data frequencies is supposed large (large means more than 10), and we can approximate the interdeparture of reservations from the fundamental frequency to a given data frequency like a Poisson arrival process. Thus

$$\mathrm{E}[e^{-s\mathbf{W}}] = \mathrm{E}[e^{-s\mathbf{F}}]\mathrm{E}[e^{-s\mathbf{D}}] \ .$$

THEOREM 1 (adapted from [6]): *With slotted* ALOHA, *the reservation protocol is stable if* $\lambda_f < e^{-1} \approx 0.367$. *In this case we have*

$$\mathrm{E}[e^{-s\mathbf{F}}] = \frac{1-e^{-\rho s}}{\rho s} \frac{\lambda_f e^{-(R+\rho)s}}{\gamma - (\gamma - \lambda_f)T^\star(s)e^{-(R+\rho)s}} \ ,$$

with

$$\gamma e^{-\gamma} = \lambda_f \ ,$$

and $\gamma \leq 1$. *In particular*

$$\mathrm{E}[\mathbf{F}] = \frac{\rho}{2} + \Big(\frac{\gamma}{\lambda_f} - 1\Big)(R + \rho + \tau) + R + \rho \ .$$

With unslotted ALOHA, *the reservation protocol is stable if* $\lambda_f < \frac{e^{-1}}{2} \approx 0.183$. *In this case we have*

$$\mathrm{E}[e^{-s\mathbf{F}}] = \frac{\lambda_f e^{-(R+\rho)s}}{\gamma - (\gamma - \lambda_f)T^\star(s)e^{-(R+\rho)s}} \ ,$$

with

$$\gamma e^{-2\gamma} = \lambda_f \ ,$$

and $\gamma \leq 0.5$. *In particular*

$$\mathrm{E}[\mathbf{F}] = \Big(\frac{\gamma}{\lambda_f} - 1\Big)(R + \rho + \tau) + R + \rho \ .$$

Proof. The quantity τ is much larger than ρ, thus we are in the hypotheses of [6], the distribution of the number of transmission attempts, on each slot, can be modeled as an i.i.d. Poisson distribution of rate γ. This approximation is called the *Poisson retransmission* approximation.

The probability of successful transmission on a random slot is $\gamma e^{-\gamma}$. Thus we have the equilibrium identity

$$\gamma e^{-\gamma} = \lambda_f \ . \tag{1}$$

Thus the maximum available λ_f is e^{-1}. If $\lambda_f < e^{-1}$ then γ is the first root of (1). The probability for a random transmission attempt to be successful is $e^{-\gamma}$, say $\frac{\lambda_f}{\gamma}$. Thus the number of collisions that a reservation packet may experience follows a geometric distribution of rate $\frac{\lambda_f}{\gamma}$. If we assume that the feedback of an attempt of transmission is available $R + \rho$ time units after the beginning of the transmission, whatever be the result of the feedback (collision or success), we can convert this last proposition in the Laplace transform:

$$\mathrm{E}[e^{-s\mathbf{F}}] = \frac{\lambda_f e^{-(R+\rho)s}}{\gamma - (\gamma - \lambda_f)T^{\star}(s)e^{-(R+\rho)s}} \ .$$

For the clearness of the proof, we have intentionaly omitted, in this last expression, the fraction of slot a packet has to wait before the first transmission, in the slotted protocol. If we take into account this quantity, we have minor correcting terms:

$$\mathrm{E}[e^{-s\mathbf{F}}] = \Big(\frac{1 - e^{-\rho s}}{\rho s}\Big)\frac{\lambda_f e^{-(R+\rho)s}}{\gamma - (\gamma - \lambda_f)T^{\star}(s)e^{-(R+\rho)s}} \ . \tag{2}$$

and, in particular, we get

$$\mathrm{E}[\mathbf{F}] = -\frac{\mathrm{d}\mathrm{E}[e^{-s\mathbf{F}}]}{\mathrm{d}s}(s = 0) \ .$$

For unslotted ALOHA the line of reasonning is similar, and the probability of a successful transmission is now $e^{-2\gamma}$. That leads to the new identity

$$\gamma e^{-2\gamma} = \lambda_f \ .$$

Thus, it is obvious that $\lambda_f < \frac{e^{-1}}{2}$. The probability that a random transmission be successful remains $\frac{\lambda_f}{\gamma}$, thus the expression of $\mathrm{E}[e^{-s\mathbf{F}}]$ holds (but without taking in account any fraction of slot for the first transmission, of course). ∎

Remark: The reader may notice that E[F] does not diverge when $\lambda_f \to e^{-1}$ (and thus when $\gamma \to 1$). This is not really surprising, since the Poisson retransmission approximation is less accurate when λ_f is close to the critical rate, e^{-1}. But it has been shown, by the large deviations [7], that, for any given $\lambda_f < e^{-1}$, the Poisson retransmission approximation tends to be exact when the mean retransmission delay, τ, tends to infinity. Thus the assertion that $\mathrm{E}[\mathbf{F}] \to \infty$ when $\tau \to \infty$ holds.

THEOREM 2: *The Laplace-Stieljes transform of* $\mathbf{D}$ *is*

$$\mathrm{E}[e^{-s\mathbf{D}}] = \frac{(1-\beta\lambda_d)sB^\star(s)e^{-Rs}}{s-(1-B^\star(s))\lambda_d} .$$

Proof: Global queues for datas are equivalent to independent FIFO queueing systems with service time $\mathbf{L}/b_d$ and Poisson input rate λ_d. The mean length of record, β, on data frequency is large in comparison to the discrete unit time, ρ, on the fundamental frequency; thus the input process from the reservation frequency can be modeled as a continuous Poisson input. The queueing system is then a classical one; there is an explicit expression of the delay [8] (which involves the propagation delay R). ∎

The mean delay E[D] is given by $-\frac{\mathrm{dE}[e^{-s\mathbf{D}}]}{\mathrm{d}s}(s=0)$.

4 Comments and future works

We can optimally tune the protocol so that reservation and data protocols both destabilize at the same input rate. This leads to $e\lambda_f = \lambda_d\beta$, or $\frac{e\rho}{b_f} = \frac{\beta}{N\,b_d}$.

For the numerical applications, we took:

(i) $b_f = 1$ Gbits per second and $b_d = 100$ Mbits per second, $N = 37$, thus the offered bandwidth is 4.7 Gbits per second;

(ii) $r = 100$ bits, the traffic is 99% voice (without data frequency request, or $\mathbf{L} = 0$ bit) and 1% data with $\mathbf{L} = 100{,}000$ bits, thus $\beta = 1000$ bits;

(iii) the mean retransmission delay $\tau = 10\,\mu$s, the propagation delay $R = 1$ ms, or the radius of the network is within 150 km.

The conditions of the numerical application are intentionally extremal. Figure 3 gives the mean delay (y in propagation delay unit) *versus* the input load (x in 10,000,000 messages per second).

Such schemes could reveal particularily efficient for integrated services networks For example, the reservation packets can include additional information such that service types, priorities. Static or dynamic priorities can be modelled in queueing system like in [9]. These priorities can be valuable tools for integrating services in real time conditions.

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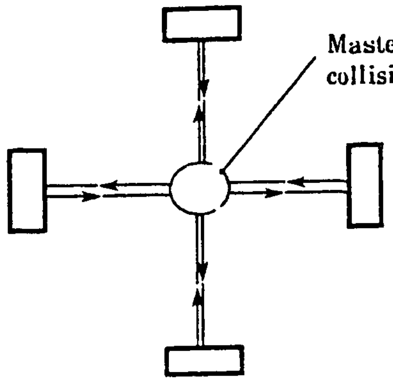
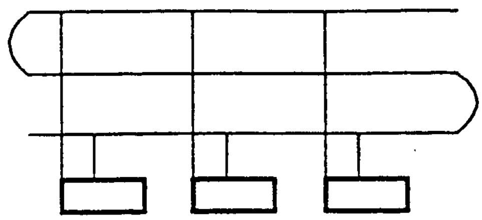


Star topology with branch of the same length.



Topology in S with outbound and inbound channel.

FIG 1 Various kind of topologies for high speed networks.

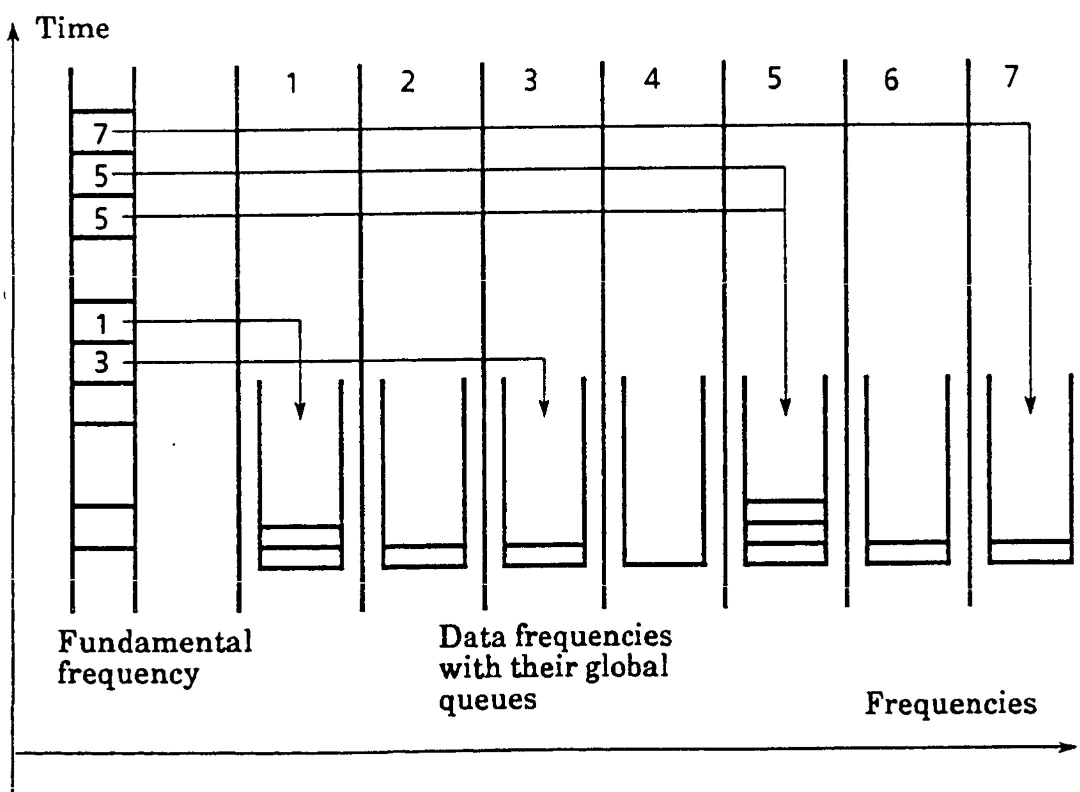


FIG 2 Reservation scheme for frequency allocation.

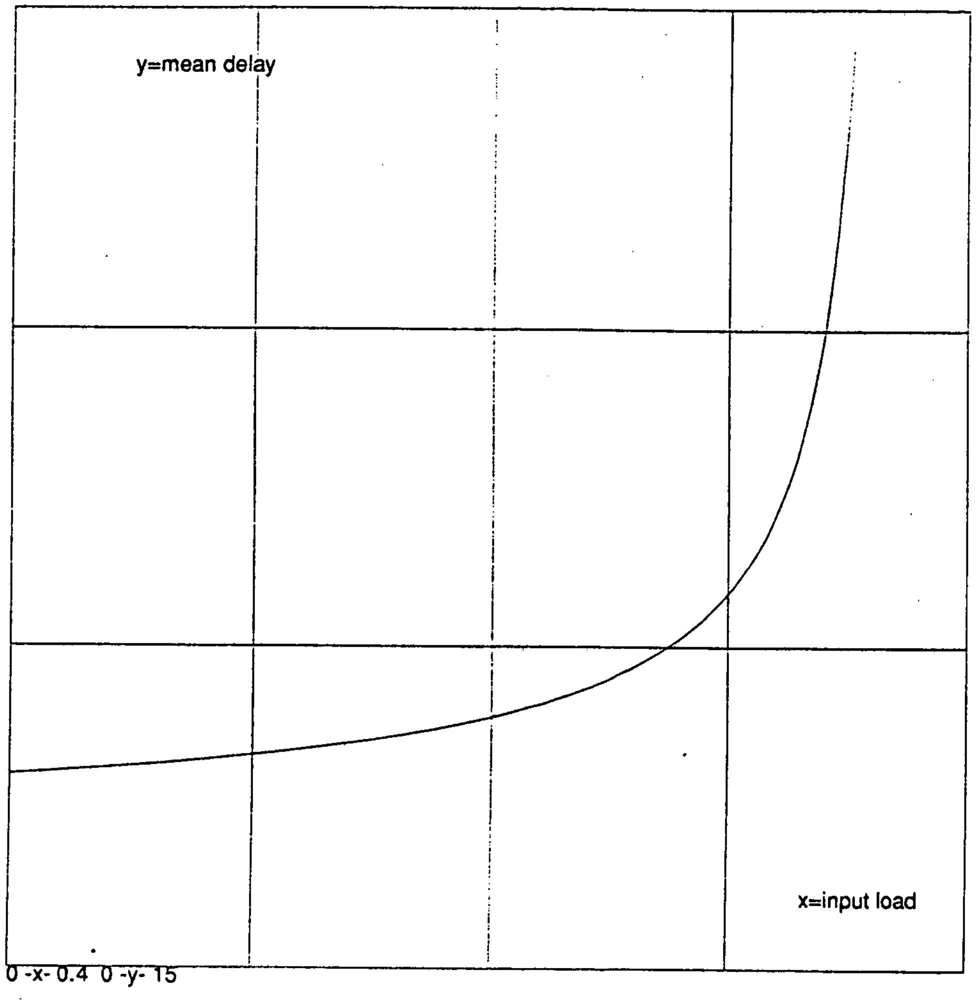


FIG 3 **Mean delay (in propagation delay unit) versus input load in 10^7 messages per second.**