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THROUGHPUT EVALUATION IN ALOHA TECHNIQUE AND ITS DERIVATIVES ERASURE CODING IN SATELLITE NETWORK COMMUNICATIONS

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Abstract

The present work concentrates on the Aloha technique and its derivatives where we examine the throughput of the pure Aloha, Slotted Aloha and the Multi-copy Aloha respectively to show the most performing among them in terms of throughput. Then we integrate the Erasure Coding in each of these techniques to ameliorate their reliability and the transmission level. The results obtained are identical to those presented in literature.

I. Introduction :

Contention-based medium access control (MAC) protocol is a key component for the success of wireless data networks. Conventional random access protocols like ALOHA and Carrier Sense Multiple Access (CSMA) suffer from packet collision which leads to low throughput. Aimed at improving the throughput performance integrate erasure coding with contention-based MAC protocols for recovering collided packets has been discussed by [1]. The frame ALOHA scheme in the multiple-access broadcasting channel with the capture effect was demonstrated by [2]. We must add at our analysis, the work of [3] which the so called embedded Channel access (ES –Aloha) has done.

In this paper, we particularly examine the random access protocols with collision resolution namely Aloha and its derivatives. When two users transmit their packets in the same time, only one packet is liable to pass and the packets sent simultaneously get mutually destroyed causing what we name a collision. The random access protocols present in general better delays than techniques of fixed access (we can reach up a maximum throughput of 1unit, i.e., a continuous transmission) because of an efficient resolution of collision [4]. In the case when a big number of sources are often inactive, the random access allows a more efficient use of the

channel. Besides, the system is put in use with much simplicity thanks to the decentralization of random access protocols. In random access techniques many sources can attempt to transmit packets in the same time which can provoke collisions and a delayed transmission. In satellite networks we can use random access techniques either directly for information transmission, or for reservation, i.e. requesting the allocation of a fixed frequency band [5].

II. The random access Aloha technique and its derivatives :

a. The Aloha technique :

In the Aloha system, the delay is a consequence of collision and the transmission is completely decentralized. At the end of transmission of each packet of each source, the source receives the information if the packet has been received or if there has been a collision, in which case there will be a delayed retransmission [6]. The probability that n packets arrive in two different times is given in [7]:

$$P(n) = \frac{2 \cdot \lambda \cdot e^{-2\lambda}}{n!} \quad (1)$$

Where λ is the traffic load.

The probability $P(0)$ that the packet be successfully received without collision is:

$$P(0) = e^{-2\lambda} \quad (2)$$

So the throughput is given as follows:

$$S = \lambda \cdot P(0) = \lambda \cdot e^{-2\lambda} \quad (3)$$

b. Slotted Aloha:

In the Slotted Aloha technique, time is discretized in time parts called slots, which refer to the maximum propagation time, where each station sends a packet at the beginning of the slot, and thus all the stations will be synchronized. This latter ameliorate the situation in comparison with the non-slotted Aloha technique because two superposed frames can only be possible on a maximum slot instead of two slots (as they start at the beginning of the same slot). By this technique throughput can reach the maximum value: 0.36 (bad use of the channel). We consider n as the number of users, P_i as the probability that a given user send a packet, and S_i as the probability that a packet be successfully received. If there is no other user in a state of transmission at the beginning of the time slot, the probability function S_i will be according to [6]:

$$S_i = \frac{P_i}{(1 - P_i)} \prod_{i=1}^n (1 - P_i) \quad (4)$$

When a throughput is S and the traffic is λ we can write:

$$S_i = \frac{S}{n} \quad \text{et} \quad P_i = \frac{\lambda}{n} \quad (5)$$

$$\frac{S}{n} = \frac{\lambda}{n} \cdot \left[\frac{1}{\left(1 - \frac{\lambda}{n}\right)} \right] \cdot \prod_{i=1}^n \left(1 - \frac{\lambda}{n}\right) \quad (6)$$

$$S = \lambda \cdot e^{-\lambda} \quad (7)$$

c. The throughput in Aloha and S.Aloha:

The throughput in Aloha technique (non-Slotted) present a weak immunity in front of collision, and a low level of transmission efficiency ($S_{\max} \approx 0.185$) and also an unstable communication regime. However, the slotted Aloha leads to higher throughput ($S_{\max} \approx 0.37$), better synchronization and bigger capacity in avoiding collisions.

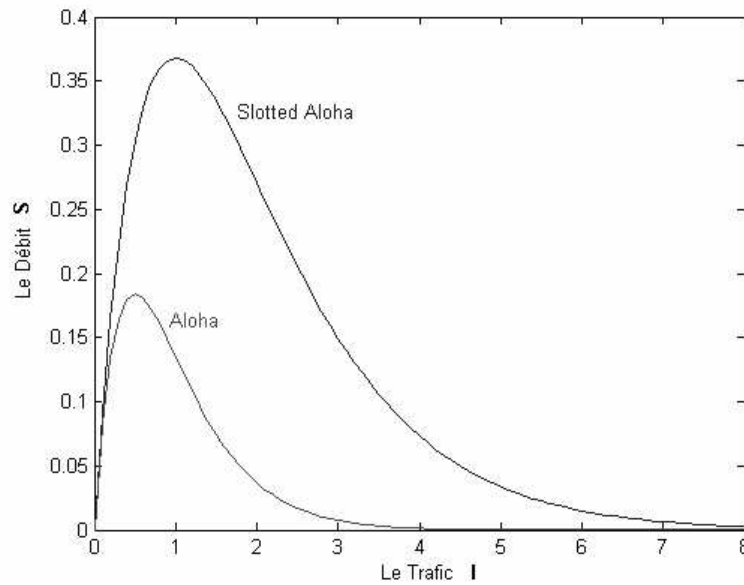


Figure 1: Throughput in Aloha and S.Aloha.

d. The Multi-copy Aloha:

When we send m copies of a packet with Slotted Aloha technique (Multi-copy), the success probability of the transmission of this packet or the probability that a packet, out of the m sent copies will not collide; will be more important in comparison with the case where only one copy is sent (S.Aloha). This can be true only when the other packets are sent in one copy or when the channel traffic remains stable and free from perturbation. To maximize the probability of

transmission success, we assume that all users send the same numbers of copies (m) [7]. The Multi-copy Aloha is generally conceived for the following systems:

- Satellite systems which offer a better probability of transmission success,
- Multi-channel Aloha systems,
- Aloha reservation systems with a higher probability of success.

We consider that the packet arrival is a Poisson process. For the simple Slotted Aloha, we assume that the average delay of transmission is higher than 5 slots, whereas the average value of the delay for the m copies including the first transmission must be as high as 5 slots.

For the traffic, we have according to [7]:

$$\lambda = \lambda_1 + \lambda_2 + \dots + \lambda_n = \sum_{i=1}^n \lambda_i \quad (8)$$

The average number of (N) copies per packet equals:

$$N = \lambda^{-1} \cdot \sum_{i=1}^n i \cdot \lambda_i \quad (9)$$

The probability P_i for the packet i to be successfully received is:

$$P_i = 1 - \text{prob}[\text{all the copies are in collision}] = 1 - (1 - e^{-N \cdot \lambda})^i$$

$$\text{The throughput } S_i = \lambda_i \cdot P_i \quad (10)$$

For k copies, we will have:

$$S_k = \lambda \cdot P_k = \lambda \left[1 - (1 - e^{-k \cdot \lambda})^k \right] \quad (11)$$

$$\text{for } k=1, 2, 3, \dots \text{ And } k = \frac{\ln 2}{\lambda} \quad (12)$$

So the throughput:

$$S < \frac{\ln 2}{k} \cdot \left[1 - \left(\frac{1}{2} \right)^k \right] = S_k \quad (13)$$

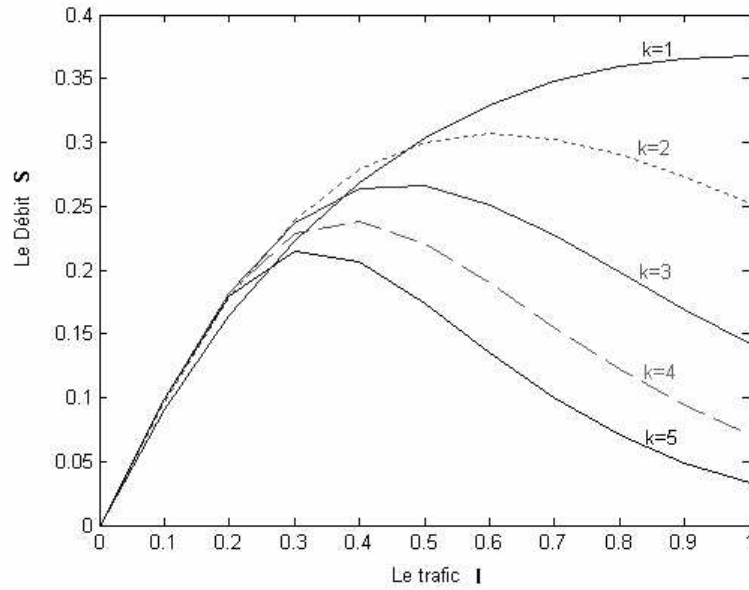


Figure 2: Throughput in Multi-copy Aloha.

In figure.3, the variation of success probability P in a relation to the traffic λ with $1 \leq k \leq 5$. We see that to maximize the success probability of transmission, only one copy should be sent when the channel traffic is superior than 0.48, when $\lambda \in [0.28, 0.48]$ we can transmit only 2 copies etc. The figure shows that when λ is small, the probability P can reach the maximum value ($p=1$) by using the superior k .

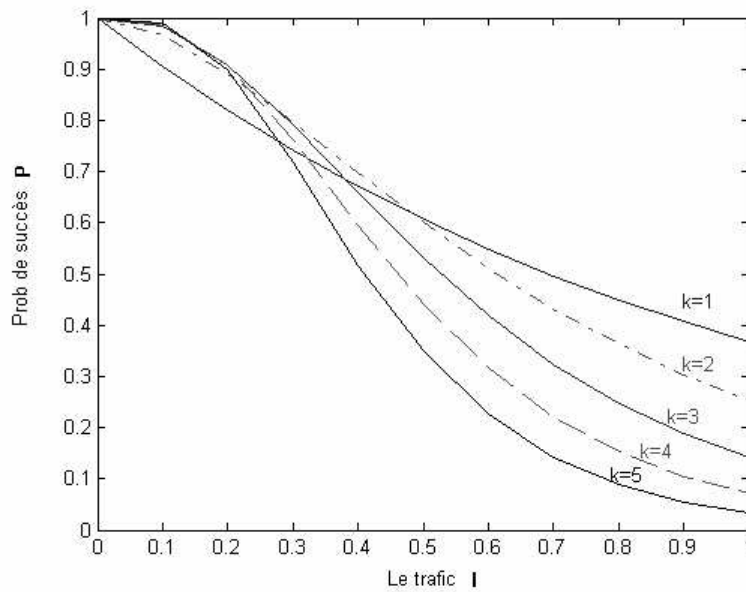


Figure 3: Success probability in Multi-copy Aloha.

III. The Erasure coding :

The communication with the space sources at other extreme of the solar system presents a problem of the reliability of the transmitted message. A transmission through such a distance is

necessarily subject to parasites (normally due to various sources of electromagnetic perturbations). However in such a domain and in many other domains, it is essential that the information collected by the stations be received. We add to the message to be sent additional information which allows the message to be reconstructed at the receptor [8]. The error corrector codes constitute a device which aims at ameliorating the transmission reliability on a noisy channel, the method they use consists of sending on the channel more data, exceeding the amount of information to be sent. A redundancy is thus introduced. If this redundancy is structured in an exploitable manner, it is then possible to correct possible errors introduced by the channel. We can thus despite the noise, find the whole information sent at the beginning [9].

The purpose of Erasure coding is to recover the lost packets if their position is known in (N, K) erasure codes. An (N, K) code words consist of N code packets, when there is a K original packets and (N-K) as redundant packets. The k original packets can be recovered with success if we receive K packets out of N coded packets (Figure 4). The (N-K) redundant packets are generated following certain functions. It is well known that the Reed Solomon code is a good candidate for Erasure coding [10]. We give an example of a generation of two redundant packets.

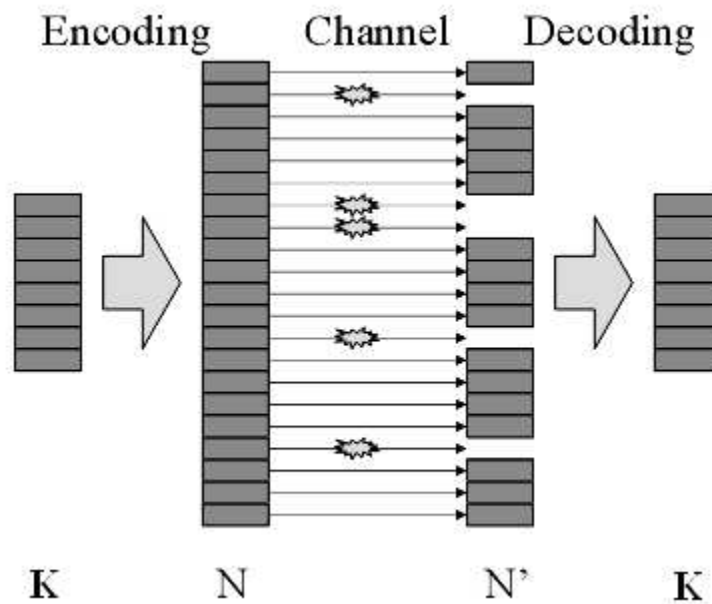


Figure 4: Mechanism of Erasure Coding.

➤ We assume that we have k original packets of m bits each, the first redundant packet is generated via the following equation (14) [11]:

$$C_{k+1,i} = \left(\sum_{j=1}^k C_{j,i} \right) \text{mod} 2 \quad (14)$$

Where $C_{i,j}$ is the $i^{\text{ème}}$ bit of $j^{\text{ème}}$ packet.

The second redundant packet can be generated according to the following equation (15):

$$C_{k+2,i} = \begin{cases} \left(\sum_{j=1}^i C_{j,i+1-j} \right) \bmod 2, \dots \dots \dots 1 \leq i \leq k+1 \\ \left(\sum_{j=1}^{k+1} C_{j,i+1-j} \right) \bmod 2, \dots \dots \dots k+2 \leq i \leq m \\ \left(\sum_{j=1}^{k+m-i+1} C_{i-m+j,m+1-j} \right) \bmod 2, \dots \dots \dots m+1 \leq i \leq m+k \end{cases} \quad (15)$$

- We have to note here that the size of the second redundant packet is $m+k$, however the size between packets may be ignored when $m \gg k$. In this work, we assume that all packets have the same size to simplify the calculus. This had been verified in [11].

a. S.Aloha with Erasure coding:

a.1 Scheme description:

The slotted Aloha technique is very popular in satellite and mobile communication networks. It had been demonstrated in [12] that the use of Multi-copy Aloha technique can ameliorate the performance of the Slotted Aloha system throughput by sending multiple copies of packet when the system traffic is inferior to 0.48. We can treat Multiple-copy Aloha as a diagram $(m, 1)$ Erasure codes, where each packet is coded in one word of m copies of packets. The original packet is successfully received, if one of this m copies is correctly received where this diagram is going to increase m times the throughput of the system. We propose to adopt more of (N, K) coding diagram, for example the Reed-Solomon codes, to ameliorate the performance of Slotted Aloha. On arrival of the k packets, there are (N, K) words of Erasure coding. And when there are k packets of N received packets, we have k original packets which can be recovered. This allows a tolerance of $(N-K)$ of lost or noisy packets. The system throughput increases N/K times which make the system more controlling than Multi-copy Aloha.

a.2 Functional procedure :

The application of our proposed diagram functions as follows [1]:

1. We code the k packets in an (N, K) words of Erasures code, where we assign an identifier for each packet that the receptor will use for packets identification.

2. The N coded packets are randomly and independently transmitted in the next m time-slots (m generally greater than N) for each original sent packet, the temporizer is activated (if the information of this packet is not received before the temporizer is expired, this packet will be retransmitted).
3. At the receptor only correctly received packets (including those successfully received with Erasure coding) are recognized and will be retransmitted according to Slotted Aloha system diagram.

b. Analytical Model :

Now we construct the analytical model to study the performance of the Slotted Aloha throughput with Erasure coding, we assume that:

- Traffic and retransmitted data constitute a Poisson process of an average λ packets per time-slot (P/T_s).
- The conduct of data linking can reach the equilibrium state.
- The diagram of (N, K) Erasure codes is used, i.e. for a group of k original packets, we added $(N-K)$ redundant packets.

After the coding procedure, the resulting traffic has the throughput of $N\lambda/K$ as in the conventional Slotted Aloha. The probability P that a coded packet be received successfully without collision is:

$$P = e^{-N\lambda/K} \quad (16)$$

The probability P_K that K coded packets be successfully received is:

$$P_K = \sum_{i=K}^N \binom{N}{i} P^i (1-P)^{N-i} \quad (17)$$

We put $P_{n,m}$ the probability that an n ($n < k$) coded packets are received, and m out of n received packets are original packets, we obtain:

$$P_{n,m} = \binom{k}{m} \binom{N-k}{n-m} P^n (1-P)^{N-n} \quad (18)$$

* We can see that an original packet can be successfully received in the two conditions:

- ✓ At least k out of N Erasure coded packets are successfully received
- ✓ We receive only n out of N coded packets, where $n > k$ and m out of n received packets are original packets, and the original packet under consideration is one of the m packets (with the probability m/k).

Thus the probability P_S that an original packet is successfully received (or retrieved) is equal to:

$$P_s = P_k + \sum_{n=1}^{k-1} \sum_{m=1}^n \frac{m}{k} P_{n,m} \quad (19)$$

The throughput S of the system is thus given through the equation:

$$S = \lambda P_s \quad (20)$$

* When $K = 1$, the system becomes a Multi-copy Aloha and the throughput becomes $S_{multi} = \lambda P_1$ when $P_1 = P_{k(k=1)}$. When $N = K = 1$, the system becomes similar to the Slotted Aloha, and the throughput will be equal to $S = \lambda P_s = \lambda e^{-\lambda}$.

We see clearly that the traffic load λ increases, and the coding rate increases as well. This means that the part of superfluous traffic is reduced to avoid worsening the collision probability. It is also easy to verify that when given the same rates (N/k), the throughput increases when N increases (and k increases thereafter), due to the packets received mechanism with Erasure coding. However the throughput amelioration is neglected after N becomes high enough.

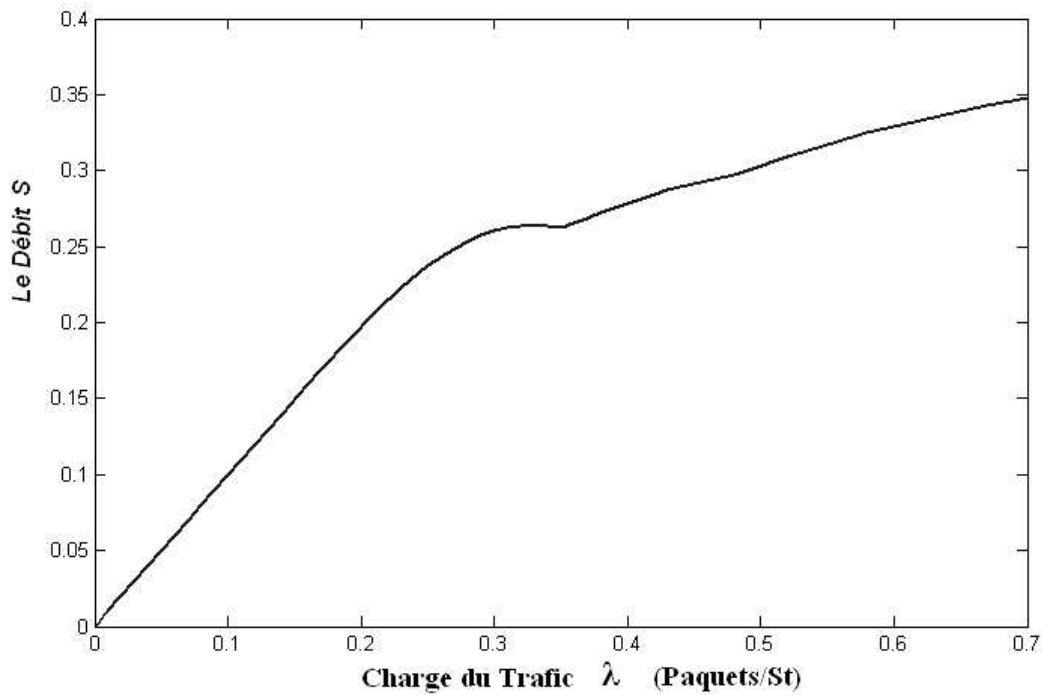


Figure 5: Throughput in S.Aloha with Erasure Coding.

The Figure IV.5 Figure 5 shows the performance of the obtained system then it is compared to that of S.Aloha and Multi-copy Aloha (Figure 6).

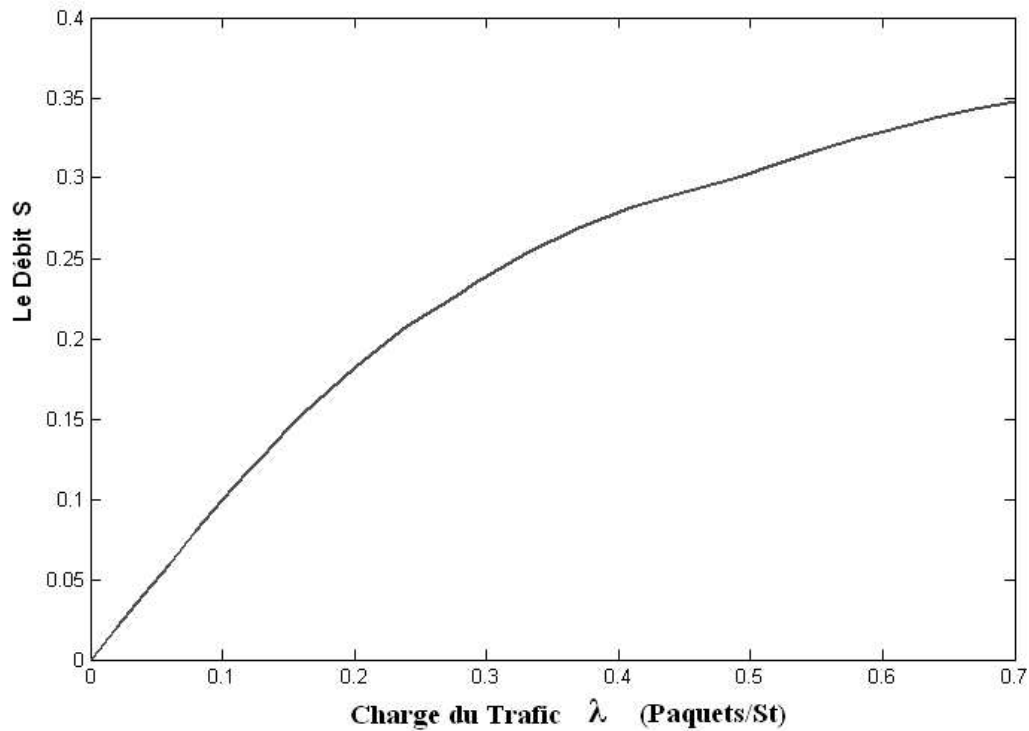


Figure 6: Throughput in Multi-Copy Aloha with Erasure Coding.

It is clear that when the traffic load is between 0.1 and 0.35, our diagram seems that of Multi-copy Aloha. When the traffic charge is very low the 3 diagrams are similar as the collision probability is also very weak [13].

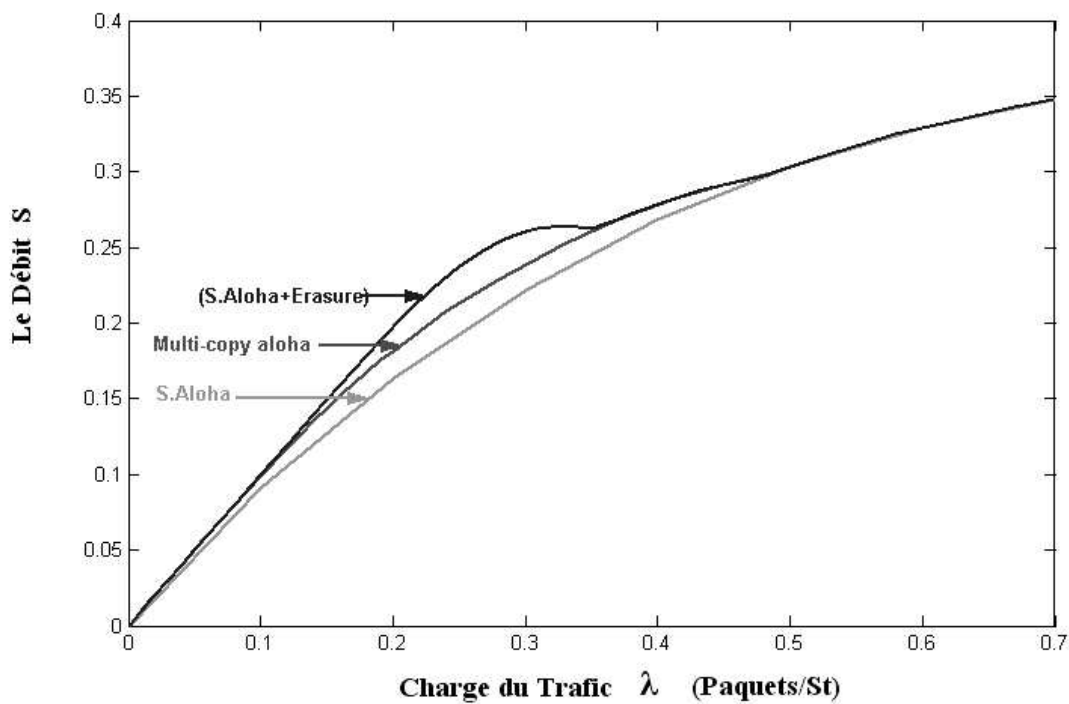


Figure 7: The effect of Erasure Coding on Aloha's protocols.

III. Conclusion:

In this article we propose the use of Erasure coding with the random access Aloha technique and its derivatives to show the performance of such random access protocols. We notice that when the Erasure coding is implemented, it would be easy to recover the k original packet, when k out of N coded packets is received. On the other hand, we see that the use of Erasure coding is beneficial only when the traffic throughput is increased at the communication medium. When the throughput is low enough, the collision probability is low as well and this implies that Erasure coding is not necessary for recovering the collided packets. However when the throughput is high, then the collision is already serious and thus the use of all techniques of error control become necessary to ameliorate the situation. The results we obtained are identical to those found in [1] as far as Erasure coding application on Aloha technique is concerned.

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