Martinet: A Disciplinarian Protocol for Resource Access in DTN

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***Abstract*—This paper analyses the congestion on a LEO satellite architecture with intermittent connectivity. The satellites are used to sense and gather data from ground terminals. The DTN (Delay Tolerant Networking) architecture allows the terminals to wait for the next contact when the satellite is not in the line of sight. The lack of connectivity of the network may create starvations for some stations. A model of the network is provided using Queueing Theory which allows to determine a probability of loss. This derivation proves that loss depends more on the number of terminals than on packet lifetime. The proposed scheduler and protocol allow to distribute traffic and loss fairly among stations. A testbed has been designed to validate the protocol.**

***Index Terms*—Scheduling, DTN, Modeling and performance evaluation**

I. Introduction

The Centre National d'Études Spatiales (CNES) aims at developing off-the-shelf technical solutions. This strategy reduces the cost of each Space mission. Unmanned Aerial Vehicles (UAVs) or Wireless Sensor Networks (WSNs) can sense data to corroborate observations of the satellites. In disasters situations, public telecommunications facilities might be severely damaged. Hence, collection of *in-situ* data by observation satellites is an option to easily merge ground and remote data and provide it quickly to users. We model the evolution of the network with queues and we propose mechanisms to guarantee fairness to satellite terminals.

II. Motivations

In the context of LEO satellites, terminals have to handle long periods of satellite unavailability. That is why the proposed architecture relies on the Bundle Protocol [1]. The system is composed of a set of terrestrial terminals collecting data from a sensing field and of LEO satellites collectors [2].

Obviously, one of the main issues of this scenario is the period of unavailability of the satellite. This problem is represented in queueing theory by a gate [3]. Customers arrive in front of a gate which opens and closes periodically or not. Hebuterne derived in [3] results on a queue with a gate separating from the server. The condition of stability of the system is given by the following condition: the mean arrival rate multiplied by the mean time between two openings has to be smaller than the maximum size admitted at each opening.

Furthermore, with a monitoring scenario, customers arrive by batch and periodically. Since the customers have to pass through a gate after the queue to reach the server, departures are bulky too. Most papers dealing with vacations and bulks link the vacation to the occupancy of the queue [4]–[6].

The other main issue of the scenario we consider is the impatience of the customers. Movaghar focused on customer impatience until the end of service [7] when a customer might be discarded while he is being served.

III. Analytical Study

We model the system as a queueing network. We consider only one satellite to simplify the model. We will prove later that this assumption is not responsible for a lack of generality.

We will study here the system in a crisis situation. All terminals have only critical data to send. Each Bundle possesses the same initial lifetime. Hence, the impatience of the Bundles is constant. Each station receives the same amount of traffic between two satellite rounds. We consider the amount of traffic received by each station is smaller than satellite capacity. However the sum of these data is greater than this same satellite capacity. The stability condition of [3] is respected by each station, but not by the whole network.

With such a system, it is obvious that Bundles will be dropped. We have more incoming Bundles than served ones and so the system is unstable. However, even with these assumptions, it is possible to guarantee service to stations which could not access the satellite.

Our proposition relies on sending the same amount of traffic for each source in a satellite pass. By doing so, we can guarantee that a portion of each traffic is served during a satellite round. In order to minimise loss because of the traffic ageing, the Bundles which are parked first are the ones with greatest deadlines. In Storage Routing [8], such a policy would be named PushFreshestNetworkAge, since freshest Bundles are stored on other nodes. This proposition decreases Bundles deadline expiry. Let's define the following parameters:

- m the number of ground terminals,
- N the capacity of the satellite queue,
- C the capacity of a ground station.
- λ the critical data arrival rate,
- $\frac{1}{\mu}$ service time for a Bundle to reach control centre,
- T the period between two satellite rounds,

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- t duration of contact with satellite for each terminal,
- d the data rate between ground stations and the satellite
- θ the impatience of each Bundle (remaining lifetime),

We assume $m < N$. We assume $\theta > T + 1/\mu$, then on average $max(0, m \cdot \lambda \cdot T - N)$ Bundles remain in the queues at each satellite round. These results are independent from the distribution of traffic sources, from the served stations and the arrival time of Bundles.

We assume $m \cdot \lambda \cdot T > N$, hence $\exists\, i_{ful}$ / $i_{ful} \cdot \lambda \cdot T = N$. arrivals are realised by batch and just before the satellite is in the line of sight of the station. For each incoming Bundle, its ability to reach the destination before its lifetime expires, depends on n, the number of Bundles in the queues when a new Bundle arrives. We note V_n the sojourn time of an incoming Bundle finding n Bundles in the system: $V_n = n \cdot \frac{\lambda \cdot T}{N} \cdot T$. If $V_n > \theta$, the Bundle has no chance to reach the destination.

The number i_{ful} is the index of the satellite terminal which fills the satellite. It means that when the satellite collects data from the i^{th}_{ful} station, its queue has reached its capacity. It is from this station that the proposed mechanism begins.

Before the station i_{ful}, each terminal on the ground sends its data for the duration t of the contact with the satellite. Once the satellite goes further, the Martinet Protocol allows other stations to access the satellite. The parked part noted D_i depends on the value of i. The amount of each traffic within the satellite is : $\forall j < i,\ P_{i,j} = min(\lambda \cdot T, \frac{t}{d})$. Then the amount of parked Bundles is, per traffic : $D_{i,j} = \frac{P_{i,j}}{i}$. The total parked traffic is : $D_i = (i-1) \cdot D_{i,j}$. Hence the satellite has room for :

$$R_{i,i} = \frac{D_i}{i} = \frac{(i-1) \cdot min(\lambda \cdot T, \frac{t}{d})}{i^2}$$

The station i has received D_i Bundles from the satellite and sent $R_{i,i}$ Bundles. Nevertheless, since the arrival rate and the contact duration is the same for each ground terminal, we have $R_{i,i} < P_{i,i}$. Hence, for stations after i_{ful}, $D_i + (P_{i,i} - D_i)$ Bundles remain on the ground. D_i Bundles come from the $(i-1)$ previous terminals and the remainder is the part of Bundles pertaining to i which could not be sent.

This mechanism is based on the deadline timestamp of the Bundles. Bundles with largest deadline are parked first. The assumption concerning an identical arrival rate on each station does not limit the results of the proposition. If each station has λ_i as arrival rate, the parking rule is adapted to maintain fairness. We provide a fair access to the satellite to each source.

In order to maintain fairness among traffic sources, we propose to weight the accessed portion to the satellite by the volume of data of each traffic, which is equivalent to weight by the arrival rates. When the satellite is full and a node wants to transmit data to the satellite, the remaining portion of each traffic j is calculated such as : $\sum_{j=1}^{i} P_{i,j} \times f_i = 1$ where $P_{i,j}$ is the volume of traffic j when the node i wants to send data to the satellite. Hence the remaining volume of each traffic is $R_{i,j} = f_i \times P_{i,j}$ and the terminal i keeps a data volume equal to the data volume it wanted to send, corresponding to the sum of parked data of each traffic.

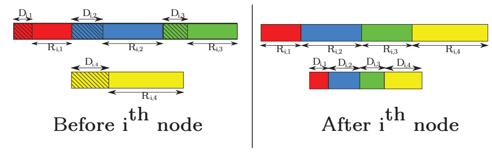

Figure 1. Traffic distribution within satellite when passing above i^{th} node

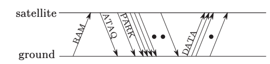

Figure 2. Satellite Round with Parking

Figure 1 presents the evolution of traffic distribution when a full satellite passes above a station i. On each figure the above queue is the satellite one while the bottom one corresponds to the i^{th} terminal. The mechanism and its results are still valid, but we point out that the parked Bundles are fairly selected from each traffic. The same portion of each traffic is carried by the satellite but not necessarily the same volume.

IV. Protocol for a Fair Traffic Distribution

The purpose of Martinet is, when the system is unstable (traffic yields to infinite queue lengths), to distribute traffic among stations such as each terminal is able to access the satellite resource. In order to manage the access to the satellite, Martinet requires that the ground stations consult the satellite to know the available capacity of the queue. Either the satellite is able to handle all Bundles, or the satellite has to park some on the station before to be able to receive new Bundles.

We need two Protocol Data Units. One for the ground to ask for access to the satellite. We name it RAM for Request About Memory. The second one is the answer of the satellite and we name it ATAQ for Answer To Access the Queue. Figure 2 shows how Bundles are exchanged between the satellite and the ground when the satellite is full. In figure 2, the satellite is full and can no longer accept incoming Bundles without parking some Bundles. However, we do not want to lose these Bundles because of an overflow on the satellite. So the satellite indicates how many Bundles will be parked by the satellite on the station and how many Bundles the station will be able to transmit to the satellite.

We estimate that the Martinet Protocol shall be above the Bundle Protocol. Since the mechanisms required by Martinet to operate are based on Bundle Protocol fields such as the creation timestamp time and the lifetime, Martinet PDUs are exchanged between nodes able to deal with Bundles. Then, to make the implementation of Martinet easier, we define Martinet as a payload of Bundle Protocol. Figure 3 presents how RAM and ATAQ are encapsulated within Bundle.

As indicated in [1], we use for the block type a value between 192 and 255 which is a range available for private and experimental use. We choose to use the value 251 to indicate that data shall be given to the Martinet agent. The Block body data contains either a RAM or an ATAQ message.

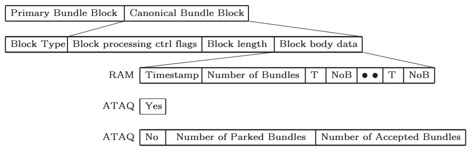

Figure 3. Martinet PDUs encapsulation within a Canonical Bundle Block

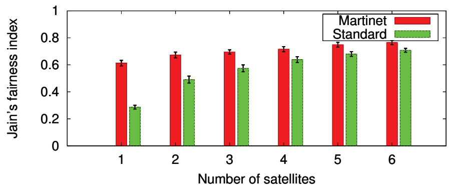

Figure 4. Global Fairness related to the number of satellites

V. Evaluation

The simulations are run with The ONE simulator [9]. We consider a scenario with 5 ground terminals, several satellites and a destination. Each satellite is able to carry data. Each satellite queue is far smaller than the ground terminals queues. The satellites are on the same orbit. We name cycle the period between one pass of a satellite and the next pass of the same satellite. For scenarios involving more than one satellite, the direction of the spacecrafts on the orbit is not the same. The choice of multiple directions aims to study our protocol in unfavourable conditions. The number of satellites grows from one to six to observe the influence of this parameter on the Martinet Protocol behaviour. The metric we focus on is the fairness. We use Jain's formula to calculate the fairness.

Since we focus on the fairness among traffic sources when carrier nodes have not enough memory to handle all data, we shall adapt incoming traffic as a function of the maximum data carriers can handle. Each satellite has the same amount of memory, then we take as a reference the scenario with one satellite. The ratio between the volume of incoming traffic and satellites buffer size remains the same for each simulation.

The results of our simulations are shown on figure 4. The optimum is not reached because we cannot drop parts of Bundles. The lack of fairness between traffic sources comes from the fact that within each satellite, there is always at least one traffic which transmits more data than others. We note that while the number of satellites grows, the fairness increases. Indeed, as we explained above, even with Martinet each traffic cannot share the same portion of the satellite buffer.

We implement the Martinet Protocol on Unix machines implementing DTN2 the reference implementation of the Bundle Protocol. We use 2 source stations, one destination terminal and one LEO satellite. Each station sends a traffic which correponds to 66% of the satellite buffer capacity. The array I sums up the results of the implementation tests. As we mentioned earlier, the use of the Martinet Protocol does not worsen the delivery within the network. Furthermore, the fairness among traffic sources is better with nodes implementing Martinet than nodes which do not. In standard scenario, the satellite is filled to 66% of its capacity by the first node, then the second node fills the satellite. When nodes use the Martinet Protocol, the first node fills also the satellite buffer to 66%. However, when passing above the second node, the second node asks to send all data to the satellite. Then the algorithm computed within the satellite, parks some Bundles of the first node within the second one. The second node sends a number of Bundles indicated by the satellite, close to half satellite capacity.

Table I
Comparison of delivery ratio distribution

	Standard	**Martinet**
Global Delivery Ratio	0.75	0.75
Delivery Ratio Distribution per Traffic	0.66 / 0.33	0.45 / 0.55

VI. Conclusion

In this paper we focus on a network whose connectivity between the source and the destination is ensured by satellites and can be extended to few mobile nodes. We analyse a problem of resource starvation for some nodes when a monitoring network receives more incoming traffic that can be handled. We proposed mechanisms to ensure a fair service to each terminal on each pass of each mobile node. In order to allow these mechanisms to achieve their purpose the Martinet Protocol is proposed. The messages of this protocol provide access to each nodes whose data have a deadline on the same range. Hence, fairness is provided according to the deadlines of the Bundles. An implementation of the Martinet Protocol is tested with some endpoints to emulate a hybrid satellite and terrestrial monitoring network and validated through simulations run with the ONE tool. As a perspective of this work, we plan to add intermediate nodes which do not implement neither Bundle Protocol nor Martinet.

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