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Message fragmentation assessment in DTN nanosatellite-based sensor networks

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ABSTRACT

This paper proposes a proactive fragmentation mechanism for an optimal DTN message transfer. DTN message transfer is presented to give coverage to a terrestrial sensor network by using a nanosatellite communications link. Satellite communication is modeled with a multi-access mechanism with priority in downlink traffic (ALOHAGP). This new multiple access protocol is based on unslotted ALOHA extended with an adaptive contention mechanism. It uses satellite feedback to implement the congestion control, and to dynamically adapt the channel effective throughput in an optimal way. The effective throughput has been optimized by adapting the protocol parameters as a function of the current number of active sensors received from satellite. Also, regarding the optimal size of a bundle, there is a lack of standard negotiation methods of bundle sizes that can be accepted by a bundle agent in satellite communications. Thus, too large bundles are dropped and too small messages are inefficient. We have characterized this kind of scenario obtaining a probability distribution for frame arrivals to nanosatellite and visibility time distribution providing an optimal proactive fragmentation of DTN bundles. We have found that the proactive effective throughput (goodput) reaches in some cases almost 97% of the reactive fragmentation approach.

1. Introduction

Nanosatellite-based sensor networks consider a low-cost small satellite (<50 kg) in low Earth orbit (LEO) acting as communication gateway for sensors distributed in places difficult to access. In highly disruptive environments, there are few solutions proposing a communication infrastructure to provide efficient simple data transmission with multiple access. Delay-Tolerant Networking (DTN) [1,2] is an approach that tries to address technical issues of disruptive environments. In [3] we proposed a new architecture for a DTN nanosatellite-based sensor network using a new protocol named Aloha contention based multiple access with gateway and downlink priority (ALOHAGP).

The use of DTN for Nanosatellite-based Sensor Networks also has some challenges related to transmission optimization, delivery success and bundle fragmentation. Fragmentation techniques are classified in proactive fragmentation and reactive fragmentation. In proactive fragmentation, a node splits a bundle into fragments of a predetermined size prior to transmitting. In reactive fragmentation, the sender node starts sending the entire bundle and the bundle fragments are generated only when a link failure occurs, for example caused by a loss of visibility to the satellite. In this reactive fragmentation case

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both the sending node and the receiving node consider as a valid bundle both the original part of the bundle not sent and the part of the bundle which was received at the receiving node. In both cases the fragmented bundle is reassembled only at its destination.

The main disadvantage of the reactive fragmentation is that it is incompatible with the Bundle Authentication Block feature of the Bundle Security Protocol [4]. The usage of proactive fragmentation solves this problem, but requires determining the optimal bundle size, which is a non-resolved issue, highly dependent on the satellite visibility time and the contention mechanisms defined in the multiple access scheme used for sensor network within the nanosatellite coverage.

Related to the optimal size of a bundle, there is a lack of standard negotiation methods of bundle sizes that can be accepted by a bundle agent in satellite communications. Thus, too large bundles are dropped in proactive fragmentation.

In this paper we propose as main contribution of our work a message fragmentation assessment of DTN bundles in simulated environment characterized by high disruption and small payload transmission capabilities. We proposed a proactive fragmentation technique that considers an optimized frame size obtained through analysis and simulations of our proposed protocol ALOHAGP, which offers reliable delivery of DTN messages between sensor and nanosatellite node. In the analysis we balance the number of frames contained in the bundle with the probability of successfully reception of a given frame.

The remaining of the paper is as follows: Section 2 summarizes related works and Section 3 presents an overview of the scenario, architecture and simulation parameters. Section 4 shows the results and a discussion about these results are provided. Finally, in Section 5 some conclusions are derived and a discussion about future work is presented.

2. Related work

This section studies related work in Bundle Protocol fragmentation mechanisms, algorithms and problems, such as negotiating the optimal size of a bundle and the effect of retransmission.

Regarding the use of DTNs in real-world scenarios, there are some approaches in agriculture [5], vehicular networks [6] and also, in laboratory environments [7], showing high data transfers.

The effect of fragmentation on message delivery success was studied in [8] showing that fragmentation could increase overall connectivity if we know a priori the message size and contact duration distribution. Proactive fragmentation is particularly adequate for satellite networks where the connectivity periods are known. A proactive and reactive DTN fragmentation using two ground stations in order to transfer large files from space was realized by Ivancic et al. [9], where very large files transfers are proactively fragmented at the source. Their evaluation reveals the difficulty in determining the optimal bundle size, which is a non-resolved issue, highly dependent on the satellite visibility time and the contention mechanisms defined in the multiple access scheme used for sensor network within the nanosatellite coverage. We have extended this evaluation to one hundred sensors in our simulations, and we establish an optimized message size and contact duration distribution for our scenario.

Several fragmentation algorithms and studies are described in the literature. In [10] several fragmentation algorithms have been studied for different land scenarios. Fragmentation studies for environments related to the space scenario, such as Vehicular Delay-tolerant Networks, have been developed by [11], stablishing that the use of fragmentation allows the transfer of messages larger than the typically short contacts between vehicles, resulting in an increased delivery ratio and decreased delivery latency. Also, if the fragments of the proactive fragmentation are well adjusted to the contact opportunity, this may perform slightly better than reactive fragmentation. We optimize this setting for our proposed scenario.

Problems of the fragmentation effect in DTN for space have been identified in [12]. One of them is that it is not feasible to provide a method for advertising or negotiating the optimal size of a bundle to be accepted by a bundle agent. Instead of using an advertising or negotiation method, in this paper we propose a method for calculating the optimal bundle size by balancing the number of frames contained in the bundle with the probability of a successful reception of a given frame. Finally, considering other supporting communication layers below DTN, some works [13] describe that there is a strong correlation between the DTN layer and the lower layers. The DTN fragmentation results described in our study are strongly related to the behavior of lower layer protocols as ALOHAGP.

Related to the effect of retransmission some works [14] studied retransmission algorithms for Bundle layer in DTN architecture and compared them to the robustness provided by TCP, where retransmission parameters are properly set. In our work, we rely in the ALOHAGP protocol, which provides an exponential backoff mechanism to manage retransmission of frames, which prevents contention channel congestion. A detailed description of our proposed ALOHAGP protocol can be found in [3].

3. System description

3.1. Overview and system architecture

We describe a scenario (Fig. 1) similar to the HUMSAT [15] or WAPOSAT [16] proposals. We consider a sensor network (e.g. water quality sensors), hereinafter sensors (S), with intermittent coverage of the nanosatellite. Sensors send their data during nanosatellite variable visibility time. Given the disruptive nature of this type of scenario, we use a DTN solution, proposed in [3], which provides end-to-end communication in such environments. In this context, it is proposed that each sensor node and nanosatellite supports the DTN Bundle Protocol (BP) of the DTN architecture.

The architecture and protocol stack for the proposed system can be seen in Fig. 2. We have the following layers [3]: