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An implementation of Software Defined Radios for federated aerospace networks: Informing satellite implementations using an inter-balloon communications experiment

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ABSTRACT

Novel space mission concepts such as Federated Satellite Systems promise to enhance sustainability, robustness, and reliability of current missions by means of in-orbit sharing of space assets. This new paradigm requires the utilization of several technologies in order to confer flexibility and re-configurability to communications systems among heterogeneous spacecrafts. This paper illustrates the results of the experimental demonstration of the value proposition of federated satellites through two stratospheric balloons interoperating with a tracking ground station through Commercial Off-The-Shelf Software Defined Radios (SDRs). The paper reports telemetry analysis and characterizes the communications network that was realized in-flight. Furthermore, it provides details on an in-flight anomaly experienced by one of the balloons, which was recovered through the use of the federated technology that has been developed. The anomaly experienced led to the early loss of the directional link from the ground station to the affected stratospheric balloon node after 15 min in flight. Nevertheless, thanks to the federated approach among the systems, the ground station was still able to retrieve the balloon's data in real time through the network system, for which the other balloon operated as a federated relay for 45 min in flight, uninterrupted. In other words, the federated approach to the system allowed triplicating the useful lifetime of the defective system, which would have not been possible to realize otherwise. Such anomaly coincidentally demonstrated the value of the federated approach to space systems design. The paper paves the way for future tests on space assets.

1. Introduction

The emergence of new space distributed system paradigms, such as Federated Satellite Systems (FSS) [1] poses new challenges on space communications and networking technologies. In order to support space mission de-centralization and cooperation among heterogeneous spacecraft [2], flexible and reconfigurable solutions are required.

This paper presents a flight test of a Software Defined Radio (SDR) [3] realized on a network of two intercommunicating stratospheric balloons, interoperating with a tracking ground station. Software-defined radios take advantage of modern Digital Signal Processing (DSP) techniques to obtain re-configurable modulation, coding, encryption and Radio

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Frequency (RF) front-end characteristics. Therefore, SDRs can perform functions unachievable by conventional communications systems, such as physical and media access layers interoperability between spacecraft with diverse RF communications systems. Besides theirs advantages, SDRs have some general drawbacks such as higher power consumption and lack of software reliability [4].

However theirs characteristics make SDRs a promising technology for FSS. In satellite federations, a communications network based upon inter-satellite links (ISL) [5] enables the exchange of computing, storage and downlink bandwidth resources among participant missions. Such missions decide to join the federation on the basis of the perceived value of the transactions, usually at the cost of including and operating ISL equipment. Would SDR-enabled nodes exist within the federation, participant spacecraft – even already deployed ones – would have the option to use their mission-specific communications subsystem and use SDR-enabled nodes, or *negotiators*, to share resources with any other federate. Fig. 1 illustrates this concept.

The negotiated FSS architecture on Fig. 1 depicts a scenario where intermediary nodes would broker resource exchange contracts and provide the means for communications interoperability between missions. For the sake of this scenario's feasibility, a modest mass and cost of the enabling technologies is desirable. Commercial-off-the-shelf (COTS) SDR solutions, such Nuand's BladeRF and NI USRP [6] provide the means to base FSS negotiator nodes upon small spacecraft [7]. Notwithstanding radiation hardening issues, the testing of COTS SDRs is useful to understand the tradeoffs involved and potential of this technology.

This paper characterizes the long-range performance of an in-flight network realized with commercial off-the shelf SDRs when operated at high altitudes, to perform FSS-like in-flight data relay. The experimental approach chosen involves a flight test with two stratospheric high altitude balloons (HABs) and a tracking ground station (GS).

First, this paper briefly reviews the literature related to SDRs for space applications. Second, the experimental approach is described. Third, the results of the flight test are reported, including the description of an in-flight anomaly recovered through the proposed federated approach. Lastly, this paper presents conclusions on the performance and potential of COTS SDR systems for FSS.

2. Literature review

This section describes the relevant literature to this work, including works on SDRs, SDR programming methods, and the state of the art on space SDRs and related networking concepts.

The concept of Software Defined Radios was introduced in 1993 by Mitola III [8] as a digital radio that could be reconfigured in fundamental ways by changing the underlying software code. In the mid-1990s the first military radio systems appeared in which software was controlling most of the signal processing digitally, enabling one set of hardware to work on many different frequencies and communications protocols [9]. In the late 1990s, SDRs started to spread to the commercial sector. In the late 2000s, various set of commercial and hobbyists` SDR platforms appeared (USRP N210 and the ZeptoSDR, HackRF and BladeRF) [7]

These commercial off-the shelf SDRs are usually programmed by using the GNU Radio toolkit, which provides signal processing blocks written in C++ and Python for live systems implementation, simulations and analysis. The current version of GNU Radio has many different types of blocks for signal coding, modulation/demodulation, filtering and error correction [10,11]. Live transceiver systems are possible based on existing blocks [12].

Notable implementations of SDR systems in space applications include NASA's SCaN (Space Communications and Navigation) testbed onboard the ISS [13] and the Frontier radio systems [14], both oriented to support the SCaN network concept which aims a to establish a network among all space probes in the solar-system, greatly enhancing the operations and accessibility to all of NASA's exploration assets [13]. In the domain of small satellite technology, another notable SDR system is Aerospace Corporation's 915 MHz SDR [15], which is expected to fly on Aerocube 7 together with an optical link experiment. Aerocube 7 is undergoing launch preparations at the moment of writing this paper. Aerocube's SDR uses Linux OS, and a custom MAC layer [15] solution, although the developers intend to switch to TCP/IP [16] in the next developments [15]. Aerocube's SDR system achieves 10 Mbps with 8 W power.

Satellite communications are the prime potential beneficiary of SDR, but the increasing bandwidth and data rates requirements still pose challenges at digital devices level, especially for on-board applications. TT&C transponders look much more mature in terms of space

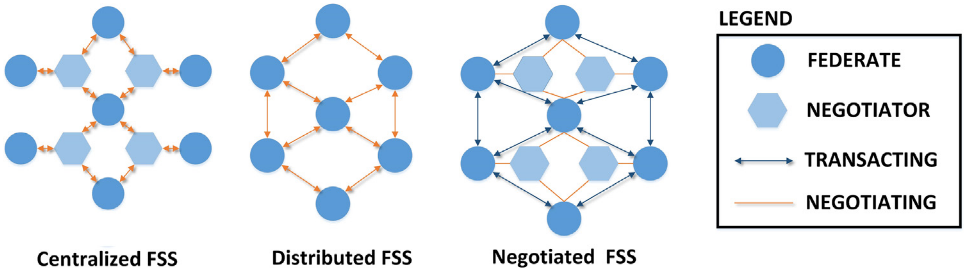

Fig. 1. Families of FSS architectures, redrawn from [1].