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DSP implementation of integrated store-and-forward APRS payload and OBDH subsystems for low-cost small satellite

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Abstract

The developed system, based on the DSP (Digital Signal Processor), provides an integrated store-and-forward APRS (Automatic Packet Reporting System) payload and OBDH (On Board Data Handling) subsystems at a very low cost and on a single board with dimensions less than 10 cm × 10 cm, thereby enabling a new level of performance for CubeSat-class spacecraft. In this paper, we consider the problem of designing a low-complexity AFSK and GMSK modems for a satellite communication link where the constraints on satellite power budget, antenna size, and data rate are such that the available transmit power, aboard the Picosatellite, is 1 Watt. To cut down the cost of the Picosatellite, we give a particular attention to software optimization due to use of small amount of 8K words Radiation Hardness ROM memory containing the application program. We have defined a methodology approach based on two design steps: algorithmic optimization, and optimal programming using Assembler language. Due to the radiation in space and the constraints of the Picosatellite, some measures regarding volume, mass, power, cost and radiation tolerance, had to be taken into consideration when the system was designed.

Keywords: Satellite design; Signal processing; Store-and-forward APRS payload; OBDH subsystem

1. Introduction

The CubeSat-class spacecrafts have the advantages of being able to perform as a test bed for new systems and core space technologies to be applied to space programs, for much lower cost, shorter schedule, and less risk. For this reason, the world leaders in space technology, including the US and Europe, are focusing their efforts on smaller satellites under the motto of "Faster, Cheaper, Better" that can perform missions traditionally assigned to large/medium satellites in the past.

In accordance with this trend, and in the absence of any Cubesat dedicated to APRS mission so far, our Picosatellite payload mission will provide various APRS services, such as mobile localization of ships and data collection from autonomous weather stations in inaccessible sites located on the Moroccan territory using store-and-forward scheme, as shown in Fig. 1. Also, it plays the role of digipeater scheme and sends telemetry data of the Picosatellite to all amateur ground stations all over the world. The APRS communications system was developed by Bob Bruninga [3].

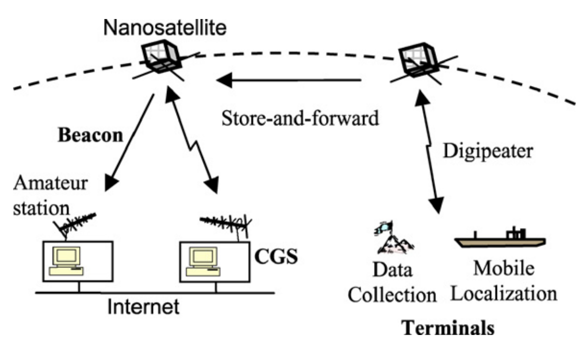

Fig. 1. APRS services using LEO nanosatellite.

The CubeSat program [27] and its launch opportunities, as has been published by CalPoly et al., aims to send a satellite, with dimensions $10 \times 10 \times 10$ cm^3 and mass one kilogram

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into Low Earth Orbit (LEO). The Picosatellite uses the AX.25 [20] packet radio protocol, for APRS payload at 1200 bit/s, and for Telemetry/Telecommand (TM/TC) operations at 4800 bit/s. The Picosatellite will operate on the 145.825 APRS satellite frequency.

2. System description

The Mission life for the Picosatellite is estimated as 6.5 months. The Picosatellite will have Four modes: Store-and-Forward APRS mode, APRS Digipeater mode, Beacon mode and Command mode.

The AX.25 protocol provides Connection-Oriented and Connectionless transmissions. The connectionless transmission method will be used in digipeater and beacon modes, whereas the connection-oriented method will be used in store-and-forward APRS and Command modes.

In store-and-forward APRS mode, the terminals use the Aloha multiple access [30] to send their messages to the Picosatellite and wait for an acknowledgement from the Picosatellite, which stores the correct messages in an on-board storage system, and delivers this to the destination Central Ground Station (CGS) in a later time in the same original format. The packets are position-stamped and time-stamped. Between the storage and the retrieval of the message, the Picosatellite moves around its orbit and the earth rotates on its axis. These movements change the location of the Picosatellite's footprint, and the Picosatellite effectively carries the messages from terminal users to the CGS station. Only one CGS station will download all the stored packets using GMSK modulation at 4800 baud. In this mode, terminals will not use the existing AX.25 firmware. Instead, they will use a stop and wait ARQ (Automatic Repeat Request) protocol which will be implemented only at 40 build-in-house terminals [29] inside the Moroccan territory. When the terminal transmits its APRS packets, it will wait for acknowledgement and will set its timer. If this timer expires without reception of an acknowledgement, the entire packet is scheduled for retransmission after a random interval time until receiving the acknowledgement.

In the APRS Digipeater mode, which is a real-time bent-pipe relay, all the radio amateur stations, situated all over the world, could transmit their APRS packets without waiting for an acknowledgement. The received packet will be tested if there is an error in the packet. The erroneous packet will be rejected and the correct packet will be retransmitted after adding the satellite's callsign in the Address field of the AX.25 packet. This mode is useful when both the source and destination radio amateur stations are at the same Picosatellite's footprint. In this mode, the Picosatellite could work with the existing APRS satellites or future ones in constellation.

In the Beacon mode, the Picosatellite sends periodically the basic telemetry (Temperatures, currents and Battery voltage) to the earth to know the life of the Picosatellite. This telemetry is encoded in an APRS Telemetry format in the Information field of AX.25 packet and is identified by the character *T* as following:

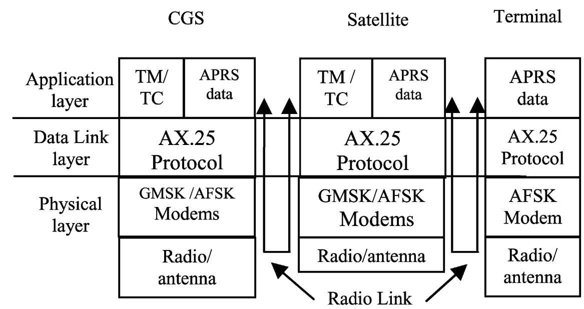

Fig. 2. Satellite communication layers.

T#SSS,111,222,333,444,555,11111111, where SSS is the sequence number followed by the five 3 digit analog values and the eight binary values. A CGS station could gather the Picosatellite APRS telemetry data from the radio amateurs all over the world via Internet. The gathered data will be archived to a database and be accessed by Internet.

In the Command mode, the CGS station sends telecommand (TC) to the OBDH aboard the Picosatellite and receives the telemetry (TM, the housekeeping data) from the OBDH to know the health status of the Picosatellite.

The Picosatellite has two communications channels (the application layer) (Fig. 2), which can be multiplexed over the same transceiver. The first channel carrying the TM/TC data whereas the second channel carrying the APRS data. On bottom of the application layer, we used the AX.25 protocol, which is an amateur radio adaptation of the ITU-T X.25 protocol. The AX.25 supports the requirements for amateur satellite communication. The AX.25 packets are sent over the radio links (the Physical layer), which use AFSK (Audio Frequency Shift Keying) for APRS data, and GMSK [19] (Gaussian Minimum Shift Keying) for TM/TC data, over the same 145 MHz (uplink and downlink) VHF band.

At VHF frequencies the antennas, receivers and transmitters for both the ground and the space segment, are readily available and inexpensive [14]. The Doppler shift, is kept at 3 KHz or below for the Picosatellite parameters (altitude, minimum elevation angle, frequency band) [8], which can be ignored.

In general case, the transmitted signal is corrupted by channel noise, by Doppler and multipath effects so that the bit decoding is not easy. In our case, the Doppler effect is negligible, and the multipath effect is also negligible using low data rate.

To enhance the radio link in Command mode, between the CGS station and the Picosatellite, we added a Forward Error Correction (FEC) by using convolutional coding and Viterbi decoding [17].

3. Picosatellite subsystems design

3.1. Subsystems requirements

The requirements of small satellites are significantly different from their ancestors conventional satellites, and new design techniques are needed to meet these evolving requirements. The unique requirements of the store-and-forward APRS Pi-