The FedSat Communications System

E. S. Seumahu[1], T. S. Bird[2], W. G. Cowley[1], A. J. Parfitt[2], S. Reisenfeld[3]
Cooperative Research Centre for Satellite Systems
1. Institute for Telecommunications Research, University of South Australia
Mawson Lakes, S. Aust. 5095 AUSTRALIA
Phone: +61 8 8302 5223 Fax: +61 8 8302 3873 E-mail: steve.seumahu@unisa.edu.au
2. CSIRO Telecommunications & Industrial Physics
PO Box 76, Epping NSW 1710 AUSTRALIA
3. School of Electrical Engineering, University of Technology, Sydney
PO Box 123, Broadway NSW 2007 AUSTRALIA

Abstract

The Australian Cooperative Research Centre for Satellite Systems (CRCSS) was approved in mid 1997 and inaugurated in January 1998. The Centre's first major space mission is to develop an innovative research microsatellite, FedSat, for launch in late 2000 to commemorate the centenary of Australian Federation. Communications experiments between the satellite and the earth segment are to be carried out in three frequency bands, viz. Ka-band, S-band and UHF. This paper describes the basic elements of the FedSat communications system.

1. System Overview

As shown in Figure 1, the FedSat communication system consists of a space segment and a 5-part earth segment [1],[2]. The space segment in turn consists of the communications payload (CP) and the platform TT&C communications unit. The CP utilises the UHF and Ka-band frequencies whilst the TT&C functions are carried out at S-band. The earth segment elements are UHF mobile terminals (including ocean buoys), UHF ground station, Ka-band transportable terminal, Ka-band ground station and S-band TT&C ground station.

Functionally, the communication system is made up of the following subsystems: the Ka-band subsystem, the UHF subsystem, the S-band TT&C subsystem, and UHF/Ka backup TT&C subsystem. The bands are:
Ka: 29.9-30.0 GHz (E-S) & 20.1-20.2 GHz (S-E)
S: 2025-2075 MHz (E-S) & 2200-2290MHz (S-E.
UHF: 312-315 MHz (E-S) &400.15-401.0MHz (S-E).

2. Ka-band Subsystem

The space segment of this subsystem consists of Ka-band transmitting and receiving antennas, Ka-band transmitter and receiver, IF chain, and a Baseband Processor (BBP). The Ka-band components reside in a separate unit [3] that connects to other units of the CP at the IF through coaxial cable and to the antennas via rectangular waveguide runs. The IF chain input/output frequency is 1.5 GHz and within the IF module the frequency is translated to a secondary IF of 21.4 MHz. Both transmit and receive horn antennas are designed to provide approximate uniform earth coverage and are mounted directly on the earth-pointing face of the satellite bus.

The corresponding earth segment has one fixed/transportable Ka-band terminal in Sydney and one fixed Ka-band ground station in Adelaide. Each of these consist of Ka-band transmitter/receiver, 1.2m parabolic antenna, IF/Ka-band up/down converters, Modulator/demodulator and BBP [4].

The Ka-band subsystem can operate in either the "bent-pipe" mode or the "packet switching" mode. In the bent pipe mode the baseband processors are by-passed at the IF frequency. In the packet switching mode, the space segment is configured as shown in Figure 2. The Ka-band link will be used for advanced communications, propagation and microwave device lifetime experiments with LEO satellite systems, and as telemetry back up.

3. UHF Subsystem

The space segment of this subsystem consists of UHF transmitting and receiving antennas, UHF transmitter and receiver, HF/UHF up/down converters and BBP [5]. The HF and UHF components are contained in one unit of the FedSat CP. The UHF subsystem can operate in either the "bent-pipe" mode or the "store & forward" (S&F) mode.

The UHF earth segment consists of one UHF ground station in Adelaide and many mobile terminals (MT) such as buoys, land-mobile, laptop or hand-held terminals, scattered around Australia and the southern ocean region. The UHF ground station is used in bent pipe mode for applications such as voice-band communication to and from the MT's. In bent-pipe mode some mobile terminals can also communicate with each via the ground station. In S &F mode, the UHF subsystem is used together with the TT&C subsystem to provide an Advanced Data Acquisition and Messaging (ADAM) subsystem.

3.1 The UHF ADAM subsystem

The UHF ADAM subsystem will introduce a new type of packet data service well suited to environmental data acquisition by low earth orbit (LEO) satellite. Existing systems typically provide very low data transfer capabilities (e.g. up to hundreds of bytes per satellite pass). By using two way messaging techniques, including a custom multiple access scheme and error control, this subsystem will allow much larger transmissions, and control of the data acquisition platforms.

An example of a promising application for the ADAM subsystem is to significantly enhance data capture in the Array for Real-time Geostrophic Oceanography (ARGO) project. ARGO is a component of the international Global Ocean Data Assimilation Experiment (GODAE). The proposed array will consist of a large number of submergible buoys called PALACE floats. (PALACE stands for Profiling Autonomous LAgrangian Circulation Explorer).

A Time Division Multiple Access (TDMA) scheme has been designed for the FedSat ADAM subsystem. Terminals request traffic slots depending on their data upload requirements in an Aloha-style request slot. Slot allocations are broadcast in the TDM downlink, plus terminal commands, and error control information. The scheme is well suited to a LEO satellite communicating with 1 to 5 terminals simultaneously. The uplink transmission rate is nominally 4 ksymb/s. Uplinked data will be stored on FedSat until it is downlinked to the FedSat telemetry tracking and control (TT&C) station. Turbo coding will be employed on the uplink in order to achieve the best performance. Two-way messaging allows an automatic repeat-request (ARQ) protocol to be implemented so that very high levels of data integrity can be achieved. Strong forward error correction, ARQ and (possibly adaptive) link control protocols and coding will be employed to cater for different channel conditions. Link protocols are currently being simulated with a channel model which includes shadowing loss, for example due to wave obstruction of the line-of-sight signal component.
Two way communications provides for much more efficient use of bandwidth and link capacity than a one way system which relies on repeated transmission of short packets in order to obtain reliable message transfer. Power consumption is also a critical parameter for mobile terminals in this type. Even assuming the same power consumption, the overall power per transmitted bit will be more than two orders of magnitude better than conventional terminals.

Position location of mobile terminals may be determined by Doppler techniques. The multiple access scheme and modem processing are designed with the requirements for Doppler estimation in mind.

As well as the data acquisition capability, the ADAM subsystem will also provide low-rate two way messaging services for transmission of messages between remote terminals or to/from the TT&C station in Adelaide. This will allow terminals to send or receive messages to or from the internet. The FedSat UHF payload has been designed so that remote terminals will be relatively simple and low cost. There is significant scope for miniaturisation of terminal electronics.

4. S-band TT&C Subsystem

The space segment of the TT&C subsystem is based on the SIL series of standard S-band equipment. The subsystem will provide downlink data rates of up to 1 Mbps, and an output power of 2W. Suppressed carrier, binary phase shift keyed (BPSK) modulation is employed, conforming to European and NASA standards.

The on-board receiver is a flexible, low-cost, and high performance device, with a sophisticated all digital sub-carrier demodulator. The receiver accepts telecommand data BPSK modulated on to a sub-carrier, with up-link rates of between 8 bps and 4 kbps. Redundancy will be provided through the experimental communications payload, with an UHF up-link at 4 kbps, and a Ka-band downlink with 128 kbps or 256 kbps capability.

Communications are secured using two separate S-band receive and transmit antennas on the top and bottom of the spacecraft, making four antennas in all.

The heart of the earth segment of the S-band subsystem is a SIL Satellite Ground Station (SGS) rack which is designed to complement the SIL space segment facility. The antenna, tracking system and operational control centre are located at the Institute for Telecommunications Research (ITR) in Adelaide.

5. UHF/Ka-band Backup TT&C

In the case of failure of the S-band space segment, a back-up subsystem will be set up, consisting of the uplink component of the UHF subsystem and the downlink component of the Ka-band subsystem
On the earth segment side, the corresponding parts of the UHF ground station and the Ka-band ground station will be activated.

6. ARQ Protocol

To carry out the various functions of the FedSat communication system, new frame structures and ARQ protocols have been studied and developed. An example of a packet frame format for the Ka-band uplink is shown in Figure 3.

The ARQ protocol adopted for FedSat transmission is a basic sliding window protocol, with a receiver window size of one [6]. For each successfully received packet, FedSat sends an acknowledgement, which is simply the next expected packet number in the sequence. When the MT (generic mobile terminal) receives this acknowledgement, it means that all previous packets up to the packet number have been successfully received and sent to the on-board storage system. If FedSat receives a packet out of sequence, or the CRC check fails, the packet will be discarded and no acknowledgement sent. If an MT has not received an acknowledgement for a packet, the MT should restart the transmission from that packet. The latency between transmitting the packet and receiving the acknowledgment is approximately 2 frames, depending on the slot number used.

If the downlink is lost, the MT is required to stop transmission and wait until the downlink is reacquired before recommencing transmission. If FedSat has not received any packets from an MT in the last 60 seconds, it will de-allocate the slots, assuming the MT is no longer in communication range.

When an MT has successfully transmitted all packets, the MT will transmit an “end of allocation” packet to FedSat to ask for confirmation that all packets have been received. Once received, FedSat responds by sending an acknowledgment and waits 5 frames before de-allocating the channel, to ensure that the MT has successfully received the acknowledgement.

To provide means for verifying the proposed protocols for the ocean buoy application, a simulation was constructed using the network-modelling tool Opnet. The node structure of an ocean buoy is shown in Figure 4. The radio receive, transmit and antenna processes are provided by Opnet.

The buoy process contains all the procedures required by a buoy to communicate with FedSat. With the buoy likely to experience periods of shadowing due to the large ocean waves, the shadower process is used to simulate the communications channel. The channel is simulated using a simple 2-state Markov model, as shown in Figure 5, consisting of a clear sky state and a shadowed state where both TDM frames and TDMA packets between the buoy and FedSat are discarded. A third state is also used to represent when FedSat appears below 20 degrees elevation, halting communication. The simulation result for a high elevation pass is shown in Figure 4.

7. Conclusion

The communication system for the FedSat LEO satellite has been designed to provide a highly flexible platform for testing the benefits of small, low-power and low-cost satellites. It has been planned to make FedSat a multi-purpose tool for carrying out many of the research and development objectives of the CRCSS.

Acknowledgements

This work was carried out with financial support from the Commonwealth of Australia through the Cooperative Research Centres Program.

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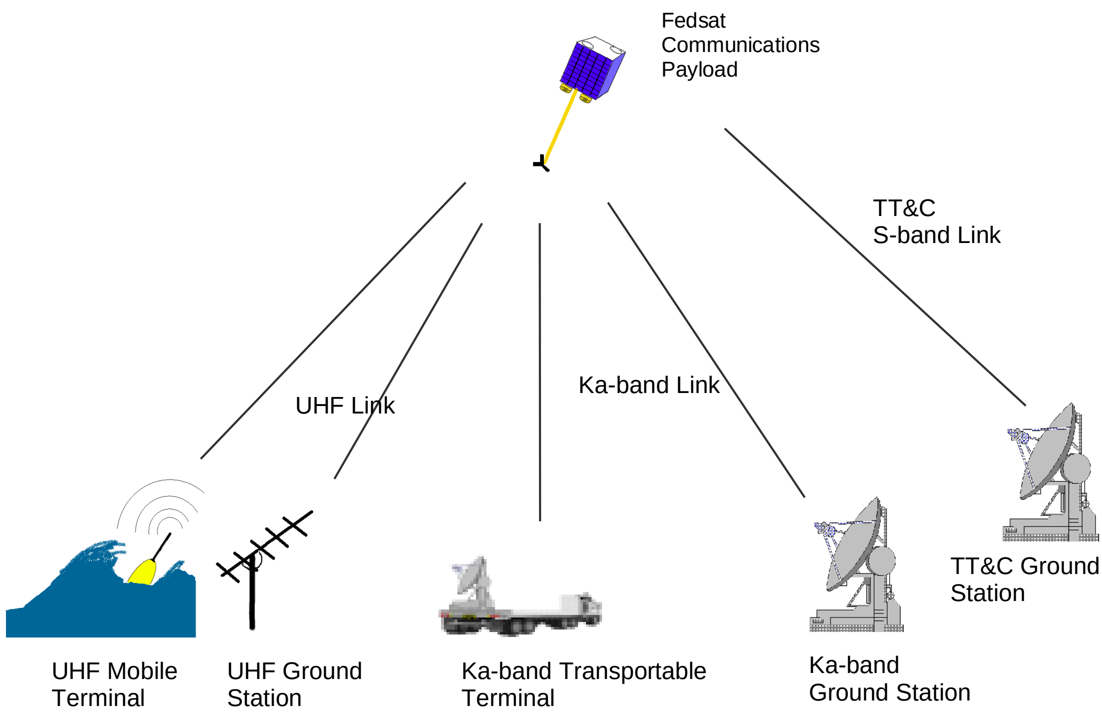

Figure 1 Communications system components

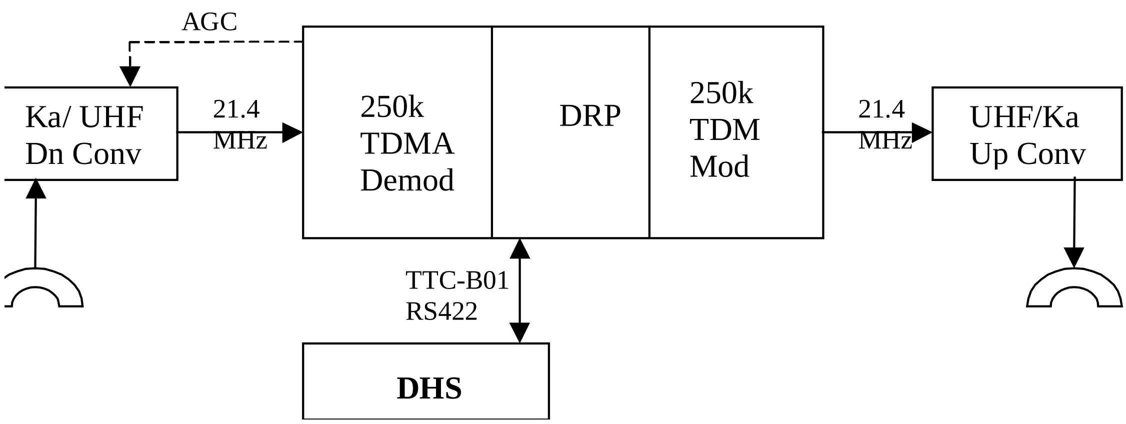

Figure 2 Ka-band space segment in packet switching mode

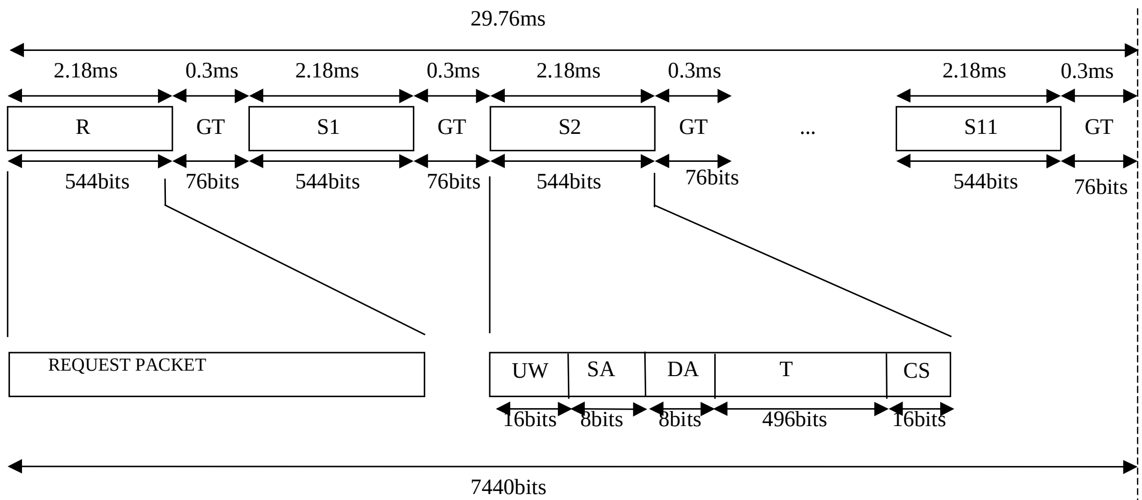

Figure 3 Frame format for Ka-band uplink

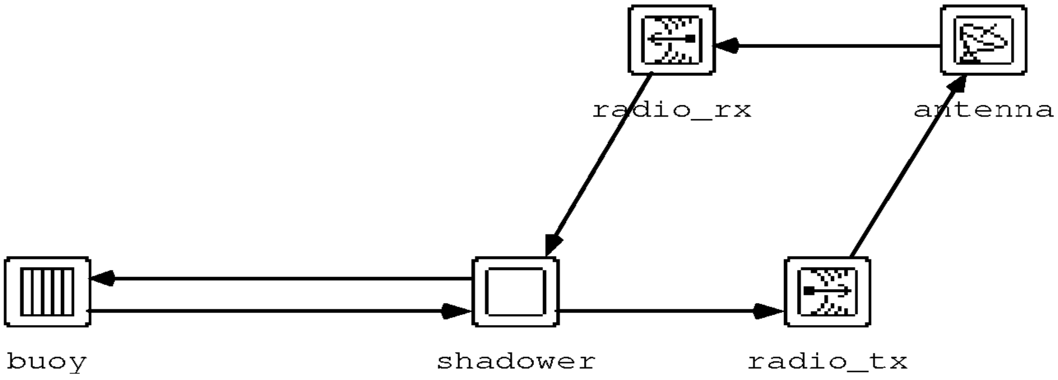

Figure 4 Opnet buoy node structure

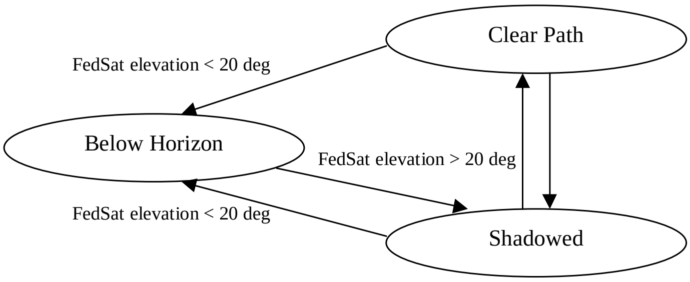

Figure 5 Markov chain model

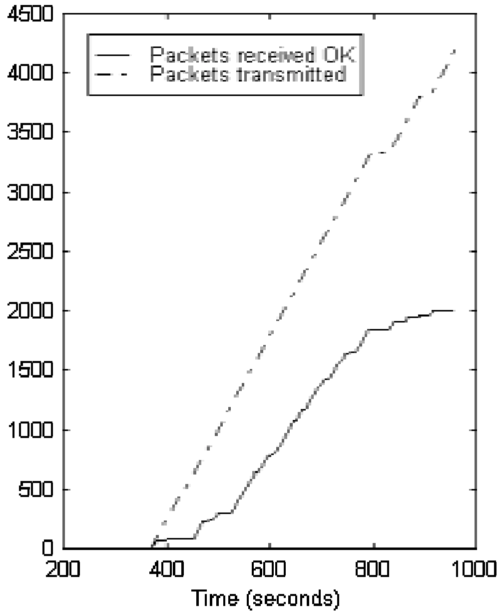

Figure 6 Simulation result for UHF mobile terminal