Proceedings of the 14^{th}
KACC, Octorber 1999

A Study on the CDMA-based TT&C Design and Experiment Concept

° Ho-Jin Lee* and Hee-Sook Mo*

*Satellite Communications Systems Dept., R&B Tech. Lab., ETRI, 161 Gajong-Dong Yusong-Ku, Taejon, Korea 305-35
(Tel : 82-42-860-5769; Fax : 82-42-860-6949 ; E-mail: hjlee@etri.re.kr)

Abstract

ETRI has successfully completed and delivered to KARI the KOMPSAT Mission Control System. This system was designed to work in the conventional TT&C modulation scheme with the pre-assigned frequencies. As a way to accelerate in catching up with future TT&C technology evolutions, a preliminary study needs to be carried out to prepare for the development of a spread spectrum applicable to TT&C. A brief study was carried out to review some points to be considered in designing and implementing spread spectrum schemes to the ground TT&C system intended for a LEO spacecraft. Also a simulation and link design revisit was performed to see the operational and technical benefits with the KOMPSAT TT&C parameters. An experiment concept is proposed to test as many functions at a time once the prototype is developed. In this configuration, a ground-model TT&C transponder is connected via LAN to the ETRI-developed KOMPSAT S/W simulator and linked to the KOMPSAT TM/TC processing s/w via spread spectrum signals through a GEO satellite bent-pipe link. A satellite data relay link simulation could be carried out in this configuration.

1. Introduction

Current satellite TT&C (Telemetry, Tracking and Command) systems for space services are increasingly facing the problems such as frequency band shortage, increased data rate capacity, interference. To solve this, an application of spread spectrum or more precisely DS-CDMA (Direct Sequence Code Division Multiple Access) communication technologies to satellite TT&C has been spotlighted mainly by ESA and European companies. As the satellites increase in number to compete for relatively crowded orbits slots and frequency resources, since most of TT&C link is assigned to use specific frequencies such as 2GHz S-band, interference problems between links become substantial and an issue in satellite designs. Moreover, noting the fact that the power flux density for the 2GHz band is limited to $-144dBW/m^2/4KHz$, one can easily understand that TT&C telemetry design has been driven to devise ways to reduce EIRP while giving a sufficient margin to the ground station at the same time for keeping track of the satellite and a high data rate playback telemetry reception.

Another issue is that the 2GHz band is currently shared on a co-primary basis between space services and terrestrial fixed and mobile services. As the increase of the point-to-multi-point system for fixed service, sharing problems became more difficult than ever. The jamming avoidance is required to and from terrestrial mobile links, especially high density mobile systems such as IMT-2000 appeared in the near future, sharing same frequency band.

On the other hand, telemetry data rates continue to grow according to the increasing complexity of the payloads. Currently the real-time low data rate has been limited to 4kbps, but this wouldn't be the case any longer because the spacecraft functions will be more flexible with the onboard s/w upload capability from ground. Even higher telecommand and telemetry rates will be required for high density solid state memory onboard operations and more autonomy intended for cost saving by reducing contact periods.

Since the LEO systems consist of a large number of satellite constellation, it has been necessary to devise a common TT&C scheme applicable to and sharable among all the spacecrafts and ground TT&C stations without exclusive allocation of TT&C links individually. This enables to save the costs to a great extent in manufacturing and system deployment, and even in operation.

Furthermore to get a TDRSS (Tracking and Data Relay Satellite System) or DRS (Data Relay System) service for extending LEO real-time operational coverage, user LEO spacecrafts should have TDRS/DRS-compatible CDMA communication links. The TT&C link can be switched to according to ground command or onboard stored command either omnidirectional TT&C antenna or communication antenna targeting for data relay service once installed additionally.

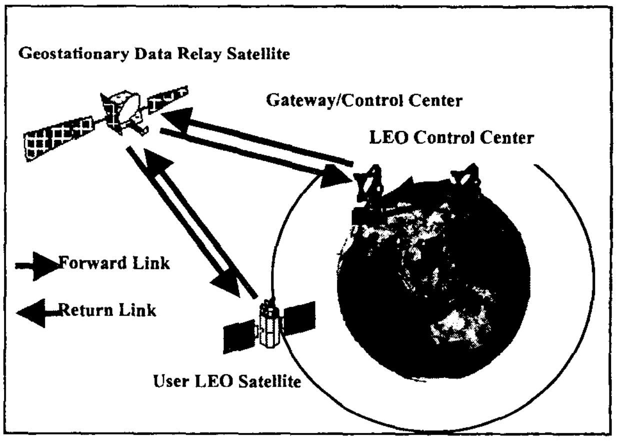

Fig. 1. Satellite Data relay Concept

All these situations seem to lead LEO's and even GEO TT&C systems hopefully to be evolved to new schemes, i.e., spread spectrum method, to cope with and overcome the expected problems. Technology itself has been proved and applied in the real operation but the whole change to new systems requires a lot of investment to both TT&C transponder and ground station, it may take a long time for this scheme to prevail. For the time being as a transition a dual mode implementation of TT&C signal modulations, i.e., conventional modulation and spread spectrum PSK modulation, will be more realistic and popular. In spite, it looks no doubt necessary to develop the required technology and to apply to the forthcoming satellite and ground control systems before we are stuck in the way of system deployment and operation.

2. Spread Spectrum Application to TT&C

Spread Spectrum Communications

The main principle of spread spectrum communication is the bandwidth occupancy much higher than original. Because of this lager bandwidth the power spectral density is lower and the signal looks like noise in the channel. It was initially used only in military satellites to overcome jamming and provide security to users. One of the multiple access method using spread spectrum is CDMA (Code Division Multiple Access) and it has been applied to satellite communications and global positioning systems. Of the CDMA schemes, DS (Direct Sequence) type is used most popularly which uses a pseudo random noise (PN) sequences. The information signal is modulated by a spreading signal or PN-code and the resulting wideband signal is transmitted. Upon reception, the signal is demodulated with a synchronized copy of the code and the information is recovered.

Spread spectrum can provide substantial benefits over conventional TT&C communications systems. These advantages include 1) elimination of interference from other systems operating in the same frequency band due to reduced power spectral density, 2) resistance to jamming that is a protection of TC and TM links from any other links thanks to the PN-code decoding particularly for narrow-band jamming, 3) security enhancement of TC/TM links, 4) capabilities of random access for multiple access to be dealt with, 5) relative robustness to fading or multi-path distortions because of a large bandwidth modulated by PN-code, and 6) good ranging performance. This scheme, however, entails some disadvantages like higher system complexity, difficulty of synchronization, and requirement of wide bandwidth.

One of the parameters useful in specifying the performance of a DS/SS signal in the presence of interference is known as the processing gain. Processing gain(Gp) is defined as the ratio of the signal bandwidth to the message bandwidth and is described in the following equation:

$$Gp = Ws/Wm = 2 * Tm/Tc \tag{1}$$

where Wm is bandwidth of the message $1/Tm$, Ws is the signal bandwidth, Tm is the message bit duration and Tc is the chip duration. The mean square value of the output interference signal Jo can be expressed as follows:

$$Jo^2 = J / Gp \tag{2}$$

where J is the interference power and Gp is the processing gain. Thus the interference is reduced by a factor equal to the processing gain. The resulting output SNR(signal-to-noise ratio) becomes after some manipulations as follows:

$$SNRo = Pr/(No/2Tm + J / Gp) = Gp/(No*Gp/2Tm + J) \tag{3}$$

where Pr is the received signal power and No is noise power. Noting that $Gp/Tm=Ws$, and input SNR, $SNRi$, can be expressed as $Pr/((No*Ws/2)+J)$, then the output SNR can be written by

$$SNRo = Gp * SNRi \tag{4}$$

This result means the output SNR is gained by the factor of the processing gain. More details can be found in reference [1].

Satellite Constellation TT&C Applications

CDMA has been applied to satellite voice and data communications. The typical example is Globalstar, a constellations of satellite in LEO for mobile services. However, this system doesn't use spread spectrum schemes for TT&C. Another LEO system, which is rather a new system to be launched in late 2001 operating as a constellation of 80 satellites at 1469Km altitude, the SkyBridge will establish TT&C link for a wide range of data, voice, and video broadband services as Fixed Satellite Service. Because of the Ku-band frequency utilization for service, its TT&C frequency band was chosen as Ku-band instead of S-band. Nevertheless, the purpose of using the spread spectrum techniques for TT&C remains same as in the case of S-band. This includes no allocation of any exclusive spectrum for each satellite, jamming avoidance to protect the GEO satellites and associated ground stations and terrestrial systems working in the same band, and economics of mass production of smaller TT&C transponders. The acquisition and tracking of the satellites is to be achieved on the telemetry spread spectrum signal. Owing to the digital ASIC and MMIC, the onboard TT&C receivers and transmitters are designed in a compact configuration and under validation and manufacturing [2].

TT&C Data Relay Applications

Most outstanding CDMA application to TT&C can be found in the area of inter-orbit satellite links for TT&C data relay service. Since the interference problem can be avoided by lower power in spread spectrum CDMA scheme, a standard DS/CDMA high rate data communication in a dedicated or multiple access mode is used for several frequency bands including S, C, Ku and Ka bands. NASA communication relay system, TDRSS provides extended view times for LEO satellite communications links over at least 85% of its orbit. The space segment currently consists of 6 geostationary orbit satellites, of which 3 are available for operational support at any given time. The TDRSS services are designated as Forward or Return, Multiple Access(MA), or Single Access(SA). Forward service is a communication service to deliver control commands originated at the customer control center to the customer spacecraft in orbit routed through the TDRS. Return service is the communication service in the reverse direction with respect to the forward service. Typical use of this return link is for the return of science data and spacecraft status of health information. As the access method, MA service is provided as a dedicated return services to LEO customer satellite with real-time, playback, and science data rates up to 100 kbps. Up to five simultaneous customers per TDRS at a time are supported. For this return service, a time-shared forward service is allowed up to 10kbps data rate for individual customer, with one customer per TDRS at a time. Customer tracking service is also supported by one-way or two-way ranging to the customer satellite through TDRS.

TDRSS can provide tracking support to provide all positions, time, and frequency data needed to maintain customer satellite orbit prediction, orbit determination, and attitude determination and control. This tracking is done at the TDRSS control center WSC by extracting tracking data(range and range rate data) from the customer's downlinked telemetry link to TDRSS. The TDRSS tracking support, with NASA orbit determination involved, is capable of providing 50 to 100 meter accuracy (week to week) with the customer satellite S/C signal Doppler frequencies up to +/- 230KHz and Doppler rates up to 1.5KHz/sec. Attitude monitoring and correction can be also supported. In this case, the customer should send the attitude orientation parameters back to NASA and can receive information necessary to make attitude maneuvers [4].

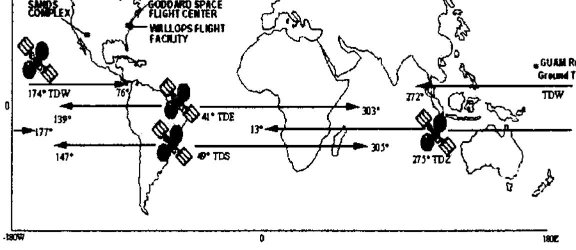

Fig. 2. The TDRS Satellites Coverage

ESA has developed an experimental prototype spread spectrum transponder (ESBT) operating in the 2-GHz band, which was designed for Inter Orbit Links (IOL) between SPOT4 in LEO and the Artemis telecommunication satellite in GEO. Currently this ESBT sets up experimental telemetry (TM) and telecommand (TC) links between SPOT4 and Artemis ground station. The received state-of-health (SOH) data are fed to the SPOT4 mission control center . The TM and TC data rates are rather low-rates, 4kbps and PN code rate is 3Mbps. This capability is significantly enhance the SPOT4's housekeeping telemetry coverage. In other words, whereas the mission control network normally provides just 10 to 15 minutes contact time per pass, this configuration is offering 30 to 40 minutes continuous contact. This would be critical particularly when monitoring satellite onboard operations should be watched closely and continuously during recovery actions after safe-hold mode. Also ESA is developing a standard S-band TT&C transponder intended primarily for small satellite users. The design was to meet technical requirements and essential features, yet to give lower power consumption, mass and low recurring cost. The primary mode of operation is intended to be for IOL using spread spectrum modulation using a 3Mbps chip rates suppressed carrier signal via the European DRS and the U.S. NASA TDRSS, and the Japanese NASDA DRTS. This was chosen for use on the Kistler Aerospace K-1 reusable 2-stage launch vehicle starting to lift LEO satellites from the year 2000[3].

Japan has launched the geostationary COMETS and conducted an IOL communications experiments for relaying S-and and Ka-band communications between LEO satellites up to 1,000Km and ground stations. Its IOL antenna has a gimbal driving mechanism to acquire and track satellites in low earth orbit. The communication link parameters recommended by the Space Network Interoperability Panel (SNIP) was adopted and S-band links are compatible with NASDA DRTS and NASA, and ESA. On the other way, Japan is also developing DRTS to verify and demonstrate advanced in-orbit data relay system technologies, network operations, and communication control technologies between satellite and ground stations. DRTS consists of two satellites, DRTS-W at 90E and DRTS-E at 170W longitude. DRTS-W is scheduled to be launched in 2000 and DRTS-E in 2002. Note that when a LEO satellite passes over a ground station the contact time is limited to about 20minutes maximum but with two DRTS almost 70 to 80 percent of the orbit can be contacted from ground regardless of its flying area. Japan is also performing a data relay test by using ETS-VI.

3. A TT&C Design Example

KOMPSAT TT&C

The KOMPSAT spacecraft uses a conventional TT&C modulation scheme. The key parameters of TT&C link are shown in Table 1. A simulation was performed to apply spread spectrum method to the KOMPSAT as an example to see what it looks like.

A Spread Spectrum TT&C Link Design

Assuming that the modulation scheme is changed to DS/CDMA, we can redesign the current TT&C link. We have revisited as a simulation the KOMPSAT TT&C link budget with the assumption of the KOMPSAT parameters and spread spectrum. Here we assume the PN code rate 3Mcps and BPSK with suppressed carrier (-30dB) so that the processing gains are set to 31.6dB and 3dB for real-time(RT) and playback(PB) respectively according to Eqn. (1). Note that since the original RT telemetry signal power exceeded the PFD limit, the design has been changed to give much lower power by attenuating 25dB. This modification was done outside the transponder and it incurred some additional adverse effects.

Table 1. The KOMPSAT TT&C Link Parameters

Parameters	Downlink	Uplink
Carrier Frequency	2256.0MHz	2077.4MHz
Subcarrier Frequency	1.024MHz(RT)	16KHz
Satellite EIRP	-23.43dBW for RT -1.73dBW for PB	
Satellite G/T		-35dB/°K
Data Rate	2.048Kbps/1.5Mbps	2000bps
Modulation	BPSK/PM (RT) PM(PB)	BPSK/PM
Ground EIRP		52.0dBW
Ground G/T	16.5dB/°K	

The modified TT&C link budget, by introduction of DS/SS scheme, shows new PFD values meet the regulations without additionally attenuating the telemetry signal, in turn this enables elimination of 25dB or 3dB loss while giving higher power margin for telemetry signals. This implies smaller, lower-power consumption transmitter can be used instead. Note that for uplink case the telecommand signal is also spread by the ratio of 31.7dB relative to current design. The modified margins with DS/SS as well as no attenuation are drawn in Fig. 3, which are now increased by –1.67dB, 30.17dB, 3.97dB, -1.79dB compared to the original for carrier, telemetry, carrier PFD, and telemetry PFD respectively.

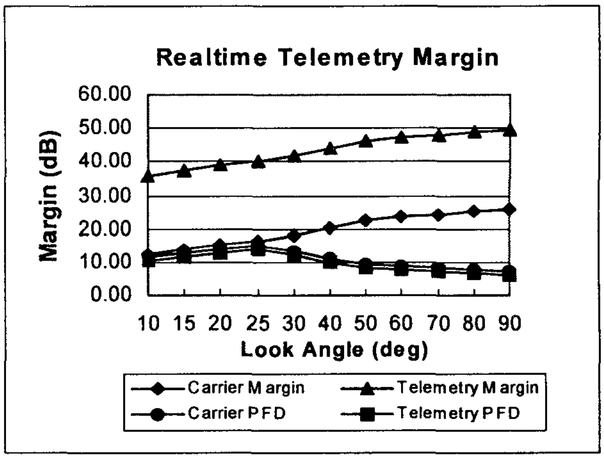

Fig. 3. The Revised Telemetry Margins for DS/SS Applications

TT&C Ground Station

The TT&C ground station should have a wideband DS/SS coding/decoding system to mate the satellite TT&C. The gain margin due to spreading can be reflected on the ground antenna size or HPA power or transponder power. Even under the worst case, we found some design trade-off can be achieved in terms of dimension, power, and cost while reserving the required telemetry margin. Current KOMPSAT design relies on the tone ranging for range measurement but when PN-code is used as a range measurement, once the received code is synchronized with transmitted code and decoded, the range is acquired quite accurately, up to several meters in the same manner as in GPS receiver. Rather a longer code is used for ranging compared to command but its epoch should be synchronized to the command code. Coherent mode operation is required onboard. Note that the primary means of orbit determination for KOMPSAT is GPS navigation data downlinked through telemetry.

Tracking the spread spectrum signal needs a synchronization process in demodulation. For monopulse tracking, the sum channel synchronization is performed first and then applied to the error channel. The chip synchronization should be performed in a very small amount of time (typically less than 100msec) for real time pointing accuracy [5].

Satellite Data Relay Simulation

The use of the data relay satellites is roughly analized by the assumption that next series KOMPSAT is hosting the spread spectrum TT&C transponder. Even though the TT&C parameters and formats should be carefully selected to be compatible with the current TDRS system, we just see what the contact coverage and time would look like if the LEO satellite under consideration has the same orbit characteristics as KOMPSAT as long as it has spread spectrum TT&C link in S-band. Fig. 4 shows the global coverage of TDRSS on September 1,1999 with respect to the current KOMPSAT. In this simulation we have assumed that the TDRSS has 8.7° beam coverage, which can be lager by virtue of the S-band arrary antenna pointing control. As indicated before, the coverage track covers most part of its orbits by which the KOMPSAT control station can control the satellite in an extended period of time. Fig. 5 shows the contact time slots and their durations.

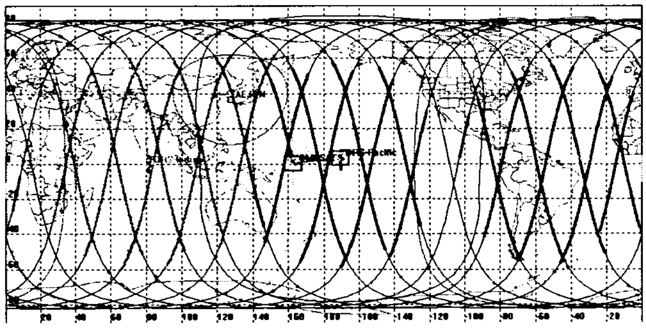

Fig. 4. A TDRSS Coverage Tracks Simulation for KOMPSAT

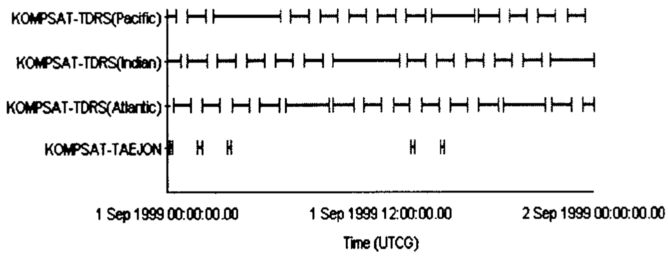

Fig. 5. The TDRSS Coverage Time slots and Duration Simulation

4. An Experiment Concept

A concept of experiment was devised when the SS technology is developed for an application to the next generation remote-sensing LEO satellites like KOMPSAT. Since the development of a functional prototype of transponder seems more realistic approach, we have introduced a ground model transponder that is very similar to the ground transceiver equipment. Thus the transponder prototype is located on the ground and the test link is connected through a geostationary satellite acting as bent-pipe. Currently since we have no S-band communication channel, we are developing Ku/Ka-band equipment, which requires more technical skills and smaller dimension than in S-band. Instead of dummy satellite concept [6], we are connecting the satellite simulator to the ground-model transponder. Due to the KOMPSAT simulator's functions of TM generation, TC reception, orbit propagation and geometric contact, with a satellite network control s/w supported, rather a comprehensive testing of SS link acquisition, tracking, and data relay can be covered. On the other hand, as the ground part, the KOMPSAT control processing s/w is used for TM processing and TC generation with developing transceiver. Of course the ranging is also involved with the test with a Doppler simulation function setup. Fig. 6 depicts the configuration for this experiment concept.

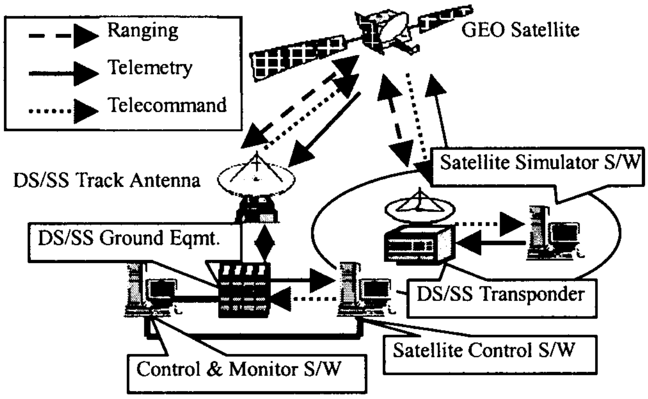

Fig. 6. An Experiment Configuration Concept for Development

5. Concluding Remarks

We have studied the various features of introducing spread spectrum communication to the satellite TT&C. It shows more advantages than traditional design and many applications started to adopt as a next generation scheme. Also this trend looks more outstanding in the near future to resolve the resource problem and is emerged as standard just like CCSDS. By assumption of the KOMPSAT application, we have revisited the TT&C design and found out its benefits in terms of performance and cost. A consideration of an experiment setup showed a concentrated development strategy example. This new technology should be developed and tested for the use in the next generation LEO programs. Especially, in order to develop low cost, commercially viable onboard TT&C transponder and ground transceiver, RF MMIC design and a simplified DSP/ASIC chip design should be mature enough and DSP software should be concentrated as in [7].

References

[1]Bernard Sklar, *Digital Communications, Englewood Cliffs, New Jersey, Prentice Hall*, 1988

[2]R. Nasta and J. Gillot, "Spread Spectrum TT&C For The SkyBridge Constellation", *Proc. of the First ESA Workshop on Tracking, Telemetry and Command Systems*, ESTEC Noordwijk, Netherland, Jun. 24-26, 2.8, 1998

[3]B.E. Leadlay et. al., "The ESA Developed Small S-band User Transponder", *Proc. of the First ESA Workshop on Tracking, Telemetry and Command Systems*, ESTEC Noordwijk, Netherland, Jun. 24-26, 4.1, 1998

[4] NASA's Tracking and Data Relay Satellite System (TDRSS) On-line Information Center, http://www530.gsfc.nasa.gov/tdrss/tdrsshome.html

[5]F.Dumez and A. Bourgeois, "Dual-channel and Single channel Monopulse Tracking Receiver of a Spread Spectrum LEO Satellite Telemetry Signal", *Proc. of the First ESA Workshop on Tracking, Telemetry and Command Systems*, ESTEC Noordwijk, Netherland, Jun. 24-26, 8.5, 1998

[6]K. Ishihara, et. al., "Attempt to automated space network operations at ETS-VI experimental data relay system", *Proc. of the SpaceOps 94*, Greenbelt,MD., Nov. 15-18, DM1e, 1994

[7]J.P. Cousty et. al., "Polar Platform Dual Mode Transponder Overview of the Advantages/Disadvantages of Changing Technology", *Proc. of the First ESA Workshop on Tracking, Telemetry and Command Systems*, ESTEC Noordwijk, Netherland, Jun. 24-26, 4.4, 1998