Development of Ku-band Mobile Satellite Internet Access System

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ABSTRACT

This paper describes the main characteristics and architecture of a satellite mobile internet access (MSIA) system developed by ETRI.
MSIA system provides Internet service, broadcasting, and digital A/V service in both fixed and mobile environments using Ku-band geostationary earth orbit (GEO) satellite. A Ku-band two-way active phased array antenna installed on top of the transportation vehicles can enable the transmission of signals to satellite as well as signal tracking and reception. The forward link and return link are a high speed Time Division Multiplex (TDM) and CDMA transmission media, respectively, both of which carry signaling and user traffic.

1. INTRODUCTION

Today, it is increasingly required the mobile multimedia service including Internet service by satellite communications channel or broadcasting channel. Mobile satellite service networks have been designed to provide data to ships, trains, buses, and aircrafts (access to Internet, e-mail, internal corporate networks on vehicles).
We have been keeping track of the trend in satellite services calling for broadband & mobility and undertaking the development of the technologies of high-speed IP backbone networks, broadband two-way access platforms, satellite mobile two-way Internet platform, and high efficient transmission [8].
We developed the low-cost DVB-RCS (Digital Video Broadcasting-Return Channel Satellite) VSAT equipment, called BSAN (Broadband Satellite Access Network) system for interactive multimedia service. The system has targeted a Ka-band based broadband system development but also designed to adapt Ku-band Out Door Unit (ODU) until the Ka-band equipment market matures. BSAN system has adopted the open DVB-RCS standard as available as the European specification ETSI EN 301 790. Open standard allows the interoperability between hub and user terminals and lower-cost market opportunities through consumer's wider choice and mass production. For achieving high utilization of return link resource, multi-frequency time division multiple access (MF-TDMA) method is adopted. The rate ranges from 128Ksps to 4,096Ksps as recommended in the DVB-RCS standard [1]-[4].
We have been developing a mobile satellite Internet access (MSIA) system based on similar BSAN platform. It is capable of providing high-speed Internet applications and satellite broadcasting service for land and maritime vehicles in their moving environment [7],[8]. The MSIA system is an advanced system toward supporting terminal mobility. An active phased array two-way antenna will be installed on the top of the transmission vehicles, as a dual TX/RX micro-strip array antenna operating in Ku-band [5],[6]. Multiple Frequency Direct Sequence-Code Division Multiple Access (DS-CDMA) is applied for uplink multiple access. Current design targets on the uplink tx rate up to 384Kbps. This market will call for big ships, trains, buses, and airplanes to provide mobile information, entertainment, and business environment.
In this paper, the design of MSIA system is presented. MSIA system configuration and architecture are introduced in Section 2. In Section 3, the hub subsystem of MSIA system is presented. Mobile Remote Terminal (MRT) for MSIA system is discussed in Section 4.

2. MSIA SYSTEM

MSIA system is capable of providing Internet applications and satellite broadcasting service for land and maritime vehicles in their moving environment. MSIA system consists of hub and MRTs connected in a star topology. The system network model is shown in Fig. 1
MSIA system requirements and associated services are as follows:

- Two-way Satellite Communication
- Broadcasting Service Reception
- Variable User Data Rate Support
- Star Topology Support of Satellite Network
- International Standards Support (e.g. DVB)
- Modular Architecture
- Easy Installation (Integrated RF and Antenna, Two-way Set Top Box)
- Easy Maintenance (diagnostic utility)
- Satellite Scan and Tracking
- Interference Minimization to the nearby Satellites

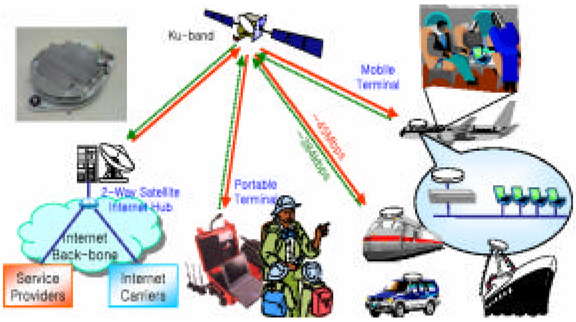


Fig. 1. Configuration of MSIA network.

The hub architecture of MSIA system is composed of Central Satellite Interface Subsystem (CSIS) and Central station Radio Frequency Subsystem (CRFS). The transmission part of CSIS is consisted of an A/V Encoder, a MPEG2 Encoder, a Re-multiplexer (REMUX), a DVB-S Modulator and a Tx Data Processor (TDP). The receiving part for return link is consisted of an Rx Data Processor (RDP) and a CDMA Demodulator Unit (CDU). The functional block diagram of CSIS is shown in Fig. 2.

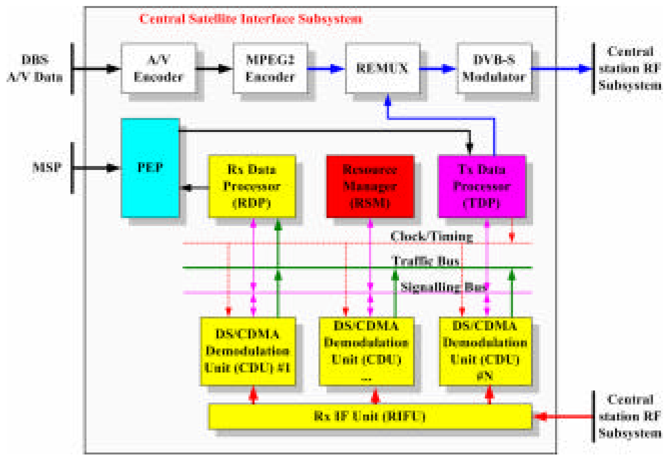


Fig. 2. Functional block diagram of CSIS.

MRT is the terminal equipment providing users with mobile satellite Internet services. It consists of Two-way Set-Top Box (STB) Subsystem (TWSS) and Active Antenna Subsystem (AAS).
The characteristics of MSIA system are given in Table 1. It includes the link budget for MSIA system. The mobile service is a secondary service for Ku band satellite communications. It needs allocate small power for reducing the interference to main service on return link channel. For reasons of that, MF DS-CDMA is applied for uplink multiple access. Forward link is conformed to the DVB-S standard. The MSIA system is an advanced system toward supporting terminal mobility. No open algorithm for resource allocation is found in the literature. It is necessary to define a resource allocation problem in a newly proposed system. As a solution, we mathematically formulated the resource allocation problem. Resource management supports congestion control, dynamic resource allocation, the service classification of MRT. Resource allocation policies are shown in Table 1. Link budget, also, represents the MSIA system for Ku band. Link margin is given about 0.7 dB for considering to 2.2 dB rain attenuation, which is set the availability to 99.7 % annual time.

Table 1. MSIA System Characteristics

Item	Characteristics
Forward Link	DVB-S, 2~40Mbps with 1Mbps increment
Return Link	- Maximum Rate: 384 Kbps - IP over ATM(AAL5), MF DS-CDMA - Concatenated RS and CC - Turbo coding (optional) - Variable FEC Code Rates: 1/2, 2/3, 3/4, 5/6, 7/8
Resource Allocation Policies	- Fair allocation to all the same class MRT - Classification policy: higher class gets more time slots

	Computational Complexity: Linear (this is the minimum) to the number of MRT and slots	
Hub System	- STAR topology hub - Antenna: > 4.6m diameter - EIRP (Nominal): > 56dBW	
MRT	- PCI Interface (STB) - OS: Linux - Required C/N: 7.0 dB - Antenna Size (Ku): 80cm - EIRP(Nominal): 35 dBW - G/T: 10 dB/K	
Link Budget	Hub EIRP	62 dBW
	Hub G/T	30 dBW/K
	Satellite EIRP	54.7dBW (Koreasat-3)
	Satellite G/T	13.5 dBW/K
	MRT EIRP	35 dBW
	MRT G/T	10 dB/K
	Link Availability	99.7 %
	Rain Attenuation	2.2 dB (for Ku Band)
	Link Margin	0.7 dB for Forward
	C/N	8.8 dB

3. MSIA HUB

The hub operates forward link transmission via the DVB-S standard where IP packets are encapsulated into MPEG2-TS packets. The Tx data processor handles the IP data by Multi Protocol Encapsulation (MPE) of DVB-S. The IP packets are transformed to the Digital Storage Medium-Command and Control (DSM-CC) private section packets. They are sequentially converted into MPEG2-TS packets.

The hub simultaneously receives the return link signals. A bank of CDU receives IF signals from Receiver Intermediate Unit (RIFU) through antenna and performs feed-forward burst-mode demodulation. Return link frame consists of several burst types. CDU distinguishes and extracts the information from Physical Random Access Channel (PRACH), Acquisition (ACQ), Dedicated Physical Acquisition Channel (DPACH), and Dedicated Physical Channel (DPCH)[1]. While DPCH data are passed to RDP, other channel information is used not only to recover the carrier phase and timing information, but also to measure the timing, frequency and power errors for reporting to Resource Management (RSM).

After the demodulated DPCH bursts are reassembled to a series of ATM cell, CDU passes them to RDP. RDP converts ATM cells to IP packets using 2 Segmentation And Re-assembly (SAR) chips for the traffic data. These are transferred to Internet Service Provider (ISP) addressed by the IP address in packets via router or gateway, whereas Monitor and Control (M&C) data are sent to RSM.

RSM has to generate DVB-Program Service Information/Service Information (PSI/SI) tables on the basis of DVB-S and DVB-RCS standards for MRTs, to allocate the bandwidth resources, i.e. time slots/frames and frequencies, corresponding to the request from MRTs.

Especially, CDU and RSM are explained briefly as below

CDU is able to characterize each channel and allocate transmission rate according to the service operation. The data rates are implemented by three kinds of rates, 32, 64, 128 Kbps per frequency band for prototype. The structure of CDU is illustrated in Fig. 3.

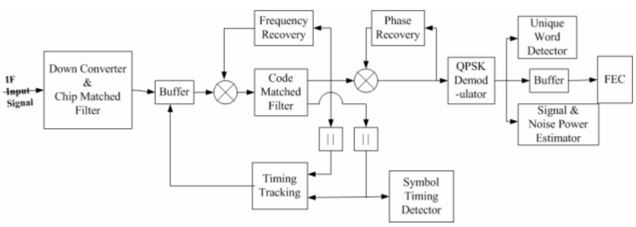


Fig. 3. Structure of CDMA Demodulation Unit(CDU)

[1] PRACH is for the purpose of maintaining synchronization and control information to the system. ACQ and DPACH bursts can be used to achieve synchronization prior to operational use of the network and only used to identify itself during logon, respectively. DPCH bursts are utilized to carry useful data from MRT to the hub station.

The features, specifications and demodulation constraints of the demodulator are summarized in Table 2. The maximum initial frequency offset is given by frequency budget of end-to-end link including RF/IF components. It is about 20 kHz. The maximum speed of MRT targets Korea Train Express (KTX).

Table 2. Demodulator specifications and demodulation constraints

Return link RF center frequency: MRT→SAT	≈ 14.25 GHz	
Return link RF center frequency: SAT→CRFS	≈ 12.5 GHz	
Low IF center frequency	4.096 MHz	
Chip rate	2.048 Mcps	
ADC sampling rate	16.384 MHz	
Max. speed of MRT	300 km/hr	
Max. initial frequency offset	PRACH	20 kHz
	ACQ	4.5 kHz
	DPACH	4.5 kHz
	DPCH	4.5 kHz
Spectrum Shape	Square Root Rased Cosine(SRRC) with 0.35 rolloff factor	
Channel Codec	Concatenated RS and CC, Turbo (optional)	

CDU consists of downconverter & chip-matched filter, code-matched filter, symbol timing detector (Searcher) & unique word detector, timing recovery block, frequency recovery block, phase recovery, block, demodulator, and Forward Error Correction (FEC) block.

The downconverter converts a digital low IF(4.096MHz) signal to baseband I/Q signals. The chip-matched filer is square root raised cosine filter with 41 filter taps. The code-matched filter performs complex code despreading. Unique Word (UW) detector correlates with known UW sequence to check burst start position. After demodulation, FEC block performs channel decoding. The key algorithm for signal recovery at CDU is introduced as follows.

The timing recovery of CDU has two-step operation for timing synchronization acquisition. The initial timing position is estimated by a half chip step at symbol timing detection block. The accurate timing position can be acquired at timing recovery block, which tracks the symbol timing position based on the estimated initial timing information. The reason of use the two-step operation, it is impossible to extract the symbol timing error when timing errors are given over one-chip. The timing recovery block's location is shown in Fig. 3. The timing recovery block controls the variable length of delay block to the direction of decreasing timing error for code matched filter output. The algorithm of timing recovery is used non-coherent tracking loop. The timing error estimator block consists of early-late discriminator, second-order loop filter, error clipper, accumulator, and quantizer.

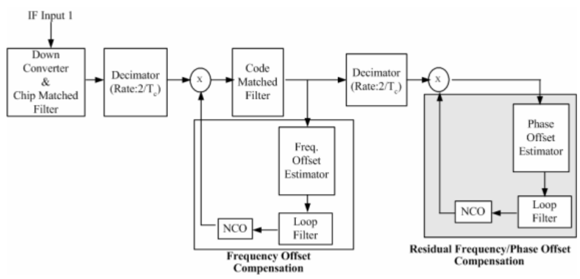


Fig. 4. Carrier recovery block for CDU.

The carrier recovery block diagram is shown in Fig. 4. As mentioned before, the carrier recovery block is composed of frequency recovery block and phase recovery block. The frequency recovery consists of frequency offset estimator, loop filter, and Numerical Oscillator Control (NCO) block.

The frequency offset estimator estimates the frequency offset by using Balanced Quadricorrelator (BQ) method. In complex coordinate, we divide the quadrant of received signal equal parts as the sixteenth. Allocating numbers to the phase of received symbol, we estimate the instant frequency offset by using the difference between previous symbol's phase and present symbol's one. It is general structure but a simple hardware structure. The loop filter works to converge the frequency recovery loop by multiplexing proper gain. The loop filter gain is set by a gearshift method.

The estimator is operated by two modes; one is coarse frequency offset estimation (mode 1) and the other is fine frequency offset estimation (mode 2). In mode 1, after initial symbol timing acquisition, it estimates frequency offset during 32-chip length for PRACH burst. The maximum initial frequency offset is ± 20 kHz in mode 1 operation. It is given by frequency budget of end-to-end link including RF/IF components. We also consider Doppler shifting for frequency offset. The initial frequency offset is estimated by using phase difference of two adjacent symbols. Then, the frequency offset remains below ± 5 kHz for all bursts (PRACH/ACQ/DPCH) during 128-chip length. The recovered output signal has below ± 300 Hz leakage frequency offset after mode 2 operation.

The phase recovery block has phase offset estimator, loop filter, and NCO. The phase offset estimator estimates phase offset and residual frequency offset corresponding to the leakage frequency offset after frequency recovery. There are two different algorithms according to burst sequence types for phase recovery; one is operated for preamble transmission duration and the other is for UW or encoded data transmission duration. The simple decision directed loop algorithm is used for phase recovery. The preamble is pilot symbol and the demodulator knows the preamble symbol. The phase offset estimator estimates phase offset by comparing input symbols to the known preamble symbols which are represented 1+j. After phase estimate during the preamble, it estimates phase offset using the difference between the received symbols and QPSK decided symbols for UW and encoded data. It means decision- directed method is used for carrier phase recovery.

RSM carries out log-on and log-off process of all MRT, and has functions of subscriber management and authentication. RSM collects the information of synchronization offset of each MRT, and transfers that information to desired MRT to keep synchronization.
RSM accepts resource demand from every MRT and performs optimum resource management. RSM has functions such as channel assignment and release according to user demands or system operation/error status. RSM processes SI signal information table defined in DVB-S PSI/SI and wireless interface specifications of interactive satellite channels for mobile satellite Internet access, and distributes/transfers it to every MRT or desired MRT in specified time. Especially, RSM transfers information on resource assignment and burst time plan to CDU and have CDU demodulate using the information. RSM transfers messages related to DVB PSI/SI table, message of synchronization offset correction, resource assignment and MRT operation status/control requirement to MRT via TDP.
Fig. 5 shows the time diagram for the capacity request and allocation procedure performed in RSM. MRTs in need of capacity send a capacity request (CR) message to RSM. Then RSM makes a terminal burst time plan (TBTP) table according to the CR message and sends the TBTP table to the MRTs. The timeslot scheduling algorithm employed in the MSIA system is an optimal algorithm. For timeslot scheduling, a binary integer programming problem was formulated and an efficient solution algorithm using a problem decomposition technique was proposed to improve the computational complexity in solving the binary integer programming problem. Details for such an approach can be found in Lee's paper [9].

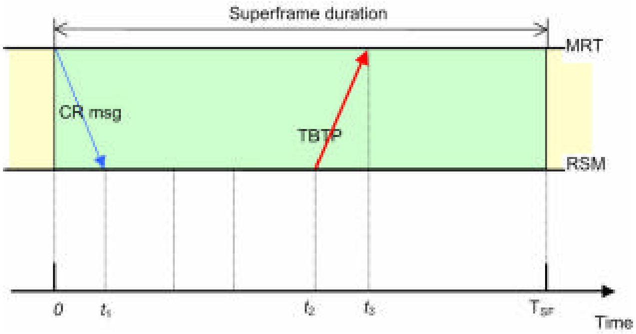


Fig. 5. A diagram of the terminal burst time plan (TBTP) table generation.

4. MSIA MOBILE REMOTE TERMINAL (MRT)

For return link, CDMA scheme is used to reduce inter satellite interference. Chip rate is 2.048Mcps, which is the appropriate value to keep quasi-synchronization on condition that time and frequency shift by movement of MRT are considered. The number 32, 64, and 128 are used as spreading factor. Data are spread by multiplying signal to the Preferentially Phased Gold Code (PPGC).
MRT is composed of Two-Way STB Subsystem (TWSS) and Active Antenna Subsystem (AAS) as shown in Fig. 6. MRT is a group terminal, which provides a lot of users with multiple channels of multimedia services. TWSS is implemented as a transportable STB for being installed in cars, ships, or planes.
TWSS is consisted of a TX/RX Data Processing Unit (TRDPU) and a CDMA Modulation Unit (CMU). TRDPU sets up and manages the interactive Internet service according to the procedures defined for MSIA system. The procedures include MAC process (terminal log-on/log-off process), assigned resource management and network synchronization, and so on. TRDPU reconstructs MPEG2-TS from analog IF signal of 950MHz ~ 2150MHz fed by AAS. TRDPU is distinguished between Forward Link Signaling (FLS) messages, A/V stream and user traffic from MPEG-2 TS stream. FLS messages are DVB PSI/SI and return link SI table information for terminal management. User traffic is IP-based Internet service data to provide Internet multimedia services.
After PID filtering of input MPEG-2 TS stream, user traffic is translated into IP packet and transferred to users through user interface like Ethernet or USB Port. Terminal management information is used to control MRT to maintain network synchronization. TRDPU receives digital satellite broadcasting channels supported by Koreasat-3 using PSI/SI information. To transmit traffic of IP packet type to hub station using return link, TRDPU carries out translation of IP

datagram to ATM Adaptation Layer 5 (AAL5) ATM Cells. TRDPU controls user authentication method which TWSS supports.

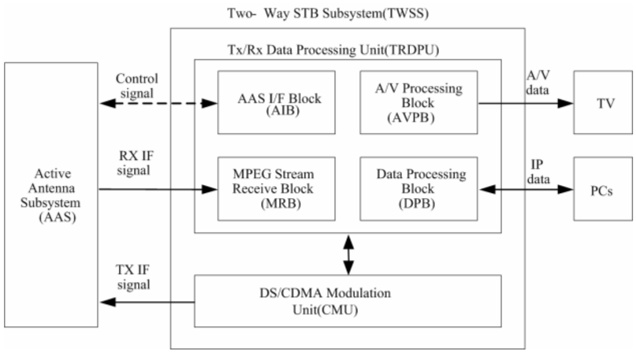


Fig. 6. Functional Block Diagram of MRT

CMU carries out channel encoding, spreading, and IF/RF modulation to transmit data of users provided by TRDPU and up-converts modulated signals. Structure of MSIA CMU is shown in Fig. 7.

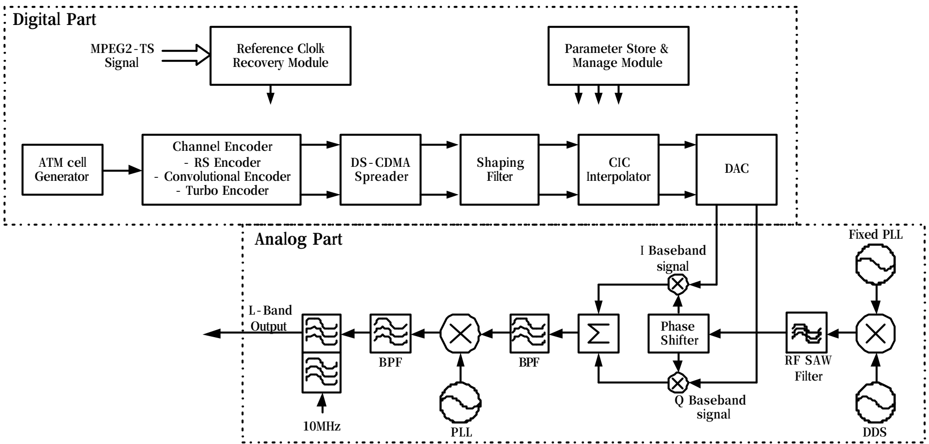
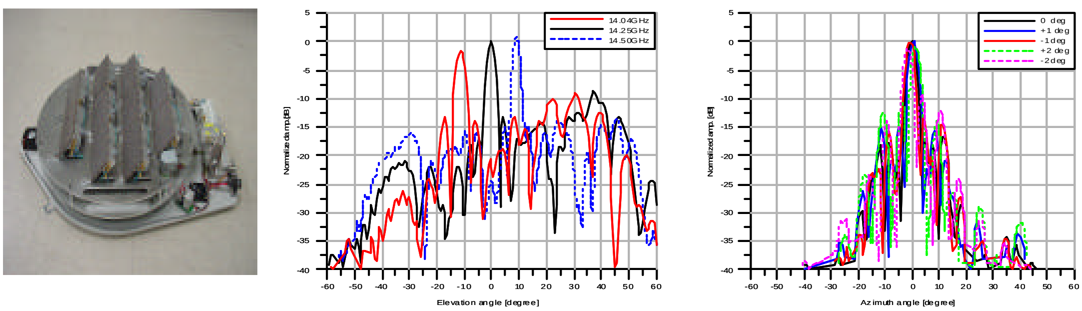


Fig. 7. Structure of CMU.

A dual Tx/Rx micro-strip active array antenna(AAS) was developed for MSIA system. Rx antenna was designed to accommodate wideband reception of Internet data and DBS signal. Its frequency ranges are 14.0 to 14.5GHz in Tx and 11.7 to 12.75GHz in Rx, and their polarizations are Vertical Pol of 76^o (VP) and Horizontal Pol of -14^o in Tx, Rx respectively. The number of elements of 8x4 in sub-array and its spacing of 18mm are chosen from the beam scan characteristics for azimuth of 4^0 and elevation of 8^0, respectively. shows structure of active antenna system and its measured Tx beam patterns during elevation and azimuth scans.The measured characteristics of active antenna such as Tx EIRP, Tx IMD and Tx beam patterns are well met to ITU-R required specification.



Active array antenna　Tx pattern during elevation scan　Tx pattern during azimuth scan

Fig. 8. Active antenna and its beam patterns

5. CONCLUSIONS

In this paper, the development of satellite broadband two-way multimedia access systems has been addressed. The mobile services turn out to be a prominent market for satellite multimedia. Currently available mobile services are limited to the DBS and narrow-band data services like email. Broadband multimedia service including high speed Internet must be provided to the mobile or transportable terminal with a broadband return channel.

A GEO-satellite based mobile Internet access network is under development for providing cars, ships, trains with interactive multimedia services including DBS in a mobile environment by using active phased array antenna and spread spectrum return link technology. The Ku-band mobile terminal is designed not to give any harmful interference to the satellites while providing variable data rate according to mobile channel condition.

We are now expecting that the MSIA will be used in future wireless multimedia service system such as mobile DBS and mobile satellite internet systems. For successful deployment of GEO based mobile multimedia services in the vehicles, low cost antenna systems and remote terminals should be prepared. And we challenge to achieve the broadband communications for GEO satellites in mobile environment.

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