Store and Forward Communication Payload Design for LEO Satellite Systems

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Received: April 2015 Revised: March 2016 Accepted: June 2016

Abstract
This paper presents the design and implementation of store and forward (S&F) communication payload for Sina-1satellite. The S&F subsystem uses VHF and UHF radio links for receiving and transmitting messages. The main purpose of the system is to provide the handling of transmitting/receiving of packet type messages via satellite. A message from one ground terminal is stored in satellite on-board memory and delivered as the satellite passes over the destination ground terminal. The two ground terminals do not have to see the satellite at the same time, and a single satellite can provide global communications coverage. The main specifications of store and forward subsystem are calculated and presented. Data transmission on downlink is performed in time division multiplex (TDM) mode. Multiple access to receiving channel of on-board transceiver (uplink) is performed according to split channel reservation multiple access (SRMA) protocol. The effect of different parameters such as the number of users, packet length and visibility time is analyzed. Phase shift keying (PSK) modulation is used for downlink and uplink transmissions. In order to enhance the performance of satellite communications link, error correction technique is used in this payload. Link calculation reveals that a packet service of 4.8 kbps can be provided without satellite tracking mechanisms. Finally the structure of the on-board S&F transceiver is presented.

Keywords: Sina-1, LEO satellite, data transmission system, transceiver, SRMA

1. INTRODUCTION

Low Earth Orbit (LEO) satellites are a low cost worldwide communication system. These satellites are located at about 500 to 1500 Km altitude. The received signal power is good enough for earth terminals and delay is also less due to its location at less altitude than Geo-stationary satellite. A satellite in low Earth orbit has only limited coverage, with a footprint diameter near 6000km. Data transmission system stores signals received from the uplink and this message then can be broadcasted later or retransmitted on demand. A single satellite in low earth orbit can therefore provide a global messaging service. This concept was first proposed by Brandon in 1957 [1] and was implemented on the Courier satellite in 1960 using on board tape recorders. A digital data transmission system transponder was pioneered on UoSAT-2 in 1984. The UOSAT networks show that a complementary role can be played by cost effective microsatellites in low earth orbit carrying digital data transmission system transponders [2]. By combining them with gateways acting as relays, information can hop from one satellite to another in order to reach destination faster than waiting for a single satellite to fly over the destination [3]. In store-and-forward APRS mode of CubeSat-class spacecrafts, the terminals use the Aloha multiple access to send their messages to the satellite and wait for an acknowledgement from the satellite, 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 implemented modules include AX.25 protocol, AFSK modulation, Convolutional encoding, and GMSK modulation [4]. ANUSAT is another satellite that carries aboard a data transmission system payload operating in Amateur (digital) mode with VHF uplink and UHF downlink operating in amateur frequency bands [5]. It provides digital communication facilities between a numbers of universities/colleges and amateur satellite radio operators. FSK receiver and turbo coder for data transmission as a technological payload is also being developed for technology validation.

The store and forward communication payload is a full duplex communication link with short and periodic access times dictated by orbital visibility. The main mission of the system is the transmission of data in the packet mode through a low-orbit satellite and the intermediate data storage in the on-board transceiver. User terminals can retrieve a directory of files stored in the spacecraft message system memory or download a specific file. Users can also upload a file to the satellite either for later broadcasting or for retrieval by some other station half-way around the world. In addition to serving several users who need the same data, there is also a need to serve users who need more traditional file and message forwarding facilities [6]. Over hundreds of users are within the satellite's footprint. The drawback of a single-satellite LEO system is that message delivery is delayed, as stations need to wait for the satellite to come into range before they can upload a message. Therefore the message must be stored on-board in the satellite onboard until the destination ground station comes into the footprint. These combined delays can range from a few seconds to 12 hours. Such delays are unacceptable for telephone or real-time service, but other applications such as electronic mail and data-platform or sensor monitoring do not depend on immediate data delivery [7].

A broad range of services can be conceived and provided by mean of S&F satellites. Some applications for example are telemedicine, file transfer on-demand, data transfer to/fro remote sites, military applications [8]. Real time telehealth is not feasible for the progressive countries like African countries. The major reason is the higher cost of hardware and communication channels. Whereas, the store and forward method based telehealth can be a cost-effect solution. It has been identified that a major problem with store-and-forward method is long time-factor that can be longer to 48 hours in certain cases. To address this issue, a concept of virtual telemedicine is proposed and an improved framework in [9]. Such store and forward satellites can be used as a communication infrastructure for sensor networks [10]. Bedon [10] and Fiza [11] investigate the potential application of a delay and disruptive tolerant network (DTN) architecture in some satellite-based scenarios. In fact, DTN nodes send ‘bundles’ of data (data units at the bundle layer) to the next DTN node, which applies the store-and-forward technique to store them in a local database until the next-hop is available. CCSDS proposed overlay architecture for DTN which is suitable for space to overcome the problem associated with intermittent communication [12].

In this paper, we have described the main considerations and solutions which should be chosen during the design and implementation of the store-and-forward payload. The store-and-forward design needs to be relatively inexpensive while at the same time should be computationally robust. Additionally it should provide the necessary interfaces for each subsystem and consume limited power.

2. SINA-1 SATELLITE AND ITS MISSION

Sina-1 satellite is the first Iranian satellite and space explorer launched on Oct. 28, 2005 on board a Cosmos-3M Russian launch vehicle. It was launched from the Plesetsk Cosmodrome in Russia. The satellite has dimensions of 80*130*160cm, weight 160kg (Fig. 1). Sina-1 satellite is a deployable solar panels configuration. It consists of two modules; payload module and service module. The service module and payload module are assembled of close isogrid milled aluminum alloy (AM6-O) using inserts and bolts fasteners. For the grounding of satellite units plates are coated whit Sn-Bi conductive coating.

Imaging payload is the main payload of Sina-1 satellite; therefore the launching satellite onto sun-synchronous orbits was preferable. In sun-synchronous, satellite ascends over the equator at the same time every day everywhere on earth. It makes it easier to calibrate, correct and compare your images. Therefore, Sina-1 was inserted into a sun-synchronous near-polar orbit at an altitude of 700Km and has a period of 98.64min. Sina-1 satellite subsystems include: Imaging payload, data transmission system payload, onboard computer system, telemetry and telecommand system, power supply subsystem, attitude determination and control subsystem, radio frequency system, thermal control, mechanical system and structure subsystems. Each subsystem of the spacecraft, including the S&F, designed and implemented with the goal of low cost and low complexity. The satellite hardware and software design should also achieve high reliability and minimize risk.

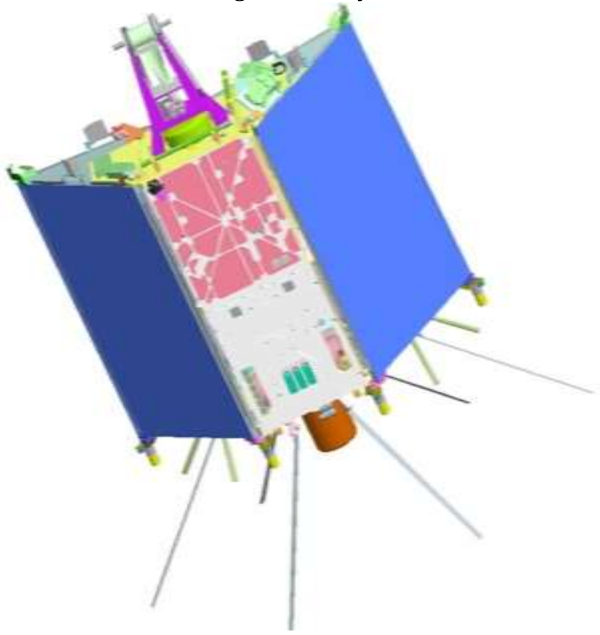

Fig. 1. Sina-1 Satellite

Fig. 2 shows the electrical block-diagram of Sina-1 satellite. Sina-1 communication subsystem consisted of two transmitters, two receivers and the related antennas. The onboard computer (OBC) monitors and controls the performance of the all subsystems. This task is performed via the software of the central computer through periodical monitoring of the electrical and thermal status of the subsystems. A PIC micro-controller is used as a main controller in on board satellite controller. Power subsystem consists of solar panels, battery, power regulation and power distribution units. This subsystem collects the solar energy and transforms it to electrical power with the help of solar arrays and distributes electrical power to other subsystems of the satellite. A PIC microcontroller was also used in power subsystem to control power charging and power peak tracking systems.

The attitude determination and control subsystem controls the orbital path and provides attitude control.

Sina-1 is stabilized by an earth pointing gravity boom and by two magnetorquers and 2 reaction wheel systems. The thermal control is done using passive control methods with elements like multi-layer and heaters. Sina-1 satellite includes an imaging payload which images the earth surface. In panchromatic mode it images a swath 50 km with a resolution of 50m and in multi-spectral mode it images a swath 500 km with a resolution of 250m. Sina-1 satellite is also attended data communication within a data transmission system payload. Sina-1 satellite is also attended data communication within a data transmission system payload. Data transmission system is shown in Fig. 3. Ground stations can be either mobile (installed on various vehicles) or stationary. Messages transmitted through the system can be of various sizes. This subsystem provides data exchanging among the ground stations in the near real time, monitoring and controlling various objects, and transmitting various data in store & forward mode.

Fig.4. shows the functional block diagram of communication links of Sina-1satellite. S&F subsystem can be used as reservation of telemetry and telecommand (TT&C) subsystem, therefore the reliability of TT&C subsystem increased. S&F processor send its telemetry parameters (such as temperature, voltage …) to the on-board computer and receive command from the OBC subsystem. S&F telemetry and telecommand data are transferred to and from the OBC using a serial port. In Sina-1 satellite, CAN bus is used to exchange data between store & forward subsystem and satellite OBC. The VHF/UHF channels are intended for the S&F payload and telemetry/telecommand subsystem. At VHF/UHF frequencies the antennas, receivers and transmitters for both the ground and the space segment, are readily available and inexpensive. Furthermore the Doppler frequency shift in this frequency is low and its compensation is easy.

In the next sections, we described the main considerations and solutions which should be chosen during the design of the store-and-forward payload.

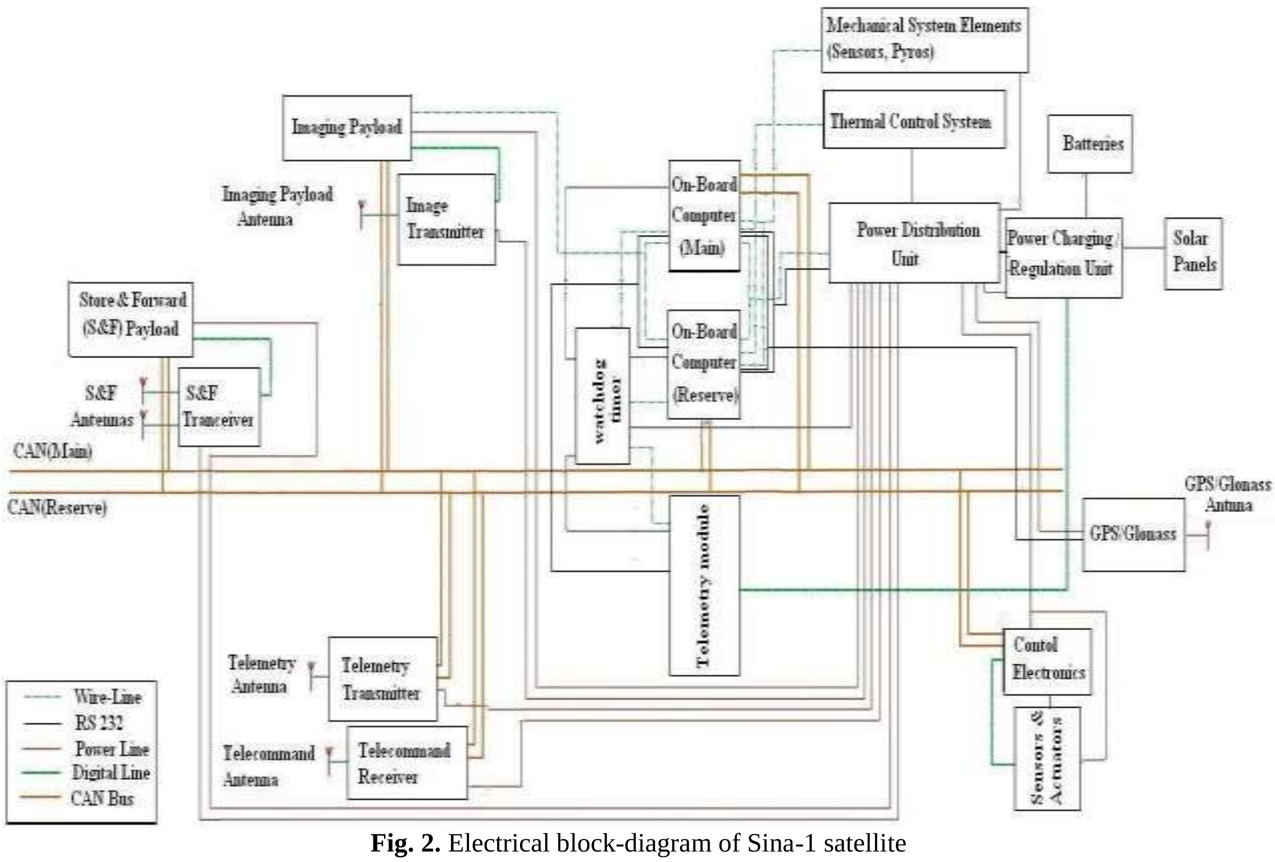

Fig. 2. Electrical block-diagram of Sina-1 satellite

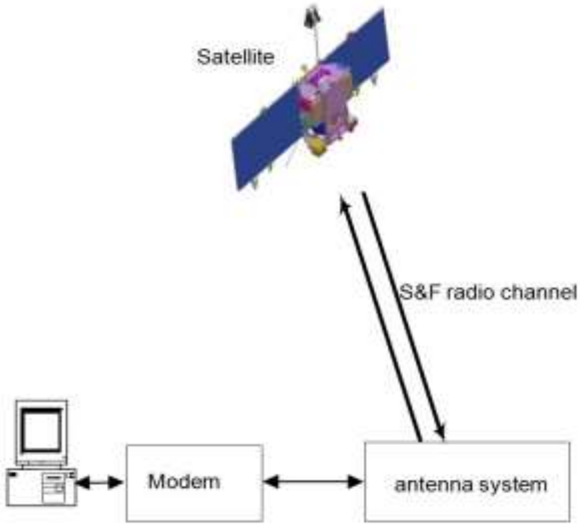

Fig. 3. Data transmission system link diagram

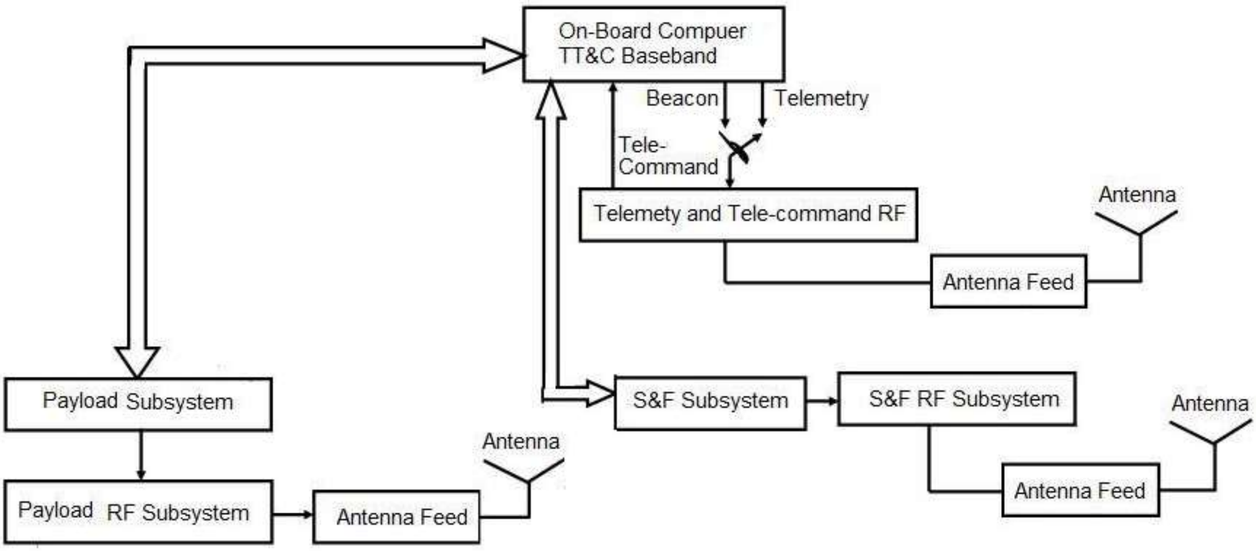

Fig. 4. Structure of communication subsystems

3. MULTIPLE ACCESSING

Fixed assignments, wherein each station is permanently assigned a specific time or frequency slot, are inappropriate for LEO store and forward message relay, because the number and identity of the ground stations in the satellite footprint changes continuously. Therefore, a random access solution seems appropriate multiple accessing (MA) method for a large number of user terminals with burst traffic consisting of small variable length data messages.

It is more difficult to find a solution that provides both good spectrum efficiency and a simple allocation method. Aloha gives fairly poor channel utilization. CSMA may be a suitable option if the propagation conditions are good between all the terminals (no hidden terminals) and if the detection delay is short. There exist no multiple access schemes which are consistently superior to all others. SRMA is both simple and efficient over a large range [9]. SRMA protocol is a centrally controlled scheme that divides the available bandwidth into two frequency time multiplex channels: one for transmitting accessing information (multiple accessing) and one for messages [13]. Users' access to the channel is followed SRMA protocol. Uplink data transmission from the user terminal to the satellite is carried out through two different channels: random access channel (RA) and reserve mode/transmission channel (RM). In RA channel users, access to the on-board receiver is based on slotted ALOHA SRMA protocol. The RM channel is provided to transmit at least one long message of users to the satellite for the period of transmitting.

The SRMA efficiency is [13]:

$$C = \begin{cases} \dfrac{1}{1+\dfrac{L_a}{L_m}e}, & for\ ALOHA \\ \dfrac{1}{1+2\dfrac{L_a}{L_m}e}, & for\ Slotted\ ALOHA \end{cases} \quad (1)$$

where L_a is the number of bits in a request packet, L_m is the number of bits in a message packet, and e is the Neper number.

Downlink data transmission from satellite to the users is carried out through one channel, (Fig.5) with time duplex of packets intended for various ground stations or station groups. The RM channel is intended for transmitting long messages from the terminal stations to the on-board transceiver. Diagram of the user terminal functioning in downlink is shown in Fig. 6. This channel is reserved for a certain time for the specific terminal station to transmit one or more messages on board. If the messages are ready for transmission at the terminal station, it will send a request to the on-board transceiver via RA channel. The request is received by the on-board transceiver and is put in a request queue. RM channel is reserved for different users in a sequence, according to the messages priority. After this, the terminal station has received the acknowledgment of the RM reserving, and the transmitter frequency changes from RA channel frequency to RM channel frequency. Data is transmitted in packet mode, both in the downlink channel and in the RM channel. The satellite manages the request queue and informs the user about his time frame for transmission of the packet. To ensure this mode, special synchron packet (SYNC) is inserted into the data transmission (from the satellite to the terminal station) channel signal. In the terminal station receiver, the terminal station local time scale is extracted from received SYNC. If at the terminal station there is a transmission packet, the terminal station sends it at the moment of time tied to the beginning of the time window. If two or more stations transmit packets in the same time window, the packets collision takes place and the on-board receiver is not able to correctly receive the packet.

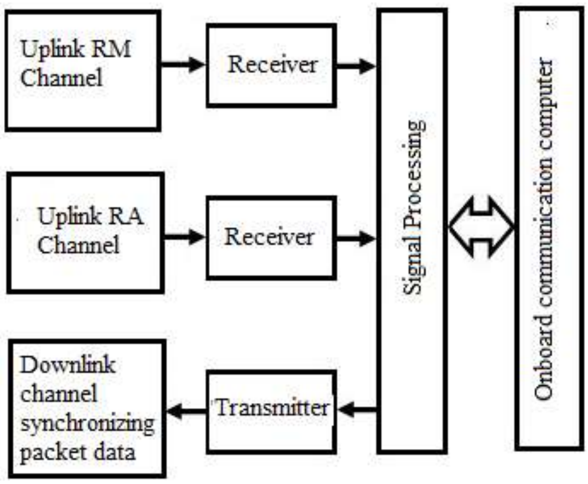

Fig. 5. Onboard transceiver structure

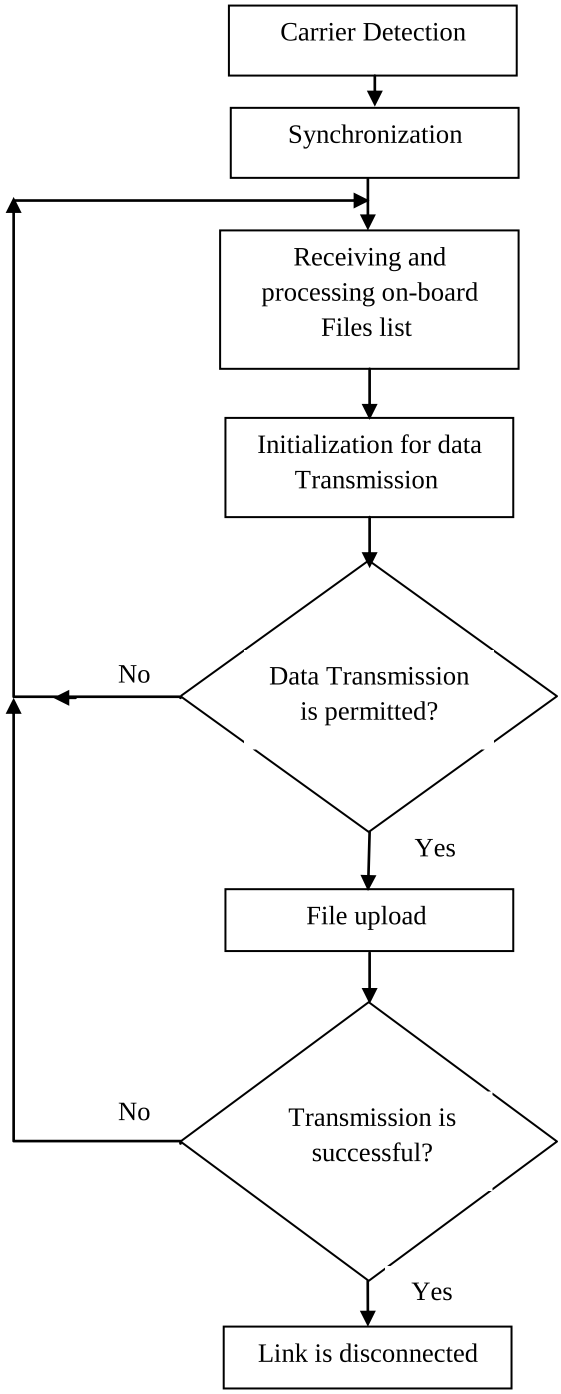

Fig. 6. Diagram of the user terminal functioning

If there is no reception collision and the packet is received correctly, the on-board transceiver confirms the packet reception by sending the correct reception acknowledgement via downlink channel.

Increment in the number of users, drops the overall throughput because a greater number of collisions was happened. Fig.7 illustrates the influence of the errors in uplink and downlink radio channels on the RA channel efficiency. It is observed that the SRMA system has a very good performance at a packet length of 250 bytes in BER of 10^{-6} and 10^{-5} and satellite visibility time of 700 seconds, but in BER of 10^{-4} efficiency decreased and the optimum packet length decreased to150. It can also be observed that a sharp decrease of the efficiency takes place in the BER of 10^{-4}, therefore, in the channel with a large level of errors the larger efficiency is reached at the smaller packet size. If the satellite visibility time decreased, the multiple accessing time decreased; therefore, the collision increased. At significantly higher packet length, a sharp increase in collisions occurred and therefore efficiency decreased.

Fig. 8 shows the efficiency versus packet length for three different visibility times in BER of 10^{-4}. The goal is to design a system with limited visible time for different scenarios. One scenario is for maximum link usage in which a user access to link and sent its data in all duration of visibility time (700 sec). Regarding the maximum visibility time, the second scenario is for users positioned at the margin of visible region with visibility time of 50 sec or less. Finally the third scenario is considered for a time between these two viability time durations. As it is observed from Fig. 8, for BER of 10^{-4} in all scenarios, the optimal packet size is 100 bytes. Generally, it can be said that when the BER is low (near 10^{-6}), the visible time more than 300 sec, is not much influencing the efficiency and therefore, the limited visible time condition can be selected in the system design (Fig. 9). As it is seen, visibility time less than 300 second affects the efficiency and should be considered in the system design. On the other hand, for the visibility time more than 300 sec, natural noise affects the efficiency more than time restriction. From whatever that we have discussed it can be conclude that, first, in the case that independence of users, the goal is to benefit from link, packet sizes are selected equal to 250 bytes, and second, if the aim is to provide access for users in the margin of the visible region, the packet sizes are chosen equal to 100 bytes. Therefore, the long messages is divided into several fragments and then the reverse steps performed by the receiver.

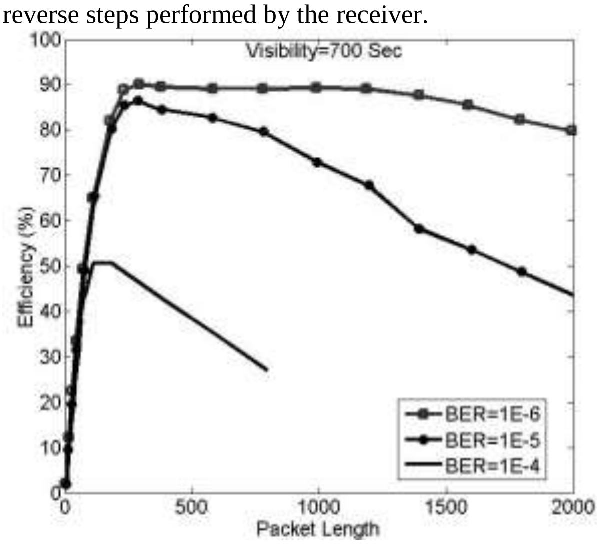

Fig. 7. Efficiency of SRMA in different visibility time

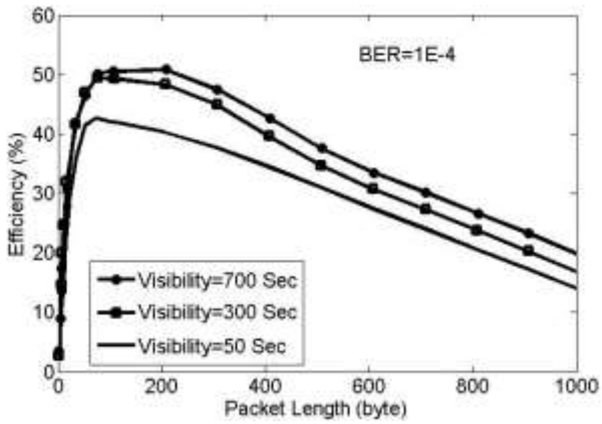

Fig. 8. Efficiency of SRMA in different visibility and BER of 10^{-4}

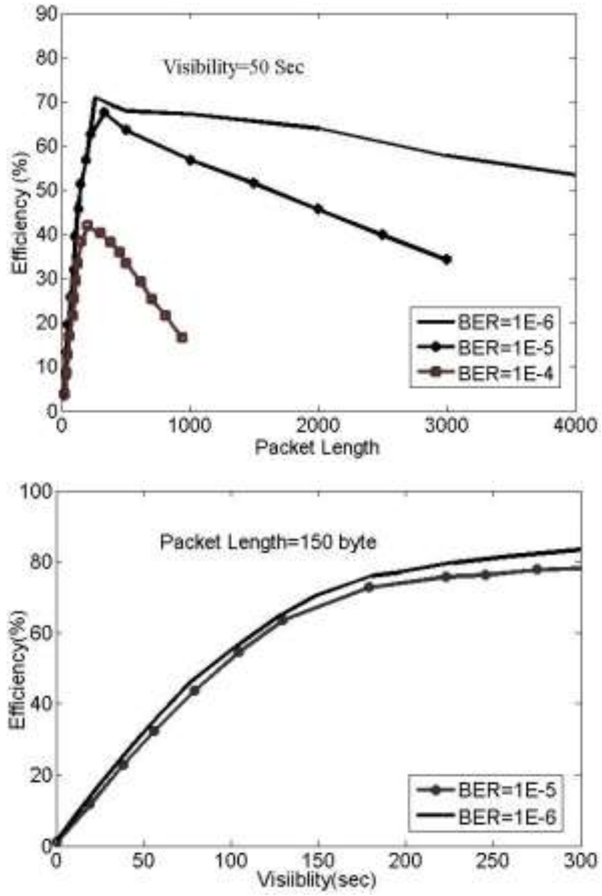

Fig. 9. Efficiency of SRMA in different BER and visibility time with packet length of 150 byte

4. CODING AND MODULATION

Choice of coding and modulation schemes affects how successfully data can be transmitted over the satellite link. Although many schemes are possible, the problem is that transmitter and receivers must use matching schemes. In this system, an independent coding and modulation is used; therefore, the spectral efficiency may be obtained by scaling the uncoded spectral efficiency by the code rate and applying coding gains to required uncoded E_b/N_0 values for BER performance. As it is seen from Figs.10 and 11, BPSK modulation has the best performance; therefore, this modulation has been used with square-root raised-cosine shaped pulses.

To enhance the radio link between the users and the satellite, a forward error correction scheme was added. Despite the success of block codes, there are several fundamental drawbacks to their use. First, due to the frame-oriented nature of block codes, the entire code word must be received before decoding can be completed. The second drawback is that block codes require precise frame synchronization. The third drawback is that the most of the algebraic-based decoders for block codes work with hard decision decoding, rather than soft decision. However soft-decision decoding seemed to be too complex to be implemented [14-15].

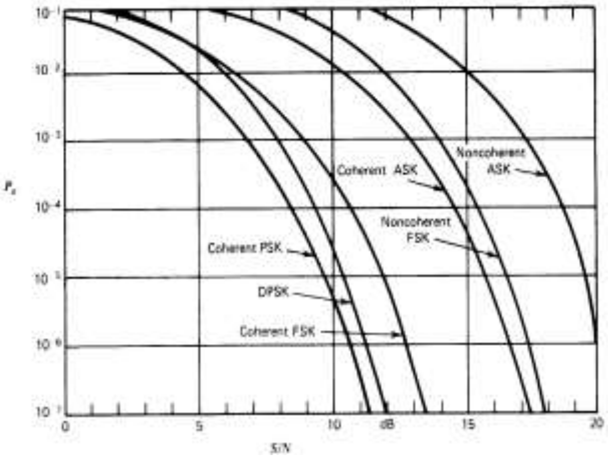

Fig. 10. Performance of different modulation scheme in rural environment [18].

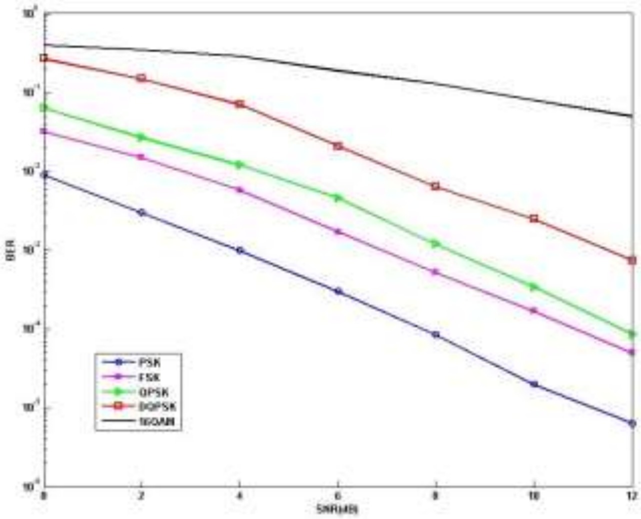

Fig. 11. Performance of different modulation scheme in Suburban environment (Rice factor = 4 dB) [14].

Performance comparison (upper bands) between convolutional coded BPSK and OPSK with coding rate of 1/2 and rice factor (ζ) of 0 and 10 dB are shown in [17]. It can be seen, the performance of rate 1/2 convolutional code with QPSK is worse than BPSK. However, for fading channel relative degradation is slight. It is also seen that by increasing the constraint length, the code performance enhances but decoding complexity increases. Because of appropriate performance and acceptable complexity, constraint length of 5 was selected for data transmission system payload. Also in fading channel (ζ=0), for BER of 10^{-6}, E_b/N_0 of 11 dB is required, which is less than required SNR in link budget calculations.

4.1. Doppler Shift and Its Correction

The satellite orbital motion and the earth's rotation can result in Doppler shift in the received radiation spectrum that is:

$$\Delta F = (V_R / c) \times F_0 \tag{2}$$

where ΔF is the Doppler frequency shift, F_0 is the signal frequency, V_R is the satellite velocity relative to the ground station and c is the light speed.

In order to calculate the value of frequency Doppler shift the satellite orbit can be considered absolutely circular with 700 km average altitude and 98 degree inclination. Because of large Doppler changes in the communication link, Doppler has to be precorrected to make ensure that user terminals can easily synchronize to the central transmitted frequency. The user terminal memory contains the current satellite orbit parameters that are periodically updated upon receiving of the journal, which contains orbit determination parameters. Besides, the user terminal station is aware of its position (stations are equipped with GPS receivers). The user terminals are equipped with a processing unit which uses a software to carries out the Doppler correction of the transmitted and received frequencies. To make its calculations, the software needs terminal geographical position, UTC time and the satellite orbit parameters. The first two parameters are given by internal GPS receiver of user terminals while the third parameter is given by the receiving journal. The main S&F user terminal is near the satellites central ground control station, therefore this terminal could receive the satellite orbit parameters from the central station which regularly communicates the updated the satellite orbit parameters to all the terminals. Based on these data, the terminal station processor calculates the Doppler frequency shift and sets the receiver and transmitter synthesizers taking into account the obtained value.

4.2. Link Budget

Calculation of the radio channel power parameters is based on the assumption that the received signal to noise ratio at the receiver input allows to achieve the specified bit error probability. The small satellite platform offers limited downlink power and a small antenna. The on-board antennas patterns are rather different from optimum. In other words, the signal power density in the border of the coverage area is lower than in the middle. Thus, in order to ensure acceptable communication with small elevation angles, the terminal station antenna should have maximum gain in the horizontal plane (80–85° direction from the vertical) and its pattern should be symmetrical relative to the vertical axis. Link budget calculation (Table 1) for this system reveal that a packet service of 4.8 kbps can be provided using both a simple onboard antenna and a user terminal without satellite tracking mechanisms. The link budget shows that a 4.8 kbps can be achieved with user terminals having an output power of 5 W. As it is seen for the elevation angle above 10 degrees, the link performance is satisfying.

Table 1. Link budget parameters

Fundamental Parameters	**Uplink**	**downlink**	**Uplink**	**downlink**	**Uplink**	**downlink**
Frequency (MHz)	146	435	146	435	146	435
Transmit Power (Watts)	5	5	5	5	5	5
Transmit Line Loss (dB)	1	1	1	1	1	1
Transmit Antenna Gain (dBi)	1.8	1.8	1.8	1.8	1.8	1.8
Bit Rate (kbps)	4.8	4.8	4.8	4.8	4.8	4.8
Elevation Angle (degrees)	5	5	7	7	10	10
Range (km)	2563	2563	2389	2389	2155	2155
Polarization Loss (dB)	4.8	4.8	4.8	4.8	4.8	4.8
Atmospheric Fading Margin (dB)	0.5	0.5	0.5	0.5	0.5	0.5
Multipath Fading Margin (dB)--for 1 direct array and 1 reflected array.	6	6	6	6	6	6
Received Noise (dB) above KTB,	3	3	3	3	3	3
Receive Antenna Gain (dB)	5.3	5.3	5.3	5.3	5.3	5.3
Receive Line Implementation Loss (dB)	1	1	1	1	1	1
Receive Bandwidth	9.6	9.6	9.6	9.6	9.6	9.6
Receive Noise Figure (dB)	2	2	2	2	2	2
Required Receive Signal/Noise (dB)--This is for a bit error rate of 10^{-8}.	12	12	12	12	12	12
Transmit Power (dBm)	37.0	37.0	37.0	37.0	37.0	37.0
Free Space Path Loss (dB),	143.9	153.4	143.3	152.8	142.4	151.9
Receiver Noise Floor=KTB (dBm),	-134.2	-134.2	-134.2	-134.2	-134.2	-134.2
Effective Receiver Noise Floor (dBm)	-131.2	-131.2	-131.2	-131.2	-131.2	-131.2
Transmit Effective Radiated Power (dBm)	37.8	37.8	37.8	37.8	37.8	37.8
Propagation Losses (dB)	155.2	164.7	154.6	164.1	153.7	163.2
Signal Level At Receive Antenna (dBm)	-117.4	-126.9	-116.8	-126.3	-115.9	-125.4
Signal Level At Receiver Input (dBm)	-113.1	-122.6	-112.5	-122.0	-111.6	-121.1
Received Signal/Noise (dB)	18.1	8.6	18.7	9.2	19.6	10.1
E_b/N_o(dB)	21.07	11.59	21.68	12.2	22.58	13.1
E_b/N_o(margin)dB	**9.1**	**-0.41**	**9.68**	**0.2**	**10.6**	**1.1**
Required S/N for Rate 1/2	8.1	8.1	8.1	8.1	8.1	8.1
Signal/Noise Margin with FEC (dB)	**10.0**	**0.5**	**10.6**	**1.1**	**11.5**	**2**

5. PROTOCOL AND FILE SIZE

The file size and bit rate depend on a number of factors, including message length, satellite visibility time, protocol structure, random access algorithm, and the number of users. While high bitrates, the probability of collision drops and the size of transmitted and received message can be increased, But higher bit rates need more power and frequency bandwidth. Rates of 2.4, 4.8, or 9.6 Kbps are chosen based on user traffic. The minimum memory size is calculated assuming a single user only because in this scenario the whole visibly time period is used for data receiving. In a multiple user scenario, a proportion of the visibility time period is used as a two-way reservation set-up paging channel between terminals and the base. Therefore the required memory size is less than single user only scenario. Given a satellite daily access time of 40 minutes (4 observation orbits), a bit rate of 4.8 Kbps and a multiple access time of 15 seconds, the maximum transmitted data for one user is:

$$\begin{aligned}&Maximum\ transmitted\ data=\\&\left[\begin{matrix}(satellite\ daily\ access\ time)-\\(observed\ orbital\ number)*(MA\ time)\end{matrix}\right]*(bit\ rate)\\&=(40*60-4*15)*(4800)=11232000\ bit\\&=11.232\ Mbit\end{aligned} \tag{3}$$

Therefore the minimum size of memory is 12 M. To ensure reliable data storage the stored data must be triplicated. For this purpose the ROM data capacity must exceed 32 MByte. If the protocol header is about 20 %, which is reasonable while using block code, the maximum efficient transmitted data is:

$$\begin{aligned}&Maximum\ efficient\ data\ =\\&(efficient\ transmitted\ data)*\\&(1-(percentage\ of\ \ protocol\ header))\\&=11.232*.8=8.9856\ Mbit\approx 9Mbit.\end{aligned} \tag{4}$$

When increasing the number of users, multiple access time increases, therefore the overall data rate decreases. Because the messages transmitted through the system can be in various sizes, the message average size is about 4 Kbytes and the message maximum size is 64 Kbytes. Messages longer than 64 Kbytes have to be split into shorter ones.

It is possible to increase the store and forward capacity by using a satellite constellation which is not in scope of this paper. Store and forward satellite constellations use a sparse network of LEO satellites. The design process of data transmission system payload of a LEO satellite constellation is the same as our design process except in constellation a routing process should be added. Satellites are interconnected by gateways relaying message. Most of these satellites used asynchronous transfer mode (ATM) protocol for routing process [19, 20]. The communication protocols use a layered approach, like conventional computer communication protocols. At the lower level, HDLC is used to provide packet multiplexing.

6. ON-BOARD TRANSCEIVER

The on-board transceiver is initialized by the on-board store and forward computer. The average time of on-board transceiver operation during one orbital pass of the satellite for a user terminal at Tehran is about 10 minutes. During one orbit, the transceiver can be initialized several times when the satellite passes above the user terminal location areas. The transceiver consists of two identical radio frequency paths. Each channel includes two receivers and one transmitter. Receivers of both channels can operate in two modes: random access mode and reserving and messaging mode. Each modem consists of receiving channels, one transmitting channel, and a modem controller. The modem controller ensures the processing of the received and transmitted messages as well as controlling the signals from the communication processor, output power level and setting the operating parameters. The general structure of the on-board transceiver is shown in Fig.12. The on-board receiver (Fig. 13) is made according to the scheme with a double frequency conversion and ensures simultaneous data reception in two frequency channels. The high-frequency section (channel), low-noise amplifier, and the first frequency converter are common for both low-noise channels. After the signal passes through the first intermediate frequency amplifier, it is split in two similar channels. After the second converter, it enters the analog-to-digital converter and then to the signal processor. The signal processor performs filtration, demodulation, and decoding of the received signal. The received packet is temporarily stored in the memory device of the signal processor and then it is transmitted to the OBC via RS-485 interface. A sufficient ROM capacity should also be used to store at least three copies of software code. For this purpose the payload includes a minimum 32 MByte flash memory. All data are stored three times in physically independent configuration areas of the flash memory. The S&F onboard computer may work with one of them without functionality loss. RAM is necessary to execute the on-board software code and store the data temporary. A full-duplex CAN interface is also used for serial communication with the satellite on-board computer which corresponds to the standard CAN 2.0B. I^2C driver is also used for the reception and handling the temperature sensor data of the S&F onboard computer.

The block diagram of the S&F on-board transmitter is shown in Fig. 14. The packet transmitted via RS-485 interface from the S&F onboard computer enters the signal processor and is temporarily stored in its memory device. After this, the signal processor forms modulation and the modulator output is filtered and supplied to the balanced mixer. The signal of *SYNTH2* synthesizer is supplied to the second input of the balanced mixer. Finally the signal is filtered and amplified and transmitted by antenna.

An effective technique for tolerating faults in S&F subsystem is to use of redundant radio equipment and redundant on-board S&F computer units. Using same components to construct redundant system improve the reliability of spacecraft. When a component becomes unreliable or fails completely, it can be isolated and a redundant component can be configured for use.

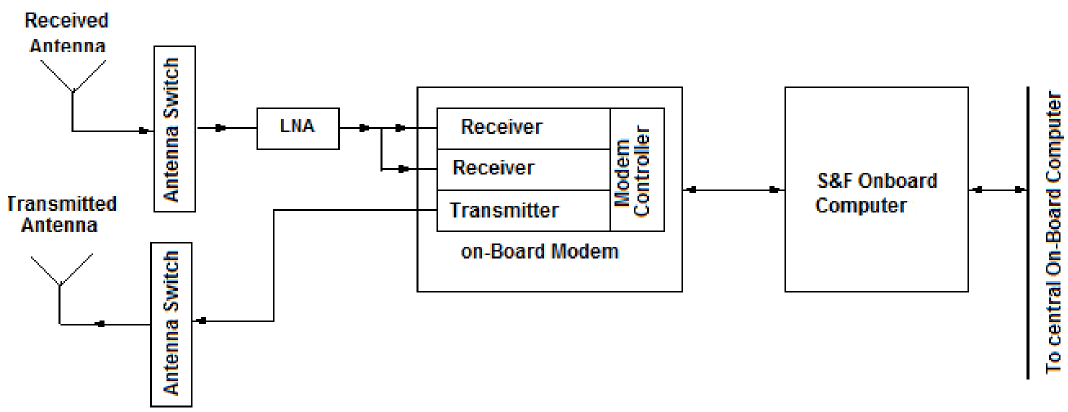

Fig. 12. Structure diagram of the on-board S&F transceiver.

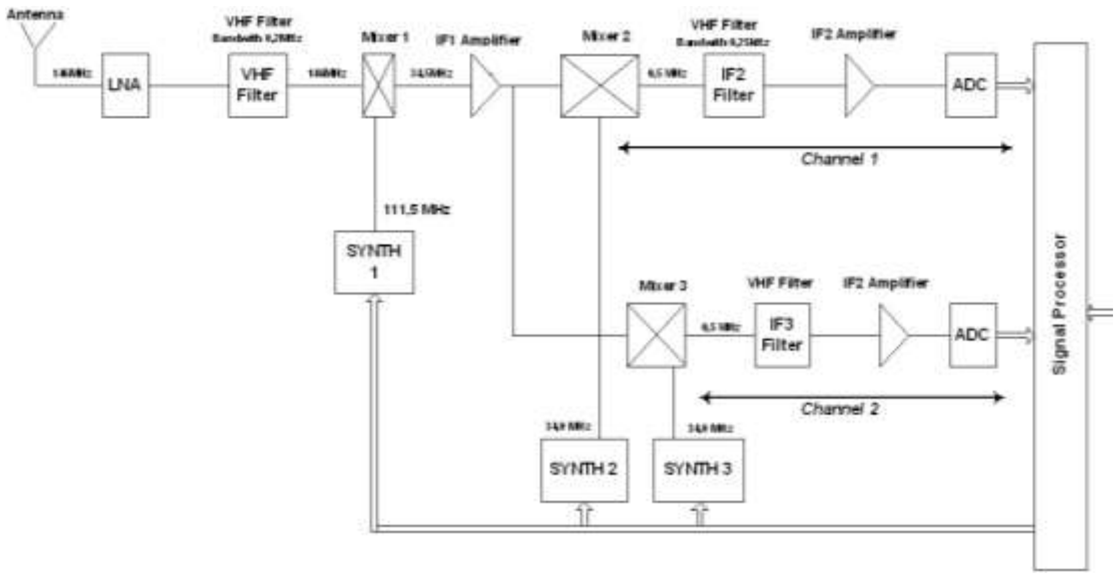

Fig. 13. On-board receiver block diagram

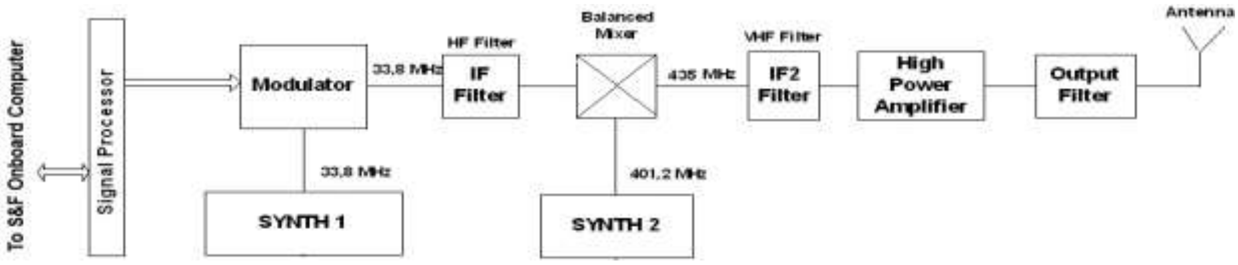

Fig. 14. Block diagram of the S&F on-board transmitter

CONCLUSION

In this paper, the design process and the characteristics of a typical store-and-forward system was presented. Users' access to the channel is based on SRMA protocol. We have shown that the SRMA system has a very satisfying performance at a packet length of 250 bytes in BER of 10^{-5}. PSK modulation with rate 1/2 convolutional coding and Viterbi decoding is used in onboard and user terminals to enhance the radio link quality of service. Link calculation for this system has shown that a service of 4.8 kbps can be provided using a simple onboard antenna system configuration. Onboard receiver and transmitter used circular-polarization antennas. The on-board transceiver structure was described which consists of two receivers and one transmitter. Each receiver can operate in two modes: random access mode and reserving and messaging mode. Finally the on-board transceiver structure and electronic hardware of payload processor was introduced and discussed.

REFERENCES

[1] W.T. Brandon, **"A data courier satellite system concept"**, *Proceedings of the XXIII Convegno Internationale*, Genoa, Italy, October 1973.

[2] Allery, M.N. Ward, J.W, **"The potential for store-and-forward communications using small satellites in low Earth orbits"**, 3rd *European Conference on Satellite Communications - ECSC-3*, 2-4 Nov 1993.

[3] H. C. Sánchez, L. Franck,A. L. Beylot **"Precomputed routing in a Store and Forward satellite constellation",** 2007 *IEEE 66th Vehicular Technology*, pp. 240-243, Baltimore, MD.

[4] A. Addaim a, A. Kherras a, E.B. Zantou b, **"DSP implementation of integrated store-and-forward APRS payload and OBDH subsystems for low-cost small satellite"**, Aerospace *Science and Technology* 12 (2008) 308–317.

[5] K. Thyagarajan, J.P. Gupta, P.S. Goel, K. Jayaraman**," University small satellite program—ANUSAT"**, *Acta Astronautica* 56 (2005) 89 – 97

[6] R. J. Diersing, **"The development of low earth-orbit store-and-forward satellites in the amateur radio service"**, *IEEE Telesystems Conference*, pp. 378-386, 19-20 May 1992, Texas.

[7] M. H. Hadjitheodosiou, **"Store-and-forward data communications using small terminals and microsatellites"**, *Third IEEE Symposium on Computers and Communications*, 1998, pp: 79-83, College Park, MD, 30 Jun-2 Jul 1998.

[8] M. Antonini, A. D. Luise, M. Ruggieri, D. teotino, **" Satellite data collection & forwarding systems"**, *IEEE A&E Systems Magazine*, pp. 25-29, September 2005

[9] S. Kareem and I. S. Bajwa, **"A virtual telehealth framework: applications and technical considerations",** *IEEE 7th International Conference on Emerging Technologies*, Islamabad, 5-6 Sept. 2011

[10] H. Bedon, C. Miguel, A. Fernandez, and J. S. Park, **"A DTN system for nanosatellite-based sensor networks using a new ALOHA multiple access with gateway priority"**, *Smart Computing Review*, Vol. 3, No. 5, October 2013.

[11] S. Fiza, **"FPGA implementation of space qualified bundle protocol for satellite communication"**, *international journal of innovative research and studies*, Vol. 3, Issue, 5, may 2014

[12] V. Cerf, et al., **"Delay tolerant networking architecture"**, RFC4838, Reston, Virginia; ISOC, April 2007.

[13] F. A. Tobagi and L. Kleinrock, **"Packet switching in radio channels: part III-polling and (dynamic) split-channel reservation multiple access"**, *IEEE Transactions on Communications*, Vol. Com-24, No. 8, August 1976.

[14] D. Abbasi-Moghadam, V. T. Vakily, keyghobad, **"choice of coding and Modulation in space communication systems"**, *WOCN 2004*, Mascut, Sultan Qabous university, Oman.

[15] D. Abbasi-Moghadam, V. T. Vakily, **"Combination of Turbo Coding and Cryptography in NONGEO Satellite Communication Systems",** *4th International Symposium on Telecommunications (IST2008)*, Tehran, Iran, Aug. 2008

[16] M. C. Valenti, "The evolution of error control coding", [Online]. Available: http://wenku.baidu.com/view/07226b2abd64783e09122b86.html?from=related

[17] Chen, Y.-L., **"On the performance of rate 1/2 convolutional codes with QPSK on Rician fading channels"**, *IEEE Transactions on Vehicular Technology*, Vol.: 39, Issue: 2, pp. 161-170, May 1990.

[18] J. G. Proakis and M. Salehi, **"Digital Communications"**, (5th edition*), Mc. Grow Hill International edition*, 2008.

[19] T. Koritza, J. M. Bellardo, **"Increasing CubeSat downlink capacity with store-and-forward routing and data mules"**, *IASTED International Conference on Wireless Communications*, Alberta, CAN. Jul. 2010.

[20] H. Cruz-Sanchez, L. Franck, A-L. Beylot**," Precomputed routing in a store and forward satellite constellation"**, *2007 IEEE 66th Vehicular Technology Conference*, doi: 10.1109/VETECF.2007.6