Simulating and Auditing the Messaging System of the Leo Maroc-Tubsat

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Abstract: The use of a single LEO microsatellite for data collection implies a complex hardware and software architecture both of the satellite payload and the ground terminals, especially when they are designed to be small, lightweight and economical. On December 10th 2001, the CRERS launched its first experimental LEO Satellite (MAROC-TUBSAT). The aim of this paper is to present the results of the OPNET simulation of the low cost Store and forward communications system of MAROC-TUBSAT and some propositions to enhance its performances.

Key words: Microsatellite, Communication System

INTRODUCTION

The use of a single microsatellite in a low earth orbit combined with low cost ground terminals allows a very economical space communications system. Large rural areas could be covered by the satellite and be supplied with various services, such as data collection, messaging and mobile localization. A central ground station could gather data via the microsatellite from worldwide remote sites. The store-and-forward communication payload allows taking advantage of the global coverage of the satellite in a low earth orbit by reducing the ground infrastructure. By making the ground terminals autonomous and intelligent, the ground station receives data regularly from inaccessible zones where human presence is expensive and difficult to support. In this paper we present an OPNET model of an experimental LEO satellite messaging system network, an evaluation of the maximum number of terminals processed in a given area (Moroccan territory) and the performances of the used protocol.

1. System Architecture

The network consists of a sun-synchronous polar orbit microsatellite (altitude 1000Km, inclination 98°) and many fixed and mobile terminals.

1.1. Store and Forward Communication

Overview

Some Technical Characteristics of the satellite communications system are as follow:

- TTC Half duplex PTT (push to talk) UHF bidirectional channel, Modulation FFSK, 1200/2400 Baud, 3.5W RF output,
- Messaging Half duplex PTT (push to talk) VHF bidirectional channel, Modulation FFSK, 1200/2400 Baud, 5.0W RF output,
- Store-and-Forward Communication system,
- Aloha stop-and-wait access method, CRC and FEC check.

Digital Store-and-forward communication via LEO (Low Earth Orbit) satellites is a method for non-real-time communication of digital information. The originating ground terminal sends the collected data message to the LEO satellite, the satellite stores this message in its on-board memory, and the destination ground station later retrieves it. Between the storage and the retrieval of the message, the LEO satellite moves around its orbit and the Earth rotates on its axis. These movements change the satellite’s communications footprint, bringing it to different areas of the Earth. Thus, the satellite physically carries the message from one ground station to the other, and the destination ground station is not necessarily in the satellite footprint at the same time as the originating ground station.
The drawback of a single-satellite LEO system is the delay in the message transfer from the ground terminal to the central station due to the nonpermanent visibility of the satellite. The originating ground terminal must wait for the satellite to come into range before it can upload a message, and then the message must be stored on-board the satellite until the destination ground station comes into its footprint. These combined delays are not suitable for telephone communication but are rather dedicated to other applications such as messaging or data-platform monitoring with limited financial budget.

The main missions achieved by the system are data collection, localization (position reporting), and messaging.

The data collection mission consists of collecting various data from remote sites. Examples include drifting buoys for oceanography and autonomous weather stations in inaccessible sites. The messaging mission allows message exchange between two ground terminals or between a terminal and a central station. This is useful in the areas not covered by any other communication system: examples include latitudes above 80 degrees where the GEO satellites coverage is no longer available. Any mobile with a localization ground terminal can be tracked by the central station which plots its path on a map using data received from the terminal. Ground terminals for all the three missions have the same hardware, except the message source which is a keyboard for messaging, sensors for data collection and a GPS (Global Positioning System) receiver for mobile localization.

During the non visibility of the satellite, the ground terminals collect data (position or sensor value) at regular intervals and store it in its memory. When the satellite comes into range the whole data stored is packetised and transmitted. The amount of data that a ground terminal is allowed to transmit depends on the capacity of the satellite RF channel and the number of terminals we want to operate.

An orbit calculation algorithm is implemented inside the ground terminal to predict the satellite passes. At any time the terminal is able to predict any satellite passe and its elevation angle relative to its current position. This feature has many advantages. First, the terminal can operate in an automatic manner without any human operator or any interrogation from satellite (CSMA) [OPN 02]. Second, there is no need for a PC or laptop which makes the terminal heavy and difficult to carry. Third, a power saving method is achieved: the terminal transmitter is keyed only when the satellite is in good visibility range. Fourth, since each terminal calculates the satellite elevation angle, a certain priority in the transmission protocol can be implemented for the terminals in order to increase the system capacity in terms of number of terminals processed.

1.2. Satellite Communication Session

Once the satellite comes into range the ground terminal starts a communication session to transmit all the collected data in its memory using a stop-and-wait ARQ (automatic repeat request) protocol. Data is segmented into packets with constant length (2480 bites) which are successively sent to the satellite along with a calculated CRC (Cyclic redundancy check). The same packet is retransmitted until an ACK (acknowledge) is received. After each packet received successfully the satellite need about 0.6666 s to handle the packet and send an ACK. The length of the acknowledge packet is 800 bits. During the period of the ACK sending, no packet can be received by the satellite (PTT). Each time any packet is to be transmitted, the terminal calculates satellite elevation to check if it is still visible. The communication session ends when all previously stored packets are acknowledged by the satellite or when the satellite is out of visibility. The ground terminal then returns to stand-by mode.

The access to the satellite channel is purely random. All the ground terminals using the satellite transmit their packets without caring about the other terminals. When a collision occurs the packet is retransmitted after a random interval time. The Aloha multiple access [ABR 92] is chosen for its simplicity in implementing the hardware and software of ground terminals as well as the satellite payload.

2. OPNET Simulations

As mentioned above, the network consists of a microsatellite and fixed or mobile terminals dispatched worldwide. The aim of this study is to evaluate the performances of the communication system within a given area.

Figure 3 presents the top level of the OPNET developed network. It includes a satellite node and
terminals nodes.

Figure 3: Network model

2.1. Nodes Models

Terminals are allowed to send messages only when the satellite is in the visibility range. Hence, we developed two models to simulate this. The first one is based on a satellite beacon with an onboard transmitter able to warn the terminal when visibility occurs [OPN 03]. The second one is an orbito process in the terminal node. This process is able to calculate the elevation of the satellite and warn the terminal when it is positive via a statistic wire. Both of the models lead to the same results.

Figure 4: CSMA Satellite and Terminal Nodes

Figure 5: Orbito Satellite and Terminal Nodes

Since the CSMA mechanism was detailed in several tutorials and contributed models and since there is no CSMA in MAROC-TUBSAT satellite, in the following paragraphs, we’ll present only the orbito mechanism.

2.2. Terminal Process Models

The main process in the terminal node is the Tx_Process. This process handles packets arriving from the Generator, queue them and wait for the satellite visibility. When this event occurs and the queue isn’t empty the transmission begins. During this state, a packet is sent and a timer is set on. The process wait for an acknowledge packet from the satellite (via Rx_Process) according to the stop-and-wait protocol. If the acknowledge is received, the process goes to the idle state, otherwise it continues to resend until receiving the acknowledge packet or until the satellite goes out of visibility.

Figure 6: Tx_Process Process Model
Another important process in the terminal node is the orbito process (Figure 7). This process calculates the satellite elevation each 10s, and instructs the Tx_process to begin a communication session when the elevation is higher than 10°. A self interrupt is used because OPNET is event oriented rather than time oriented. OPNET provides the satellite coordinates using an STK file and the process calculates the terminal-satellite vector coordinates in the ECF (Earth Centered Fixed) system. By means of a transformation matrix, the terminal-satellite vector is expressed in the topocentric coordinate system relative to the terminal location. The satellite elevation is then derived using simple trigonometric formulas. If the satellite elevation is greater than the desired mask, the process generates an interruption to the Tx_process via a statistic wire.

Figure 7: Orbito Process

Each ground terminal then knows exactly when the satellite is coming into its range. The time point at which a terminal begins its communication session is not the same for all the terminals, and the session stops as soon as all the data packets stored in the terminal queue are successfully transmitted. The number of terminals simultaneously present in the satellite footprint is then constantly changing during the satellite pass.

2.3. Satellite Process Models

The Satellite node consists of 1 processor, 1 subqueue, 1 transmitter, 1 receiver and 1 antenna module. After the initialisation, the OnBoard_Process module enters a wait state and waits until receiving a packet. If the received packet is valid, then an Acknowledge packet is sent to the terminal. Otherwise, the packet is destroyed and the process comes back to the wait state.

Onboard the Maroc-TUBSAT a push to talk transceiver was used, allowing just transmitting or receiving. Since OPNET doesn’t offer such device in the standard models we added a (PTT) state in the Onboard_Process. The process enters this state every time the transmitter is busy and changes the attributes of the receiver so that no reception is allowed.

At the end of the simulation the statistics are recorded before the exit.

The process Nb_Terminals (Figure 9) calculates periodically the number of the terminals able to communicate with the satellite.

Figure 9: Nb_Terminals Process

2.4. QoS assumptions and analytical predictions

Let us assume that our system must allow each terminal to send 4.5 packets per day. Each packet consists of 2480 bits. We’ll try to find out the number of terminals able to work successfully in a same area under those assumptions.

During the simulation (1 Day), the satellite ephemeris (Latitude, Longitude and Altitude) are predicted thanks to a file imported from the Satellite Tool Kit (STK). According to this file, the satellite is visible 5 times in the chosen location of the terminals (-6.79314°, 34°.0537). The satellite visibility time is 5027s during the considered day.

Table 1: Period of satellite visibility

<table>
<thead>
<tr>
<th>Passage</th>
<th>Beginning</th>
<th>End</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>08h43mn54s</td>
<td>08h57mn56s</td>
<td>0842s</td>
</tr>
<tr>
<td>2nd</td>
<td>10h26mn05s</td>
<td>10h43mn15s</td>
<td>1030s</td>
</tr>
<tr>
<td>3rd</td>
<td>12h11mn15s</td>
<td>12h16mn19s</td>
<td>0304s</td>
</tr>
<tr>
<td>4th</td>
<td>20h26mn46s</td>
<td>20h42mn25s</td>
<td>1959s</td>
</tr>
<tr>
<td>5th</td>
<td>22h09mn40s</td>
<td>22h24mn32s</td>
<td>0892s</td>
</tr>
</tbody>
</table>

- Only within those time windows, the satellite can receive and process the packet. The time of receiving a packet at a baud rate of 1200 bits/s is:

\[ T_{reception} = 2.066 \text{ s} \]

While the processing and ACK sending time is:

\[ T_{handling} = 0.6666 \text{ s} \]

- The overall time to receive correctly one packet is:

\[ T = 2.7326 \text{ s}. \]

- The handling time represents 24% of the overall time. So, Only \( T = (5027 * 76)/100 = 3820 \text{s} \) is allowed to the reception of the packets.

- If we have only one terminal transmitting continuously, the maximum bits that can be received by the satellite is:

\[ N_{bits} = 1200 * 3820 = 4584000 \text{ bits} \]

That represents:
\[ N_{\text{packet}} = 1848 \text{ packets}. \]

- Now, to satisfy the previous QoS assumptions insuring each terminal to send successfully 4.5 packets per day, the maximum terminals that can be disserved if there were no collisions is:

\[ N_{\text{max}} = \frac{1848}{4.5} = 410 \text{ terminals}. \]

- Taking into account that the efficiency of aloha protocol is 18.4\% [TAN 90], the maximum number of terminals that can be deployed successfully in a given area is:

\[ N = 410 \times 0.184 = 75 \text{ terminals}. \]

3. Results

3.1. Communication Channel characterisation

The Communication time on the satellite single channel is not regular, due to the dynamic behaviour of the system. Satellite passes and their durations depend on the terminal geographical location. Figure 10 illustrates satellite passes over terminal\_1 and terminal\_2 during 2 days and shows that during some passes, not all the terminals are present in the satellite footprint. On the other hand, for a same terminal, the satellite visibility time depends on the pass number. Simulations over a long period of time showed a repetition period of 13 days in the satellite visibility passes.

![Figure 10: Satellite elevations](image)

The random channel access protocol used takes advantage from this situation in that way sometimes only few terminals are using the satellite making the traffic load lighter and resulting in better throughput.

Figure 11 shows the number of ground terminals simultaneously present in the satellite footprint during 2 consecutive passes. The graph illustrates 2 situations where the traffic load on the channel can be very different. In the first pass, the satellite is covering only a part of the Moroccan territory and only a maximum of 37\% of the ground terminals are communicating over the channel.

![Figure 11: Satellite in-view terminals](image)

3.2. Network capacity optimisation

The traffic requirement of the microsatellite network is 4.5 packets a day each terminal. Several simulations have been made to find out the maximum number of ground users that can be serviced over a geographical area limited to Morocco. Given random access protocol is used, the optimisation parameter is the retransmission time \( T_r \).

![Figure 12: Pkts Revd Vs. Tr](image)

Figure 12 shows the number of packets received onboard the satellite for different values of \( T_r \). For small values of \( T_r \), a lot of collisions occur and the amount of successfully transmitted packets is also small. For bigger values of \( T_r \), the number of received packets onboard the satellite is limited by the time of the visibility pass. The maximum number of onboard received packets is reached for an optimum \( T_r \) which depends on the number of ground terminals. More terminals in the network yields higher \( T_r \).
To determine the network capacity, the maximum number of satellite received packets must match the number of the generated packets by all the ground terminals. Scenarios with different number of terminals have been simulated and showed that for the required traffic a maximum of 80 terminals can be handled by the satellite using an optimum $Tr$ of 500 seconds. All the terminals queues are regularly emptied during the satellite passes (figure 13), thus successfully transferring the data generated by the terminals to the satellite. A long time simulation showed a stable network where the terminals succeed in transmitting all their generated packets.

Using more than 80 terminals makes the network unstable leading to traffic congestion. Figure 13 shows that when using 100 terminals, packet queues sizes are permanently growing.

A part from network stability, another important parameter to be considered is the packet transfer delay which defines the time a packet is waiting in the terminal queue before being successfully transmitted to the satellite. When using 80 terminals, the queue size grows up to a maximum of 5 packets, resulting in a transfer delay of slightly more than one day. By reducing the number of terminals to 40, the delay is cut down to a maximum of 11 hours which is the natural limit.

### 3.3. Channel throughput

Aloha channel is characterized by its familiar S/G channel throughput vs. channel traffic curve which shows a maximum of 18% throughput when the channel traffic equals 0.5. In other terms 36% of the total packets transmitted to the satellite (including retransmitted packets) are successfully received by the satellite. Running several simulations, we got the graph of figure 14 representing packets received onboard the satellite versus the total submitted packets. The maximum yield effectively reaches 36% validating the theoretical figure.

For a 40 terminals scenario, the curve is flattened because the maximum number of received packets reached the total packets generated by the terminals for different values of $Tr$. This means that the satellite is still able to handle packets while all the traffic generated by the terminals has been processed. We can put more terminals to generate more traffic but at the expense of increasing transfer delay.

### 4. Conclusion

Simulations have been carried out to study the capacity of a single LEO microsatellite based system for data collection using intelligent ground terminals. Using pure ALOHA with a stop-and-wait access protocol, it is possible to handle 80 ground terminals with a traffic load of 4.5 packets a day for each terminal that matches the figure given out by analytical calculations. Data transfer delay which is not critical in this application is approximately one day. To cut down the transfer delay to the natural limit of 11 hours, the number of ground terminals must be reduced down to 40.

### REFERENCES


