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Communication Duration and Missed Passes among Terminals and Satellites for Search and Rescue Services

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Abstract

Aims: NOAA's (National Oceanic and Atmospheric Administration) - LEO environmental satellites provide continuous coverage of Earth, supplying high-resolution global meteorological, oceanic and space observation data. These satellites are part of the international Search and Rescue Satellite Aided Tracking (SARSAT) system. SARSAT is designed to provide distress alert and location data in order to assist on search and rescue operation. SARSAT system detects and locates distress beacons (406MHz) activated at distress location. System calculates the distress event location using Doppler processing techniques. Each satellite pass transmits information about distress location. Passes with too short communication duration, are considered as missed passes. Communication duration analysis, among SARSAT satellites and local user terminal (LUT) dedicated for search and rescue services are provided. LUT implementation process and the mask record are also given.
Study Design: Simulation
Place and Duration of Study: NOAA Satellite Operations Facility, Suitland, MD, USA, October, 28 - December 24, 2009.
Methodology: Communication analysis, are based on the hypothetical terminal assumed to be implemented in Kosovo (LUTKOS). Four hypothetical beacons indicating random distress locations are considered. Satellite orbital altitude of 860 km, orbital time of 102 minutes and inclination of 98.7 º. Communication duration is considered for period 1-30, October 2009. 57560 satellite passes were considered to conclude about missed passes.
Results: For Doppler processing at least four events are required. Duration of 250s is considered as the lower margin, providing at least four Doppler events. The highest events density was in between 300s to 700s, sufficient for distress location determination. Only 3% of total considered passes were below 250s. The ratio of missed passes over total passes for the whole ground segment results as 0.17%, or in average 0.021% per month.
Conclusion: Through LUTKOS simulation, it is confirmed communication reliability and proper functionality of LUTKOS with a single SARSAT satellite.
Keywords: Satellite, LUT, communication duration, missed pass.

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1 Introduction

COSPAS-SARSAT is an international, humanitarian satellite based search and rescue system which operates continuously, detecting and locating transmissions from emergency beacons carried by ships, aircrafts and individuals. This system was originally sponsored by Canada, France, the former Soviet Union and the USA [1,2]. In cases of aircraft, marine or individual distress the location determination accuracy and the time required to alert rescue authorities depends on the communication reliability between the LUTs and satellites [3,4].

2 Sarsat System

USA portion of COSPAS-SARSAT system is operated by the NOAA (National Oceanic and Atmospheric Administration) SARSAT (Search and Rescue Satellite Aided Tracking) Office in Suitland. NOAA environmental satellites carry SARSAT packages. The Mission Control Center (USMCC) is located in Suitland, Maryland [1]. The basic COSPAS - SARSAT concept is illustrated in Fig. 1 [1].

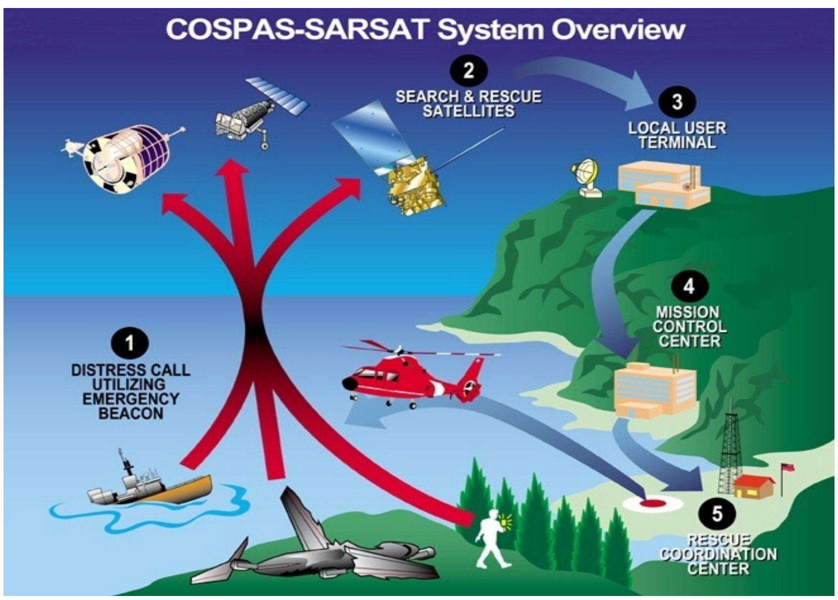

Fig. 1. COSPAS-SARSAT concept

1. In case of distress anywhere in the world, when and where lives are at risk the emergency beacons are activated manually or automatically.
2. Emergency alerts received by the satellites are retransmitted to 45 automatic (unstaffed) Local User Terminals (LUTs) worldwide.
3. Alerts are routed to a Mission Control Center (MCC) in the country that operates LUT. Routed alerts include beacon location computed at the LUT. The alert is received by one of the system low - Earth - orbiting (LEO) satellites.

4. After validation processing (based on Doppler Effect) alerts are relayed depending on beacon location or country of registration (beacons of 406MHz) to either another MCC or to appropriate Rescue Coordination Center (RCC).
5. US RCCs are operated by the Coast Guard and the Air Force [1,2].

SARSAT system uses satellites in Low Earth Orbits (LEO). Doppler shift processing is applied for location determination. Table 1 presents the orbital parameters and the status of SARSAT LEOSAR payload instruments as of October 2009 [1,2]. Global is related to global coverage, whereby F means Fully Operational.

Receive-only ground stations, specifically designed to track the search and rescue satellites as they pass across the sky are known as Local User Terminals (LUT). These LUTs and appropriate MCC (Mission Control Center) to whom these LUTs are interconnected, create the US SARSAT ground segment.

Table 1. SARSAT LEOSAR status

Satellite	**Orbital Parameters & Payload Instruments**				
	Mean Motion (rev/day)	**Altitude (km)**	**Orbit Period (hh:mm:ss)**	**406 MHz**	**Global**
SARSAT - 7	14.2475	809.45	01 : 41 : 04.2	F	F
SARSAT - 8	14.1251	850.91	01 : 41 : 56.7	F	F
SARSAT - 9	14.2405	811.80	01 : 41 : 07.2	F	F
SARSAT-10	14.1125	855.21	01 : 42 : 02.2	F	F
SARSAT-11	14.2149	820.43	01 : 41 : 18.1	F	F
SARSAT-12	14.1095	856.25	01 : 42 : 03.5	F	F

The distress signal is received by satellite uplink and then it is transmitted to LEOLUTs by downlink. The main functions of a LEOLUT are:

- Track the SARSAT satellites;
- Recover beacon signals;
- Perform error checking;
- Perform Doppler processing;
- Send alert to Mission Control Center.

A mission control center (MCC) serves as the hub to collect, store and sort alert data from LUTs and other MCCs. NOAA operates eleven LEOLUTs in six locations, as presented in Table 2 [1]. These multiple LEOLUTs provide total system redundancy and allow for a maximization of satellite tracking. There are two LEOLUTs in each of the following locations. Two independent, yet functionally and physically identical systems manufactured by “EMS Technologies”, are implemented. Since each LUT operates independently, they are denoted as 1 and 2. The LEOLUT in Maryland is used for test purposes.

- Miami, Florida (FL1&FL2);
- Vandenberg, California (CA1&CA2);
- Fairbanks, Alaska (AL1&AL2);
- Wahiawa, Hawaii (HI1&HI2);
- Andersen, Guam (GU1&GU2);

- Suitland, Maryland (LEOLUT Support Equipment).

Table 2. LEOLUT coordinates

LEOLUTs Locations	Latitude	Longitude
Maryland (MDLUT)	38.852	-76.937
Florida (FLLUT)	25.61	-80.38
California (CALUT)	34.66	-120.55
Alaska (ALLUT)	64.97	-147.51
Hawaii (HILUT)	21.52	-151.99
Guam (GULUT)	13.34	144.56

Emergency distress beacons are essentially specialized radio transmitters for search and rescue purposes. Beacon can be activated manually or automatically. From Feb. 2009, all these rescue beacons transmit on 406MHz. Emergency beacons are classified as [1,2]:

1. Emergency Position Indicating Radio Beacons (EPIRBs) for maritime applications,
2. Emergency Locator Transmitters (ELTs) for aviation applications, and
3. Personal Locator Beacons (PLBs) for individuals.

Few characteristics of 406 MHz Beacons are shown in Table 3 [5]:

Table 3. 406 MHz Beacons characteristics

Output power	5W
Transmission	Burst (500ms on every 50sec)
Modulation	Phase
Frequency stability	High

The transmitted power output must be within limits of $5W \pm 2dB$. The 406MHz carrier is modulated with information such as beacon identification, synchronization frame, and the nature of emergency. Looking at the time slot of 500ms (Table 3), only 160ms are dedicated for poor carrier and the rest is for modulated data [5]. Beacon identification transmission is mandatory for accessing a user registration database. This database can supply the beacon type, its country of origin and the registration number of the maritime vessel, aircraft or individual. In USA beacon's registration is obliged by law, and there are approximately 270,000 registered beacons by 2010.

3 Doppler Effect

LEO satellites move at around 7.5 km/s ensuring sufficient velocity relative to a fixed point on the ground to generate a perceptible Doppler shift in the frequency of the emergency beacon signal, thereby yielding e reasonably accurate position of distress location [6]. The basic system concept requires users to carry distress radio beacons, which transmit a carrier signal when activated. The transmitted signal by a beacon is picked up by LEO satellite, and because the satellite is moving relative to a radio beacon, a Doppler shift in frequency is observed, and the shifted frequency and time tag is registered at a satellite processor (SARP) [7].

If the line of sight distance between the transmitter and satellite is shortened as a result of relative motion, the wavelength of the emitted signal is also shortened, consequently frequency is increased. If the line of sight distance is lengthened as a result of the relative motion the wavelength is lengthened and therefore the received frequency decreased. Denoting the constant emitted frequency by f_0, the relative velocity between satellite and beacon measured along the line of sight as v, and the velocity of light as c, then to a close approximation the received frequency at the satellite, is given by [8]:

$$f = \left(1 + \frac{v}{c}\right) f_0 \tag{1}$$

The relative velocity v is positive when the line of sight distance is decreasing (satellite and beacon moving closer together) and negative when it is increasing (satellite and beacon moving apart). The relative velocity v is a function of the satellite motion and of the Earth's rotation, and can be approximated as [8]:

$$v = \frac{R(T_X) - R(T_{X-1})}{T_X - T_{X-1}} \tag{2}$$

where $R(T_X)$ and $R(T_{X-1})$ are satellite ranges at times T_X and T_{X-1} respectively, for $(T_X - T_{X-1})$ arbitrarily small. The frequency difference resulting from relative motion is [8]:

$$\Delta f = f - f_0 = \frac{v}{c} f_0 \tag{3}$$

when v is zero, the received frequency is the same as the transmitted frequency. When beacon and satellite is approaching each other, v is positive, resulting on positive value of Δf. When the beacon and satellite are receding, v it is negative, resulting in a negative value of Δf. The time at which Δf is zero is the *time of closest approach*.

The determination location is based on time of the closest approach and on slope of Doppler curve. This is presented in Fig. 2. The beacon of 406MHz, when has view of site with the satellite hits the satellite with bursts of 406MHz for 500ms, periodically every 50s. The satellite processor records the frequency and time tag. This beacon's hit with recorded frequency and time tag represents a Doppler Event (*DE*). The number of Doppler events depends on visibility time between a beacon and satellite. Fig. 2 illustrates the case with 7 Doppler events. In Fig. 2, T_C represents the time of closest approach. With T_{C-N} are denoted times of Doppler events before the closest approach and with T_{C+M} times of Doppler events after the closest approach. At bottom of Fig. 2, frequency shifts of respective events are presented.

CIR Report 214 gives the following approximate relationship for estimating the maximum Doppler shift [8]:

$$\Delta f_{dm} \approx \pm 3 \cdot 10^{-6} f_0 \, s \tag{4}$$

where f_0 is operating frequency and s is number of revolutions over 24 hours of the satellite with respect to a fixed point on the Earth. LEO satellite with an orbital period of 100min makes 14 revolutions over 24hours, but in average (6-8) times with respect to a fixed point on the Earth. Thus, for 406MHz beacon, the maximal expected frequency shift is approximately 8 KHz. In Fig. 2, $N = M = 3$ but not always N, M are equal since it depends on time when the beacon hits the satellite, related to the time of the closest approach. Denoting DE as total number of Doppler events, it is:

$$DE = N + 1 + M \tag{5}$$

where "1" is related to Doppler event at the closest approach. DE depends on visibility, respectively on communication duration. Considering the maximal possible duration of 15 min (900s) [6] for the case where satellite is just above the beacon, and the fact that beacon hits on every 50s, then $DE = 18$.18 events are very ideal to have.

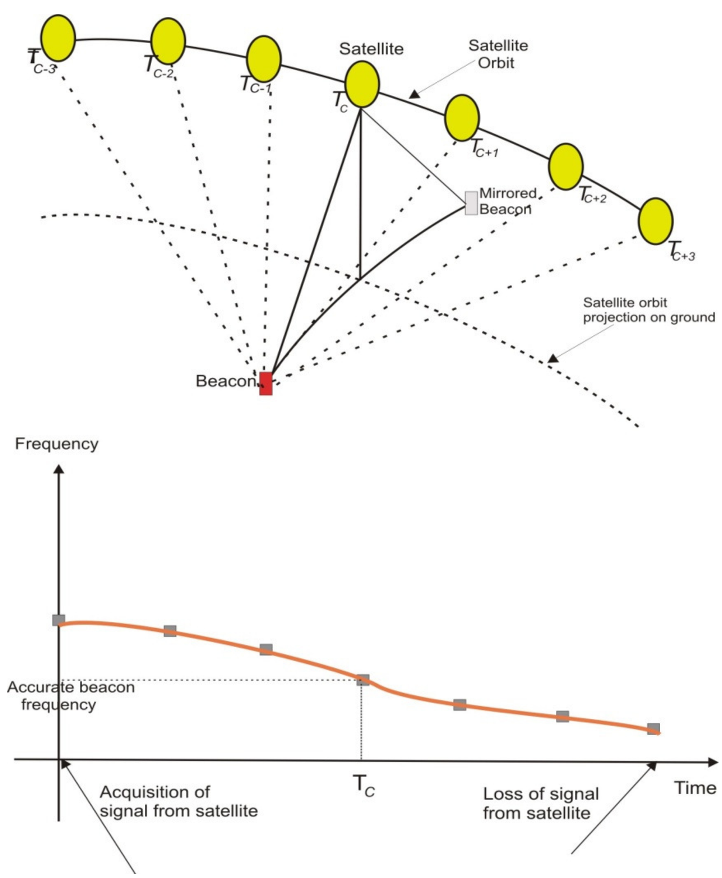

Fig. 2. Doppler events and respective frequency shifts

The approach to predict the location accuracy category of SARSAT hits based on parameters of the Doppler curve fit work reasonably well, but it is far from ideal. Through simulations (probability computation) it is confirmed Doppler processing successfulness by receiving at least four beacon messages during the satellite path [9]. Thus, yields:

$$4 \leq DE \leq 18 \tag{6}$$

4 Communication Duration

The SARSAT concept is based on receiving the signal from a beacon at a distress location and transmits the signal toward a ground station or Local User Terminal (LUT). The LUT establishes communication with the satellite only when it is within the satellites visibility.

The tracking software provides real-time tracking information, usually displayed in different modes (satellite view, radar map, tabulated, etc). The display mode of “radar map” includes accurate satellite position with the ground station considered at the center, as in Fig. 3, presented. The perimeter of the circle is the horizon plane, with North on the top (Az = 0º), then East (Az = 90º), South (Az = 180º) and West (Az = 270º). Three concentric circles represent different elevations: 0º, 30º and 60º. At the center the elevation is El=90º. Most usual software parameters which define the movement of the satellite related to the ground station are: AOS_{time} – Acquisition of the satellite (time), LOS_{time} – Loss of the satellite (time), AOS_{Az}– Acquisition of the satellite (azimuth), LOS_{Az} – Loss of the satellite (azimuth), *Max El-* Maximal Elevation and *Orbit* – Orbit number. The satellite’s movement (satellite’s pass) is presented with the satellite’s path in a radar map (red line). Thus, the communication duration is defined as,

$$Duration = AOS_{time} – LOS_{time} \tag{7}$$

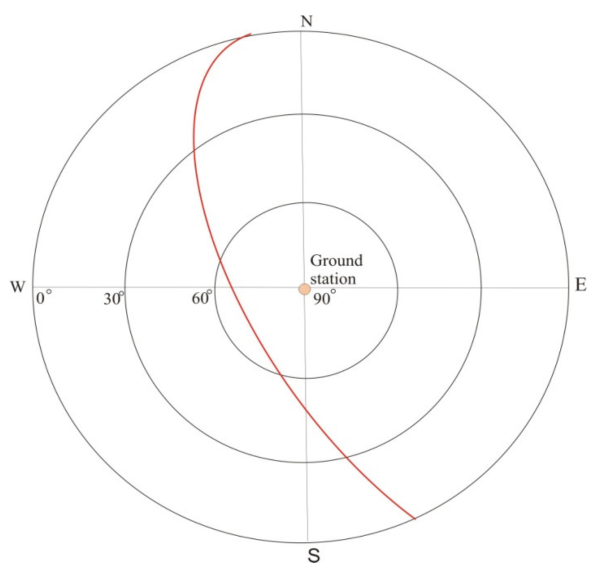

Fig. 3. Radar map display

Equation (7) defines the theoretical duration of the communication between the satellite and a ground station. Practically, this duration is always shorter because of natural barriers during acquisition and loss of satellite. In order to avoid the problem of natural barriers, designers predetermine the lowest elevation of the horizon plane which is applied during link budget calculations [10,11].

There is a clear relationship between communication duration and Maximal Elevation. The relationship between maximal elevation and communication duration for SARSAT LEO satellite daily passes is presented as in Fig. 4. Higher Maximal Elevation provides longer communication between the satellite and beacon.

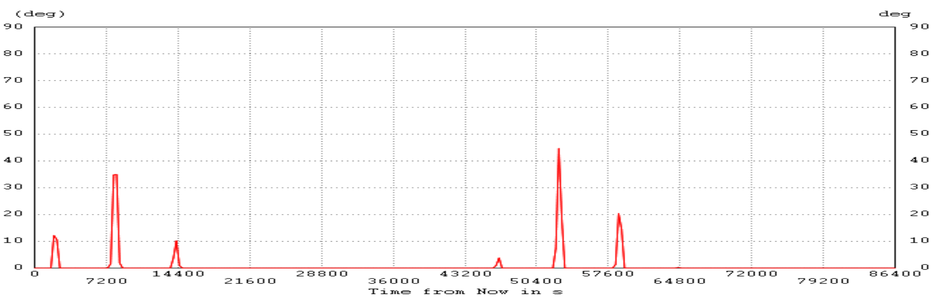

Fig. 4. Maximal Elevation and communication duration

5 Lutkos Simulation

The hypothetical Local User Terminal assumed to be implemented in Kosovo and considered for further simulation is defined as LUTKOS (Local User Terminal in Kosovo). For SARSAT system, the uplink transmitter is distress beacon, and the LUT is downlink receiver. Thus, the proper operation for search and rescue services should be analyzed for uplink as seen from random beacons appearance and for downlink as seen from satellite to a fixed LUT. Four hypothetical beacons are considered for analysis on uplink, and a fixed ground station LUTKOS for downlink is considered, as presented at Table 4.

Table 4. Coordinates of LUTKOS and Beacons

Location	Latitude	Longitude
LUTKOS	42º30´	21º
BC1	50º	10º
BC2	50º	30º
BC3	34º	30º
BC4	34º	15º

For simulation purposes, the coordinates of LUTKOS site are considered as; Latitude of 42º30´ and Longitude of 21º. Satellite's orbit is considered as circular with no eccentricity, the orbital altitude of 860 km, orbital time of 102 minutes and Inclination of 98.7º as presented in Fig. 5. The satellite's antenna conic angle is 60º. Practically, this means that at least high Alps Mountains in Austria and very large area of Mediterranean Sea to be covered with search and rescue services.

This range provides coverage on the Earth's surface of around 2.5 Million square kilometers.

The goal of this simulation is to confirm reliable data communication between assumed LUTKOS ground station and SARSAT satellites, and to confirm the visibility of hypothetical beacons with SARSAT satellites in terms of Doppler events compliance (Eqn. 6). These two facts will prove the proper operation of LUTKOS dedicated for search and rescue services. Single satellite is considered for simulation. The presence of more satellites improves results.

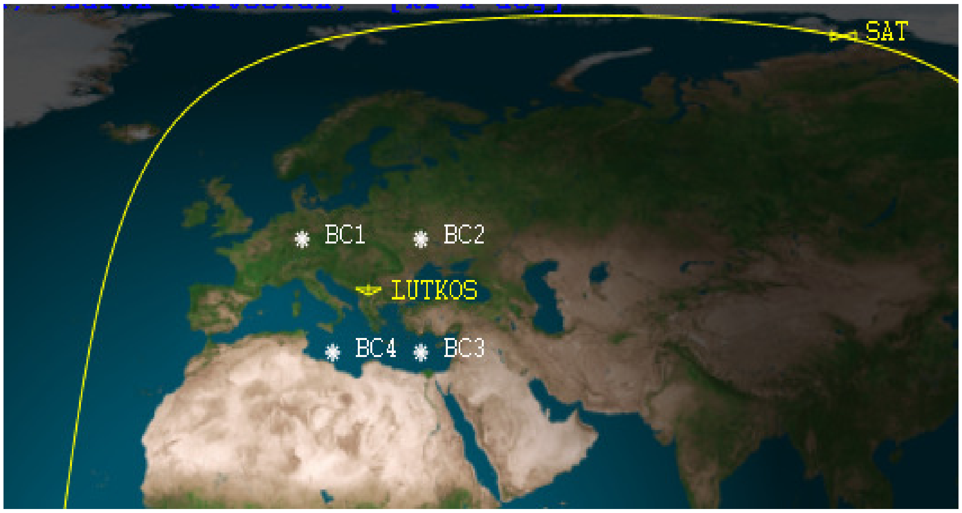

Fig. 5. Satellite, LUTKOS and Beacons

Analyses are related to a period of one month, considering around 200 satellite passes in order to conclude about operation and service performance. Three typical cases in Figs. 6, 7 and 8 are further presented [12].

1. During the satellite pass (presented in Fig. 6) beacons BC1 and BC4 are within a satellite footprint. Other two beacons (BC2 and BC3) are out of footprint. LUTKOS is within a footprint. In this case the signals from beacons BC1 and BC4 can be received by the satellite. The satellite can transmit the signal to LUTKOS, and LUTKOS further to respective MCC. Action can be taken. Eventually, distress signals from BC2 and BC3 should be waiting for the next pass or other satellite.

2. During the satellite pass (presented in Fig. 7) all beacons and LUTKOS are within a footprint. From the search and rescue view, this is the most optimistic case. Each beacon can communicate with satellite and the satellite further can download data to the LUTKOS.

3. During the satellite pass (presented in Fig. 8) only Beacon BC1 is within a satellite footprint. LUTKOS and other beacons are out. This is a pessimistic case, since the distress beacon communicate with the satellite but cannot communicate with LUTKOS, so satellite should look for another LUT to download data. This is a delay.

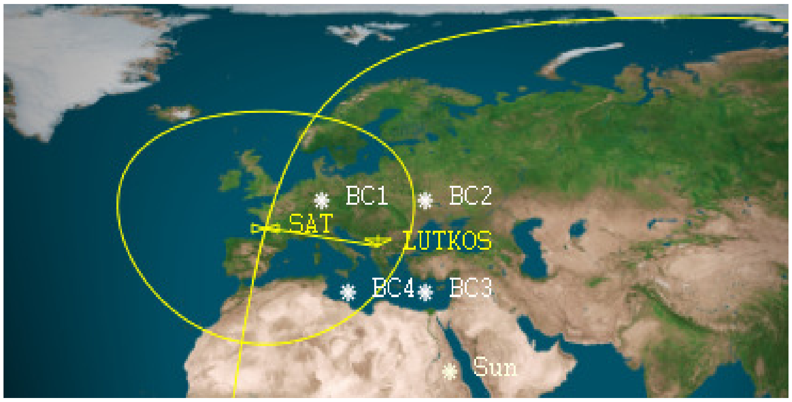

Fig. 6. The first case

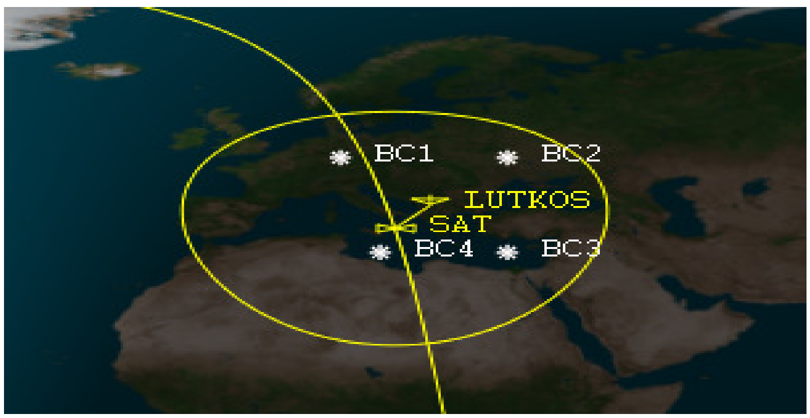

Fig. 7. The second case

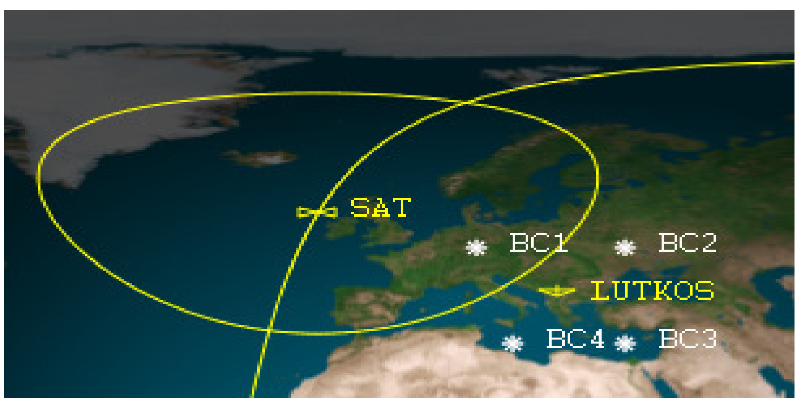

Fig. 8. The third case

6 Results and Discussion

6.1 Communication Duration Simulation Results

Analyses are related to a period of one month, respectively from October, 1 to October, 30, 2009. It is conducted Maximal Elevation angle and Communication Duration. The applied software provided these data in tabulated format including Date, Rise and Set real time, and Duration. Fig. 9 presents the Maximal Elevation during the considered (October, 1- 30) period between LUTKOS and SAT. Higher maximal elevation provides longer communication.

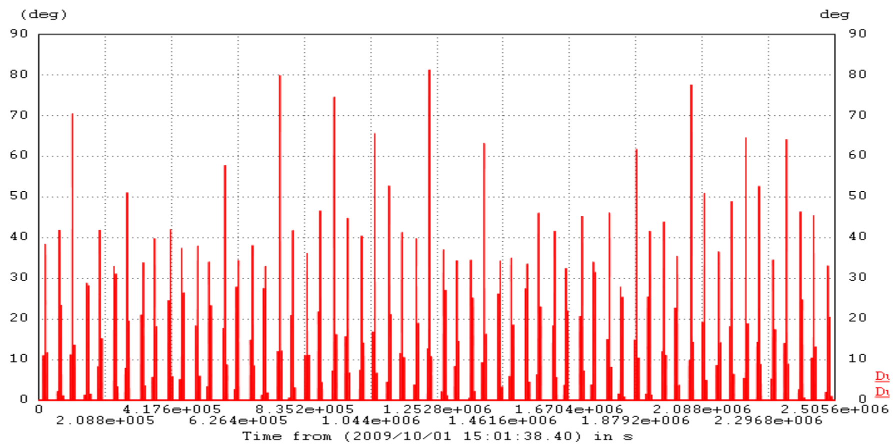

Fig. 9. Maximal Elevation

For Excel presentation, are chosen the best and the worst passes, in order to create real opinion about the range of communication duration, presented in Fig. 10. Fig. 10 show results of communication duration between the LUTKOS and satellite, where only one pass is under 200s, few around 300s, but the highest density is concentrated in the range of 400s - 700s, or between (6-12) minutes. This communication duration well satisfies data download from the satellite to LUTKOS.

The same approach is conducted for all beacons, so the best and the worst pass is considered, and then presented in Figure 11. For all beacons within a period of one month are treated around 700 passes. Successful Doppler processing is defined by reception of at least four beacon messages during the satellite path. Considering that beacon hits on each 50s, for Doppler processing it is mandatory a communication duration of at least 200s. For analyses of this simulation, the lower margin of duration it is considered time of 250s, which will provide at least four Doppler events. In Fig. 11 around 20 passes are below 250s, representing around 3% of total considered passes. The densest range is from 300s to 700s, what is sufficient time for Doppler processing and distress location determination.

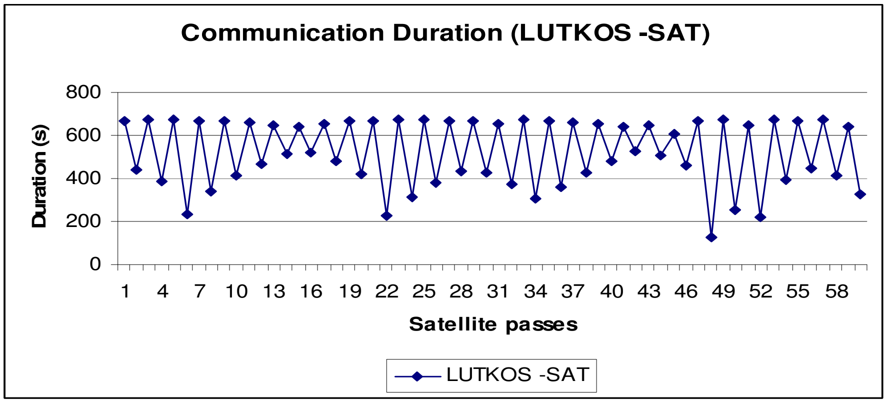

Fig. 10. Communication Duration (LUTKOS - SAT)

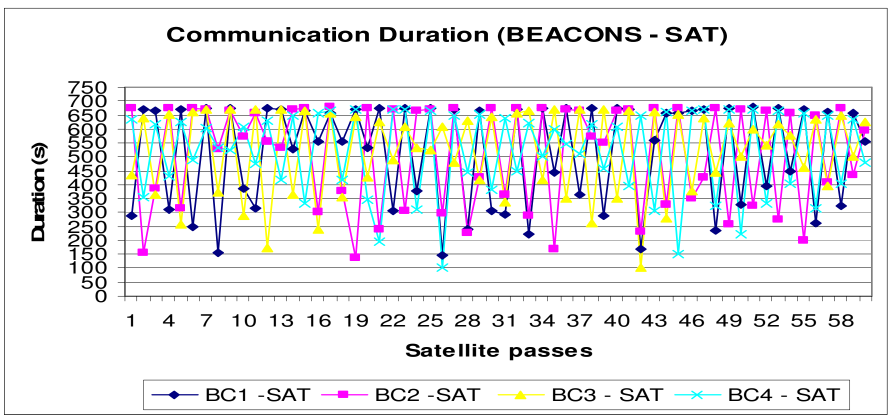

Fig. 11. Communication Duration (BEACONS - SAT)

Two facts above, confirm that LUTKOS can properly operate and be a part of LUTs network.

6.2 Missed Passes Results

Passes which do not establish communication or do not provide sufficient data for Doppler processing are considered as *missed passes.* U.S. SARSAT ground segment records of missed passes for the period of February, 1 to September, 30 of 2009 (8 months) are analyzed. The designed horizon plane for LUTs is above 5º. Planned missed passes for maintenance or software upgrade purposes are not considered. Satellite anomalies and communications issues between LUTs and MCC are not considered. The intention was to analyze missed passes caused by hardware/software malfunctioning at LUTs and missed passes under low elevation which do not provide solutions. The analyses are done related to each site/ month and each site/ satellite, and presented in Tables 5 and 6. Both tables show that for considered period of 8 months the U.S. SARSAT ground segment communicating with 6 satellites, had 98 missed passes caused because of malfunctions at LUTs. This means, in average 1.225 missed passes per site/month with all satellites, or in average 0.24 missed per site/month/satellite. The total number of passes during this period of 8 months was 57560, and the ratio of missed passes over total number of passes for the whole ground segment is 0.17%, or in average 0.021% per month. Thus, monthly ground segment performance indicator is 99.979%.

Table 5. Missed passes as site / month

	Feb.	March	Apr.	May	June	July	Aug.	Sep.
CA1	0	1	0	1	0	2	1	1
CA2	0	1	1	2	2	1	0	1
HI1	0	1	0	0	1	0	1	3
HI2	0	0	3	0	0	0	2	1
FL1	1	1	1	0	2	1	2	5
FL2	0	0	1	0	0	1	2	2
GU1	0	1	0	0	3	4	1	0
GU2	0	0	2	3	4	0	2	3
AL1	3	0	0	0	6	1	3	0
AL2	0	2	0	3	3	1	5	4

Table 6. Missed passes as site / satellite

	S7	S8	S9	S10	S11	S12
CA1	1	0	3	1	0	1
CA2	1	0	3	2	1	1
HI1	1	0	0	3	1	1
HI2	1	0	2	2	1	0
FL1	0	2	3	3	2	3
FL2	0	1	1	1	2	1
GU1	3	0	1	3	0	2
GU2	2	0	2	6	2	2
AL1	1	4	3	2	2	1
AL2	1	2	4	3	6	1

7 Conclusion

In principle any satellite mission can be accomplished by a single satellite and single ground station, but the rationale behind building more ground stations and launching more satellites is to increase the coverage and the number of measurements to observed object or area. U.S. SARSAT is data communication system dedicated for search rescue purposes oriented on determination of distress locations worldwide. Thus, for search and rescue services, the multiple LUTs provide total system redundancy and allows for a maximization of satellite tracking. LUT implementation is associated with the mask record in order to provide communication under too low elevation. The terrain mask depends on topography and the record procedure is provided through this paper.

The performance of the ground segment is of high importance on this process. Through analysis of an 8 month period, a high ground segment performance is confirmed. This performance guarantees on time alert to rescue services and aides life saving rescue efforts. The implementation of the SARP global mode enables processed data stream (PDS) capturing at multiple sites covering also missed passes. The data capture redundancy ensures uninterrupted service of a critical life-saving system. Through LUTKOS simulation, it is confirmed communication reliability and proper functionality of LUTKOS with a single SARSAT satellite. More SARSAT satellites seen from LUTKOS enhance the performance for search and rescue services.

DASS (Distress Alert Satellite Mission) is a new future approach intended to enhance the international satellite-aided search and rescue (SAR) system by installing 406 MHz SAR instruments on the Medium Earth Orbit (MEO) navigational satellites [GPS (US), Galileo (EU), and Glonass (Russian Federation)] and by introducing new processing algorithms.

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Author's contribution

Author, Dr. Shkelzen Cakaj, designed the study, performed the simulation and the statistical analysis.

Competing Interests

Author has declared that no competing interests exist.

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