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A NOVEL EMERGENCY SYSTEM FOR LOW EARTH ORBIT SATELLITES USING GALILEO GNSS

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Low Earth Orbit (LEO) satellites have a limited direct contact time with the stations of their ground segment. This fundamentally constraints a timeliness reaction of the mission control center in case of emergency situations onboard the LEO spacecraft. To enable such a rapid reaction to emergency situations onboard LEO satellites, it is proposed to use a Search and Rescue (SAR) beacon onboard that spacecraft to transmit an alert message via Galileo satellites which support SAR through the Cospas-Sarsat (C/S) system to the satellite mission control center. While SAR up to now is limited to terrestrial, maritime, and aviation user scenarios, this space user concept presents a novel emergency system which helps facilitating the valuable space assets which LEO satellites in many cases represent. However, such a space user system faces various technical, system, and business challenges as well as legal and regulatory issues. The frequency band assigned for the SAR system is limited to low power satellite emergency position-indicating radio beacons and is foreseen for earth-space transmissions only. The International Telecommunication Union (ITU) should agree on opening this band for space-space communication for space user distress beacons. The Distress Alerting Satellite System (DASS) and the SAR/Glonass system will also operate in this band and an agreement will be required for these as well. A visibility analysis is presented for LEO to Galileo satellites. Depending on the placement of the antenna of the distress beacon on the LEO spacecraft, between 6 and 21 Galileo satellites are visible. The space user beacon may cause interference to the current SAR system when it's signals collide with those of Earth-bound users in time or overlap in frequency at the Galileo transponder. When they collide in time one of the signals might still be processed if one of the signal levels is significantly higher than the other. Upon sharing the same frequency, both signals could be lost in a worst case scenario. This overlap in frequency can be caused by Doppler shifts. Therefore, a Doppler analysis was performed and Doppler shifts of about ≈11 kHz were identified. Next to frequency overlaps the traffic load in the adjacent channels can increase. Different methods to prevent these Doppler shifts were analyzed. To reduce system complexity and benefit from existing technology, the space user beacon could be similar to that of an Earth beacon. However, the repetition time could be increased and the frequency channel selected for the Doppler analysis is chosen such that the interference is minimal. A high level design of the SAR payload onboard the LEO satellite was performed and different protocol options were valuated.

1. INTRODUCTION

Currently, SAR is only applied to distress situations of humans in terrestrial, maritime or aviation environments. However, spacecraft are typically very precious assets in space corresponding to values of several hundred million of Euros. Extending existing or planned SAR services to handle LEO spacecraft anomalies is therefore an innovative and challenging proposal. An emergency situation onboard a spacecraft is given, e.g., when the spacecraft enters safe mode. Then typically Fault Detection, Isolation, and Recovery (FDIR) measures or automated procedures are activated. However, at the time of occurrence of such an emergency, the satellite may still be hours from the next contact to its ground station. With the proposed transmission of a SAR message via SAR-supporting satellites and the Cospas-Sarsat system, a short response time for the satellite's mission control centre is realized.

This, in turn, can be used to prepare ground operations for the contingency, include other ground stations or even contact the spacecraft through a return link.

Existing and future space systems which could support such an approach were looked at and the SAR functionality of the Galileo Global Navigation Satellite System (GNSS) was identified as a potential candidate for such a service. On the LEO satellite, being in an emergency situation, a beacon could be used to forward the emergency message via SAR transponders on several Galileo spacecraft to Medium Earth Orbit Local User Terminal (MEOLUT) ground stations which could identify the originator of the emergency and inform the mission control center accordingly.

2. SAR SYSTEM FOR SPACE USERS

2.1 Concept Description

Communication between a ground station and a LEO satellite is limited, not considering advanced systems such as the Tracking and Data Relay Satellite System (TDRSS). Failures onboard the spacecraft, such as caused by actuators or sensors, will only be detected when the satellite is in view of the ground station. The satellite will switch to safe mode when a critical subsystem fails to prevent an even worse failure. The safe mode will guarantee a minimal functionality on board, but no warning is given to the ground station operator and no preparations can be made to handle this emergency situation until there is contact with the ground station.

This concept has been filed by the first author and been granted in 2007 [1]. The patent describes a system which creates a distress signal onboard the satellite and sends it through, such that in advance is known that a system failure has occurred. In Fig. 1, the general mission architecture is presented and described in the sequel; A distress signal is established onboard a satellite when a serious system failure is occurring and the foreseen communication unit sends out the distress signal. This signal is received e.g. by a Galileo satellite, equipped with a SAR transponder and retransmitted to a terrestrial receiver station, the MEOLUT, designed and build to receive the SAR distress signals. Then the distress signal is processed, identified and transmitted from the MEOLUT and SAR mission control center to the appropriate satellite mission control center.

Existing and future space systems which could support such an approach were identified and the Galileo GNSS system was selected as possible candidate. An advantage of using Galileo is that it is in a Medium Earth Orbit (MEO) with good and global visibility to LEOs and it will already have a SAR system implemented. It also provides a Return Link Message which offers additional opportunities.

2.2 System Level Mission Architecture

The Mission Architecture of the space user system will be for a large part based on the current SAR system because it will transmit it's signal via the same SAR transponder and SAR ground station. The general mission architecture was shown in Fig. 1, the mission architecture at system level is depicted in Fig. 2. In case of an emergency in a satellite subsystem a signal is transmitted to the onboard computer, which will generate a distress message and send it to the Galileo SAR transponder. Upon reception at the SAR transponder, it will pass through the Low Noise Amplifier (LNA) after which the first Local Oscillator (LO) is mixed with the carrier signal to convert it to an Intermediate Frequency (IF).

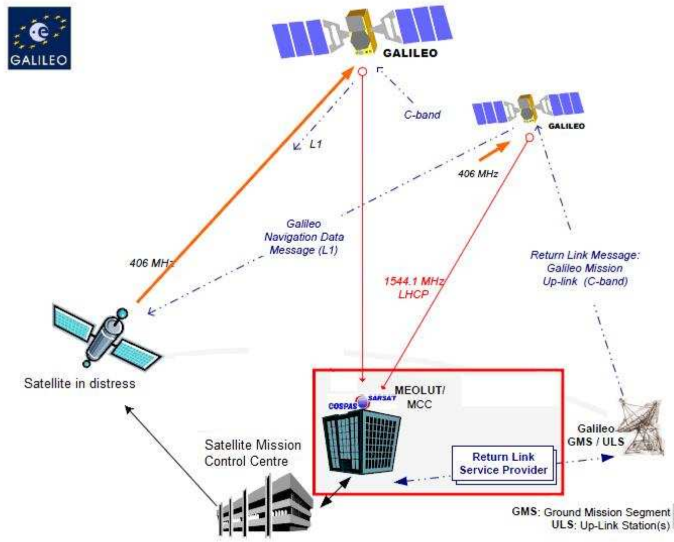

Fig. 1: SAR General Mission Architecture [2]

The signal is then passed through the bandpass filter and a second LO after which it is converted to the 1544 MHz downlink frequency [3]. The signal is then transmitted to the SAR ground station via an L-band antenna. At the SAR ground station the signal will be processed and the SAR message retrieved.

2.3 Business Opportunities

The main target group for such a space user distress system are large and expensive LEO satellite missions, like ,e.g., Envisat. These projects have a high insurance cost, and the implementation of a distress beacon reduces the risk of failure of the mission and could lower the insurance costs.

2.4 Legal and Regulatory Aspects

One of the major obstacles to the implementation of a space user distress system are legal and regulatory issues. The frequency band used for the SAR system is 406.0-406.1 MHz. According to the ITU this band is used for the mobile-satellite service and is limited to low power satellite emergency position-indicating radio beacons and for earth-space transmissions [4]. Implementing such a system would require the ITU to open the band for space-to-space communication signals with a non-human rescue purpose.

Another aspect that should be taken into account is the DASS and SAR/Glonass system, the American and Russian SAR system respectively. They also will be receiving signals due to distress situations in the 406.0-406.1 MHz band and should agree that the space user signals will be passing through their system.

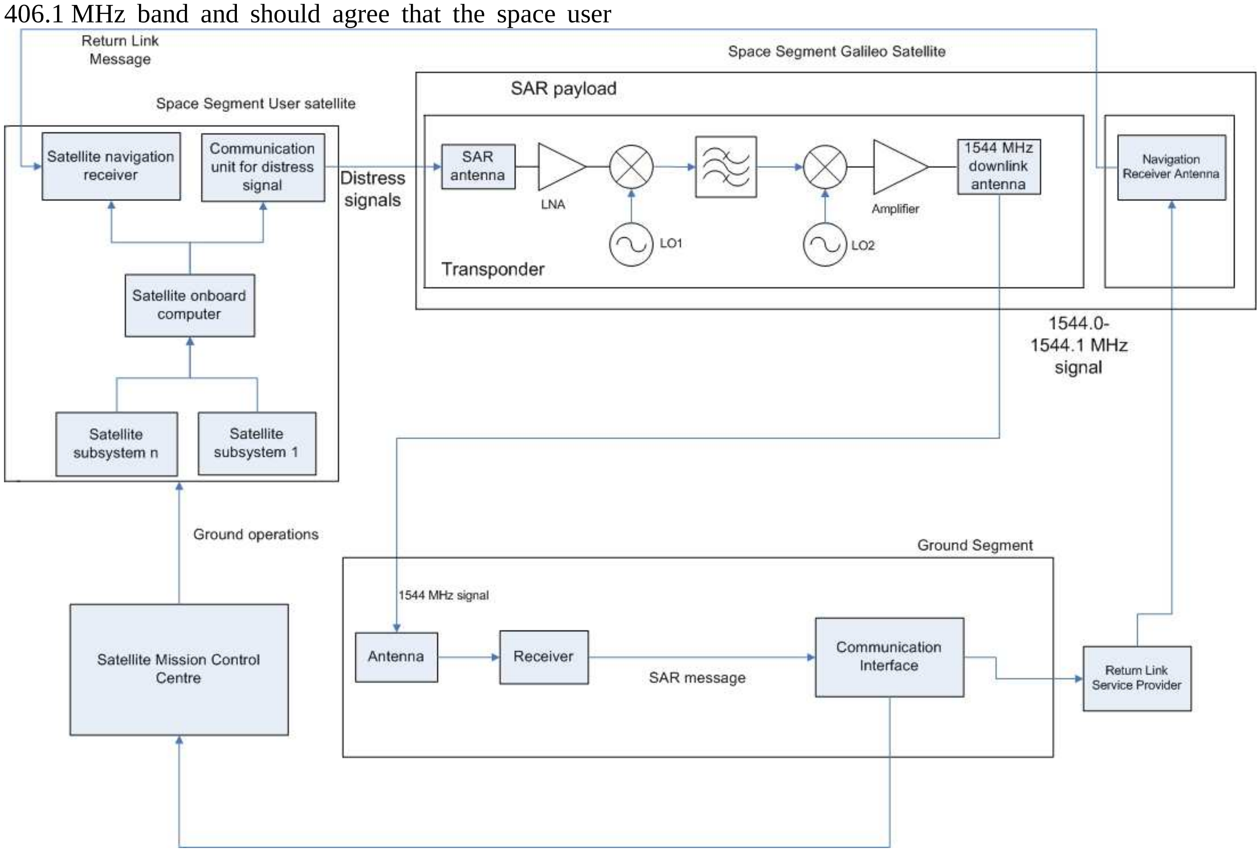

Fig. 2: System Level Mission Architecture for a space user distress application. Arrows indicate only SAR relevant infromation flux [1],[3],[5]

One could argue that the implementation of the system would be applicable for a very limited amount of satellites, so the amount of interference would also be very limited.

3. VISIBILITY ANALYSIS

A visibility analysis is performed to determine the number of Galileo satellites that are visible to the LEO satellite. Two situations were assumed, one in which the SAR antenna on the user satellite is placed at such a height that there are no obstructions by the spacecraft structure and one where the antenna is directly placed on top of the spacecraft surface. For the simulations, the LEO satellite Envisat was selected as an example, as it represents the target group for the space user distress system. The orbit is assumed to be circular, because calculations showed that the difference between the Doppler shift of an elliptical orbit with an eccentricity of the order 10^{-4} is small compared to a circular orbit. Similarly a pure Keplerian motion is assumed for both the user satellite and the Galileo satellites.

The visibility is determined using a geometrical approach (Fig. 3). First, the Keplerian elements of the Galileo satellites and Envisat are converted to Cartesian coordinates after which the angle δ between the vector from Earth to Envisat and the vector from Earth to Galileo can be determined

$$\delta = \cos^{-1}\left(\frac{r_{leo}}{\|r_{leo}\|}\cdot\frac{r_{gal}}{\|r_{gal}\|}\right). \quad [1]$$

This angle is then used to determine the half cone angle α under which the Earth is seen

$$\alpha = \sqrt{r_{gal}^2 + r_{leo}^2 - 2r_{gal}r_{leo}\cos\delta}; \quad [2]$$

The minimum value of α is determined based on

$$\alpha_{\min} = \sin^{-1}\left(\frac{R_e + h_t}{R_e + h}\right); \quad [3]$$

with R_e being the Earth radius, h the altitude of Envisat and h_t the tropospheric height which is assumed as 40 km. In case α is larger then α_{min} then the Galileo satellite is visible to the LEO satellite.

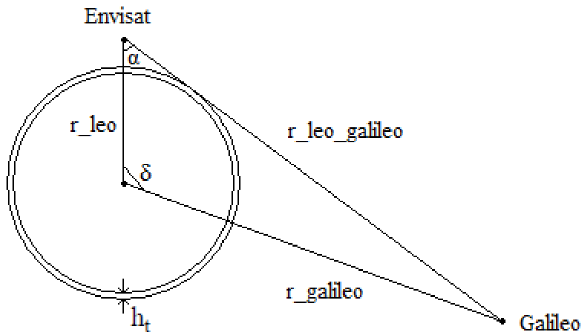

Fig. 3: Visibility geometry of a Galileo spacecraft with respect to Envisat

When the antenna is placed at a height above the top surface of the user satellite, which is 6.74 m for Envisat to have no obstruction by the structure, the number of visible satellites is between 15 and 21 (Fig. 4). If the antenna is placed on the surface of the user satellite, the minimum value of α is 90° and the number of visible satellites is limited to between 6 and 12 (Fig. 5). The simulations are performed over a time period of one Galileo orbit, i.e. 14.078 hours. A large number of satellites are visible under both conditions. In case the satellite has an attitude control failure, this large amount of satellites is beneficial.

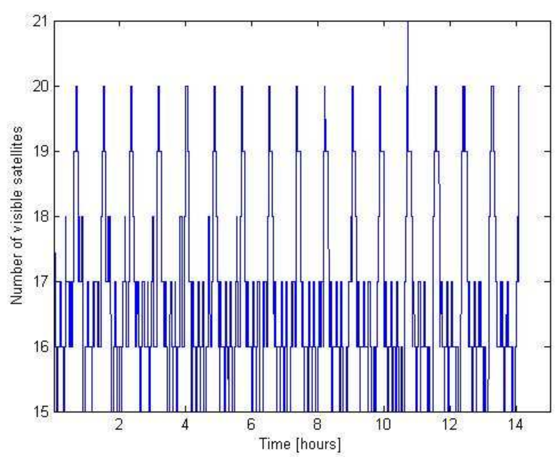

Fig. 4: Number of visible satellites over time when SAR antenna is placed at a certain height above spacecraft surface.

4. INTERFERENCE ANALYSIS

The main interference between signals originating from a space user beacon and an Earth-bound beacon occurs if the signals are received at the Galileo transponder at the same time (bursts) or at the same time and with the same frequency. When only collision in time occurs there is a chance the strongest signal is still properly received if there is a significant difference between their signal power level [6]. In case of time and frequency overlap both signals may be lost in a worst case scenario.

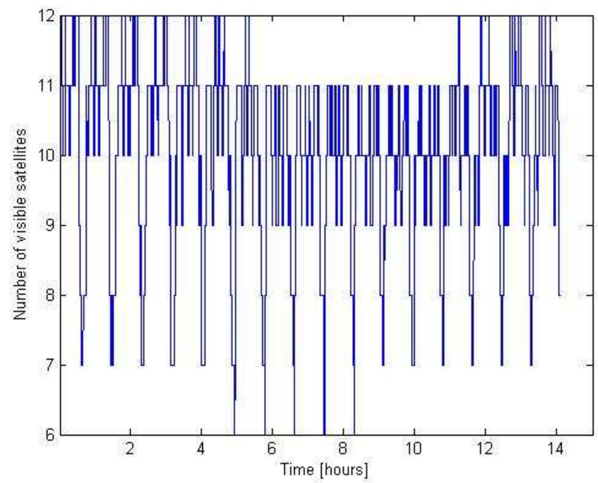

Fig. 5: Number of visible satellites over time, transmitting beacon antenna placed on the satellite surface.

4.1 Collision in time

When more than one beacon is active in the same visibility area, their bursts can collide in time[6]. To determine the probability of collision In time, the number of active beacons in the visibility area needs to be known. The current Cospas-Sarsat system consists of 6 Geostationary Search and Rescue (GEOSAR) satellites. The ratio of a GEOSAR satellite coverage area over the Earth surface is 0.42[6]. The ratio determined for a Galileo satellite is 0.39. There is only a small difference between both ratios and therefore the same number of active beacons was assumed for the Galileo satellite as for the GEOSAR. According to the forecast given in annex G of C/S document T.012 [6] the number of active beacons in 2008 will be 12.71, in 2013 22.35 and in 2018 this will be 25.7. Therefore the calculations are performed for 2 to 26 active beacons.

The probability of collision in time for a long message is given in Fig. 6. A long message consists of 144 bits for which the first protected data field is contained in bits 25 to 85. As expected the probability increases when more beacons are active. When the first protected data field is correctly received, this is sufficient to generate a distress alert. The message received is a valid message. The probability of the collision in time of the first protected data field of a long message, which provides a valid message is slightly smaller then for the complete message.

4.2 Doppler Shift

When two beacons interfere, they can also interfere in frequency. In a worst case scenario this causes both signals to be lost. In case a DRU (Data Recovery Unit) is applied, the message that is currently processed could be lost together with the message of the same frequency that arrives at the DRU[7].

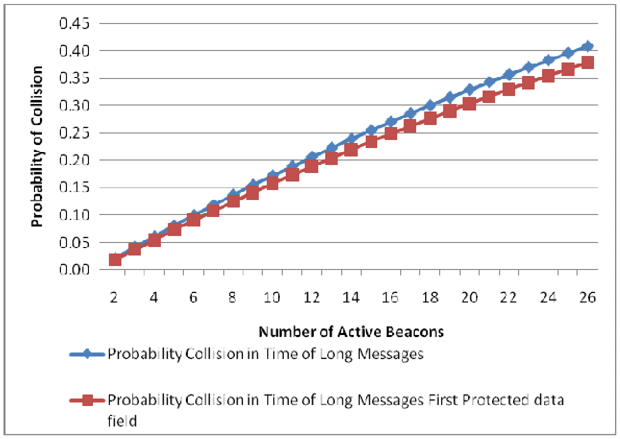

Fig. 6: Probability of Collision in time for long messages and first protected data field

These Doppler shifts can also increase the traffic load in adjacent channels. Therefore the size of the Doppler shift is determined in the sequel.

Doppler shift due to relative motion

The Doppler shift between the user spacecraft and the Galileo spacecraft can be approximated as

$$\Delta f = \frac{V_{rel} f}{c} \cos\theta; \qquad [4]$$

where V_{rel} is the magnitude of the relative velocity of the LEO satellite with respect to the Galileo satellite, f is the transmit frequency, c is the speed of light and θ is the angle between the relative velocity vector and the Line of sight between source (LEO satellite) and the receiver (Galileo satellite).

By way of example, the Doppler shift received at Galileo satellite #1, 11 and 21 is shown in Fig. 7. The Doppler shift is set to zero when the Galileo satellite is not visible.

The frequency band within the SAR payload on the Galileo spacecraft is divided in 19 channels for transmission of the earth beacon distress signals and 6 channels for e.g. Doppler limitations with a 3 kHz spacing each. According to the 406 MHz channel assignment table stated in C/S document T012 part 2 annex H[6] the 406.079 MHz channel is not used by the current SAR system because of Doppler limitations and SARP-2 (Search and Rescue Processor) limitations. Galileo will be using a transparent repeater and therefore the SARP-2 limitations do not apply for the space user system. At this stage of the analysis it is assumed the 406.079 MHz channel could be used for the space user system.

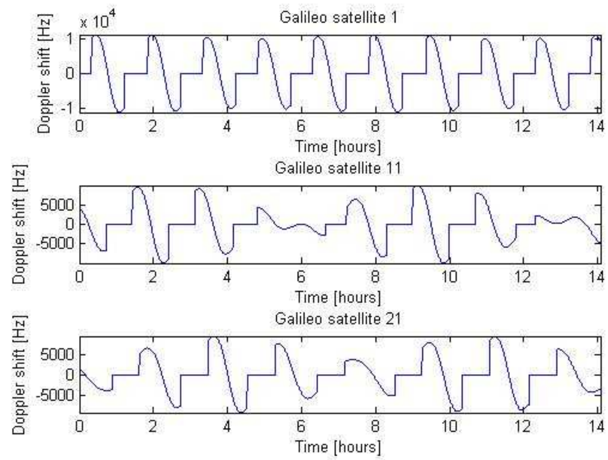

Fig. 7: Doppler shift between the user satellite and selected Galileo satellites

The determined Doppler shifts between the space user and Galileo satellites are between 9000 Hz and 11200 Hz. This is slightly larger compared to the transmission of earth beacons to the current Cospas-Sarsat Low Earth Orbit Search and Rescue (LEOSAR) system which has Doppler shifts of +/- 9000 Hz. But for the future SAR/Galileo system the Doppler shift of the earth beacons will be different then for the LEOSAR system. These Doppler shifts are calculated for one Earth-based beacon at a random location and the results obtained are between the 500 and 1000 Hz. Compared to these values the Doppler shifts of a space user to Galileo are much larger then an Earth beacon transmitting to Galileo.

The Doppler shifts caused by a space user at a frequency of 406.079 MHz will only interfere with the adjacent channels R (406.073 MHz) and S (406.076 MHz) for the signals received by the Galileo transponder. Currently these channels are not in use, but it is taken into account that in case of capacity increase these channels may be opened.

The Doppler shifts in the LEOSAR system will be in the range of 20 kHz, which could cause interference with four channels i.e. channel N (406.061 MHz), O (406.064 MHz), R and S assuming the LEOSAR system will still be in operation when capacity is increased and these channels are opened for use. When a signal of an earth distress beacon is processed in the DRU and a signal of a space user beacon arrives with the same frequency, due to the Doppler shifts, before processing is completed both signals could be lost. Some LEOSAR systems use a Search and Rescue Repeater (SARR). These instruments don't process the signals onboard like the SARP instruments, but when frequency collision occurs at the SARR both signals could be lost in a worst case scenario when they overlap in frequency.

Doppler shift from failure of the attitude control system

The proposed system should be robust and be operational even in severe situations, where the Attitude and Orbit Control System (AOCS) fails onboard of a spacecraft. To assess such an impact in terms of the Doppler shits occurring, it is assumed that the spacecraft is rotating at a rate of 3 deg/s. The Doppler shift obtained for this rotation rate is around 0.54 m/s and assumed to be negligible with respect to the relative motion of the user spacecraft and a Galileo spacecraft.

4.3 Avoiding harmful interferences caused by Doppler shifts

Different options to avoid the Doppler shift to interfere with an Earth beacon transmission were analyzed and are depicted in Fig. 8.

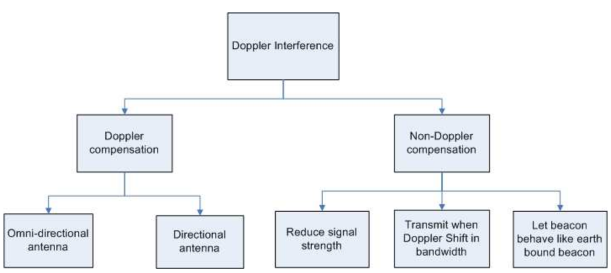

Fig. 8: Options to avoid or reduce Doppler shift.

Doppler compensation was eliminated as an option because it can only be applied for one Galileo satellite at a time and could cause even larger Doppler shifts when received at other Galileo satellites. Using a directional antenna would be an option, but a dish of approximately 2 m would be required which is too heavy for the application of a space user distress beacon and would increase the cost.

The second option is to use no Doppler compensation. Possibilities identified were a reduction in signal strength, to transmit the signal when the Doppler shift is within bandwidth and let the beacon behave like an Earth beacon.

The bit error rate (BER) for the SAR system should be $<10^{-5}$ according to the C/S R012 document [8]. Reducing the signal strength of the space user signal such that it is below the threshold of the earth beacons by allowing, e.g., a higher BER could cause a barrier below which Earth signals could be seen as noise. Because Earth beacons often send in extreme conditions close to their link budget, these signals could be seen as noise. Therefore this option was excluded.

The space user signal could be transmitted only when it is within the bandwidth. The percentage of the number of visible satellites when the signal can be received within the bandwidth can be seen in Fig. 9. There is only a small percentage of time where no reception is possible. For this application also a directional antenna would be required. As stated before this would require a too large dish and result in an increase of the cost. Therefore this option was excluded.

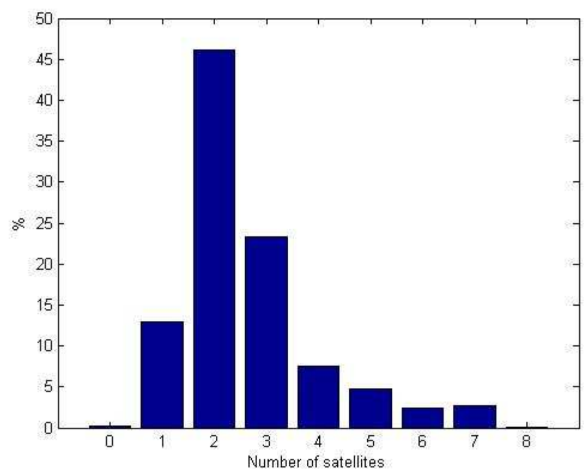

Fig. 9: Percentage of number of Galileo satellites that are within the channel bandwidth

The last option and considered to be the best method is to let the space user beacon behave like an Earth beacon. Earth beacons transmitting close to each other also have to handle Doppler shift interference. This is done by allowing a small variation in their repetition period. When two beacons collide in time, there will be a small difference between their repetition periods such that such a situation does not occur at the next burst. The repetition period of the space user beacon could be made larger than for Earth beacons. This allows more Earth signals to be transmitted and reduces the probability of collision in time (cf. Fig. 10) and consequently the total probability of collision, i.e. the probability of collision in time and frequency, caused by a space user beacon.

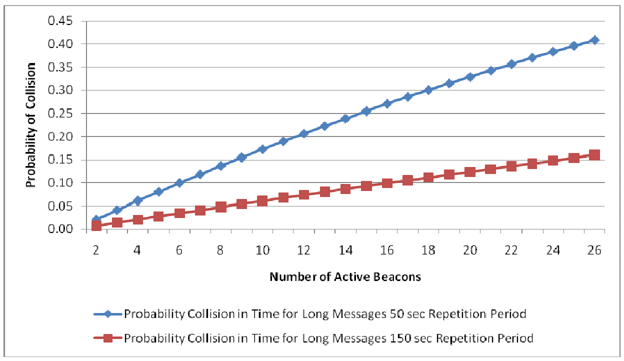

Fig. 10: Probability of collision in time for a long message format

Use could be made of the Return Link Message (RLM) to turn off the distress beacon when the message is received.

5. HIGH LEVEL PAYLOAD DESIGN

5.1 Payload System Structure

In case of an emergency situation at a subsystem of the satellite, a signal will be sent to the satellite onboard computer. From the onboard computer a signal is send to the message generator which will transmit the generated message via the transmitter, modulator, amplifier and antenna (to the Galileo satellites). The system diagram of the high level payload design is seen in Fig. 11.

For the design of the space user payload it was assumed that the transmit power has the same maximum as for an Earth beacon, i.e. 5 W+/-2dB and that the same modulation technique is applied[9].

5.2 Digital Message Structure

There are two types of SAR messages; a short message with a burst duration of 0.44 seconds and 112 bits length and a long message with a burst of 0.52 seconds and 144 bits length.
For the digital message structures protocols are defined by Cospas-Sarsat stated in C/S document T.001[9]. The digital message structure of the space user is designed such that it is compatible with the predefined protocols. To achieve this three options were identified; the protocol of a beacon with a return link message, a User-Location protocol and a standard and national location protocol.

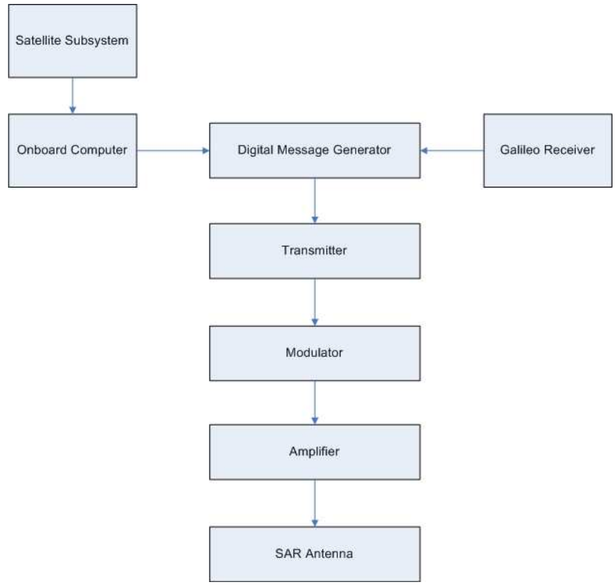

Fig. 11: High level SAR payload design

The protocol for a beacon with Return Link Message

A return link message will be implemented in the Earth beacons and for this type of beacons a new protocol was defined. The protocol of the RLM will be based on and be compatible with the National Location Protocols given in C/S document T.001[9],[10]. The 00 pattern of bits 25 to 26 will indicate that the beacon is encoded with one of the new MEOSAR protocols which will be defined by the patterns of bits 37 to 40. There will be 16 newly available protocols from which eight will be reserved for beacons having a Galileo Return Link capability:

- Four protocols compatible with the current National Location Protocol:
  - RL ELT 1000
  - RL EPIRB 1010
  - RL PLB 1011
  - RL Test 1111
- Four protocols reserved for future return link beacons compatible with future Cospas-Sarsat beacons which are optimized with the MEOSAR system.

The pattern 00 of bits 25 and 26 indicates a short message format.

In Cospas-Sarsat the code 1001 for the long message format is reserved as spare and could be used for the space user beacon

- RL Space user 1001

Alternatively, one of the four reserved protocols could be used. When the message format is short, which means that bit 109 to 112 could be used for supplementary data, the disadvantage is that it is in the non-protected data field and only a small amount of data can be implemented. However, the position of a satellite is known in advance because the orbit is known. Position data is therefore not necessary and could be used to send extra information about the type of emergency of the satellite.

User-Location Protocol

The user protocol is a long message protocol and the outline is given in Fig. 12. The protocol codes are defined in bits 37 to 39 and from C/S document T.001 page A-4 [9] it can be seen that the code 101 is a spare. It is assumed that it would be possible to use this spare for a space user beacon. There is no supplementary data available but as stated before the position data is not necessary and these bits could be used.

User-Location Protocols							
bit 26	bits 27-39	bits 40-83	bits 84-85	bits 86-106	bit 107	bits 108-132	bits 133-144
1	....	Identification Data (44 bits)	Radio-locating Device	21-Bit BCH code	Posit. Data Source	Position Data to 4 min Resolution (25 bits)	12-Bit BCH code

Fig. 12: User-location protocol [9]

The Standard location and national location protocol

The standard location and national location protocol is shown in Fig. 13.

Standard Location Protocols							
bit 26	bits 27-40	bits 41-64	bits 65-85	bits 86-106	bits 107-112	bits 113-132	bits 133-144
0	....	Identification Data (24 bits)	Position Data to 15 min Resolution (21 bits)	21-Bit BCH code	Supplementary Data	Position Data to 4 sec Resolution (20 bits)	12-Bit BCH code

National Location Protocol								
bit 26	bits 27-40	bits 41-58	bits 59-85	bits 86-106	bits 107-112	bits 113-126	bits 127-132	bits 133-144
0	....	Identification Data (18 bits)	Position Data to 2 min Resolution (27 bits)	21-Bit BCH code	Supplementary Data	Position Data to 4 sec Resolution (14 bits)	National Use	12-Bit BCH code

Fig. 13: Standard location and national location protocol [9]

It consists of a long message format and the protocol code 1101 is stated as spare and could be used for the space user beacon.

The protocol of the space user system could be based on one of these protocols and it was assumed that the spares can be used. The protocol defined for the beacons equipped with a return link is a short message format which can reduce the probability of collision. The other two are both long messages, the advantage of this is that a larger amount of information about the emergency sitaution can be transmitted. An example of a space user beacon protocol based on the national standard protocol is given in Fig. 14.

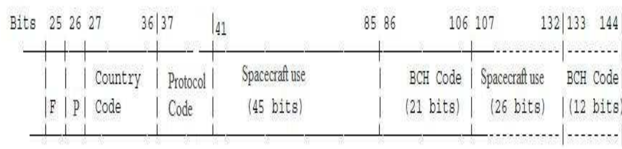

Fig. 14.: Sample Space user protocol based on national and standard location protocol (based on [9])

To avoid secutiry issues, the message could be passed through the Cospas-Sarsat system the same way as the national user, only as hexadecimal data such that they can only be interpreted by the appropriate satellite control center. The message might also be after being processed at the MEOLUT directly transmitted to the satellite mission control center instead of passing via the MCC. This would prevent other authorities to be notified about problems occurring at certain satellites.

5.3 Repetition Period

The repetition period defined by Cospas-Sarsat for an Earth beacon is randomised around 50 seconds. The interval between transmissions will be distributed over the interval 47.5 to 52.5 seconds. This is done such that when two beacons collide in time, this will not take place during the next burst.

For the space user, a larger repetition period could be selected e.g. 150 seconds, such that more Earth beacons have the opportunity to transmit their signal and the probability of collision caused by a space user is decreased. This could be done to account for possible legal issues.

5.4 Transmission time

The transmission time for a short message is 440ms±1percent and 520ms±1percent for a long message. This is assumed to be the same for space users as for Earth beacons.

5.5 Transmitter

To make optimal use of the frequency band 406.0-406.1 MHz and ensure adequate system capacity, the band was divided in 19 channels of 3 kHz spacing. Taking into account the Doppler shift limitation of the space user beacon the channel 406.079 MHz was selected for use.

According to ITU regulations the 406.0-406.1 MHz band is used for low power satellite emergency position-indicating radio beacons[4]. The transmit power for space users was firstly assumed to be according to the regulations of Cospas-Sarsat that the power needs to be 5 W ± 2dB. A sample link budget was established based on the sample link budget in C/S document R012 annex J[8] and for the same nominal case the transmit power of the space user could be reduced to approximately half the value of the Earth beacon.

5.6 Modulation

The modulation of the space user beacon was assumed to be equal to the modulation of an Earth beacon. The used modulation in the system that is currently operational is BPSK and the carrier wave will be phase modulated positive and negative 1.1±0.1 radians peak in reference to an unmodulated carrier. The rise (τ_R) and fall (τ_F) times of the modulated waveform shall be 150±100 µs.

The data encoding is biphase L.

Another modulation that will be applied in future SAR beacons is Mixed Quadriphased Phase Shift Keying (MQPSK). The efficient channel coding obtained from this type of modulation could increase the link margin with several dB[8]. The amount of bandwidth needed for the same data rate as BPSK could with this system be reduced to half. In the space user application MQPSK modulation could be used instead of BPSK.

5.7 Antenna specifications

The antenna for the space user beacon shall be omni-directional to allow transmissions in all directions. The polarization should be RHCP (Right Hand Circular Polarized) or linear because the receive antenna at the Galileo transponder will be RHCP. The gain is assumed to be the same as for Earth beacons between -3dBi and 4dBi.

Different antenna options are possible:

- Dipole antenna. A disadvantage of this antenna is that it has a null at it's axis on both poles of approximately 23.8°. The number of visible satellites will be slightly smaller than assuming no null is present.

The gain is positive between 0 and 2.15dBi for -30 and 30 degrees elevation and half a wavelength. This gives a large area with negative gain which will give a small positive or negative link margin.

- Canted turnstile mounted antennas which provide good visibility and gain capabilities. Two quadrifilar helix antennas, whip or dipole antenna's could be mounted this way.

5.8 Return Link Message

The SAR/Galileo system will provide a major innovation with respect to the current SAR system by implementing a Return Link Message (RLM) through the Galileo navigation signal. This RLM will be providing an acknowledgement of reception of the distress message sent by the beacon. Beacons that are equipment with a Galileo receiver will be able to receive such a signal, which will be short SAR messages in the Galileo navigation signal. By implementing a Galileo receiver in the space user beacon this return link can be received and could be used to stop transmission of the signal when the message is successfully received. This prevents unnecessary interference to Earth beacons. The 16 bits and 96 bits for the short and long format respectively of the Return Link Message could be used by the satellite operators to send information. This might be extended to send commands to handle the emergency situation even before the satellite is visible. The return link opens exciting opportunities which should be investigated in the future.

6. CONCLUSIONS

A novel emergency system has been presented which extends current SAR applications for terrestrial, maritime and aviation users to spacecraft, encountering severe problems. Such a system would enable a continuous ability to report problems to the mission control center and could help to safeguard mission operations and reduce the risk of mission loss. Based on simulations of the visibilities and Doppler shifts, key technical and system design aspects of such a system have been addressed.

The main challenges of implementing such a system are legal and regulatory aspects. The 406.0-406.1 MHz band is currently open only for Earth-space low power satellite emergency position-indicating radio beacons. The approval of the ITU will be needed to open the band for space-to-space communication for a non human rescue purpose. An agreement should be established as well with DASS as SAR/Glonass.

The Doppler shifts that will be received by the Galileo satellites are about 11 kHz. This is relatively high but with the chosen bandwidth of 406.079 MHz only two channels will be affected by this. The Doppler shifts from LEO satellite to the LEOSAR satellites obtain values of around 20 kHz. If the LEOSAR system is still operational when channels N (406.061 MHz) and O (406.064 MHz) are opened, a total of four channels can be affected by the Doppler shift.

The best method to cope with the Doppler shifts is to design the space user beacon characteristics to be similar with that of an Earth beacon. Intentional differences in the repetition periods of Earth-bound and space users can minimize the chance of signal collisions.

The proposed concept can have a significant impact on improving robust satellite operations, reducing mission failure rates and lowering insurance cost. Making additional use of return links can improve these benefits even further.

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