Future Concepts for Galileo SAR & Ground Segment

Executive summary

April 2017, Thales Alenia Space

Ref: 0005-0008584264

TABLE OF CONTENT

ASIC	Application Specific Integrated Circuit: high processing capacity component dedicated to one code
BDP	Burst Data Packet: demodulated distress message burst and associated ancillary data
D&E	Demonstration & Evaluation: preliminary testing phase in Cospas/Sarsat developments
Encoded	Beacon position taken from its GNSS receiver (when available) reported in the distress message
EQM	Evaluation Qualification Model: for SARP, fully representative hardware (including ASIC) for test
FGB	First Generation Beacons, current beacons waveform
FOC	Full Operational Capability: date when worldwide MEOSAR coverage is achieved (2020)
GALLUT	Central ground station processing the messages demodulated by on-board processing payloads
Independent	Beacon position estimated by the MEOSAR system, using at least 3 satellites
LEOSAR	Search-and-Rescue satellite system based on LEO satellite, used from 1980 to around 2020
MCC	Mission Control Centre: operational interface between MEOLUT and Cospas/Sarsat network
MEOLUT	MEOSAR processing ground station for current system with SAR repeater payloads
MEOSAR	Search-and-Rescue satellite system based on MEO satellites (Galileo, Glonass, GPS)
Networking	Capability of ground stations to exchange measurements on beacon bursts
OMNILUT	Local ground station receiving the messages demodulated by on-board processing payloads
PFM	Proto-Flight Model: used for in-orbit payload and GALLUT/OMNILUT testing during D&E
SGB	Second Generation Beacons, specifically developed for MEOSAR, with spread-spectrum
SIT	Subject Indicator Type: format used for exchange between Cospas/Sarsat ground elements

Major acronyms and terms for MEOSAR context

Galileo contribution to the Cospas/Sarsat MEOSAR system

The Cospas/Sarsat MEOSAR system entered operation phase the 13th of December 2016, thanks to the availability of 3 MEOSAR ground stations called MEOLUTs (the French one developed by Thales Alenia Space and the two US ones), and thanks to a sufficient number of satellites.

In the coming months, the system will be extended to reach a worldwide coverage and enter Full Operational Capability (FOC), thanks to the addition of operational satellites and MEOLUTs. The FOC is to be declared in 2019: at this date, the space segment of the system will be based for 75% on Galileo satellites. Also considering the ICAO requirement for deploying in-flight activated beacons on all new commercial aircrafts from January 2021, this indirectly brings a major role for Galileo in worldwide aviation safety and security. Galileo is then the main support of the Cospas/Sarsat system today and for the next years.

In addition, Galileo is also providing an additional innovative service with its Return-Link capability. Today, the Return-Link Service is mainly intended to send acknowledgment messages, but other uses are also considered in the near future (such as remote activation in aviation to manage aircraft disappearances), which may lead to new specification on the Galileo SAR service.

Objectives of the study

While the MEOSAR is moving to FOC with Galileo satellites that are equipped with SAR transparent payloads, ESA is already investigating its future Galileo-2 (G2G) system for new features.

In this framework, one of the aims of the ESA study on Future Concepts for Galileo Search And Rescue was to define a preliminary design of a new SAR payload capable of processing both First Generation Beacon (FGB) and future Second Generation Beacon (SGB) signals.

The purpose of the ESA study was also to analyse various communication architectures to transmit the signals back to the Earth, and to assess the overall system performance.

The study has been conducted with the following drivers and constraints :

- the existing MEOSAR service, based on a space segment with SAR transparent payloads, will be operational for the next 15 years. Galileo-2 will still be contributing to the Cospas/Sarsat MEOSAR system and will then maintain its transparent payloads in line with the Cospas/Sarsat system requirements and needs;
- thanks to the improved location performances and miniaturization of beacons, the Cospas/Sarsat service is going to be adopted by more and more people all around the world, leading to an increased traffic in the next decade. The future SAR payload will have to take into account this increased flow.
- the new on-board processing function shall minimize the impacts on Galileo and Cospas/Sarsat systems, and on Galileo satellites. In particular, the delivery of messages will have to use the existing Galileo or Cospas/Sarsat telemetry channels. The cost and effects of both the payload and the ground segment will have to be reduced.

Added value of SAR processing on-board G2G satellites

The addition of on-board processing on Galileo-2 satellites would bring 4 advantages and opportunities compared to the current system:

- Worldwide homogeneous performance.
  With a SAR transparent payload, the quality of both the distress detection and localization depend on the closest MEOLUTs. Even if there are minimum commissioning requirements, past tests have shown that performance varies from one MEOLUT to another. In addition, the performance is not homogeneous because each country owning a MEOLUT establishes a minimum coverage area corresponding to its rescue area, where the performance shall be optimized. Even if other regions around this rescue area are also simultaneously covered thanks to the large MEO satellite footprints, the quality of localization in these regions is not verified during commissioning and is then expected to be degraded.

- Improved accuracy.
  In the current system, a distress alert picked up by a satellite that is not in the field of view of a MEOLUT is lost. With a processing on-board the satellites and a ground centralization of the processed data, all the satellites in the beacon field of view can be used for localization. Taking into account the beacon antenna mask (FGB antennas cannot emit in the zenith direction, whereas future SGB antennas do), this would increase the accuracy by 30%. The accuracy could also be improved by networking MEOLUTs in order to exchange and combine measurements. However, this option is not recommended because this network would be composed of MEOLUTs from different providers, which could make the calibration process more difficult.

- Return-Link with reduced latency.
  It could be possible with this on-board processing to implement the Return-Link directly on-board the satellite, with a latency reduced from a few minutes today to a few seconds. This on-board Return-Link concept cannot be generalized because of possible multiple Return-Links by several satellites for the same beacon, and because of operational risks (in case of false detection for instance); however, it might be interesting in specific emergency cases for the delivery of information to surrounding people for instance.

- Direct downlink of distresses on simplified LUTs.
  Classical MEOLUTs request high reception capabilities and processing functions (in particular for Second Generation Beacons), as the received distress signal is only transparently forwarded by the SAR payload. With on-board signal processing, ground reception and processing are far less complex. Then, it is possible to deploy simplified LUT stations (called **OMNILUT** in the study) with reduced cost. OMNILUT could even be transportable and used by rescue teams or other users to get continuous and instantaneous information on distress beacons during search activities.

Space segment – Processing payload design

The use of on-board processing was already implemented in the LEOSAR system. Thales Alenia Space developed the on-board processing of the last generation of SAR processors in the late 1990's. The implementation of on-board processing for MEOSAR will use the same principle, but with the following modifications:

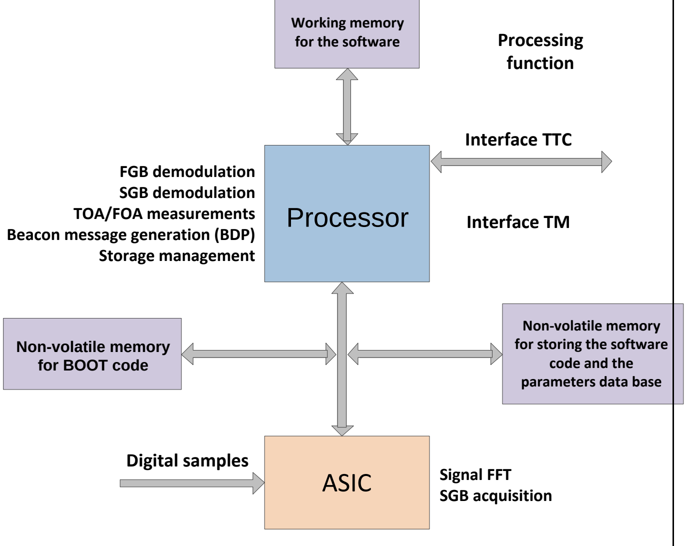
- Increase of the number of simultaneously processed beacons, due to a higher traffic and a larger footprint
- Addition of on-board measurement calibration to ease the ground processing (in particular for OMNILUTs), by exploiting ephemeris that are directly available on-board the satellite
- Modification of the beacon data packet formats (BDP: Burst Data Packet) to include additional information for MEOSAR, in particular Time Of Arrival measurements
- Adaptation to Second Generation Beacons (SGBs).

This last requirement on SGB processing is important because the acquisition of these beacons is very consuming in terms of processing power, and requires specific hardware on the MEOLUTs that already implement the SGB processing today.

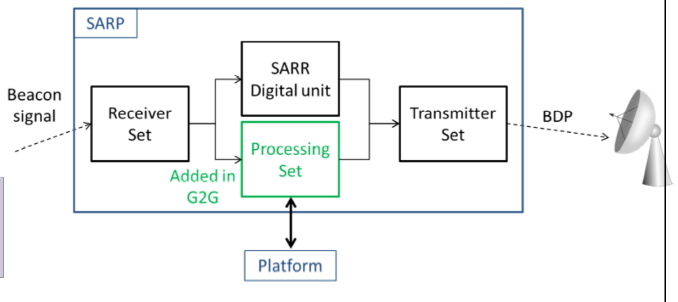
For an on-board implementation, taking into account the simplicity of the acquisition function (in terms of number of code lines), the number of models to produce, and the sufficient schedule, an ASIC development will be the preferred option. This leads to an ASIC + processor classical design, which is already used on LEOSAR on-board processing payloads or on satellites with GNSS receivers.

The following figures provide the general schemes of the processor function, taking into account the repeater function that will also be implemented in the digital domain for an easier integration and an improved jamming protection.

SAR processor



SAR processor and repeater



The implementation of the on-board processing does not require any modification on the RF receiver part: it can be directly re-used from the current Galileo-1 design.

Ground segment - GALLUT

Unique ground station with worldwide coverage

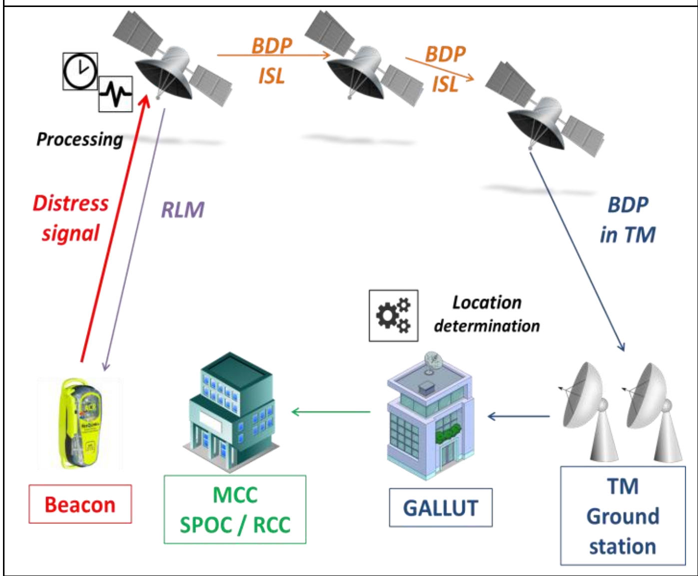
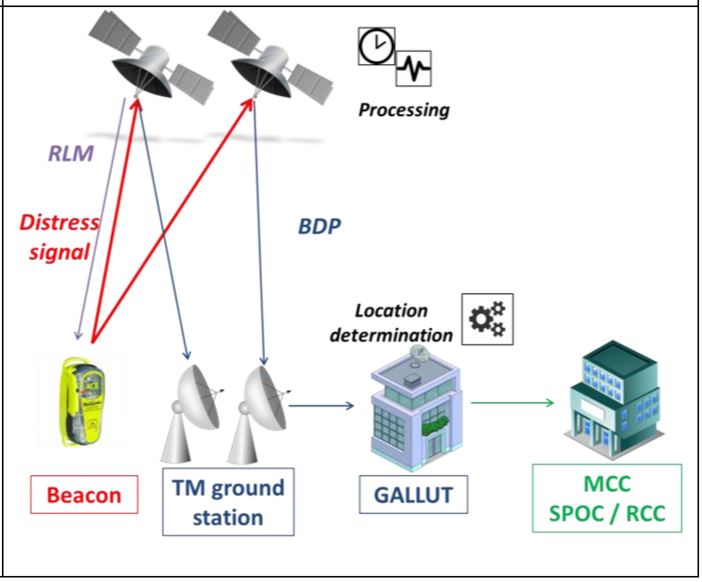
Architecture

The implementation of a unique ground station (called **GALLUT)** collecting Burst Data Packets (BDP) transmitted by all G2G SAR payloads will be possible thanks to the use of the Galileo telemetry:

- with the current solution using classical telemetry ground stations: this is the most simple, but depending on evolutions on TTC system on Galileo-2, there may be some latency and impact on Galileo ground stations for the data delivery to the GALLUT;
- or with the Inter-Satellite Link (ISL): the data rate for SAR demodulated messages is low compared to current requirements for ISL, so that if an ISL is implemented on Galileo-2, it would be relevant to include in it the SAR data flow.

The GALLUT would be connected to a unique Cospas/Sarsat Mission Control Centre (MCC), which will significantly simplify the interface with the Cospas/Sarsat system.

The 2 possible architectures (one with ISL and one without ISL) are depicted below:

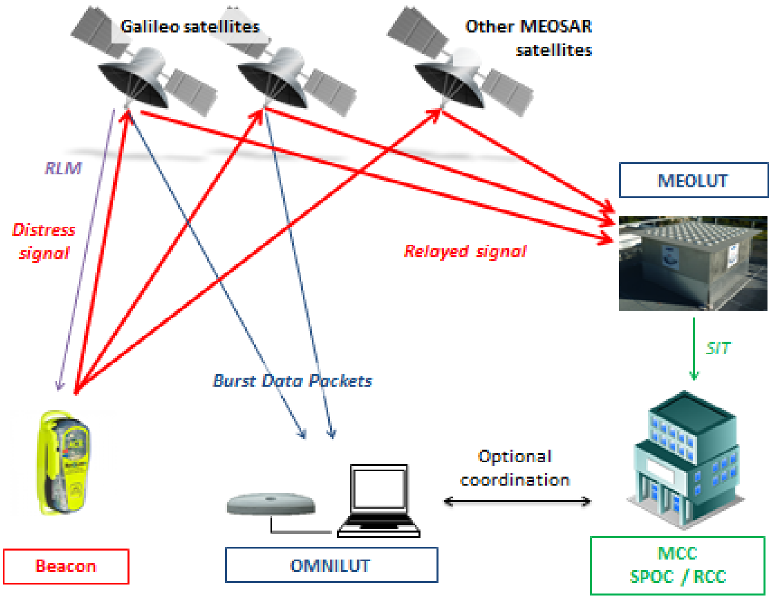
With ISL	Without ISL
	

Ground segment – OMNILUT

Simplified ground station with local coverage

Thanks to the reduction of data rate by on-board processing, the link budget for the delivery of BDPs on L-band is much better than the one with a transparent payload. This gain has to be shared between the satellite transmission power and the ground station G/T: then it becomes possible to receive the BDPs with a simple hemispherical antenna.

The following figure provides the overall architecture, which preserves the transparent function (the relayed signal and the MEOLUT are still present).



Depending on the number of satellites in common visibility of the beacon and the OMNILUT, an independent localization (i.e. only using Cospas/Sarsat satellite reception) can be achieved by the OMNILUT with three or more satellites. Otherwise, it shall rely on the capability of the beacon to get a location from its internal GNSS receiver and to include it in the emitted signal (encoded position).

The data could be downlinked in the part of the L-band already used by Cospas/Sarsat, or in another telemetry band. The first option seems the most simple and can be efficiently combined with aGALLUT, but if other channels are opened on Galileo-2 for telemetry, in particular to specific types of users, the possibility to add the BDP flow in it should also be considered. If the L-band is used, the simultaneous reception of signals from different Galileo satellites can be solved with various solutions, among which the Code Division Multiple Access technique is the preferred one. It could use the same code length than for SGB signals (38400 chips/s) for an easier consistency and implementation in Cospas/Sarsat. It might be delivered for instance in the 1544.16 MHz – 1544.24 MHz band.

Ground segment – Expected performance

The maps on the next page compare the positioning accuracy of FGBs (left column) and SGBs (right column) for a MEOLUT, an OMNILUT and a GALLUT, all placed in Toulouse. The colour code of the figures goes from blue (min value) to red (max value) as follows:

- For FGBs : [0 km - 5 km]
- For SGBs : [0 m – 300 m]

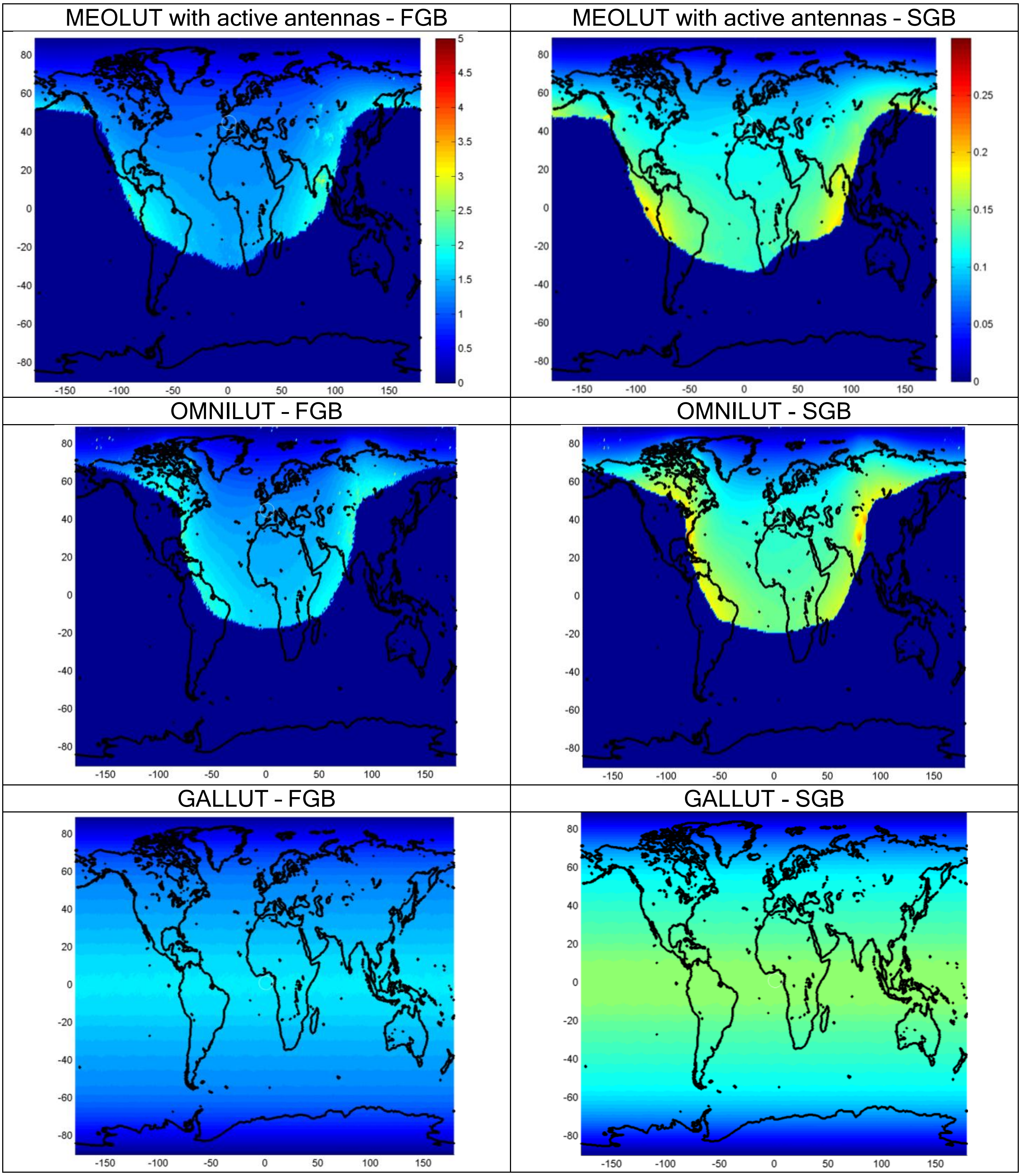
There is no localisation possible in deep blue zones.

Because the GALLUT is connected to ground stations located all around the Earth, it has constantly access to BDPs transmitted by all Galileo satellites. Therefore, the positioning is very accurate everywhere.

The OMNILUT coverage and positioning accuracy are slightly smaller than the ones for a MEOLUT, especially for FGBs which do not emit above 60° (limited antenna pattern). Indeed, an OMNILUT does not have access to GPS and GLONASS satellites, so that the minimum of three satellites in common visibility of the beacon and the OMNILUT is less often reached.

To cope with this reduced OMNILUT coverage, three solutions can be investigated:

- Increase the number of stations, knowing that an OMNILUT will still be less expensive
- Implement networking (measurements exchange), but it requires a worldwide connectivity
- Use the OMNILUT as a local add-on/improvement, in complement with a GALLUT

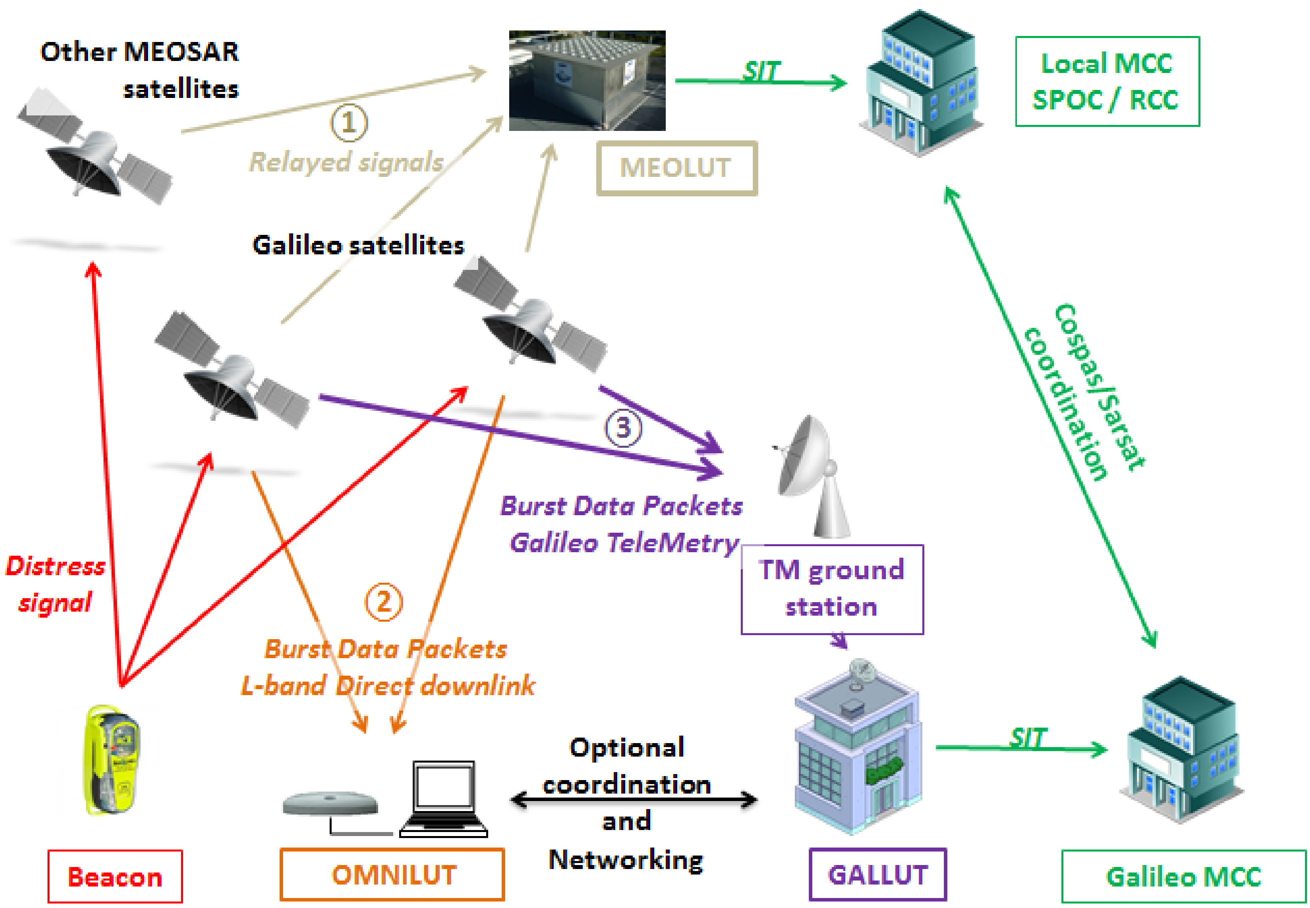


Positioning accuracy maps

Ground segment – Recommended architecture

The recommended solution is then to maintain/implement 3 types of downlinks (see the figure below):

- (1) To maintain the transparent capacity and the MEOLUT implementation as it is today, to maintain contribution of Galileo to the Cospas/Sarsat system
- (2) To implement a direct downlink of on-board processed data in L-band, in the Cospas/Sarsat band, with a CDMA approach for multi-access and a link budget compatible with OMNILUT.
- (3) To implement a "worldwide" downlink system inside Galileo, delivering all data to a single station (GALLUT) connected to Cospas/Sarsat. This ensures the homogeneous coverage with optimum accuracy. This delivery should use the Galileo telemetry system, either with an Inter-Satellite Link or not.



In terms of impact for the system, the L-band transmission power required for data delivery to an MEOLUT/OMNILUT is negligible compared to the transmission power for the repeater, and the telemetry transmission to GALLUT is negligible compared to other considered telemetry data flows for Galileo-2. Therefore, this number of various links does not appear critical while significantly improving the service.

Development plan

The main driver of the development plan is the ASIC that has to be implemented in the processing payload to process SGBs. The development can be anticipated, but it seems reasonable for the final definition to wait for the start of exploitation of these SGBs inside Cospas/Sarsat, which is expected in 2020. From this date, a duration of 24 months is considered for the finalization of the ASIC, its integration and validation inside the EQM, which leads to a final payload qualification in 2022. From this date, the flight models can be produced quite rapidly, if required by the Galileo program.

As soon as possible, it would be interesting to launch a first satellite with this payload. Indeed, this would allow the final implementation and validation of GALLUT and OMNILUT functions (similarly to a Cospas/Sarsat Demonstration & Evaluation phase), and if possible updates of MEOLUTs for reception of the direct signal. One particular interest of the GALLUT is that it can provide distress information with only one equipped Galileo satellite (only with encoded position, similarly to a GEOLUT), and have a continuous increase of the service quality with the addition of new satellites.

There is no major technical risks for the development, which could be done both for board and ground components using current technologies, with only a focus on the ASIC even if the number of code lines is low (parallel acquisition function with Fast Fourier Transform).

The main point to analyse for the development will be the evolutions and interfaces with the Galileo-2 downlink system, in particular for the delivery of data to the GALLUT. For this reason, it will be crucial to have a finalized system design for the SAR processor function, and in particular to provide all the beacon models and associated data rate volumes as input for the design of Galileo-2 overall telemetry system. Possible impacts of latency and associated recommendations for the system design shall also be taken into account.

A safe development plan could then be implemented as follows:

Element	2018	2019	2020	2021	2022	2023	2024	2025
Cospas/Sarsat SGB	Final definition		Exploitation					
SARP development	PDR	CDR	ASIC and EQM		PFM	Flight models		
In-orbit testing (D&E)						D&E		
GALLUT/OMNILUT			Development			Exploitation		
Galileo-2		Galileo TTC Design			Development			

With this schedule, the Initial Operational Capability (IOC) could be decided in 2025, and the Full Operational Capability (FOC) as soon as the number of Galileo-2 satellites is sufficient.

Conclusion

The study has led to the definition of a beacon traffic model for 2025 including SGBs, a preliminary payload design, and first level description and specification of the system. These activities have shown the feasibility and the schedule compatibility of such an initiative, raising in particular the question of the ASIC development for the acquisition of SGBs, but this development does not seem a major constraint if the program is started in line with the Cospas/Sarsat and Galileo-2 developments.

The study has thus shown the interest and the feasibility of the addition of on-board SAR processing capacity on future Galileo satellites, complementary to the transparent function.

The use of such a SAR payload mainly opens two major system improvements:

- the availability of a worldwide homogeneous reception capacity with higher accuracy than minimum Cospas/Sarsat requirements, with only one ground station (GALLUT). The latency would depend on the Galileo-2 telemetry architecture, but it could be very limited if an Inter-Satellite Link or an improved Telemetry network is implemented;
- the availability of a direct local downlink capability, possibly in L-band, for reception by simple ground receivers like omnidirectional antennas linked to laptops. This could help for the dissemination of message updates and the coordination of rescue services.

In both cases (worldwide Telemetry and local L-band SAR transmission), the data rates and associated transmission power are low compared to the sizing of the other services: their impact to the current design would then be low.

Furthermore, this initiative could thus maintain Galileo as a major contributor and innovation driver in the worldwide Cospas/Sarsat Search-And-Rescue system.