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COGNITIVE RADIO FOR SATCOM APPLICATIONS: THE SCREEN PROJECT

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Spectrum allocation for current wireless communication systems is performed by the regulatory and licensing bodies, who allocate spectrum bands for given applications. This strict allocation severely limits the effectiveness and flexibility of the spectrum use. Cognitive radio (CR) has been demonstrated as a key emerging technology to provide flexible and efficient use of the available spectrum by allocating frequency bands dynamically, and to improve the performance of radio systems in congested or jammed environments. Frequencies that are reserved or usually occupied can be exploited if the cognitive radio system identifies them as being free. Such a system is also able to monitor and deal with degrading communication performance or regulatory constraints. It automatically adjusts radio settings to use the best wireless channels in its environment, ensuring appropriate quality of service, efficiency and versatility.

The SCREEN project proposes to extend the concept of cognitive radio to space and particularly to SatCom applications. This is an on-going project funded by the Horizon 2020 European Union programme.

CR has never been used or tested in space, since previous research has been focused in terrestrial technologies. By addressing this topic and demonstrating its capabilities and benefits for space applications, SCREEN will contribute to a better management of this scarce resource that is bandwidth. While it has already been demonstrated that CR technology radically improves the performance for terrestrial applications at many different levels, the same benefits also apply in Space and especially in the SatCom segment, where the services provided need to ensure quality to the clients, for market competitiveness. CR has the potential to enable different approaches for managing the growing satellite communication demands and provides flexibility to explore new types of hybrid networks. SatCom operators will benefit from having the flexibility to allocate frequency slots dynamically, according to the instantaneous traffic patterns, instead of reserving fixed bands within regulatory constraints. Additionally, by optimising the spectrum management, SatCom operators can accommodate more users at the same time, without sacrificing the network performance.

In this paper we will describe the overall concept behind the SCREEN project and present the results of a complete framework analysis, consisting of technical conclusions, market and impact analyses, regulatory considerations/constraints and requirements. Based on this analysis we further present functional, performance and test requirements for the project, which will show the project direction and outcome, together with the expected benefits that this technology will bring to Space applications.

I. INTRODUCTION

The benefits of cognitive radio in terrestrial communications are widely used and clearly demonstrated. This technique radically improves the performances of terrestrial applications at many different levels especially for smartphone users. It is a critical factor in delivering the constant demand for high data rate and worldwide coverage.

The space industry is seeing the same increase in demand. Miniaturization and technological progress drive a need for higher bandwidth and makes space technology accessible to commercial companies and new entrant to this market (for example CubeSats).

With more companies interested in space applications, spectrum is increasingly one of the most important resources for communication. Cognitive radio has been proven to be a very effective way to approach this issue but has never been used nor tested in space.

The SCREEN project, funded by the Horizon 2020 European Union programme, addresses this issue and proposes to extend the concept of cognitive radio to space applications.

This paper presents the work accomplished and summarises the key findings that drives the implementation of the cognitive radio algorithms developed within this project.

This paper is structured in 6 chapters. The second chapter addresses the SCREEN context by introducing the concept of cognitive radio and corresponding technology, concluding with a detailed description of the objectives of the project. The third chapter presents the framework analysis done within this project. Chapter four presents the selected use case. Chapter five describes the GAMALINK platform on which the cognitive algorithms will be implemented and chapter six presents the set of requirements that was derived from the first analysis. The last chapter concludes the paper.

II. THE SCREEN CONCEPT

II.I Cognitive Radio concept

The concept of cognitive radio was introduced by J. Mitola III in 1999[1] who also coined the term "Software Radio" in 1991[2]. The software radio aims at building multi-mode and multi-band platforms in order to provide flexible communications radios that can accommodate different standards within the same hardware. This is made possible by using software versatility. For those radios, 80% of the functionality is provided in software, compared to the 80% hardware in the 90's. By the end of the 90's, the software radio concept was on the verge of being ready for commercial applications, and Mitola thought about the ways of using the versatility brought by the software radios in order to optimize the performance of communication systems. This led to the cognitive radio concept.

A CR is a system that is able to sense its operational environment and can dynamically and autonomously adjust its radio operating parameters accordingly, to achieve or to be as close as possible to pre-defined target objectives. It learns from previous experiences and deals with situations not planned at the initial time of design. Cognitive radio techniques provide the capability to use or share the spectrum in an opportunistic manner. Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. More specifically, the cognitive radio technology will enable the users to determine which portions of the spectrum are available and detect the presence of licensed bands (spectrum sensing), select the best available channel (spectrum management), coordinate access to this channel with other users (spectrum sharing) and vacate the channel when a licensed user is detected (spectrum mobility).

Fig. 1 shows the concept of cognitive radio, based on the so-called "cognitive cycle" identified by J. Mitola[1]. The cycle includes three main steps: 1) Observe, 2) Learn/Decide, 3) Apply. These steps are repeated (hence the term "cycle") in order to take into account the variability of the environment, due to factors such as mobility and usage or degradation of the environmental conditions. The spectrum sensing, decision-making and radio reconfiguration in **Fig. 1** illustrate this cycle. The learning stage has been separated from the decision making step, in order to place it more appropriately after the radio reconfiguration step. In this way, any limitations or loss of performance resulting from the radio modifications can be incorporated into the cognition process. This learning stage and knowledge regarding regulatory issues are inputs to the decision making stage.

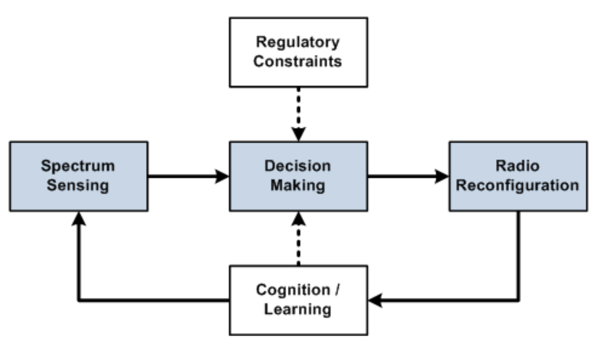

Fig. 1: Cognitive radio concept.

In more detail, the main functions of cognitive radio are:

- Spectrum Sensing: The goal of spectrum sensing is to determine the status of the spectrum usage and the activity of all users on the selected environment by periodically sensing the target frequency band. In general, a CR transceiver senses the spectrum and detects unused frequencies, so called 'spectrum holes' (i.e. band, location, and time) and also determines the method of accessing it (i.e. transmit power and access duration) without interfering with the transmission of other users. Different sensing strategies corresponding to different ways of sharing measurements can be implemented.
- Decision Making: The decision making process is essentially done by a Dynamic Spectrum Management (DSM) supervisor, whose main function is to analyse the information coming from the different inputs, decide upon the spectrum band to use and coordinate the CR users, in order to prevent multiple users colliding in overlapping portions of the spectrum. Based on interference, spectrum occupancy, spectrum coverage and received power calculations and supported by cognitive and spectrum regulation information, CRs decide on the best spectrum band to meet the Quality of Service (QoS) requirements of all communications. The QoS can be characterized by the signal-to-noise-ratio (SNR) or the average duration and correlation of the availability of spectrum holes.
- Radio Reconfiguration: Based on the decision made by the DSM supervisor, the radio transceiver needs to reconfigure itself to the new communication parameters, i.e. frequency, bandwidth, data rate, etc. This stage is mainly related with the software radio technology, which is an important enabler to provide the required flexibility, not only for the real-time reconfiguration capability, but also for running the cognitive algorithms.
- Cognition/Learning: One key aspect of CR systems is learning. Indeed a key understanding is the fundamental difference between adaptive systems and cognitive ones. Adaptive systems have a deterministic behaviour under identical conditions, while cognitive systems may continue to integrate additional learning experience and therefore behave differently under subsequent identical conditions. Therefore, this stage incorporates information from the current cognitive cycle iteration in learning techniques, which will be used in the subsequent iteration for a more reasoned decision.
- Regulatory Constraints: A key requirement of cognitive radios, in order to operate and decide autonomously is to be aware of regulatory constraints in the band that is being used. While spectrum sensing provides information regarding the current band occupation and performance characteristics, regulatory input tells the radio if the available gaps in the spectrum can actually be used and under which conditions.

II.II Software-Defined Radio as a key enabling technology

Based on the concept description, it is clear that the technical enablers for developing a cognitive radio transceiver are:

- Software-Defined Radio (SDR) architecture, which introduces the ability to perform software upgrades in a platform and run-time modification of the applied waveforms. This means that novel features such as cognitive functionalities can be introduced.
- New signal design paradigms for flexible waveform design.
- Radio channel sensing and estimation capability.
- System modelling for effective real time parameter optimization.
- Reasoning and learning algorithms.

Some of these technologies come from other fields of research, such as learning theory. However, from all those mentioned above, SDR is the most critical, since it would be almost impossible to devise the concept of an autonomous reconfigurable cognitive radio if the hardware would have to be modified to change the radio parameters.

Software-Defined Radio holds great potential for radio communications due to its flexibility. The capability to replace almost all radio components by software enables one to use any protocol/waveform as desired (within the constraints of the antenna and ADC/DAC stages) and to upload, modify or replace altogether waveforms. This capability is seen as very interesting and possibly cost saving for multiple communication applications and is considered as a building block of other technological concepts such as the cognitive radio. The ideal SDR (Fig. 2) consists of three main units: a reconfigurable digital radio, a software tunable radio along with embedded impedance synthesizer, and software tunable antenna systems[3].

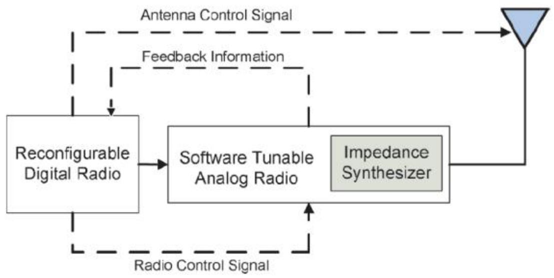

Fig. 2: Ideal SDR architecture.

The main responsibilities of the reconfigurable digital radio are performing digital radio functionalities such as different waveform generation (e.g. OFDM, CDMA, UWB), optimization algorithms for software tuneable radio and antenna units, and controlling these units. Software tuneable analogue frontend systems are limited to the components that cannot be performed digitally such as RF filters, combiners/ splitters, power amplifiers (PAs), low noise amplifiers (LNAs), and data converters. Impedance synthesis is crucial to optimize the performance of software tuneable analogue radio systems. However, due to the current limitations in size, cost, power, performance, processing time and data converters, ideal SDR architectures are costly.

SDR enabling technologies include traditional computing technologies such as Digital Signal Processors (DSPs) or Field-Programmable Gate Arrays (FPGAs) which are used to generate and demodulate waveforms and control the radio components. Other relevant components include ADCs and DACs (with increasing performance requirements on sampling rates and dynamic range) as well as software tuneable up- and down-converters with the last two being sometimes implemented using programmable application specific integrated circuits (ASICs). When using ASICs, DSPs and FPGAs, the idea is to map the algorithm to a fixed set of hardware. On the other hand, an alternative is to map the hardware resources and/or requirements to the algorithm requirements making them dynamic. This can be achieved using General Purpose Processors (GPPs). Obviously, each platform has advantages and disadvantages. DSPs provide high re-configurability with limited performance and short development cycle at low power consumptions. FPGAs provide high degree of re-configurability, high-level performance and integration and short development cycle. However, they are power-hungry, large size, and expensive devices. The main drawback of GPPs is low data throughput due to all data being transferred via the processor bus. Moreover, they are power-hungry, costly and large size devices relative to the other processors.

Defence and mobile communications efforts are leading the development of SDR technology. In particular multiple frameworks for developing SDR have been proposed and analysed including perhaps the two most well known: SCA (Software Communications Architecture) proposed in the scope of the American defence tactical radios programme JTRS and OWA (Open Wireless Architecture), which is a broader framework. Many different commercial and international bodies have embraced the SCA to become the open international commercial standard for SDRs[4,5]. The development of the SCA is an international effort led by the United States of America with help from Japan, Canada, England, and Sweden. The objective of SCA specifications is to tell designers how elements of hardware and software are to operate in harmony with each other and to provide tools for the development, maintenance and interconnection of embedded communications components. SCA defines a series of interfaces to isolate the applications from the SDR hardware. The core framework includes base application, device control and framework services interfaces.

II.III SCREEN objectives

The **SCREEN** project proposes to bring the concept of cognitive radio to Space and exploit the benefits that this technology has already shown in the terrestrial domain. The project will look into analysing, developing, implementing and testing cognitive radio algorithms for the different stages of the transceiver operation cycle: spectrum sensing, dynamic spectrum management (DSM) and decision making, radio reconfiguration and cognition/learning. The ground breaking element in **SCREEN** is however the implementation and testing. Even though some of the underlying technologies for the individual stages are not novel, the incorporation of all stages in a radio transceiver has never been done to the full extent of a cognitive, and not adaptive, system.

The key enabling technology for cognitive radio is Software-Defined Radio, which provides the required flexibility to reconfigure the radio parameters autonomously and without any changes in the transceiver hardware. However, **SCREEN** does not aim at developing the SDR platform and will use a more focused, practical and efficient approach to validate the cognitive radio concept. The consortium will make use of SDR technology developed in previous projects, which is proprietary and readily available, and use it as the underlying radio transceiver with minor adaptations that may be required by the cognitive algorithms. In fact, **SCREEN** will also make use of terrestrial research outcomes in cognitive radio resulting from other projects where the consortium has been involved. This approach capitalises the previous investment made in different projects, avoiding unnecessary duplication of efforts.

The target spectrum band for this project is the S-band. There are several reasons for this choice. On the one hand, the available SDR platform operates in this part of the spectrum, which requires less adaptation effort in terms of transceiver hardware and/or software. On the other hand, this band has a strong potential for future applications both in SatCom networks and inter-satellite links (ISLs) for multi-satellite missions, while holding great advantages from the regulatory point of view. It is important to mention that one of the main concerns of **SCREEN** is to address all regulatory issues from the initial framework analysis and requirement definition, to the post-project exploitation and standardisation activities.

In short, the overall **SCREEN** objectives are to:

- Derive cognitive radio requirements based on the SatCom and ISL market needs and specifications and taking into account regulatory constraints.
- Analyse, select, develop and simulate cognitive radio algorithms for spectrum sensing, dynamic spectrum management and learning.
- Adapt an existing SDR platform based on the radio reconfiguration requirements and use it to implement the cognitive algorithms.
- Test, validate and evaluate the prototype in laboratory and representative environments at TRL4/5 level.
- Derive an optimised CR S-band transceiver architecture, based on the performance results obtained and constraints identified during the tests.
- Address all regulatory issues and develop exploitation strategies to build an adequate framework to allow future implementations of cognitive radio in space.

III. FRAMEWORK ANALYSIS

III.I R&D projects

SCREEN build on several previous research projects as shown in Fig. 3. One of the first projects in the area was *Applicability of Cognitive Radio to Satellite Systems* (ACROSS), running from 2011 – 2012. It focussed on theoretical analyses. *Advanced Research and Innovation in Space Engineering* (ARISE) was a Portuguese RTD national project, led by TEKEVER, which had the main objective of creating the underlying competences and infrastructure to create a Space-oriented research group in the company. The project *Generic SDR-bAsed Multifunctional spAce Link* (GAMALINK) created the SDR platform that is used within SCREEN. Further major projects are:

- *Cognitive Radio for Satellite Communications* (CoRaSat)
- *Cognitive Radio for dynamic Spectrum Management* (CORASMA)
- *Cooperative Spectrum Sensing Algorithms for cognitive Radio networks* (COSSAR)
- *Cognitive Radio Oriented Wireless Networks* (CROWN)
- *Cognitive Radio Standardization – initiative* (CRS-i)
- *Space Wireless sensor networks for Planetary Exploration* (SWIPE)

III.II Legal and market framework analysis

Global trends towards increasing network activity and mobile connectivity can be identified throughout all markets. The European Union and the Organization for Economic Co-operation and Development (OECD) discovered major challenges for infrastructure and mobile bandwidth accessibility especially due to the latest developments of smartphones and tablets. Although the revenues in the telecommunication market are decreasing and anticipated to even further decrease in future, this market still holds high profit potential. A reason for that lies in the increasing number of participants that use less mobile telephone networks but communicate much more via mobile broadband with their smartphones or tablets and use cloud systems. Thus, although the revenues decrease, people become more interconnected and dependent on mobile networks which in turn results in higher infrastructure demands. Therefore, the strategies of the EU towards an infrastructure development and those of private companies towards a focus on mobile networks indicate areas to which potential profitability shifts.

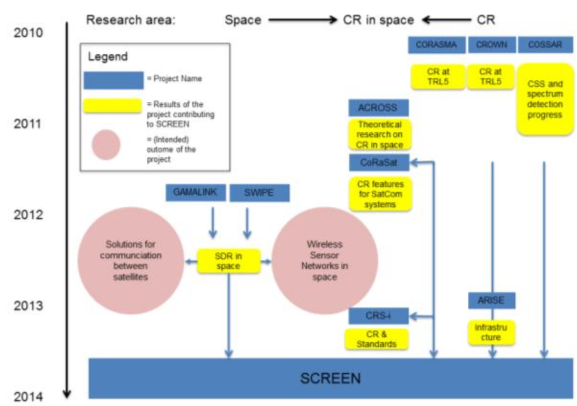

Fig. 3: Projects related to **SCREEN**.

For the **SCREEN** project, this shift results in high profitability prospects. It can be very valuable to find a way for a more efficient spectrum management. Therefore, spectrum trading is proposed as a promising solution and its efficient implementation is an objective of the Europe 2020 strategy. As the EU already works on its infrastructure and legislative developments, supporting preconditions for a technology such as spectrum trading are already set and its importance is identified. The market shifts more and more into a position in which it can benefit from the CR technology as legal and infrastructural barriers are being removed by international authorities. Thus, CR becomes a promising way to fulfil consumer needs through an improvement of current communication systems. This development will be further driven by the discovered socio-economic trends and thus leads to a situation where society and economy can profit from.

In conclusion, the EU and national authorities are aware of the deficits in spectrum management and have already initiated projects and initiatives to enable spectrum trading. Such projects were mentioned previously and initiatives were implemented through EU directives. As a result, strategies such as the Digital Agenda and also the development of the European infrastructure concerning broadband accessibility were implemented to facilitate the integration of the CR technology into markets.

IV. Use Cases

From the analysis of various previous research projects and current on-going projects, it was found that the focus of **SCREEN** should lie on the S-band, targeting the ISM (Industrial, Scientific and Medical) frequencies as they provide an easily accessible spectrum for offloading SatCom capacity in areas where the spectrum is not heavily used. **SCREEN** scope is not limited to a certain application, but rather considers the different technical setups relevant to SatCom use cases, i.e. LEO (Low Earth Orbit) constellation with decoding links vs. GEO (Geostationary Earth Orbit) bent-pipe relay architectures. In fact the SatCom and UAV scenarios are very similar in terms of concept and motivation for using cognitive radio and link architecture as will be seen in the next section. However, having in mind a general approach to applications that could benefit from CR, six use cases were identified as possible scenarios with market potential.

A comparison between these cases which were graded against different parameters is listed in Table 1.

Scenario	**Market size (1-5)**	**CR benefits (1-5)**	**Regulatory environment (1-5)**	**Total**
Small satellite constellation	4	4	4	12
UAV constellation	5	4	3	12
In-flight connectivity	2	4	1	7
Smart cars	2	1	1	4
Telemetry for high speed assets	1	3	1	5
Data for small ships	1	2	2	5

Table 1: Scenario trade off findings

The different parameters are the following:

- **Market potential:** Where a score of 5 means that there appears to be significant market potential for a satellite communications at S band and a score of 1 if there appears to be no market potential;
- **Cognitive radio benefits:** Where a score of 5 indicates significant benefits have been identified and a score of 1 if no real benefits are seen;
- **Regulatory environment:** In this case a score of 5 suggests there are relatively mild regulations and a score of 1 if a significant regulatory regime applies.

The marks are then simply totalled to determine the worthiest scenarios. From the table it can be seen that the first two scenarios are the most interesting for SCREEN. These will be addressed in the following sections.

IV.I Small satellite scenario

New technology and miniaturization is now allowing nano-satellites to collect more and more data, increasing the demand in data transfer making them data bound instead of technology bound. In addition, the market for nano-satellites is expected to grow substantially in the next decade imposing a heavy constraint/burden on the spectrum which is already congested. Cognitive radio would bring benefits to the market by increasing the link availability in the crowded frequency band and therefore increasing the capability of these satellites to download their high volume of data. The use of low cost small satellites has become a common trend in order to reduce risks and overall budget. Various commercial companies around the world are now following this model.

The baseline platform considered in **SCREEN** is a 3U LEO CubeSat at 650 km of altitude and 97.8 degrees of inclination which are typical CubeSat orbit parameters. Two communication links are considered:

- Between the ground and the LEO CubeSat via direct link;
- Between the ground and the LEO CubeSat via a GEO satellite serving as data relay.
- Between two LEO CubeSats

In order to face the always-increasing demand for data requirement, the use of cognitive radio will be explored and investigated to test the added performance for:

- Payload data for one satellite;
- CNPC (Command Non-Payload Communications) for a fleet of CubeSats.

IV.II UAV scenario

One of the major benefits of UAV over satellite is the low cost and easy maintenance of the platform. The main differences lie in the regulation of the spectrum use and the dynamics of the aerial vehicle. The UAV market is likely to become one of the major economic and technological stories of the modern age, because of the wide variety of applications and their added value. Market reports estimates the UAV market to grow significantly over the next decade with increasing civilian applications. The interest of Facebook, Google or Amazon in UAV technology is an example of the rising market.

All civilian unmanned aircraft (UA) currently in use in the UK require a remote pilot. In other literature, these may be referred to as “Remotely Piloted Aircraft Systems” (RPAS). Current civilian UA applications include aerial photography and filming, mapping and monitoring. The biggest challenges for civilian UA are safety and effective integration with other users of airspace, including how they are controlled by users, as well as insurance and privacy.

Commercial SatCom is a critical enabler of UAV operations because it provides a link for command and control, as well as imagery backhaul and dissemination. Sophisticated suites of sensors and the increasing number of UAVs underscore the need for having the right SatCom solutions meeting demand.

- These two types of data (CNPC and Payload data) can be transmitted via two ways:
- Using a direct link with the UAS gateway station in case of LoS (Line of Sight) communication;
- Using GEO satellite data relay system in case of BLoS (Beyond Line of Sight) communication.
- Using a second UAS as relay in case of BLoS communication.

The key parameters selected for the UAV platform are:

- Maximum Take-off weight = 150 kg
- Length = 3 m
- Cruising speed = 140 km/h
- Medium Altitude = 10,000 to 30,000 feet (~3 to 10 km)
- Endurance = 8 to 12 hours
- Maximum sensor and communication package = 50 kg

For **SCREEN**, it will be assumed that the UAV flies at 6 km altitude for its en-route operations (where SatCom will be used).

Despite the concept similarities of the SatCom and UAV scenarios the regulatory challenges and the market drivers however are reasonably different. This clearly shows that, from a technical perspective, both scenarios will have similar requirements in most areas. Looking at UAVs as slower satellites in lower orbits, the links involved in the two use cases are practically the same. This opens an interesting window for the **SCREEN** project requirements, which can be derived in order to be compatible with both use cases, which is more interesting from an exploitation perspective.

IV.III Regulatory Constraints

The S-band is attractive for specific niche markets where high data-rates are not required since its use is simple from regulatory point of view. Within the entire range of S-band, two specific bands are most attractive: (1) Mobile Satellite Services (MSS) band; (2) Industrial, Scientific and Medical (ISM) band, which is open and used for satellite amateur radio communications. Regarding the first use case, LEO satellite constellations, this usually involves small satellites (and mainly CubeSats), which are taking advantage of this band for being open and because a large part of it is assigned to amateur radio communications. Most missions have pursued frequency allocation via the International Amateur Radio Union (IARU) because the process is simpler, as long as the Ground Station operator is a licensed radio amateur. However, the MSS has also some advantages that should be taken into consideration: (1) it was the band proposed for cognitive radio for S-band in the CoRaSat project and the ACROSS project as well, which would allow to capitalise the available results obtained by these projects; (2) it is the only band in the S-band that allows commercial applications, which would pave the way for future sustainable exploitation; (3) UAVs use case could also use that band for the link with the GEO satellite. Based on this, both bands will be considered for the design, though the implementation and testing will be done in the ISM band, since it will require fewer adaptations in GAMALINK, the actual hardware platform provided by TEKEVER that will be used for implementation. However, the cognitive radio algorithms to be developed shall be compatible with both MSS and ISM bands.

V. GAMALINK PLATFORM

Tekever's GAMALINK (Fig. 4) is an advanced Software-Defined Radio (SDR) communications platform for space vehicles that provides simultaneous support for multiple types of ground and inter-satellite links. By creating mobile wireless ad-hoc networks in space, GAMALINK provides unprecedented flexibility for satellite constellations and flight formation missions, enabling the creation of ISLs for synchronizing and coordinating actions. Additionally, GAMALINK receives and decodes GPS signals, providing precise positioning and timing information, and supporting precise ranging measurements.

GAMALINK is available for different types of vehicles and missions, from nano-satellite missions, for which there is a CubeSat standard compatible version, to missions involving larger satellites and higher orbits, for which a radiation-hardened version will soon be commercially available. The GAMALINK main specifications are listed in Table 2. It is important to note that GAMALINK is configurable according to mission and system communication and power consumption requirements.

The Software-Defined Radio in GAMALINK natively supports a frequency range going from UHF to S-band. Even though it does not cover the entire S-band, it will still allow testing the cognitive radio algorithms. The large bandwidth supported by the platform provides flexibility to also test different algorithm approaches. Since the main goal of the project is to validate the cognitive radio technology in a controlled/relevant environment and ending up defining a cognitive radio architecture for future implementations, GAMALINK is appropriate as the enabler for the validation and the starting point for the architecture.

Fig. 4: GAMALINK platform.

Frequency range	300 MHz to 3GHz
Bandwidth	40 MHz
Data Rate	up to 80 Mbit/s
Positioning precision	5 m (GPS)
GPS update rate	5 Hz
PCB size	95.9 x 90.2 x 11 (mm)
Total PCB mass	<100 g
Data Interface	I2C, UART
Storage capacity	from 2 x 2GB
Supply Voltage	3.3V or 5V
Frequency range	300 MHz to 3GHz
Bandwidth	40 MHz

Table 2: GAMALINK specifications

VI. PROJECT REQUIREMENTS

Based on the considerations of the use cases and on the types of links analysed, it is possible to conclude that the two selected applications (small satellite constellations and UAV constellations) are very similar in terms of concept, motivation for using cognitive radio and link architecture.

This clearly shows that, from a technical perspective, both scenarios will have similar requirements in most areas. Looking at UAVs as slower satellites in lower orbits, the links involved in the two scenarios are practically the same. This opens an interesting window for the **SCREEN** project requirements, which can be derived in order to be compatible with both use cases, to as much extent as possible. The research in the project could then be applied to both scenarios, which is more interesting from an exploitation perspective. The requirements of these scenarios as defined in SCREEN project are as follows.

VI.I Satellite platform requirements

The scenario selected for SCREEN considers a constellation of LEO nano satellites, the platform in itself being a 3U CubeSat at 650km of altitude.

ID SCREEN-SAT-SYS 001
The satellite system shall be able to communicate with GEO satellite with 6 dB margin for command and control and 3 dB margin for payload data

ID SCREEN-SAT-SYS 002
The satellite system shall support 250 kbps for CNPC

ID SCREEN-SAT-SYS 003
The satellite system should target 4 Mbps for payload data download to the ground.

ID SCREEN-SAT-SYS 004
The satellite system shall use the satellite amateur band at 2.4 GHz – 2.45 GHz and the ARTEMIS ISL band at 2.1 GHz.

ID SCREEN-SAT-SYS 005
The satellite system shall make sure prevent interference with terrestrial users in the amateur band or other terrestrial bands

ID SCREEN-SAT-SYS 006
The satellite system shall make sure that the transmissions for GEO satellite are not interfered when crossing the equatorial plane (GEO signals have priority).

ID SCREEN-SAT-SYS 007
The satellite system shall make sure that the transmissions for GEO satellite are not interfered when crossing the equatorial plane (GEO signals have priority).

ID SCREEN-SAT-SYS 008
The satellite system shall transport data in IP datagrams.

ID SCREEN-SAT-SYS 009
The satellite system shall support a scalable solution from 5 to hundreds of CubeSats in the constellation

VI.II UAV platform requirements

The second scenario selected for SCREEN considers a constellation of UAV. The UAV platform is a 150 kg Unmanned Vehicle flying at 6 km of altitude with an average speed of 140 km/h. This case will only consider en route phase of the flight with the possibility to use a GEO satellite data relay for BLoS communications.

ID SCREEN-UAV-SYS 001
The UAV system shall be able to communicate with GEO satellite with sufficient margin for command and control to provide a link availability of 99.9% and sufficient margin for payload data with a link availability of 99.5%.

ID SCREEN-UAV-SYS 002
The UAV system shall support 24 kbps for control non-payload communication during en-route operations.

ID SCREEN-UAV-SYS 003
The UAV system should target 4 Mbps for payload data during en-route operations.

ID SCREEN-UAV-SYS 004
The UAV system shall use the satellite amateur band at 2.4 GHz – 2.45 GHz and the Artemis band at 2.1 GHz.

ID SCREEN-UAV-SYS 005
The UAV system shall make sure to prevent interference with terrestrial users in the amateur band or other terrestrial bands

ID SCREEN-UAV-SYS 006
The UAV system shall make sure that the transmissions for GEO satellite are not interfered when crossing the equatorial plane (GEO signals have priority).

ID SCREEN-UAV-SYS 007
The UAV system shall make sure that the transmissions for GEO satellite are not interfered when crossing the equatorial plane (GEO signals have priority).

ID SCREEN-UAV-SYS 008
The UAV system shall transport data in IP datagrams.

ID SCREEN-UAV-SYS 009
The UAV system shall comprise up to 25 UAV platforms.

VI.III Algorithm requirements

The requirements below include frequency band specifications, architecture and performance requirements.

ID SCREEN-ALG-SYS 001
The cognitive radio algorithms shall be compatible with the MSS and ISM bands.

ID SCREEN-ALG-SYS 002
The cognitive radio algorithms shall be able to work with relative velocities up to 15 km/s.

ID SCREEN-ALG-SYS 003
The cognitive radio algorithms shall be compatible with a GEO bent pipe link architecture.

ID SCREEN-ALG-SYS 004
The cognitive radio algorithms shall be compatible with a direct Ground link architecture.

ID SCREEN-ALG-SYS 005
The cognitive radio algorithms should be compatible with an intra-constellation link architecture.

ID SCREEN-ALG-SYS 006
The cognitive radio algorithms shall enable at least 24 kbps of data rate for command and control of each platform.

ID SCREEN-ALG-SYS 007
The cognitive radio algorithms should enable at least 4 Mbps of data rate for payload data transmission from each platform.

ID SCREEN-ALG-SYS 008
The cognitive radio algorithms shall gather information about the selected RF environment.

ID SCREEN-ALG-SYS 009
The cognitive radio algorithms shall decide upon the best frequency to use for communications.

ID SCREEN-ALG-SYS 010
The cognitive radio algorithms shall enable a level of cognition, by learning from previous operating experience.

ID SCREEN-ALG-SYS 011
The cognitive radio algorithms shall enable an overall latency below 2 seconds.

ID SCREEN-ALG-SYS 012
The cognitive radio transceiver shall be able to dynamically reconfigure itself to communicate in the selected frequency.

ID SCREEN-ALG-SYS 013
The cognitive radio transceiver shall have internal processing capability.

ID SCREEN-ALG-SYS 014
The cognitive radio transceiver shall have internal data storage.

The cognitive algorithms developed during the course of the SCREEN project will be implemented on the existing transceiver platform which will be modified to comply to the requirements defined above, and constitutes the main of the project and is the subject of on-going work.

VII. CONCLUSIONS

The need and benefit of cognitive radio has been proven on terrestrial communications. SCREEN is working on proving the benefit of cognitive radio for space applications as well. The two scenarios selected correspond to a real market opportunity that is forecasted to rise in the coming years. The use of CubeSat and UAV is growing and expected to keep growing in the next decade.

The requirements for the two identified scenarios are similar enough to motivate the implementation of an algorithm that is common to both systems.

Cognition is expected to be beneficial to fast moving LEO satellites for which the terrestrial frequency occupation is constantly changing and for UAV which needs to comply with strict regulations to be allowed to fly in segregated airspaces.

The cognition would increase the availability of the communication link, manage interference, manage handover, and get awareness of the environment; therefore better managing the use of the spectrum which is becoming a rare resource.

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