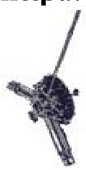
SATELLITE AND SPACE COMMUNICATIONS **SSC**

http://committees.comsoc.org/ssc/



IEEE COMMUNICATIONS SOCIETY

SSC Newsletter **Vol. 25, No. 2, December 2015**

CONTENTS

The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.
Location: Globecom’15, Dan Diego, USA
Gaslamp 2, Omni San Diego Hotel Excel Convention Center
Date: Wednesday Dec. 9th, 2015
Time: 12:30-14:00

Future SSC Meetings
May 2016, Kuala Lumpur, Malaysia
Dec. 2016, Washington, USA
June 2017, Paris, France

GLOBECOM 2015 SSC Committee Activities:

Symposium on Selected Areas in Communications:

Wednesday, 9 December 2015 • 14:00 - 15:45
Room: Aqua 300A/B
SAC 15: Satellite Networking
Chair: Igor Bisio (University of Genoa, Italy)

Wednesday 9 December 2015 • 16:15 - 18:00
Room: Indigo 206
SAC 18: Satellite Communications
Chair: Stefano Cioni (ESA/ESTEC, the Nederland)

Industrial Tutorial:

TIF-2: High Performance Random Access Schemes for Machine to Machine Applications – From Satellite to Terrestrial Networks

Speakers: Riccardo De Gaudenzi (ESA), Oscar Del Rio Herrero (ESA), Gennaro Gallinaro (ESA), and Stefano Cioni (ESA).

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
If you like to join SSC Mailing List: Instructions on how to subscribe/unsubscribe are available at http://lists.scnl.dist.unige.it/listinfo/ssc/.

SSC COMMITTEE OFFICERS

CHAIR
Dr. Igor Bisio
Department of Telecommunication, Electronic, Electrical Engineering and Naval Architecture,
University of Genoa
Via Opera Pia 13, 16145,
Genova, Italy
Tel: +39 010 353 2806
Fax: +39 010 353 2154
Email: igor@dist.unige.it

VICE CHAIR / EDITOR
Dr. Tomaso de Cola
German Aerospace Center (DLR)
Munchenerstr. 20,
Oberpfaffenhofen, 82234
Wessling, Germany
Tel: +49-8153-28-2156
Fax: +49-8153-28-2844
E-mail: tomaso.decola@dlr.de

SECRETARY
Prof. Song Guo
School of Computer Science and Engineering
The University of Aizu
Aizuwakamatsu, Fukushima
965-8580 Japan
Tel: +81-242-37-2579
Fax: +81-242-37-2548
Email: sguo@u-aizu.ac.jp

PAST CHAIR
Prof. Nei Kato
Graduate School of Information Sciences
Tohoku University
Aoba 09, Aramaki, Aoba-ku,
Sendai, 980-8579, Japan.
Tel: +81+22-795-6161
Fax: +81+22-795-6162
e-mail: kato@it.ecei.tohoku.ac.jp

COMMITTEE HISTORIAN
Mr. Louis Pollack
c/o Pollack Associates
15321 Delphinium Lane
Rockville, MD, USA 20853
Tel: +1 301 929 1295

COMMITTEE ADVISOR
Prof. Desmond P. Taylor
Dept. of Electrical & Electronic Engineering
University of Canterbury
Private Bag 4800
Christchurch, New Zealand
Tel: +64 3 364 2213
Fax: +64 3 364 2761
e-mail: taylor@elec.canterbury.ac.nz

MESSAGE FROM THE CHAIR

Prof. Igor Bisio

The Satellite and Space Communications (SSC) Technical Committee (TC) members will meet again during IEEE GC2015.

The SSC TC activities are continuing to maintain good level and to consolidate the role of out TC that exists since 1962. In more detail, in my message, I propose the usual update of the activities carried on by the SSC TC in the last six months, with specific emphasis on the issues in which there has been further steps.

Participation to TC Meetings. The SSC TC last meetings have a satisfactory number of attendees. In London during IEEE ICC 2015, we had around 35 attendees, in Austin during IEEE Globecom 2014 we had 29 attendees, in Sydney during IEEE ICC 2014 we had 23 attendees and in Atlanta during IEEE Globecom 2013 we had 40 attendees. A very good trend to be confirmed.

Advisory Board. The current Advisor, Prof. Des Taylor, who confirmed his precious availability, will chair the Advisory Board (AB) that will provide to the Officers suggestion, in general, about the TC management, and, in particular, about the envisaged revision of the TCs portfolio of the IEEE ComSoc Technical Activity Council (TAC). The otherwise members involved in the AB would be Past-Chairs of the SSC TC coming from different areas of the World: Prof. Abbas Jamalipour, Prof. Nei Kato and Prof. Mario Marchese. I hope they will confirm their availability to join the AB.

SSC Website and Mailing List. Another switching of the TC Website has been required by the IEEE ComSoc. The Secretary have moved the SSC website on a new IEEE ComSoc template (please visit http://ssc.committees.comsoc.org/) and the mailnglist is working as usual.

Current Journals/Magazines. An open Call for Paper is about the IEEE IoT Journal. It is edited by our Past-Chair Prof. Nei Kato and myself. If you look at the Call for Papers (CFP), you can note that is not entirely dedicated to satellite and space communications and networking topics but contributions from this research area are really welcome. The deadline has been extended to Dec. 31st, 2015.
Other initiatives concerning possible Special Issues are under evaluation for possible proposals. The 'Call for Topics', done during the last spring, through the TC mailinglist, has provided good ideas for possible special issues: SmallSats/Cubesats; Nanosatellites for Network Access in Rural and Isolated Areas; Terabit Satellite Communications; Software-Defined Satellite Payloads and Networks; Reconfigurable Payloads and Mega Constellations networks.
Now the ideas should become editorial initiatives.

Conference Activities (ICC/GC and others). The SSC track of IEEE GC'15, chaired by our Vice-Chair, received 29 submissions while the track of IEEE ICC'16 received 46 submissions. Concerning the representatives from our TC, for future ICC/GC, we propose for IEEE ICC and GC 2017 the following nominations: Prof. Giovanni Giambene for the Wireless Communications Symposium; Prof. Shaowei Wang for the Wireless Networking Symposium; for the SSC Track of the SAC Symposium that, as usual, is leaded by a member of the Officers' team we proposed myself for ICC'17 and our Vice-Chair Dr. Tomaso de Cola for GC'17.
Concerning other conferences, the ASMS'16 conference endorsed by our TC has been officially technically cosponsored by the IEEE ComSoc.

Finally, as discussed in the past meeting, we propose to appoint the following Work Groups (WGs) supporting the Officers on specific themes:

a) IEEE and IEEE ComSoc Awards, DLs and Fellowships:

SSC Secretary (Song Guo) - WG Coordinator

Daniele Tarchi (Italy)

Giovanni Giambene (Italy)

b) Standards:

SSC Standard Liaison (Henry Suthon) - WG Coordinator

SSC Vice-Chair (Tomaso de Cola)

Claudio Sacchi (Italy)

c) Editorial Initiatives:

Symeon Chatzinotas (Luxembourg) - WG Coordinator

Barry Evans (UK)

SSC Chair (Igor Bisio)

I would deeply thank the volunteers now members of these groups.

Prof. Igor Bisio, Chair
Satellite and Space Communications TC

SCANNING THE WORLD

Dr. Tomaso de Cola

The second half of year 2015 shows again an ever-increasing interest to the design of High-Throughput Satellite (HTS) system, from both research and industrial view point. As argued in the last five years, the increasing service and data demands of users along with the limited Internet penetration of wireless technologies in remote area opened a new area for satellite communications, aiming at achieving Tbps capacity and beyond. As already illustrated in the previous issue, this concept can be implemented by means of feeder links operating in EHF frequency bands, by exploiting both RF and FSO-optic technology. These aspects are some of the most investigated by researchers in different conference and journal papers. On the one hand, new findings about smart gateway diversity concepts are discussed. On the other hand, preliminary works on the exploitation of EHF band, focusing on the propagation impairments and the corresponding countermeasures, are populating the recent scientific literature.

Still related to the HTS concept is the development of the family of Quantum-satellites, from Eutelsat, who is expected to revolution the next decade of satellite system development. The launch of the first satellite is planned for 2018.

Its main novelty consists in the implementation of a software-defined payload, able to adapt to the traffic demands, hence making the concepts of flexible payload, already out since a couple of year, even more powerful and attracting for satellite industry and related operators.

Other exciting news for the satellite arena regards the joint venture between Facebook and Eutelsat to provide broadband Internet service via satellite to Africa countries, where the terrestrial infrastructure is underdeveloped or not providing sufficient coverage and capacity to reach all areas and citizens.

Finally, a special note has to be dedicated to the IEEE Comm. Mag. special issue about satellite communications and networking (distributed over two consecutive issues and appeared in the first half of 2015), which shows the current focus on satellite technology and the related applications deserving special attention. To this regard, some emphasis can be put on the warning/emergency services, whose support from satellite infrastructure is largely illustrated in three papers addressing different aspects of the marriage between emergency service requirements and satellite system capabilities.

Dr. Tomaso de Cola, Vice Chair
Satellite and Space Communications TC

FORTHCOMING GLOBECOM AND ICC CONFERENCES

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

ICC 2016
May 23-27, 2016, Kuala Lumpur, Malaysia
http://icc2016.ieee-icc.org/

The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 - 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. We invite you to submit your original technical papers, and industry forum, workshop, and tutorial proposals to this event. Accepted and presented papers will be published in the IEEE ICC 2016 Conference Proceedings and submitted to IEEE Xplore®.

MILCOM 2015
November 01-03 2016, Baltimore,MD
http://events.afcea.org/milcom16/Public/enter.aspx

MILCOM 2016 celebrates the 35th anniversary of the premier international conference for military communications. "Leveraging Technology – The Joint Imperative" gathers the leading minds of government, military, industry and academia in an interactive forum to further explore and define the benefits that joint-level collaboration bring to current and future communication challenges. The annual conference will take place November 1-3, 2016 at the Baltimore Convention Center in Baltimore, MD. Leaders from around the world will address the critical role communications plays in military readiness and operations. MILCOM offers industry the opportunity to discuss communications technologies and services with decision makers from all branches of the armed forces, the Department of Defense, federal agencies and multinational forces.

In the MILCOM tradition, the conference will feature an outstanding series of technical presentations, discussions and tutorials, as well as nearly 30,000 square feet of industry exhibits all under one roof. It will include more than 300 unclassified and restricted technical presentations, tutorials and panel discussions led by experts in defense communications. Topics will include the spectrum of command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) technologies and capabilities that address 21st century communications challenges related to national defense, homeland security, disaster response and interoperability. Continuing education credits will be available to all attendees.

GLOBECOM 2016
December 4-8, 2015, Washington,DC, USA
http://globecom2016.ieee-globecom.org/about

IEEE GLOBECOM is one of two flagship conferences of the IEEE Communications Society (ComSoc), together with IEEE ICC. Each year the conference attracts about 3000 submitted scientific papers and dozens of proposals for industry events. A technical program committee of more than 1,500 experts provides more than 10,000 reviews, and from this a small fraction of the submitted papers are accepted for publication and presentation at the conference. The conference meets once a year in North America and attracts roughly 2000 leading scientists, researchers and industry practitioners from all around the world. IEEE GLOBECOM is therefore one of the most significant scientific events of the networking and communications community, a must-attend event for scientists, researchers and networking practitioners from industry and academia.

IEEE GLOBECOM is a five-day event. Two days are dedicated to tutorials and workshops, while the remaiing three days are dedicated to the IF&E program and the technical symposia. The program of the technical symposia includes oral or poster presentations of about 1000 scientific papers, grouped into 13 thematic symposia, and more than 15 parallel sessions. In addition to the technical program, IEEE GLOBECOM 2016 will feature an industry forum and exhibition (IF&E) program, including industry-focused workshops, tutorials, keynote talks from industrial leaders, panel discussions, a large exposition, and business and industrial forums.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
SPECTS 2016 International Symposium on Performance Evaluation of Computer and Telecommunication Systems	July 2016 Montreal, Canada	http://atc.udg.edu/SPECTS2016/
ASMS/SPSC 2016 8th Advanced Satellite Multimedia Systems Conference 14th Signal Processing for Space Communications Workshop	September 5-7, 2016 Palma de Mallorca, Spain	http://www.asmsconference.org/
ICL-GNSS 2016 International Conference on Localization and GNSS	June 28-30, 2016 Barcelona, Spain	http://www.icl-gnss.org/2016/index.html
PIMRC 2015 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications	Sept. 4-7, 2016 Valencia, Spain	http://www.ieee-pimrc.org/
Ka-Band/ICSSC The 22nd Ka and Broadband Communications Conference and the 34th AIAA International Communications Satellite Systems Conference (ICSSC)	October 18-20, 2016 Cleveland, Ohio, USA	http://www.kaconf.org/
VTC-Spring 2016 2016 IEEE 83rd Vehicular Technology Conference (VTC-Spring)	May 15–18, 2016 Nanjing, China	http://www.ieeevtc.org/vtc2016spring/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://committees.comsoc.org/ssc/.

CoRaSat – Cognitive Radio for Satellite Communications

Alessandro Guidotti[1], Vincenzo Icolari[1], Daniele Tarchi[1], Alessandro Vanelli Coralli[1], Konstantinos Liolis[2], Jens Krause[2], Nicolas Chuberre[3], Eva Lagunas[4], Shree Krishna Sharma[4], Sina Maleki[4], Symeon Chatzinotas[4], Joel Grotz[5], Barry Evans[6], Paul Thompson[6]

[1] University of Bologna, Italy
[2] SES S.A., Luxembourg
[3] Thales Alenia Space, France
[4] University of Luxemburg, Luxembourg
[5] Newtec, Belgium
[6] University of Surrey, UK

***Abstract* — CoRaSat (COgnitive RAdio for SATellite Communications) has been a European Commission 7th Framework Programme project funded under the ICT Call 8. CoRaSat aimed at investigating, developing, and demonstrating cognitive radio techniques in satellite communication systems for flexible and dynamic spectrum access. In this paper the methodology and the main outcomes of the CoRaSat project are described, while focusing also on the major challenges that relevant stakeholders should take into account when designing a cognitive radio satellite communications system.**

INTRODUCTION

The CoRaSat (COgnitive RAdio for SATellite communications) project [1] has been a European Commission 7th Framework Programme project funded under the ICT Call 8. The partners working CoRaSat has been the University of Bologna, Italy (Coordinator), SES, Luxembourg, Thales Alenia Space, France, the University of Luxemburg, Luxembourg, Newtec, Belgium, and the University of Surrey, United Kingdom. It envisaged a flexible and smart satellite system able to exploit unused or underused frequency resources assigned to other services on a primary or secondary basis. The main objective was to maximize resource utilization and to open up novel business perspectives with lower transmission costs, where Cognitive Radio (CR) techniques are considered one of the most promising solutions [3].

To this aim, cognitive approaches and techniques have been investigated, developed, and demonstrated in specific scenarios that are relevant to SatCom. While CR techniques already proved their potential in terrestrial networks, their application in a satellite context is still in its infancy [2]. The CoRaSat project has been, thus, the first initiative providing a systematic analysis of CR techniques to SatCom and the related proof-of-concept implementation and demonstration.

Extremely valuable results have been obtained and substantiated through laboratory testbed demonstration during the project activities.

The CoRaSat project partners have also been extremely active in raising awareness on the benefit and potential of CoRaSat technologies for relevant stakeholders, including regulators, satellite operators, as well as scientific community and public [4]. It is worthwhile highlighting also that CoRaSat has been extremely active in the regulatory and standardization communities, by regularly presenting its outcomes to several National Administrations, ETSI, and CEPT. In particular, CoRaSat was invited to join CEPT FM44 and the project outcomes have been included in a CEPT SE40 report and in an ETSI SRDoc, which significantly contributed to the elaboration of two ECC Reports and a modified ECC Decision.

Based on the above considerations the CoRaSat project has achieved the challenging objective to assess, demonstrate, and raise awareness on CR-based satellite systems, paving the way for flexible and smart spectrum usage in satellite networks.

PROJECT CONTEXT AND OBJECTIVES

CoRaSat vision

CoRaSat vision is a Cognitive Radio Satellite Communications system implementing flexible and smart spectrum usage to exploit unused or underused frequency resources assigned to satellite services as primary or secondary allocation. The CoRaSat approach maximizes resource exploitation to open new business perspectives and potentially lower transmission costs, without creating any harmful interference to those satellite or terrestrial systems entitled to use the same spectrum on a primary basis, and which will thus remain practically unaware of the CoRaSat system presence.

The CoRaSat project aimed at enabling this vision by investigating, developing, and demonstrating CR techniques relevant to Satellite Communications systems for flexible and dynamic spectrum access.

CoRaSat context

In the Information Society, broadband access to the Internet is both a necessity and a human right, which enables social, political, and professional endeavors.

Satellite communications are considered a key element in achieving the challenging Digital Agenda objective of high-speed broadband access for everyone by 2020. Their inherent large coverage footprint makes them the most suitable access scheme to reach those areas where deployment of wired and wireless networks is not economically viable. However, a fundamental challenge for SatCom systems is to improve the spectrum exploitation to increase end-to-end connectivity throughput, lower transmission costs, and enhance market competitiveness. In fact, SatCom approaches to spectrum exploitation mainly consist in static frequency band separation based on geographical service areas, angle separation, service type, etc. These approaches are more and more perceived as being suboptimal as they represent a classical worst- case based system design. They do not allow for adaptation to the evolving scenario (e.g., traffic evolution, geographical mobility, infrastructure deployment scenario, etc.) and as such are introducing large inefficiencies that leave enormous margin of spectrum usage improvement and hence potential large capacity increase and cost reduction in future systems.

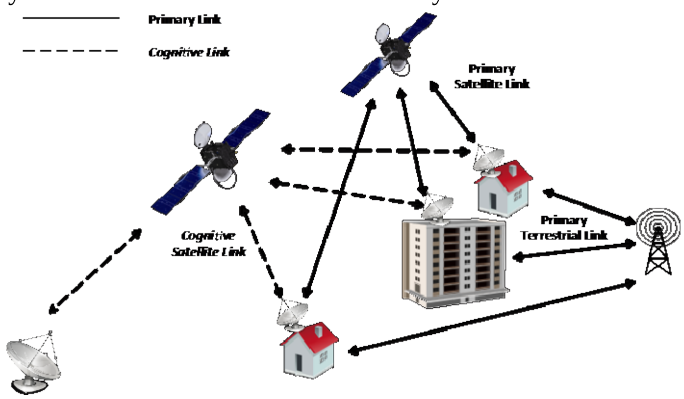


Figure 1 - CoRaSat vision.

Flexible spectrum usage is a cornerstone for the efficient exploitation of scarce spectrum resources, and cognitive approaches have already demonstrated their potential towards this aim in several terrestrial wireless scenarios, at the cost of extra complexity at system level. However, SatCom flexible spectrum usage, and SatCom Cognitive Radio in particular, is still a rather unexplored area. Before CoRaSat, the SatCom Industry and the Scientific Community have only marginally addressed the CR concepts for SatCom. No systematic analysis has yet been carried out and research has been limited to scientific papers. CR for SatCom is generally understood to have benefits for SatCom as well as threats, but no approach has been initiated to systematically assess the facts, and no proof-of-concept implementations are known, for CR SatCom systems specifically for the 2GHz and beyond bands that are of highest priority for the European SatCom Industry. At the same time, non-European initiatives are also addressing non-exclusive spectrum usage thus posing threats to the European SatCom Industry and Operators worldwide competitiveness, if no action is taken.

CoRaSat goals

The CoRaSat team, consisting of European research institutions, satellite industries, operators, and manufacturers addressed the unexplored area of CR for satellite communications in a fully-fledged approach. Starting from scenarios definition and ending with a proof-of-concept reference implementation of the considered architecture, CoRaSat identified, assessed, and demonstrated relevant techniques necessary to implement CR Satellite techniques for the exploitation of currently unused or underused spectrum frequencies by satellite services. The CoRaSat project demonstrated that, in the considered scenarios, CR benefits outnumber threats and can open up new business perspectives for the entire value chain.

Since the SatCom ecosystem requires that Regulation and Standardization bodies are aware of the potential benefits and thus implements the necessary enablers for the full exploitation of CR techniques in Satellite Communication Systems, the project specifically addressed the definition of an exploitation framework of CoRaSat concept. Outcomes of the study served as references and drivers for the definition of strategic roadmaps to be followed by the SatCom stakeholders and by European Institutional and Governmental actors towards regulatory bodies, e.g., ITU/CEPT, and standardization groups in order to ensure that the necessary actions are undertaken to enhance market competitiveness through CR communications.

SCENARIO SELECTION

Initially, CoRaSat activities mainly focused on the definition, selection, and prioritization of the CoRaSat scenarios. Seven baseline scenarios, which are reported in Table 1, have been identified, detailed, and analyzed, with the aim of selecting the most promising ones for the technical studies and the demonstration, [1]-[4]. In particular, each of them has been thoroughly characterized in the following four frameworks of Satellite Communications systems and CR techniques: i) Market/Business; ii) Regulatory; iii) Standardization; and iv) Technological.

Table 1 - The seven CoRaSat scenarios

Scenario	Frequency Band	Spectrum Range	Satellite Orbit	Link Direction
A	Ka	17.3-17.7 GHz	GSO	DL
B	Ka	17.7-19.7 GHz	GSO	DL
C	Ka	27.5-29.5 GHz	GSO	UL
D	Ku	10.7-12.75 GHz 12.75-13.25 GHz 13.75-14.5GHz	GSO	DL UL UL
E	C	3.4-3.8 GHz	GSO	DL
F	S	1980-2010 MHz 2170-2200 MHz	GSO	UL DL
G	Ka	17.7-19.7 GHz 27.8285-28.4445 GHz 28.9485-29.4525 GHz	NGSO	DL UL UL

While more details can be found in [1], the seven considered baseline scenarios have been compared against four relevant metrics:

- Market/business related metrics, including efficiency increase, interference mitigation, and expected complexity.
- Regulatory related metrics and impact to the current regulatory framework.
- Standardization related metrics, addressing considerations towards CR standardization.
- Technology related metrics, including cognition, complexity, and impairment effects.

For each scenario the impact/interest/maturity (H: High, M: Medium, L: Low) of CR approaches for each one of the four defined metrics has been assessed and prioritization performed by considering a weighted composition of the four metrics as reported in Table 2.

Table 2 - CoRaSat scenarios' prioritization

Scenario	Market Weight: 50%	Regulatory Weight: 20%	Technology Weight: 20%	Standards Weight: 10%	Overall Consolidation
A	H	H	H	M	Selected (P2)
B	H	H	H	M	Selected (P1)
C	H	M	M	M	Selected (P3)
D	M	M	H	L	Not Selected
E	L	L	M	L	Not Selected
F	M	H	M	H	Not Selected
G	M	H	M	L	Not Selected

According to the above prioritization, three scenarios (see Figure 2) have been selected and used in the subsequent CoRaSat studies for CR technical development, assessment, and demonstration:

- Scenario A - Cognitive Radio GSO Satellite downlink in Ka-band [17.3 – 17.7] GHz: GSO FSS cognitive satellite terminals (fixed/mobile) reusing frequency bands of other GSO BSS feeder link systems also operating in the [17.3 - 17.7] GHz band.
  - Incumbent User: GSO BSS Feeder Links.
  - Cognitive User: GSO FSS.
- Scenario B - Cognitive Radio GSO Satellite downlink in Ka-band [17.7 – 19.7] GHz: GSO HDFSS cognitive satellite terminals (fixed/mobile) reusing frequency bands of FS links with priority protection in the [17.7 - 19.7] GHz band.
  - Incumbent User: FS and GSO FSS.
  - Cognitive User: GSO HDFSS.
- Scenario C - Cognitive Radio GSO Satellite uplink in Ka-band [27.5 – 29.5] GHz: GSO HDFSS cognitive satellite terminals (fixed/mobile) reusing frequency bands of FS links with priority protection in the [27.5 - 29.5] GHz band.
  - Incumbent User: FS and GSO FSS.
  - Cognitive User: GSO HDFSS.

It shall be noted that, in scenarios A and B, interference generated from the cognitive FSS satellite towards the incumbent receiver is negligible. In Scenario A, since the FSS and BSS satellites occupy two separate orbital positions, interference is inherently avoided thanks to the actual antenna pointing. As for Scenario B, the incumbent system is a FS microwave link with highly directive antennas, which prevent the cognitive FSS satellite to generate harmful interference towards it. In these scenarios, coexistence between FSS downlinks and BSS/FS links is thus limited by the interference generated from the incumbent system towards the FSS terminal. Scenario C poses a different challenge as, in this case, interference might be generated towards the incumbent FS receiver and, thus, the maximum allowable transmission power for the cognitive FSS terminal shall be computed.

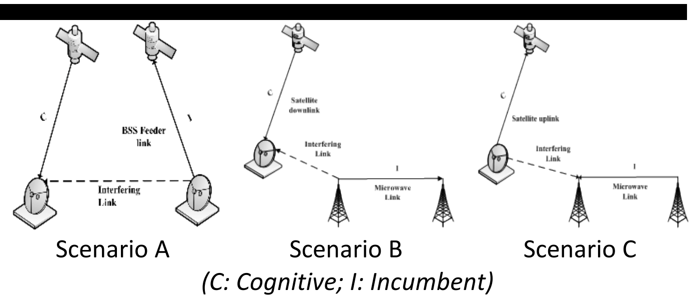


Figure 2 - CoRaSat selected scenarios.

Based on the results of a scenario-level analysis, system level and QoS requirements, and system key performance indicators have been identified, discussed, and defined. In particular, three system KPIs (Key Performance Indicators) have been considered to compare the state-of-the-art cognitive techniques initially identified:

- System capacity: overall capacity that the system can support by taking into account both the incumbent and the cognitive systems.
- Geographical availability: overall area in which the cognitive system can be implemented subject to the constraints.
- Complexity: an overall analysis of the cost benefits from both the technological and the market perspectives shall be considered and, to this aim, this KPI is taken into account.

The system level requirements have been defined in three main categories, taking into consideration geographical parameters, device parameters, and parameters related to the surrounding environment.

After the definition of the KPIs and the system level requirements, those at the cognition level are considered. Such requirements refer to parameters that are needed in order to evaluate specific techniques. To this aim, we focused on two categories (underlay and interweave) and on how they can be used in the three selected scenarios.

This resulted in the definition of a set of possible techniques (or enabling technologies) and related requirements for both spectrum awareness and exploitation: spectrum awareness, implemented through database [5] and spectrum sensing [6], and spectrum exploitation [7], implemented through resource allocation and beamforming.

These techniques have been assessed in each of the three considered scenarios.

COGNITIVE RADIO TECHNIQUES RESULTS

Database and interference modelling

Scenario A

This scenario does not pose any issue, as the number of BSS feeder links is limited across the whole Europe. Based on UK and Luxembourg databases, some typical cognitive zones around a single BSS feeder station have been derived with both the LOS propagation model and the full ITU P.452-15 propagation model, which highlighted the relevant effect of terrain diffractions. Across the analyzed sub-bands, with a threshold set at -155 dBW/MHz, it has been shown that less than 2% of the UK area is affected by BSS feeder links, and thus more than 98% of the area can be served by FSS terminals without the need for further actions. In Luxembourg, the situation is even better as more than 99% of the area is available for FSS terminal operation.

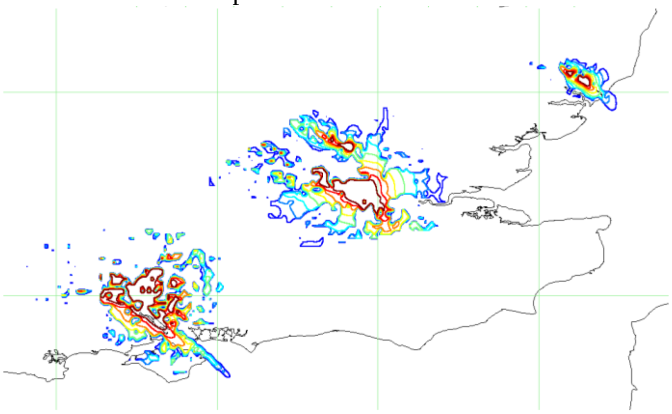


Figure 3 - Example of accumulated interference based cognitive zone across UK for the [17.46-17.50] GHz sub-band.

Scenario B

In this scenario, there is a large number of FS carriers in the UK database over the considered 2 GHz. In this case, a PSD-based spectrum analysis per MHz of spectrum was performed for a particular location, instead of a geographical area analysis as for Scenario A. Both the LOS and full ITU propagation models have been applied in this scenario as well and the nominal interference threshold was set at -154.5 dBW/MHz.

Although the number of FS links is very large, the actual interfering FS links are limited due to terrain diffraction and thus the majority of the considered spectrum is available at most potential FSS locations in the analysed regions. Additional evaluations have been performed with database information for France as well.

The high number and density of FS links in the UK database makes it the worst-case scenario, as also confirmed from the analysis results. Thus, if co-use of the spectrum is possible in the UK, then it can be considered to be even more feasible in other countries.

To avoid potentially unacceptable interference at some locations, some form of mitigation could be applied. Interference aware resource allocation approaches adopted within the FSS networks would be well matched to the problem, especially as considerable frequency agility would be required as the interference varies considerably over a relatively small area.

Scenario C

There is no appropriate and complete database available for this Scenario C, except for the Slovenia BR-IFIC database and the database for Finland. Moreover, this scenario is different as in this case interference is generated by the cognitive FSS link towards the incumbent FS link. However, the HDFSS uplink band has been agreed for uncoordinated earth stations in all except for 5 of the EU countries. Thus, without any additional work the uplink band could be doubled.

The proposed methodology is still applicable if databases are available. However, it shall be used to compute the maximum allowable transmission power for FSS at a given location such that FS protection is guaranteed. Further details on this scenario are provided in the resource allocation part.

The complete ITU-R P.452-15 methodology (including terrain effects) and calculation facilities used in this modelling has been validated and proven as a suitable approach to provide interference results.

Spectrum sensing

Scenarios A and B

Energy detection and cyclostationary feature detection algorithms have been assessed in these scenarios, also taking into account noise uncertainties. However, as previously discussed, no interference is generated towards the incumbent systems in these cases. Thus, the aim is no longer to simply detect whether a specific band is available or not, but rather to estimate the SINR level on that band. This information allows to define to which extent the considered band is available for cognitive usage.

To this aim, an SINR estimation technique was proposed and adapted to the CoRaSat scenarios. In particular, the data-aided SNORE algorithm was implemented (SS-SNIR), exploiting the knowledge of pilot blocks that are present in the DVB-S2(X) standard on which the forward links in scenarios A and B are based. As the incumbent spectrum utilization is almost constant in time, the sensing operation can be performed with a relatively low duty cycle and when no data transmission is required, to lower the computational load. The information gathered during this initial sensing phase can then be reported to the Network Control Center (NCC), which allocates to each user the most reliable sub-band. Then, in order to control that the required QoS can still be met for the cognitive user, a fast in-band sensing can be performed during data transmission as well.

The performance of the SS-SNIR estimation algorithm has been compared to data extracted from databases. In particular, the potential geographical reuse factor of a specific carrier as a function of the relative location between interferer and interfered terminals has been performed. The estimated values excellently match the SINR values obtained from the database, and thus the SS-SNIR algorithm provides a valuable solution for spectrum awareness either to complement the information stored in databases or to provide the spectrum occupancy when databases are not available.

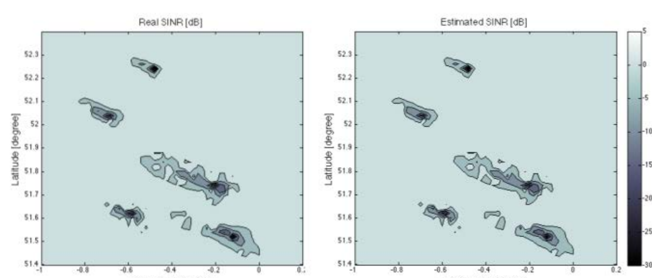


Figure 4 - Comparison between real (left) and estimated (right) SINR levels in Scenario A.

Scenario C

In this scenario, spectrum sensing cannot be applied. This is due to the high potential interference that the FSS terminal can cause against FS incumbent users and to the inadequacy of spectrum sensing in providing information on the incumbent receivers' presence and spectrum occupancy, i.e., the hidden node problem.

Even with partial knowledge from databases, this task is very challenging due to the high directivity of FS links. On the one hand, the terminal is able to detect and avoid the FS users only when it is in the same direction of the incumbent link. However, this assumption may not reflect a real scenario deployment. On the other hand, when the terminal is not in the same direction of the incumbent link, it might seem that the two links will not interfere each other due to the different geometry, while it depends on the pointing angle of the terminal with respect to the direction of the FS link. Hence, without the knowledge of the FS receiver position it is not possible to avoid interfering it with the desired assurance.

Carrier allocation and beamforming

The available resources identified through databases or spectrum sensing are then assigned among cognitive FSS terminals by means of carrier allocation (CA) and beamforming (BF) algorithms.

The CA module aims at maximizing both the overall throughput and the availability. In the former case, the SINR of each user over each carrier is exploited to compute the achievable rate, and the Hungarian algorithm is used to maximize the system sum-rate. As for maximizing the availability, the minimum SINR demand is added as constraint to the previous problem.

In order to furtherly enhance the system sum-rate, a BF algorithm has been implemented so as to increase the SINR values. In particular, both a Minimum Variance Distortionless Response (MVDR) and a Linearly Constrained Minimum Variance (LCMV) beamformers have been considered.

Scenario A

The results obtained on a per-beam basis have shown significant improvement in terms of the overall throughput over the case where only exclusive bands are used by FSS terminals. In this case, it was shown that more than a 160% improvement with carrier allocation, extended to 180% with beamforming, can be achieved.

Scenario B

In this case, carrier allocation and beamforming for low and high density beams were considered. In both cases, more than 400% improvement in throughput is achieved by applying cognitive carrier allocation mechanism. In this scenario, and for the studied database, beamforming did not show a huge improvement. This is due to the fact that the vast majority of FS links in Scenario B only use one or two carriers with low bandwidth and, thus, a FSS terminal in rare cases experiences low SINR in one or two carriers out of 69. Thus, the effect of beamforming is not as significant as in Scenario A (+20%).

Scenario C

In this case, beamforming plays a significant role as interference might be generated towards the incumbent FS receiver. A Joint Power and Carrier Allocation (JPCA) algorithm was proposed and implemented, in which the cross-channel gains at carrier level are first evaluated based on the available information in the FS database. Then, the NCC of the FSS system exploits this information to the worst FS link in terms of received interference per user and per carrier. Next, the amount of tolerable interference of the worst incumbent FS link is divided among the maximum number of FSS terminals that can potentially contribute to its aggregate interference. Subsequently, the maximum transmitted power of each FSS station is derived per each carrier and user. The resulting powers are fed to the JPCA module in order to allocate the resources by maximizing the overall throughput of the FSS system.

Numerical simulations showed that the additional spectrum combined with the JPCA module for resource allocation provide approximately a 405.8% throughput improvement with respect to the usage of exclusive bands only. When resources are not optimally distributed, the gain can be reduced down to 378.6%, which is still a significant improvement compared to conventional FSS systems.

LABORATORY DEMO

Based on the above technical analyses and achievements, the CoRaSat focus moved towards the laboratory demonstration of a two-way FSS Ka-band link that reuses the non-exclusive frequency bands on the basis of CoRaSat findings. To this aim, two main activities were performed: i) the finalization of the technical analysis of CR techniques for the selected CoRaSat scenarios and their adaptation to the CoRaSat system towards demonstration; and ii) the definition of a set of test cases and the implementation of the testbed for demonstration.

Based on this analysis and the above discussion, it has been shown that an overall significant gain in the system throughput is achievable by combining exclusive and non-exclusive frequency bands by means of Cognitive Radio techniques. In particular:

- In the [17.3-19.7] GHz forward link (scenarios A and B), the system gain is approximately equal to 3.6 times without carrier allocation schemes and 4 times with them, with respect to excusive frequency bands only.
- In the [27.5-29.5] GHz return link (Scenario C), a limited evaluation has been performed due to the lack of complete databases. However, similar gains have been achieved.
- Only approximately 10% of the terminals are expected to experience significant interference from incumbent users based on the available data in the examples considered for UK and France. In a few rare cases, this interference can be very high and a carrier reallocation is thus required.
- Moreover, the use of spectrum sensing techniques to estimate interference levels when database information is not available or incomplete has been considered.

It shall be noted that these evaluations are based on near-term satellite models with carriers of 64 MHz. Longer term satellites would require wider band carriers, which would consequently impact the applied carrier allocation scheme. However, it is expected that the resulting system gains would remain in the same order as those discussed above. This is related to the fact that using wider band carriers (from 108 MHz to 250 MHz) would reduce the flexibility of allocating the forward link while, at the same time, also reduce the impact of terrestrial interferers (scenarios A and B).

Conclusions for Scenario C will require further practical feasibility reviews before the gain and the possible usage of non-exclusive frequency bands can be confirmed. However, due to the asymmetry of the required throughput of the considered broadband access service, it is the forward link that mostly defines the overall system capacity. The resulting gains demonstrated in CoRaSat are thus significant from the perspective of designing future broadband satellite systems.

The obtained system level gains were also compared to the foreseen implementation and operational costs that might be required to introduce the usage of non-exclusive bands. The cost/benefit analysis performed in the CoRaSat project showed that up to a 7 times increase in NPV (Net Present Value) and a doubling of IRR (Internal Rate of Return) can be achieved when employing non-exclusive bands.

The CoRaSat concept was demonstrated through laboratory testbed implementation of some selected test cases. The satellite network is assumed to be based on State-of-the-Art radio interfaces: i) TDM based DVB-S2 and its evolution DVB-S2X for the forward link; and ii) MF-TDMA based DVB-RCS2 for the return link. The overall system is detailed in Figure 5, where exclusive and non-exclusive frequency operations are depicted for a specific beam coverage.

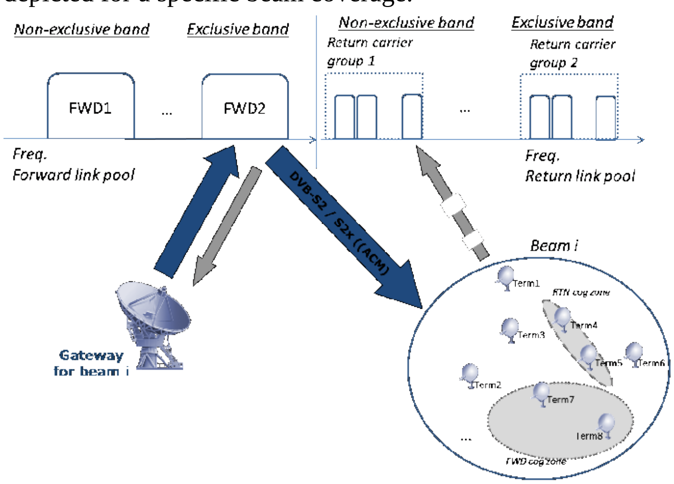


Figure 5 - Considered scenario for the demonstration setup (one specific beam coverage).

During each test, the most relevant parameters for both the forward and the return links can be controlled or recorded (e.g., C/N and C/(N+I), central frequency, bit and symbol rates, spectral efficiency, used satellite network, ModCod, etc.). The end-to-end hardware test setup provided in [4] is composed of several sub-system components that have specifically been integrated into a dedicated CoRaSat laboratory setup to address the tests outlined in the previous study phases.

Having defined and implemented the overall CoRaSat demonstrator, based on the identified storyboard test cases, a formal test demonstration was performed on a subset of the full set of test sets. In [1], the recorded results of these demonstrated test cases are provided and then related to the defined key performance indicators. This formal test campaign verified the implemented CoRaSat emulator functionalities and capabilities, as well as the implemented cognitive techniques as test functions in a dedicated CoRaSat co

The database access was emulated to compute the expected interference level for the FSS terminal forward links in specific geographic contexts. The resource allocation module was evaluated and it was shown that the efficiency improvement correspond to the values foreseen during the technical analysis. The SS-SNIR technique was tested as well, in view of unexpected interference impacts from incumbent users, which have not been reported by the database. It was demonstrated that this technique is actually capable of detecting interference and also to distinguish it from other events that might occur within the network (e.g., fading, antenna de-pointing, etc.).

On the return link, the possibility to maintain a certain FS receiver limitation in terms of power density at the reception is demonstrated in the context of these tests. The demonstrated capability of the return link reconfiguration is based on the calibration and correct configuration of the system. The highly flexible and efficient return link used was shows to be well capable of reconfiguring the link in a centralized and coordinated manner for all the terminals in the network.

ACKNOWLEDGMENT

This work has been supported by the CoRaSat research project funded by EU-FP7 under contract n. 316779.

REFERENCES

[1] CoRaSat project, http://www.ict-corasat.eu
[2] S. Maleki, S. Chatzinotas, B. Evans, K. Liolis, J. Grotz, A. Vanelli-Coralli, and N. Chuberre, "Cognitive spectrum utilization in Ka band multibeam satellite communications," IEEE Communications Magazine, vol. 53, no.3, pp.24-29, March 2015,
[3] K. Liolis, et al, "Cognitive Radio Scenarios for Satellite Communications: The CoRaSat Approach," 2013 Future Network and Mobile Summit (FuNeMS), 3-5 July 2013, Lisboa, Portugal,
[4] CoRaSat Final Report
[5] W. Tang, P. Thompson, and B. Evans, "Frequency Sharing between Satellite and Terrestrial Systems in the Ka Band: A Database Approach," 2015 IEEE International Conference on Communications (ICC), pp. 2470-2475, 8-12 June 2015, London, UK
[6] V. Icolari, A. Guidotti, D. Tarchi, and A. Vanelli-Coralli, "An Interference Estimation Technique for Satellite Cognitive Radio Systems," 2015 IEEE International Conference on Communications (ICC), pp. 2495-2500, 8-12 June 2015, London, UK
[7] E. Lagunas, S.K. Sharma, S. Maleki, S. Chatzinotas, B. Ottersten, "Resource Allocation for Cognitive Satellite Communications with Incumbent Terrestrial Networks", IEEE Transactions on Cognitive Communications and Networking, accepted for publication.