SANSA: Hybrid Terrestrial-Satellite Backhaul Network for the 5th Generation

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Abstract*— SANSA (Shared Access terrestrial-satellite backhaul Network enabled by Smart Antennas) is a project funded by the EU under the H2020 program. This paper describe the SANSA vision, approach and the benefits of the SANSA solution. The main aim of SANSA is to boost the performance of mobile wireless backhaul networks in terms of capacity, energy efficiency and resilience against link failure or congestion while easing the deployment in both rural and urban areas and assuring at the same time an efficient use of the spectrum. SANSA has two main enabling technologies, smart antennas and the hybrid network manager. By the smart antennas, each node can communicate with many of its neighbors where the hybrid network manager allows efficient use of the all the network resources. The research in SANSA is following two main paths: spectrum coexistence and self-organizing SON hybrid network. For the spectrum coexistences, the beamforming techniques that will enable the simultaneous operation of the terrestrial and satellite links considering the cost-performance trade-off. Additionally, smart dynamic radio resource management will be developed to explore efficient solutions for the hybrid scenario. Self-organizing load-balancing algorithms will be designed to aggregate the capacities of the terrestrial and satellite resources. A special care will be devoted to reduce the network energy consumption and to consider the delay in the satellite links. SANSA research efforts is focused in KA band where current CEPT recommendation allow coexistence of terrestrial backhauling services at 18 GHZ and 28 GHz with satellite-to-earth and Earth-to satellite links.

Keywords—Backhaul network, terrestrial-satellite shared access; SANSA; self-organizing network; smart antennas.

I. INTRODUCTION

The changes in user trends and the appearance of new applications in recent years resulted in a huge increase of mobile traffic worldwide. Different access network technologies such as millimeter wave access, Heterogeneous networks (HetNets) or Massive MIMO have been proposed and are being currently investigated for dealing with such traffic increments. In fact, out of the targeted 1000x increase in capacity offered in the access by future 5G communication systems, one third is expected to come from increased spectral efficiency, one third from the use of additional spectrum, and the other one third is expected to come from reduced cell sizes [1].

SANSA (Shared Access terrestrial-satellite backhaul Network enabled by Smart Antennas) is a project funded by the EU under the H2020 program and is focused on providing a solution for the backhaul of future communication systems to serve such increasing traffic volumes.

The objectives of SANSA are:

1. To increase the mobile backhaul networks capacity in view of the predicted traffic demands
2. To drastically improve backhaul network resilience against link failures and congestion
3. To facilitate the deployment of mobile networks both in low and highly populated areas
4. To improve the spectrum efficiency in the extended Ka band for backhaul operations
5. To reduce the energy consumption of mobile backhaul networks
6. To strengthen European terrestrial and satellite operators market and their related industries

The solution envisaged in SANSA is a spectrum efficient self-reconfigurable hybrid terrestrial-satellite backhaul network based on three key principles: (i) a seamless integration of the satellite segment into terrestrial backhaul networks; (ii) a terrestrial wireless network capable of reconfiguring its topology according to traffic demands; (iii) a shared spectrum between satellite and terrestrial segments. These combination will result in a flexible solution capable of efficiently routing the mobile traffic in terms of capacity and energy efficiency, while providing resilience against link failures or congestion and easy deployment in rural areas.

The project started in February 2015 and has a duration of 3 years. As depicted in Figure 1, the involved partners in SANSA are mix of academia (CTTC, ULUX, AIT, Fraunhofer IIS, telecommunications provider (OTE), companies (THALES and VIASAT) and satellite operator (AVANTI).

The rest of paper is structured as follows: the next section focuses on the considered scenarios, architecture and requirements. Afterwards, the details related to terrestrial-satellite spectrum sharing and network design are provided in Section III and Section IV respectively. Description on SANSA key enabling technology and the planned demonstrations are explained in Section V. Finally, Section VI concludes the paper.

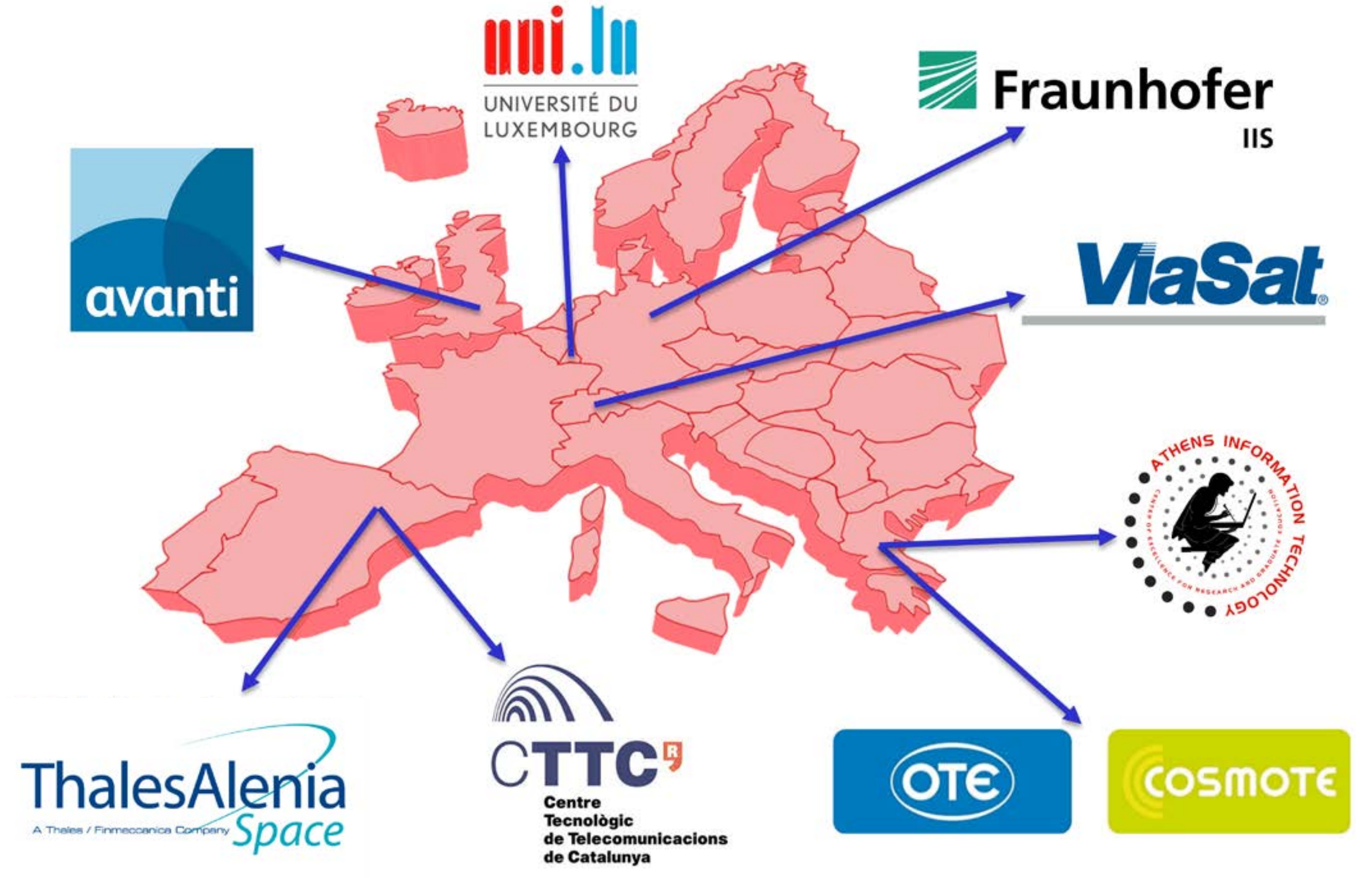


Figure 1. SANSA Partners.

II. SCENARIOS, ARCHITECTURE AND REQUIREMENTS

A. *Regulatory environment*

The regulatory environment in which SANSA is operating is one of the major aspects of the project. Ka band and more specifically bands 17.7 – 20.2 GHz for the downlink and 27.5 – 30 GHz for the uplink have been examined.

Based on current regulations in Europe, SANSA satellite terminals can be deployed in 2.9 GHz for the downlink (17.3 - 20.2 GHz) and 1.38 GHz for the uplink (27.5 - 27.8285 GHz, 28.445 – 28.9485 GHz, 29.4525 – 30 GHz) [2-3]. As not all European countries have implemented CEPT decisions, the amount of bandwidth available depends on the country. This has an effect on both the satellite system design (beam bandwidth) and the resource allocation.

An overview of the use of spectrum and technologies by 2G/3G/4G macrocell backhaul deployments has been performed in SANSA. According to the overview, in 2013 the majority of backhaul links in the field are based on the traditional microwave Line of Sight (LoS) technology. Most of LoS links will progressively move into the millimeter bands, especially in urban deployments where the distance between links is shorter and millimeter wave solutions are expected to capture the 24% of backhaul links in 2019. Micro-cell deployments will be most likely in urban scenarios and will use a combination of point-to-point (P2P) and point-to-multi-point (P2MP) links.

Furthermore, traditionally, backhaul links have been registered on a “per link” license (amounts to the 65.5% of licenses). However, the use of block assignments has increased recently to the 20.7% of licenses in operation, especially for P2MP links.

The most important findings from the regulatory analysis can be summarized as follows [4]:

1. Antenna height ranges from 20 to 60 meters.
2. EIRP ranges from 20 to 50 dBW for P2P links in 18 GHz band
3. Channels are normally 7 MHz, 14 MHz, 28 MHz or 56 MHz. The most common are the 28 MHz channels; however in the UK there is a considerable amount of links with 7 MHz channels.
4. Each P2P link has normally 1 or 2 carriers.
5. Distance of P2P links on the 18 GHz band is in the order of 20 Km.

Table I SANSA selected scenarios

	Spectrum Sharing		Satellite Carrier Bandwidth			Content Delivery Networks			Terrestrial Links	
Scenario ID	**DL only**	**UL+DL**	**SoTA**	**NG HTS**	**UWB**	**No CDN**	**Sat. only multicast**	**Sat.+Terr. Multicast**	**18GHz**	**28GHz**
Rural 1	*		*						*	
Rural 2		*	*	*			*		*	*
Urban 1			*				*		*	*
Urban 2				*				*	*	*
Urban 3					*				*	*
Moving Base Station	*		*			*				*

6. The majority of antennas for P2P links have 3-4 degrees of beamwidth.
7. Antenna gains are usually around 32-39 dBi.

B. *Use cases and scenarios*

SANSA objectives as they have been stated in the introduction helped us to identify a number of relevant use cases. These use cases are:

1. **Radio link failure:**
   SANSA network improves backhauling networks in case of link failure by providing alternative route through satellite or terrestrial links.
2. **Radio link congestion:**
   SANSA provides off-loading capabilities to heavily congested nodes.
3. **New node deployment:**
   Easy to deploy low cost nodes with low CAPEX and OPEX.
4. **Content Delivery Networks (CDN) integration:**
   SANSA supports CDN caching either through satellite or both through terrestrial and satellite nodes.
5. **Remote cell connectivity:**
   SANSA provides connectivity to isolated areas with the use of the satellite link and to moving vessels

Another important parameter that affects network design is the periodicity of the events, which can be classified as **periodic**, **semi- periodic** and **rarely occurring** events. A periodic event is an event that occurs on a regular basis, e.g. traffic variation between working and non-working hours. A semi- periodic event is an event that occurs on an almost periodic basis, e.g. a football match on a stadium and rarely occurring events are events that happen on an irregular basis e.g. concerts.

All these use cases have led to the need of specific scenarios in order to further investigate the performance of the SANSA network on each of the use cases. A selection strategy has been proposed based on the following 5 axes.

The **Ka-Band shared spectrum** between terrestrial and satellite links that could be the downlink (DL) or both uplink (UL) and downlink . The main case in the scenario definition is the DL only spectrum because there is not a need to extend bandwidth in the UL direction due to the increasing forward:return (FWD:RTN) ratio (i.e, 6:1) and it requires a change in regulations. The scenarios, where interference in both uplink and downlink exists, are provided mainly for research on interference mitigation techniques.

The **satellite carrier bandwidth** is also a very important factor regarding the scenario definition process. The main three carrier types that will be examined through SANSA are the SOTA carriers. Since SANSA is an R&D project aiming at providing backhaul solutions within the 2020 timeframe, the beyond SOTA carrier bandwidth should be taken into account. The other two references regarding carrier bandwidth are BATS [5], with a carrier bandwidth size of 421 MHz for the downlink and 21.7 MHz for the uplink and Ultra Wideband (UWB) with a carrier size of 230 MHz for the downlink and 9 MHz for the uplink.

Another important distinction between the scenarios is the **type of deployment**. Urban scenarios are the scenarios with high node density, high traffic requirements but easy access to high speed optical fibres networks as well. On the other hand, rural scenarios refer to sparsely populated areas with mainly microwave link connections and not easy access to fixed high speed broadband networks. Another type of deployment is mobile platform deployment for such as cruise ships etc.

The **CDN design** is an emerging need for modern mobile networks as this type of traffic has an increasing trend and will be dominant within the years to follow. The existence of a CDN will be examined in SANSA as well as how CDN cache should be fed, either through terrestrial or satellite link. The node design to facilitate the installation of such caching systems should be taken also into account.

The last important factor in the scenario definition process is the operating frequency (18 or 28 GHz) of the **terrestrial links**. Table I summarizes the selected scenarios according to the described strategy.

C. *KPIs and requirements*

The first set of requirements for SANSA derives from the program objectives. In order for the backhaul network to be able to transport the increasing broadband traffic it seems to be critical and the following requirements regarding the backhaul network have to be considered:

1. *Coverage:* It should be provided a good coverage in order to provide the expected QoS to the users especially in urban areas
2. *Capacity:* The backhaul network should be considered to be able to carry the average traffic and also the burst traffic which is coming quite a few times from the mobile access network.
3. *Availability:* It should provide quality, four to five nines for sensitive traffic, but in general two to three nines can be acceptable.
4. *Scalability:* The backhaul network should be easily scalable, (possibly by software means), in order for the operator not to invest a large CAPEX for new installation.

The KPIs defined for SANSA refer to the overall performance of the solution and reflect the objectives of the project focusing on the areas of improvement.

Table II summarizes the end-to-end KPIs of the SANSA solution as well as their targets.

Table II SANSA end-to-end KPIs and targets.

KPI	Target
Backhaul network capacity	Contributing to the 1,000x increase by 2020
iBN throughput	Per service targets
Service availability	99.99%
Backhaul network resiliency	Proof of concept in 5 scenarios of link failure and/or congestion
Delay	Per service type targets
Bit error rate (BER)	$<= 10^{-6}$
Spectrum efficiency	10-fold improvement within the considered Ka band segments
Energy efficiency	Up to 30% improvement compared to benchmark
Population coverage	95-99% EU coverage

II. ENABLING TECHNOLOGIES FOR TERRESTRIAL-SATELLITE SHARED SPECTRUM

A key aspect of the SANSA project is the integration of the satellite components with the terrestrial backhaul network in order to exploit the capabilities and the flexibility of a satellite based network. In more detail, satellites can provide easy and cost efficient network deployment in rural or remote areas and enable data off-loading from the terrestrial network, which in turn results in overall capacity increase. Furthermore, it also provides a new path for routing the traffic that increases the network resilience against link failures or congestion. It is also noteworthy that several satellite terminals can be deployed throughout the backhaul network giving more flexibility to the hybrid network and providing more backup solutions.

An important aspect in a hybrid satellite-terrestrial topology is related on how the coexistence of the two segments in the spectrum area is materialized. Frequency spectrum is a scarce resource that should be used in the most efficient way. Satellite operators are already demanding more spectrum for other applications such as broadcasting, so there is not so much bandwidth left for mobile backhauling. As stated before, SANSA will focus its research effort on Ka band where terrestrial backhauling bands of 18 GHz and 28 GHz are shared with the satellite-to-Earth and Earth-to-satellite satellite bands, respectively. The choice of these frequency bands have been made because they are already used in both terrestrial and satellite communications and current regulation already allows coexistence on a co-primary basis there. However, SANSA solution will be easily exportable to other frequency bands.

Although the SANSA solution presents some benefits with respect to the current backhaul technologies, it is not orthogonal to them so it can be envisaged that a combination of all the current solutions will address the backhaul networks challenges in close future.

The spectrum coexistence of the two segments will be enabled in a threefold manner by developing

- Novel interference mitigation techniques,
- Database-assisted shared spectrum techniques,
- Smart dynamic radio resource management (RRM) techniques for the shared terrestrial-satellite networks.

A. *Novel Interference Mitigation Techniques*

SANSA focuses on beamforming techniques that will allow the simultaneous operation of terrestrial and satellite links by means of their different spatial locations [6-7]. The basic idea is to equip terrestrial backhaul nodes with smart antennas capable of placing radiation nulls in the directions of the satellite terminals. Although beamforming is quite a mature technology, it has been not adopted in mobile backhaul, rather due to cost restrictions. Therefore, in SANSA we are analyzing different antenna beamforming networks and beamforming algorithms in order to propose a solution that maximizes the cost-performance trade-off. Among the techniques that are currently developed in SANSA there are cost efficient hybrid analog-digital beamforming networks for phased arrays, transmit/reflect arrays, coordinated multi-BS beamforming, multicast and symbol-level precoding. SANSA is considering new signal processing algorithms, such as precoding strategies for multibeam satellite payloads with interference constraints towards the terrestrial nodes in order to minimize the satellite induced interference.

B. *Database-assisted shared spectrum techniques*

SANSA is addressing database-assisted shared spectrum techniques. Static and dynamic information of the interfering transceivers such as location, transmit power and temporal spectrum activities is stored in a database and used to efficiently manage the shared access to the spectrum. Besides, spectrum sensing is being explored to improve the quality of

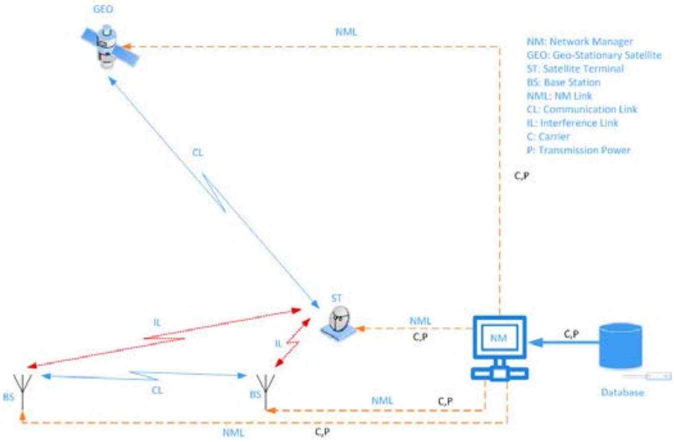


Figure 2. Schematic block diagram of database-assisted dynamic resource management in shared terrestrial and satellite networks that is envisioned in SANSA project.

the dynamic information stored in the databases and combined with network-level radio environment mapping for an improved hybrid access performance. It must be noted that the static information can be easily obtained in this case due to the collaboration between satellite and terrestrial operators providing the same backhaul service.

C. Smart dynamic radio resource management (RRM) techniques for the shared terrestrial-satellite networks

The problem of resource allocation in homogenous satellite networks has been already addressed in the past. Resource allocation in shared terrestrial and satellite networks is considered to be a new research area and it will be addressed by SANSA project. The issue of dynamic resource allocation is also inspired by the network dynamisms, such as channel variations, time-variant traffic demands, etc., which are obtained through the database. However, in this case, it is important that the quality of service (QoS) of the incumbent terrestrial base stations and satellite terminals should not be degraded by the coexistence of the satellite and terrestrial networks. This issue was partly addressed in EU FP7 project CoRaSat [8]. However, the considered resource allocation scenarios in CoRaSat were intended merely for performance analysis, in order to show the higher system capacities that can be achieved by cognitive satellite communications. Further, CoRaSat tracked this problem mostly at the user level, while in SANSA project there is a focus on the backhauling hybrid network.

The SANSA project plan to go well beyond this, and develop smart dynamic resource management mechanisms for the shared terrestrial-satellite networks by considering several scenarios, such as: traffic patterns, traffic demands, QoS requirements, service priorities, power constraints, guaranteed interference upper bound, etc. It is foreseen that the main resources to be allocated are carrier and transmission power. These resource allocation mechanisms aim to maximizing the system capacity and system availability.

A schematic block diagram for database-assisted shared spectrum access as well as dynamic resource management, which are envisioned in SANSA project, is depicted in Fig.2. Note that the interference from geostationary (GEO) satellite to the terrestrial network is controlled by the regulation, in terms of power flux density constraint, and thus is not included in this figure. As shown, carrier and transmission power are appropriately allocated by the smart dynamic resource manager among the incumbent terrestrial base stations and satellite terminals. The smart dynamic resource manager operation is enhanced by the database-assisted shared spectrum access technique.

III. NETWORK DESIGN

A. Networking aspects of SANSA network

Main SANSA objectives are to improve: resiliency, spectral efficiency, energy saving, routing for satellite-terrestrial backhauling networks. From the networking point of view, these objectives are tackled, on one hand, by using self-organizing, load-balancing algorithms; on the other, by upgrading the network topology and re-acting to network conditions. Interoperability between both components (satellite and terrestrial) is required to balance the traffic on each interface, depending on different network events such as the load of backhaul nodes. The following network elements are being developed in SANSA to achieve this aim:

- The Hybrid Network Manager (HNM). This component represents the centralized intelligence of the hybrid network, aggregates available satellite and terrestrial resources, is able to determinate the status of the network, and may reconfigure the remote nodes for deploying the optimal topology.

- The Intelligent Backhaul Nodes (iBNs). These hybrid modules constitute the mesh backhauling network, extending the functionality of current Long Term Evolution (LTE) Evolved Node B (eNBs), incorporating the SANSA smart antenna component and performing the Routing, Energy Efficiency, and Traffic Classification functions.

These two elements designed in SANSA will integrate state-of-the-art, existing backhauling components, as the eNB, terrestrial modems for Ka-band, and the interactive DVB-RCS2/S2 satellite terminals.

The **i**ntegration of mentioned network elements is depicted in Fig.3. The elements being developed in SANSA are colored in blue. Connection to the core network is made through the eNB inside the iBN. The HNM is connected to both the evolved packet core (EPC) and the satellite ground segment, and also has connectivity to every iBN. The iBN shown in detail includes the satellite and terrestrial terminals, however the architecture contemplates the possibility of having purely terrestrial or satellite connected nodes. Every iBN includes the eNB, but the novelty introduced within SANSA architecture consists in that some of the connections between nodes are dynamic (though there may still exist a backbone of fixed terrestrial links).

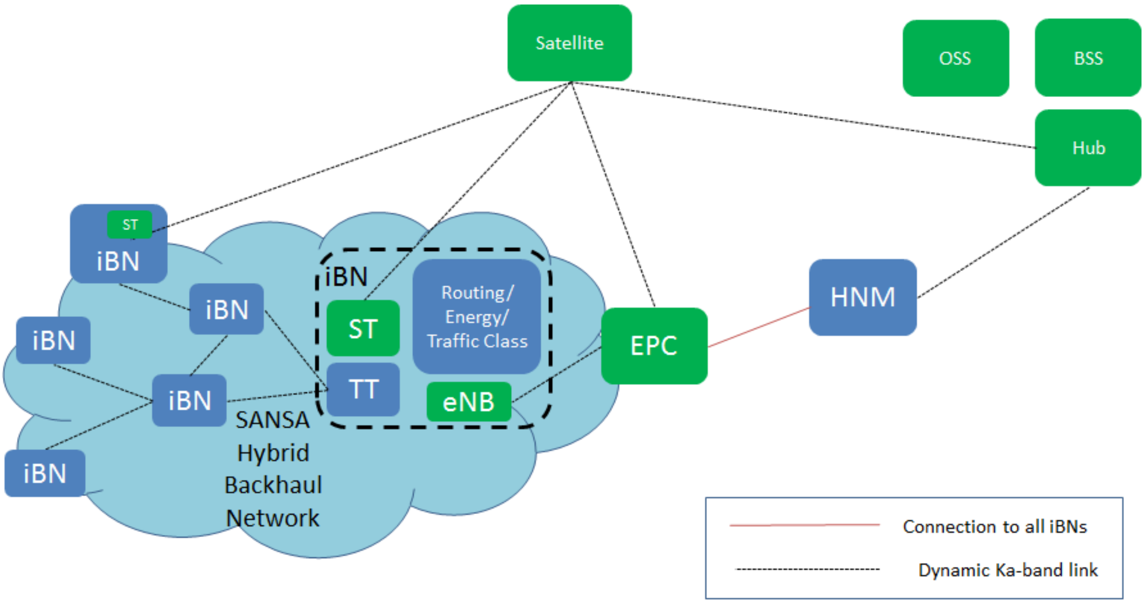


Figure 3. Network Architecture.

In the SANSA networking design, System functionalities are distributed between the HNM and the iBNs. HNM will be in charge of receiving the status of every node in the topology (e.g., SNI values of terrestrial and satellite antennas, and iBN level of congestion), and of communicating any change in the network (antenna beams establishment or removal) to every iBN. Moreover, the HNM will be capable of remotely configuring some parameters of the iBN equipment when needed. In turn, iBNs will perform routing algorithm decisions, energy management operations (e.g. node switch-on/off), and traffic classification among the different node interfaces (using terrestrial or satellite antennas).

Among the main features that are keys in SANSA networking design, which will be translated to sub-system requirements, are the following:

- **Satellite – terrestrial networks dynamic interoperability.** This feature consists of defining the criteria to select one certain interface type for traffic transmission. Since the QoS classification function is considered a local function embedded in the iBN, the traffic management strategy can be defined in the HNM and later updated in the iBNs.

- **Scalability.** The topology model must be valid for any kind of network size, and applicable to all defined scenarios. These are the main reasons motivating the de-centralization of some network functions in SANSA, directly affecting to the routing algorithm selection.

Finally, an important aspect is that of the definition of Rules. To obtain valid and efficient alternate network configuration, counter-acting networking events, a set of rules needs to be considered by the HNM (e.g., in the topology calculation algorithm), comprising the steps to validate a new connectivity matrix for the topology and a method to measure its efficiency (through KPI calculation such as throughput and latency).

B. *iBN Functions*

An iBN will embed three basic functions: Traffic classification, Routing, and Energy Efficiency.

The Traffic Classification function is in charge of determining the mapping of traffic flows to backhaul resources used to transport them. Based on flow QoS requirements, traffic classification algorithms will determine whether to use satellite or terrestrial resource for each flow in transit.

The *Routing function* is designed as a node-centric algorithms approach, in which the routes are discovered on-the-fly (i.e., on a hop-by-hop basis) while the packet traverses the network.

In particular, the node-centric routing algorithm must satisfy the following set of identified requirements

- Adaptable to the dynamicity of satellite-terrestrial wireless backhaul deployments.
- Scalable with network parameters (e.g., the number of IBNs).
- Decentralization: The routing protocol requires to operate in a decentralized manner.
- Makes the most out of the satellite-terrestrial wireless backhaul resources deployed.

The simulation framework uses Ns-3 [9], a modular discrete-event network simulator that models SANSA network elements and includes LENA/EPC [10] traffic simulator. It is important to highlight that in SANSA we conducted LENA implementation to extensions to allow any kind of transport topology in the data plane that connects the eNBs embedded in the iBNs and the S-GW located in the EPC (see Fig.4).

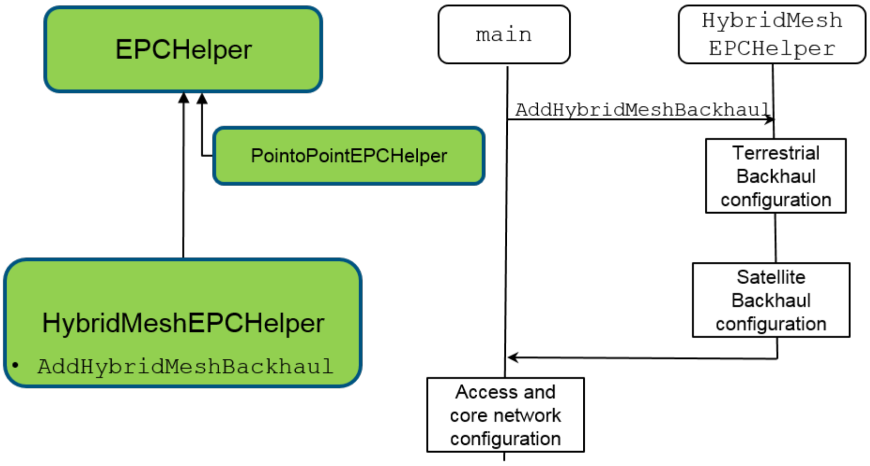


Figure 4. LENA Extensions pport Hybrid Satellite-Terrestrial backhaul.

The goal of the *Energy Efficiency function* is to control access and backhaul energy consumption, therefore reducing operator's OPEX while satisfying traffic demands. SANSA considers to tackle energy efficiency by proposing ON/OFF techniques related to both access and backhaul interfaces embedded in iBNs. In particular, when switching OFF access and terrestrial backhaul interfaces three different scenarios are contemplated:

- iBN is totally switched OFF (i.e., access and backhaul interface are switched OFF).
- iBN is switched ON with its associated access interface switched OFF. Backhaul interfaces can be used to route traffic coming from others iBNs.
- iBN is switched ON and all terrestrial backhaul interfaces are switched OFF. In this case, traffic will be transported through the satellite backhaul link.

C. *HNM functions*

The algorithms implemented by the HNM will determine several network configuration aspects. The Hybrid Network Manager can be divided in four (management) blocks:

- Radio resources: This function manages the system frequency plan.
- Topologies: In charge of reconfiguring and distributing new network topologies.
- Antennas: Dedicated to remote smart antenna/modem reconfigurations.
- Events: This module performs the monitoring of the network (e.g., link switched OFF).

Based on the network events reported by the iBNs, the HNM will re-configure the terrestrial-satellite backhaul network in order to meet the traffic demands and QoS policies. Such reconfiguration includes diverse set of both terrestrial links and a set of potential beams to the satellite and its associated neighbor terrestrial nodes. The parameters to be taken into account, are diverse: nodes geo-location, connectivity matrix, link budget for the potential links, and carrier's allocation (with acceptable interference levels).

D. *Interaction between iBN and HNM*

SANSA will tackle the aforementioned network aspects through simulations. Here we provide an example of interaction between the iBN and the HNM for reconfiguring the network topology. The HNM embeds a topology calculation algorithm. The obtained topologies (their connectivity matrix) are used to reconfigure the network topology. The initial topology setup illustrated in Fig.5 is taken from simulated scenarios using Ns-3.

In the example below, the link between nodes 1 and 2 fails. According to the initial connectivity matrix of Fig.6 it is still possible to establish a link between nodes 1 and 5, what will allow restoring the node 1 connection to the hybrid network.

The topology matrix will reflect which connections are possible between the different iBNs, and which connections are 'static', i.e. those that cannot be modified by means of the HNM, because correspond to fixed backhauling links not using dynamic terrestrial connectivity through SANSA smart antennas. Also, the matrix describes those iBNs including the satellite connectivity.

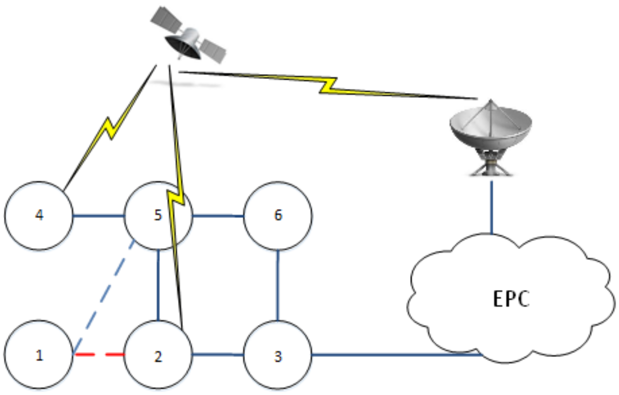
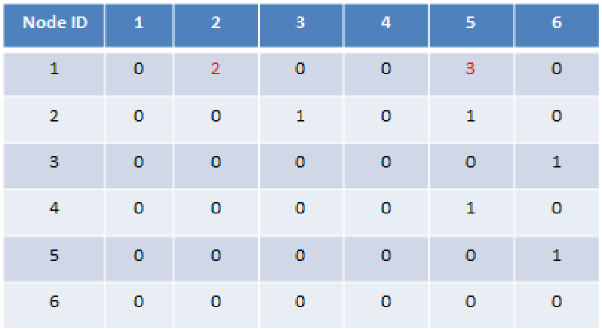


Figure 5. Terrestrial link failure event.



Node ID	1	2	3	4	5	6
1	0	2	0	0	3	0
2	0	0	1	0	1	0
3	0	0	0	0	0	1
4	0	0	0	0	1	0
5	0	0	0	0	0	1
6	0	0	0	0	0	0

Figure 6. Topology matrix.

E. SANSA Multicast Scenarios

Multicast capabilities of SANSA network, opening the door to CDN scenarios, are enabled thanks to multicast beam-forming techniques by the terrestrial antennas. Taking the proposed network architecture, modules and interfaces, this task will investigate, by use of cross-layer techniques in simulations:

- Multicast beam-forming configuration algorithms, considering traffic analysis, to optimize spectrum utilization.
- Hybrid network routing algorithms and protocols, taking advantage of multicast opportunities to optimize the system throughput, and measuring the resulting performance.

IV. ANTENNA IMPLMENTATION AND DEMONASTRATION

In the frame of the project, in order to enable the demonstration of the SANSA developments, a prototype of a smart antenna working in Ka band will be designed, manufactured and tested. The final antenna product for the application should be able to repoint the beam in different directions to compensate for example for a node failure or node change to speed up communication. Another important capability of the final antenna product should be the possibility to dynamically change the pattern to reduce interference with other terminals. This means that, not only should the antenna reconfigure the main beam, but also be able to change the pattern shape in directions other than the one selected for communication. One example of possible application of this concept is the capability of creating nulls in particular direction where for example another terminal operating at the same frequency is detected.

Viasat will be responsible for the manufacturing of a prototype antenna that would enable the demonstration of some of the concepts identified during the project. In order to guarantee the highest flexibility the option considered for the moment is a hybrid digital/analog phased array.

The hybrid nature of the phased array will enable the testing of several possible beamforming algorithms while keeping the implementation feasible and cost effective.

The prototype will most probably be able to reconfigure the antenna pattern in one axis only. This is not foreseen to have any impact on the possibility to demonstrate the pattern re-configurability of the smart antenna nor the beamforming algorithms. For the final antenna, most the pattern reconfiguration will occur along one main axis (azimuth) while along the other one (elevation) a smaller angle will have to be covered depending on the selected scenario.

Technical research activities carried out in SANSA project target the TRL 4, i.e. technology validation in laboratory environment. The technological validation will be performed in in a virtual electromagnetic environment at the facility for over the air research and testing (FORTE) at Fraunhofer IIS.

FORTE consists of a laboratory building and an antenna tower. The laboratory building is equipped with channel emulators, anechoic chamber, a motion emulator and other RF and PC equipment that is required for emulation and evaluation of radio communication systems. Antennas or terminals under test can face a nearby antenna tower from the anechoic chamber through an EM transparent window. The antenna tower emulates an operational satellite at elevations between 16° to 24°. In this virtual electromagnetic environment the terrestrial links as wells as the satellite links will be realistically emulated at the physical layer, either over-the-air (OTA) or by means of channel emulators. The core network components including the multiple base stations will be set up on which the novel hybrid terrestrial-satellite backhaul adaptive network control will be tested.

The evaluation and demonstration scenarios will be based on selected application scenarios identified within Scenario and requirements definition work-package. The evaluation scenarios aim at demonstration of the key enabling components and techniques for the shared access terrestrial-satellite backhaul network such as:

- interference mitigation,
- simplified prototype of smart beamforming antenna and
- prototype of hybrid network manager.

The proof of concept prototypes, i.e. the smart beamforming antenna and the hybrid network manager, will be integrated with the powerful Fraunhofer IIS laboratory equipment for performing a small scale demonstration and evaluation of the technologies developed in SANSA.

Two groups of demonstration scenarios are planned for evaluation of the proof of concept prototypes. The first one focuses on the low cost and low complexity beam forming antenna solution for the microwave backhaul radio links to allow the terrestrial-satellite shared spectrum access. The functionality and performance of one terrestrial-terrestrial link in co-existence to a terrestrial-satellite link will be demonstrated over the air in Ka frequency band for different angular constellations between the both links. Hereby, the interference to the satellite-terrestrial links will be monitored during the demonstration. In the first step, the beam forming antenna characteristic will be measured to calibrate the antenna beam forming network including the antenna.

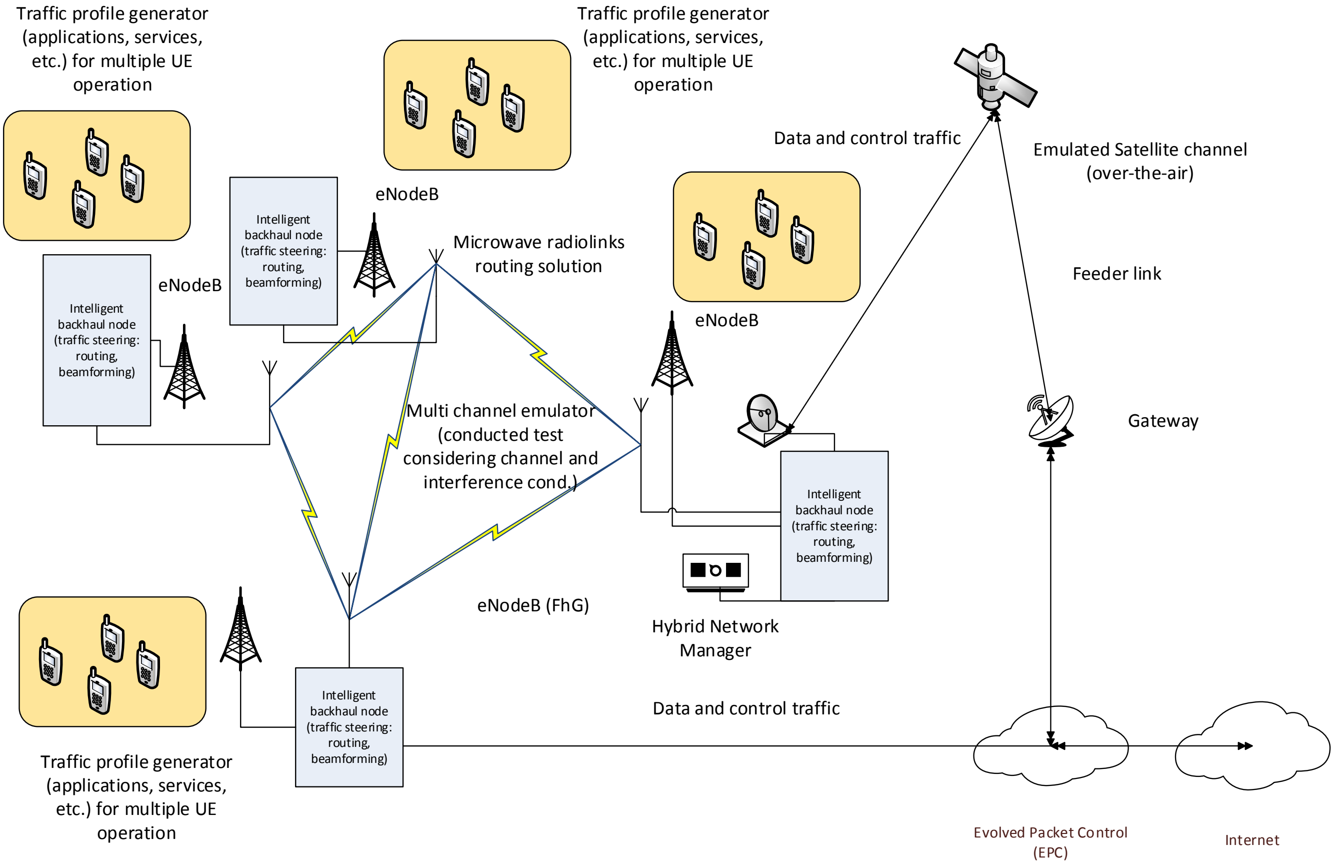


Figure 7. Demonstration of the backhaul network and resilience capacity improvement enabled by the hybrid network manager.

Afterwards, the performance of the interference mitigation techniques will be measured, in terms of interference to the adjacent satellite-terrestrial link as well as the pointing accuracy of the beam forming antenna. At last, both links will be emulated with realistic traffic over the air and the performance of the interference mitigation techniques, in terms of keeping a high link quality for both links will be demonstrated. From this demonstration the realistic interference levels can be measured and will be modeled for the emulation of multiple links backhauling link corresponding to SANSAs overall scenario.

The second group demonstration scenarios focuses on the performance of the hybrid terrestrial-satellite flexible backhaul network by including the main parts of the hybrid network manager and the intelligent backhaul nodes. The multiple terrestrial-terrestrial as well as the satellite-terrestrial backhaul links and its interference will be emulated realistically as shown in Fig.7. The satellite-terrestrial link will be emulated over the air in Ka frequency band, whereas the multiple terrestrial-terrestrial links will be emulated at L/S frequency band over a multi-channel emulator which allows to realistically include the interferences between the multiple links as well. Link failure will be emulated to demonstrate the adaptive capabilities of the hybrid network. Therefore, the intelligent backhaul nodes and the network manager will be communicating in a control plane at higher layer being connected to the available LTE core network. Furthermore, each intelligent backhaul node will be connected to an eNodeB (macro or femto cell) consisting of individual users, whose traffic will be emulated using a traffic generator or multiple UEs.

The demonstration and evaluation scenarios will help to indicate realistic performance of the prototype beamforming antenna and the hybrid network manager. Obtained results can be scaled up to predict overall performance of such a complex communication systems at the SANSA system.

V. CONCLUSIONS

This paper shed the light on SANSA approach to enable shared access terrestrial-satellite backhauling. The selected use-cases are presented where different impairments and events have been considered like radio link failure, congestion, new node deployment, remote cell connectivity together with the CDN integration. Additionally, the enabling technologies for sharing the spectrum is explained by means of novel interference mitigation techniques, database-assisted shared spectrum and smart resource management. The paper covers also the Hybrid Network Manager and the intelligent backhaul nodes as the main network elements in SANSA system, performing the routing and topology configuration functions. In addition, the paper highlights the achieved improvements in energy efficiency for both access and backhaul interfaces. Finally, the approach for antenna implementation and demonstration, to validate the SANSA design, is explained. The solution proposed by SANSA will help the future backhaul network to satisfy the required traffic demands, while being energy-efficient and resilient to the different link events.

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REFERENCES

[1] Digital Agenda for Europe," [Online]. Available: http://ec.europa.eu/digital-agenda/digital-agenda-europe.

[2] ECC/DEC/(00)07 on the shared use of the band 17.7-19.7 GHz by the fixed service and Earth stations of the fixed-satellite service (space-to-Earth)

[3] ECC/DEC/(05)01 on the use of the band 27.5-29.5 GHz by the Fixed Service and uncoordinated Earth stations of the Fixed-Satellite Service (Earth-to-space);

[4] SANSA project, Deliverable 2.1 "Review of Regulatory Environment ", July 2015 , Available at: http://www.sansa-h2020.eu

[5] BATS project, Deliverable 8.3.1, "Regulatory Roadmap", December 2015, Available at: http://www.batsproject.eu

[6] Devillers, B.; Perez-Neira, A., "Advanced interference mitigation techniques for the forward link of multi-beam broadband satellite systems," *in Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on* , vol., no., pp.1810-1814, 6-9 Nov. 2011

[7] Christopoulos, D., Chatzinotas, S., Zheng, G., Grotz, J., & Ottersten, B. " Linear and nonlinear techniques for multibeam joint processing in satellite communications". *EURASIP journal on wireless communications and networking*, *2012*(1), 1-13.

[8] FP7 CoRaSat," [Online]. Available: http://www.ict-corasat.eu/

[9] The ns-3 simulator, https://www.nsnam.org/

[10] The Lena project, available at: http://networks.cttc.es/mobile-networks/software- tools/lena