2nd Newsletter

The aim of the present newsletter is to provide information on the progress made in the SANSA project. SANSA is a Horizon 2020 project that aims to improve the operation of the mobile backhaul networks in order to meet the Digital Agenda 2020 for European Union growth requirements.

Overall concept

This second newsletter of the SANSA consortium provides innovative propositions and simulation results that can be useful for telecom vendors and operators towards the design and implementation of a new, flexible and efficient network combining terrestrial and satellite infrastructure for the backhauling traffic. This network improves the backhaul capacity through the use of smart antennas with beamforming capabilities that permit adapting the network topology to the traffic demands and also increasing the frequency reuse factor for a better spectrum utilization. Additionally, a novel hybrid network management has been conceived for SANSA networks in order to make the most efficient use of network resources. It is based on a centralized element, the Hybrid Network Manager (HNM) element, and on distributed elements in each network node, the Intelligent Backhauling Nodes (IBNs). The functionalities covered by these elements include: a topology manager capable of overcoming link failures and congestions through topology adaptation; a hybrid routing which balances the load through a given topology for increased throughput and latency; a traffic classification agent that permits offloading delay-tolerant traffic though the satellite links; and an energy efficiency agent capable of switching on and off small cells (OPEX reduction) while offloading traffic to macro base stations in order to minimize the energy expenditure.

Main contribution

Therefore, the contribution of SANSA is split into three main categories: **hybrid network management, network spectral efficiency and interference mitigation, and hybrid analog-digital beamforming antenna systems.**

1. *Hybrid network management*

Today, the deployment of high dense networks implies several challenges where point-to-point (PTP) and point-to-multipoint (PMP) wireless technologies will be combined forming multipoint-to-multipoint (MP2MP) wireless mesh backhauls. In this initial work produced within the SANSA project, backpressure is proposed for Multi-Radio (BP-MR). BP-MR is a distributed dynamic routing and load balancing protocol designed for MP2MP wireless mesh backhauls, where each node (e.g. IBN) may embed a different number of multi-technology wireless interfaces. It is shown that the BP-MR per-flow approach works effectively not only with UDP but also with TCP traffic, while retaining most of the proper features of the per-packet strategy.

Additionally, a distributed Q-Learning mechanism, which enables sleep mode in small cells based on their harvested energy and on the traffic demands, is proposed as a solution for reducing the power consumption of

SANSA networks. It is designed to increase the system throughput, offloading the macro BSs and decrease the drop rate at the macro BS.
Extensive simulations of all the functionalities embedded in the SANSA management architecture orchestrated in the HNM have been carried out. They included IBNs with routing, traffic classification and energy efficiency agents, the HNM with embedding topology management algorithms and HNM's interaction with the SANSA operator for the proper management of the hybrid satellite-terrestrial backhaul. Simulation results demonstrated that the seamless integration of satellite-terrestrial resources and the exploitation of the path redundancy and flexible topology offered by the hybrid backhaul outperforms fixed topologies with SoA routing approaches, such as shortest path, in terms of throughput and latency.

In particular, simulation results reveal the following remarkable achievements of a SANSA network:

- Up to 37% of energy efficiency improvement in combination with BP-based routing.
- More than 35% aggregated throughput improvement thanks to the joint backhaul resource orchestration by the HNM.
- Up to 150% latency improvement thanks to the joint intervention of the topology manager in the HNM, routing and traffic classification in the IBNs.

SANSA has provided new optimization mechanisms across the operators' value chain. The appearance of new elements, like the IBN and the HNM, as parts of the SANSA network can provide the necessary extra mile to increase the network capabilities, generate a real improvement in the network performance and availability and mainly the customer satisfaction.

The idea of the IBN and the HNM is to bring to the Network Operators the next level in network management, that especially focuses in the interactions between satellite and terrestrial networks over 5G. The HNM, that enables the interaction between the SANSA operator and the infrastructure, is implemented in a Graphic User Interface (GUI), as shown in Figure 1. This HNM GUI includes the final design and data control of the SANSA network.

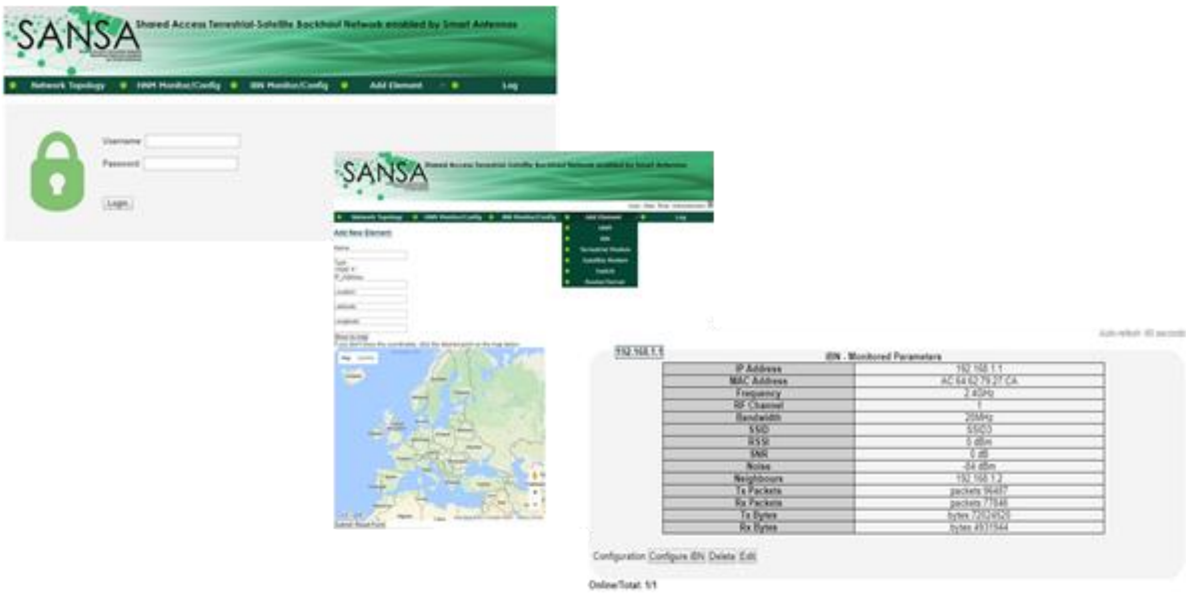

Figure 1. Hybrid Network Manager Graphic User Interface (HNM GUI)

2. Network spectral efficiency and interference mitigation

There were investigated two main technological enablers that allow efficient sharing of the spectral resources and mitigate interference over the SANSA backhaul network:

1) **Large antenna arrays**

   a. The aim was to increase the spectral efficiency (SE) of the system by allowing high frequency reuse on both satellite and terrestrial links through the use of interference mitigation and beam steering capabilities.

   b. The most promising antenna technology for the SANSA scenario was found to be the **hybrid digital-analog beamforming**.

   The simulation results for this case are shown in Table 1, where the SE gain of the proposed point-to-point hybrid analog-digital transceiver design compared to the benchmark case is illustrated. As it is evident, for 4 streams, the proposed technique achieves almost **9x more SE** than the one of the benchmark.

Table 1. Network Spectral Efficiency Gain

Streams	**1x1 Directive Benchmark**	**64x64 Hybrid Beamforming with IM**	**Gain**
1	330.8	1078.0	3.3
2	-	1752.3	5.4
4	-	2959.8	8.9

2) Smart **Radio Resource Management (RRM)**

   a. We assessed the performance and adaptation of new RRM technologies for terrestrial and satellite link scheduling, carrier allocation, power and flow control.

   b. The RRM gain arises essentially from the effort to pack a high number of backhaul links efficiently into the minimum number of carrier frequencies.

The simulation results for this case are shown in Figure 2, where the SE values for different values of carrier frequencies available are presented. The maximum SE is achieved with 3 carriers, reaching 200.28 bps/Hz. Compared to the benchmark, this translates into **2.09x gain in terms of SE.**

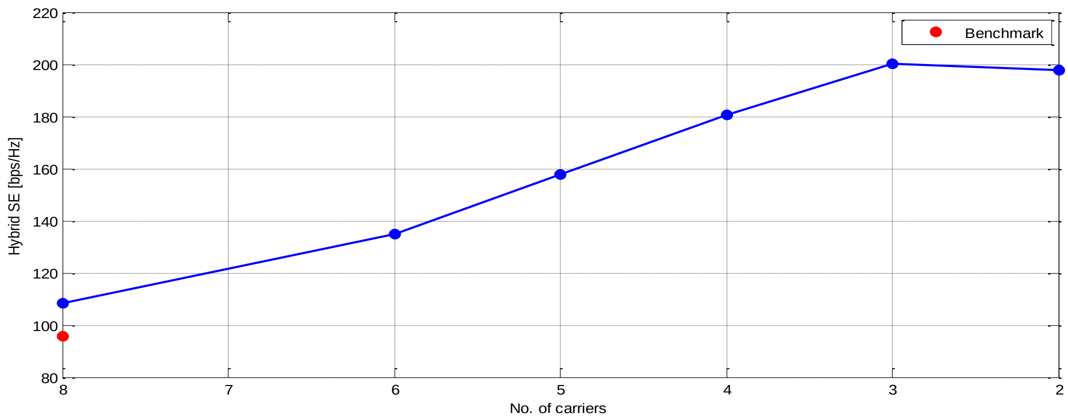

Figure 2. SE of the hybrid terrestrial-satellite network as a function of the number of carriers

It is concluded that on the one side, the implementation of RRM techniques provides limited spectral gain (approximately 2x) with relatively low cost, since it is a software-based functionality. On the other side, if the backhaul operators consider the implementation of multi-antenna technology on the backhaul nodes, then the magnitude of the benefits in terms of SE are significant. Specifically, the SE gain reaches close to 9x for multi-streaming communications in rich scattering environments, but at the expense of substantial operator expenditure in new hardware equipment (high investment cost).

Apart from the huge SE gains, having backhaul nodes equipped with antenna arrays are mandatory for the SANSA network in order to reconfigure its topology according to the traffic demands. Moreover, both technologies are key components to allow the satellite segment to be integrated in a seamless manner with the terrestrial network, and therefore, to achieve the benefits in terms of resiliency, traffic off-loading and broadcast of content.

3. Antenna array at Ka band

In this context, SANSA also demonstrated the feasibility of a hybrid analog-digital antenna array at Ka band thorough the fabrication of the proof-of-concept shown in Figure 3. Thanks to the many controls available at the array, the antenna patterns can be modified to reduce possible interference and allow spectral coexistence of satellite and terrestrial backhaul nodes. Moreover, traffic can be dynamically routed to other terrestrial nodes or towards the satellite to offload the network in case of congestion of node failure. By not employing any motor but just electronic controls, the pointing and interference reduction can be reconfigured in real time without impacting the MTBF of the terminal.

The proof-of-concept has a side-by-side partially connected configuration of 2X32 (2 digital inputs and 64 antenna groups). In other words, it is based on two subarrays of 32 antenna groups and thus, permits the independent control of two beams. Measurements demonstrated arrays gains above 30 dBi and a scanning range of +-40 degrees.


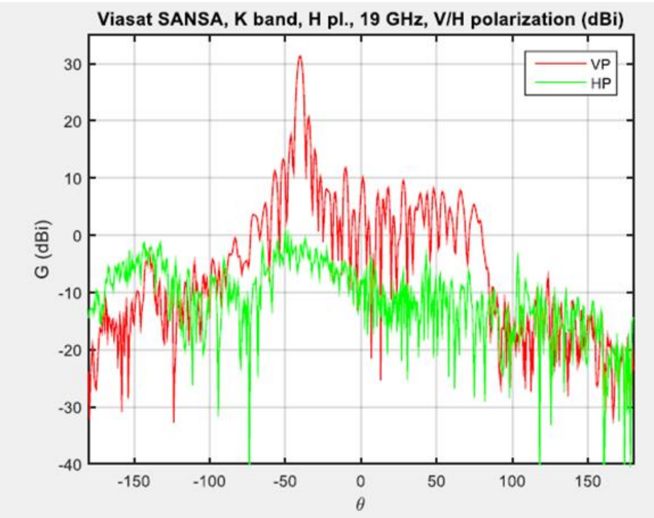

Figure 3. Ka band phased array developed during the SANSA project (left) and example of one of the measured patterns for uniform amplitude configuration and scan to 40 degrees (right).

Conclusion

In this newsletter, we have described the main outcomes of the investigated technological SANSA enablers, namely the **BP-MR routing algorithm**, the **distributed Q-Learning algorithm** for energy harvesting networks, the **RRM** and the **multi-antenna** based interference mitigation techniques, and the hybrid analog –digital antenna array.

It is shown that **energy efficiency** can be increased **by 37%**, **throughput improvements by 35%** can be achieved and **150% latency improvement** is possible. The large-antenna array that incorporates hybrid digital-analog beamforming techniques can boost the spectral efficiency **gain by 9x** in rich scattering propagation environments.

Moreover, the SANSA **end to end network management** system can be an integrated complete solution for managing and controlling the operation of the involved elements.

It is worth noting that the final newsletter will come at the end of the project in December, in which there will be a presentation of real measured data from the prototype system which is installed at Fraunhofer IIS premises in Ilmenau.