Demo:[SeBaSi] system-level Integrated Access and Backhaul simulator for self-backhauling

Amir Ashtari Gargari*, Matteo Pagin*, Andrea Ortiz†, Nairy Moghadas Gholian§, Michele Polese**, Michele Zorzi*
*Department of Information Engineering, University of Padova, Italy, {amirashtari, paginmatte, zorzi}@dei.unipd.it
†Communications Engineering Lab, TU Darmstadt, Germany, a.ortiz@nt.tu-darmstadt.de
§Wireless Communications and Sensing Lab (WISE), TU Darmstadt, Germany, ngholian@wise.tu-darmstadt.de
**Institute for the Wireless Internet of Things, Northeastern University, Boston, MA, m.polese@northeastern.edu

***Abstract*—millimeter wave (mmWave) and sub-terahertz (THz) communications have the potential of increasing mobile network throughput drastically. However, the challenging propagation conditions experienced at mmWave and beyond frequencies can potentially limit the range of the wireless link down to a few meters, compared to up to kilometers for sub-6GHz links. Thus, increasing the density of base station deployments is required to achieve sufficient coverage in the Radio Access Network (RAN). To such end, 3rd Generation Partnership Project (3GPP) introduced wireless backhauled base stations with Integrated Access and Backhaul (IAB), a key technology to achieve dense networks while preventing the need for costly fiber deployments.**

In this paper, we introduce SeBaSi, a system-level simulator for IAB networks, and demonstrate its functionality by simulating IAB deployments in Manhattan, New York City and Padova. Finally, we show how SeBaSi can represent a useful tool for the performance evaluation of self-backhauled cellular networks, thanks to its high level of network abstraction, coupled with its open and customizable design, which allows users to extend it to support novel technologies such as Reconfigurable Intelligent Surfaces (RISs).

***Index Terms*—mmWave, IAB, self-backhauling, wireless backhaul, sionna**

I. Introduction

5G mobile networks introduced the support for mmWave communications, with a further expansion towards sub-THz envisioned for 6th generation (6G) networks. This progressive shift from sub-6 GHz frequencies towards the upper portion of the spectrum represents the main technology enabler towards achieving multi-Gbps mobile throughput. Nevertheless, mmWave and sub-THz frequencies are affected by high propagation and penetration losses, as well as by a marked susceptibility to blockage, which degrade the reliability and capacity of wireless networks operating in this portion of the spectrum [1], [2]. To mitigate these unfavorable propagation characteristics, it is paramount to maximize the Line-of-Sight (LOS) coverage, and to increase the density of base station deployments with respect to traditional sub-6 GHz cellular networks. In turn, to make ultra-dense deployments a viable option from both a logistic and an economic standpoint, the 3GPP has standardized an extension of 5th generation (5G) NR known as IAB [3], [4]. The latter leverages the Distributed Unit (DU)/Central Unit (CU) split to introduce Next Generation Node Bases (gNBs) with wireless backhauling capabilities, i.e., IAB nodes, thus reducing the need for fiber drops. The IAB nodes eventually terminate the various 5G NR interfaces at a gNB connected by fiber to the Core Network (CN) and the Internet, i.e., the IAB donor.

In this context, the research community has been studying how to optimize radio resource allocation, scheduling, route selection, topology construction, and deployment planning [5], [6]. Given the lack of access to actual 5G (and beyond) network deployments, previous research efforts relied heavily on homegrown physical layer simulators to evaluation performance [7]. However, these simulators usually feature a heavily simplified model of actual IAB deployments, since they introduce strong assumptions in the upper layers of the protocol stack. Therefore, they are incapable of capturing the real network dynamics. Similarly, existing system-level simulators are outdated, and thus also fail to properly model a Rel. 17 IAB network [8]. Moreover, an experimental evaluation is prohibitive since researchers usually do not have access to commercial deployments at scale. To fill this gap, we introduce SeBaSi, an IAB simulator which accurately models large-scale wireless backhauled deployments. In this demo, we describe SeBaSi, and showcase examples of different IAB cellular networks, for which we report system-level Key Performance Indicators (KPIs).

This paper is organized as follows. In Sec. II, we describe the system model. Then, we introduce the proposed system-level simulator in Sec. III, and describe the contents of the demo in Sec. IV. Finally, we discuss possible future extension of our simulator in Sec. V.

II. System Model

In this work, we consider a Time Division Multiple Access (TDMA) cellular system where both self-backhauled and wired base stations exchange data with the User Equipments (UEs). In accordance with 3GPP terminology, we refer to the former base stations as IAB-nodes (BS-nodes) and to the latter as IAB-donors (BS-donors). The IAB-nodes exchange data with the CN and the Internet via a wireless multi-hop connection to an IAB-donor.

We assume that the IAB-nodes incorporate two Radio Frequency (RF) chains. One RF chain is reserved for commu-

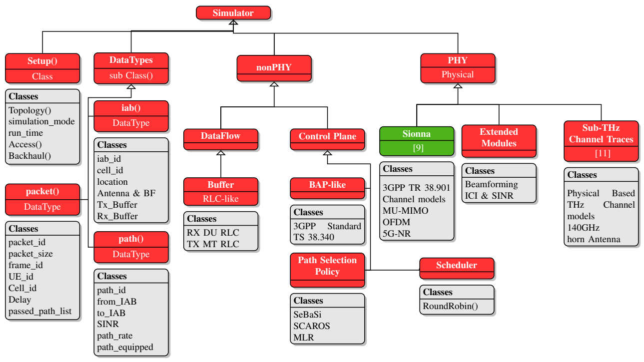


Fig. 1: Overall design of SeBaSi. The red blocks represent our additions to the baseline simulator, i.e., Sionna [9].

nication with cellular users (access network), while the other is utilized for self-backhauling. In line with the 3GPP standard [4], we assume half-duplex and in band self-backhauling, such that in each time slot the IAB-nodes can either transmit, receive, or remain idle. Without loss of generality, in this analysis, we focus on uplink traffic only.

III. SeBaSi

SeBaSi is a Python system-level simulator, built on top of the open-source 5G and 6G physical layer simulator Sionna™ [9], which models 3GPP Rel. 17 IAB cellular networks. To introduce self-backhauling functionalities in Sionna, we have implemented a number of system-level features. These extensions, which we describe more in detail in [10], comprise a Medium Access Control (MAC)-level scheduler, layer-2 buffers and backhaul path selection algorithms. Moreover, to better align Sionna's physical layer to that of 5G-NR, we also implemented 5G-NR procedures such as codebook-based beamforming and Signal to Interference plus Noise Ratio (SINR) computation. Additionally, in [11] we further extend our simulator to support sub-THz links in the backhaul, with the goal of providing a performance evaluation of the potential of sub-THz frequencies for 6G IAB.

Fig. 1 depicts the general structure of SeBaSi. For the mmWave channel, we rely on the 3GPP TR. 38.901 channel model provided by Sionna. Additionally, we model sub-THz channels using Network Simulator 3 (ns-3) Terasim [12], and produce traces which are imported into our simulator. For the upper layers, we introduce the Backhaul Adaptation Protocol (BAP) layer, to handle routing within the wireless backhaul network [13], a MAC-level scheduler that operates in a TDMA fashion, and hop-by-hop Radio Link Control (RLC) channels for modeling layer-2 buffering and data transmission.

SeBaSi, which we make publicly available[1], allows users to configure most simulation parameters, such as the simulation's runtime and mode, the packet size, and the source rate (either per UE or system-wise). The considered simulation modes are *run* mode and *debug* mode, with the latter providing additional control signals and related information. Moreover, users can customize the scenario by choosing the number and location of UEs and base stations, and the IAB topology, i.e., the wireless backhaul links among gNBs. For the backhaul scheduler, i.e., the entity which dictates which backhaul links to schedule during each time slot, users can either define custom policies, or choose among: SCAROS [7], MLR [14], Safehaul [10], and SINR-based [11]. In addition, the links can be configured to operate either at mmWave, sub-THz, or a combination of the two frequencies.

The simulator outputs an extensive set of system-level KPIs, such as end-to-end latency, throughput, and packet drop rate. Each of these metrics can be displayed per IAB node, or for the entire network. In addition, we also make available internal and/or lower layer metrics such as the generation and arrival time of each packet, destination UE, and its backhaul path. Furthermore, we report the load on each IAB node per each time step and for both the access and backhaul interfaces.

IV. Demo Description

In this demonstration, we simulate in SeBaSi two cellular deployments whose topologies mimic those of the cities of New York and Padova, respectively. To such end, we gathered 4th generation (4G) evolved Node Base (eNB) locations from the actual deployments of three mobile network operators, and considered them as either 5G IAB nodes or donors.

The overall objective of the demo is to provide examples of how to interact with SeBaSi, with different IAB deployments, and how to tune simulation parameters such as the system source rate and the frequency spectrum, by either defining new scenarios or by using the built-in examples of SeBaSi. Moreover, we provide examples of SeBaSi's output traces by displaying in real-time KPI metrics and network routing information, such as the one depicted in Fig. 2.

Specifically, we first demonstrate how to work with SeBaSi by instantiating the Manhattan, New York example. Then, we instantiate the Padova, Italy topology, and we demonstrate the performance of the backhaul scheduler Safehaul [10] in both scenarios. Safehaul is a risk-averse Reinforcement Learning (RL) solution to ensure reliability in IAB mmWave networks.

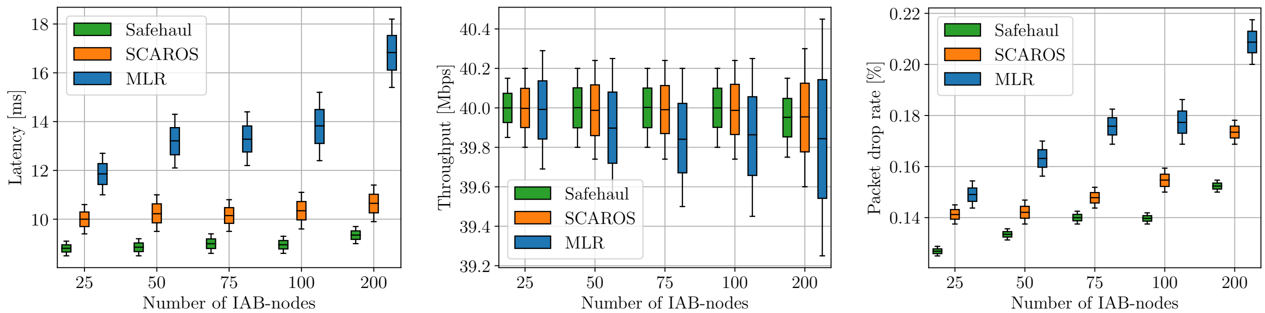
We conclude the demonstration by discussing future extensions and test-case scenarios.

V. Future work

The deployment of IABs is becoming increasingly important for seamless connectivity at mmWave frequencies as the number of UEs and their anticipated Quality of Service (QoS) grows. The operational cost for adding more IABs to meet the network's increased demand is high. Adding more of them to mitigate this issue is therefore not always possible.

A more cost-effective solution is to use RISs. RISs are energy-efficient smart surfaces that can change the direction of the impinging signal to the desired locations. The propagation characteristics may be enhanced in significant ways thanks to RISs [15]. That's because mmWave frequencies have high propagation along penetration loss, which increases with

[1] https://github.com/TUDA-wise/safehaul_infocom2023



(a) Per-UE end-to-end latency (b) Per-UE throughput (c) Per-UE packet drop rate

Fig. 2: Example of network KPIs which can be obtained from SeBaSi, for $\{25, 50, 75, 100, 200\}$ IAB-nodes and 40 Mbps per-UE source rate [10]

blockages, especially in urban scenarios. Using RISs to their full extent can thus greatly avoid this problem.

Yet, the coexistence of IABs and RISs presents particular challenges. The coordination between the RIS phase shifters along with the setting of IABs would require solving complex joint optimization problems. Also, the placement of RISs along IABs in a network would require more information on the UEs location. Moreover, RISs can interfere with other components of a cellular network, therefore, it's essential to carefully manage them such that the interference is avoided. Because of the aforementioned factors, system-level simulation is required to verify RIS's potential in actual situations. Both IAB and RIS serve as relays to increase the range of communication; IAB is active, whereas RIS is passive. Both of them function as relay elements from a software perspective, but channel modeling and beamforming in RIS are difficult [16]. We will attempt to integrate RIS into SeBaSi using the new raytracing feature of Sionna. In summary, extending SeBaSi to RIS-assisted scenarios will open a new direction in the future of mmWave networks, however, several obstacles have to be addressed in order to fully exploit its potential.

VI. Conclusion

We have described and showcased SeBaSi a system level IAB simulator and an example of self-backhauling in Manhattan, New York City. In the demonstration, we have used Safehaul [10] self-backhauling scheduler in SeBaSi to evaluate the IAB network based on KPI. Thanks to the open-source development of the tool, researchers can utilize new scenarios or extend the simulator to support novel technologies such as RIS.

Acknowledgment

This paper is partially supported by EU H2020 MSCA ITN project MINTS (grant no. 861222), the Collaborative Research Center 1053 MAKI and the BMBF project Open6GHub (Nr. 16KISK014).

References

[1] M. Polese, J. M. Jornet, T. Melodia, and M. Zorzi, "Toward end-to-end, full-stack 6G terahertz networks," *IEEE Communications Magazine*, vol. 58, no. 11, pp. 48–54, Nov. 2020.

[2] A. A. Gargari, M. Polese, and M. Zorzi, "Full-stack comparison of channel models for networks above 100 GHz in an indoor scenario," in *Proceedings of the 5th ACM Workshop on Millimeter-Wave and Terahertz Networks and Sensing Systems*, Oct. 2021, pp. 43–48.

[3] 3GPP, "NR; Overall description; Stage-2," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 38.300, Jun. 2019, version 15.6.0.

[4] ——, "NR; Integrated Access and Backhaul (IAB) radio transmission and reception," Technical Specification (TS) 38.174, Jun. 2020, v0.1.0.

[5] G. Kwon and H. Park, "Joint user association and beamforming design for millimeter wave udn with wireless backhaul," *IEEE Journal on Selected Areas in Communications*, vol. 37, no. 12, pp. 2653–2668, Oct. 2019.

[6] A. Pizzo and L. Sanguinetti, "Optimal design of energy-efficient millimeter wave hybrid transceivers for wireless backhaul," in *2017 15th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt)*. IEEE, May 2017, pp. 1–8.

[7] A. Ortiz, A. Asadi, G. H. Sim, D. Steinmetzer, and M. Hollick, "SCAROS: A scalable and robust self-backhauling solution for highly dynamic millimeter-wave networks," *IEEE Journal on Selected Areas in Communications*, vol. 37, no. 12, pp. 2685–2698, Oct. 2019.

[8] M. Polese, M. Giordani, A. Roy, S. Goyal, D. Castor, and M. Zorzi, "End-to-end simulation of integrated access and backhaul at mmwaves," in *23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*. IEEE, Sep. 2018, pp. 1–7.

[9] J. Hoydis, S. Cammerer, F. A. Aoudia, A. Vem, N. Binder, G. Marcus, and A. Keller, "Sionna: An open-source library for next-generation physical layer research," *arXiv preprint arXiv:2203.11854*, 2022.

[10] A. Ashtari Gargari, A. Ortiz, M. Pagin, A. Klein, M. Hollick, M. Zorzi, and A. Asadi, "Safehaul: Risk-averse learning for reliable mmWave self-backhauling in 6G networks," in *IEEE Conference on Computer Communications (INFOCOM)*, New York, USA, 2023.

[11] A. A. Gargari, M. Pagin, M. Polese, and M. Zorzi, "6G Integrated Access and Backhaul networks with sub-terahertz links," in *18th Wireless On-Demand Network Systems and Services Conference (WONS)*, 2023, pp. 13–19.

[12] Z. Hossain, Q. Xia, and J. M. Jornet, "Terasim: An ns-3 extension to simulate Terahertz-band communication networks," *Nano Communication Networks*, vol. 17, pp. 36–44, Sep. 2018.

[13] 3GPP, "NR; Backhaul Adaptation Protocol (BAP) specification," Technical Specification (TS) 38.340, May 2022, v.17.0.0.

[14] M. Pagin, T. Zugno, M. Polese, and M. Zorzi, "Resource management for 5G NR integrated access and backhaul: A semi-centralized approach," *IEEE Transactions on Wireless Communications*, vol. 21, no. 2, pp. 753–767, Jul. 2022.

[15] G. C. Trichopoulos, P. Theofanopoulos, B. Kashyap, A. Shekhawat, A. Modi, T. Osman, S. Kumar, A. Sengar, A. Chang, and A. Alkhateeb, "Design and evaluation of reconfigurable intelligent surfaces in real-world environment," *IEEE Open Journal of the Communications Society*, vol. 3, pp. 462–474, Mar. 2022.

[16] S. Noh, J. Lee, G. Lee, K. Seo, Y. Sung, and H. Yu, "Channel estimation techniques for ris-assisted communication: Millimeter-wave and sub-thz systems," *IEEE Vehicular Technology Magazine*, vol. 17, no. 2, pp. 64–73, Apr. 2022.