End-to-End Simulation of Integrated Access and Backhaul at mmWaves

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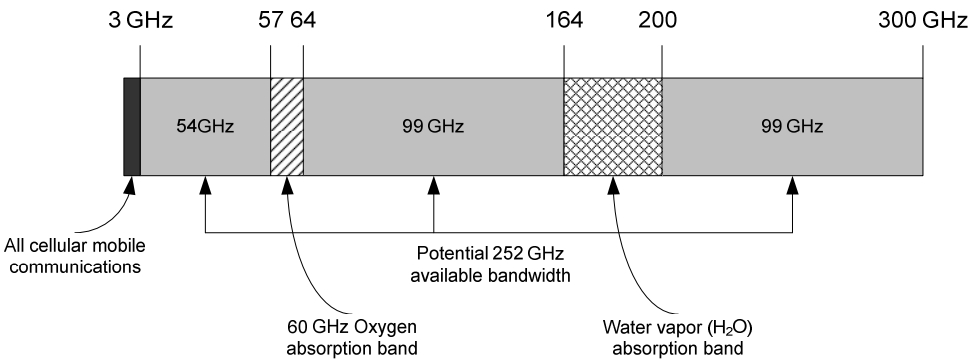
Outline

- Integrated Access and Backhaul in 3GPP NR
  - Motivation
  - Study Item
- IAB implementation in ns-3 mmWave
  - IAB node
  - Control procedures
  - Dynamic scheduler
- Results
- Conclusions

3GPP NR: mmWaves in cellular networks

3GPP NR Rel. 15 will support frequencies up to 52.6 GHz

- Potentials
  - Bandwidth
  - Large arrays in small space

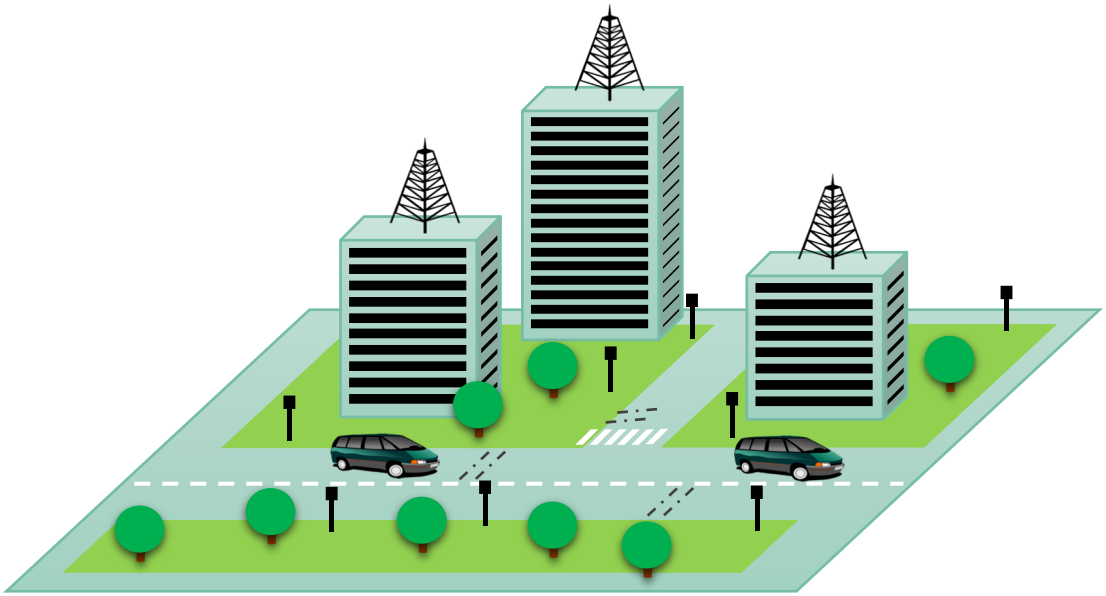


Z. Pi and F. Khan, "An introduction to millimeter-wave mobile broadband systems," in *IEEE Communications Magazine*, vol. 49, no. 6, pp. 101-107, June 2011.

- Challenges
  - High **propagation** loss
  - Directionality
  - **Blockage**

Backhaul for mmWave Deployments

High propagation loss + blockage → High deployment density



? How is it possible to provide high-capacity backhaul in such a dense scenario?

Integrated Access and Backhaul

3GPP Study Item for Release 16

- Goals:
  - Provide **backhaul** in dense deployments without densifying the transport network
  - Support in-band and out-of-band backhauling
  - IAB nodes should be **transparent** to UEs (no difference for the handset)
  - Support **multiple hops**
  - Perform **self**-adaptation of topology
  - **Reuse** Rel.15 NR specifications

3GPP, “Study on Integrated Access and Backhaul”, TR 38.874 – V0.4.0 Rel. 15

Integrated Access and Backhaul

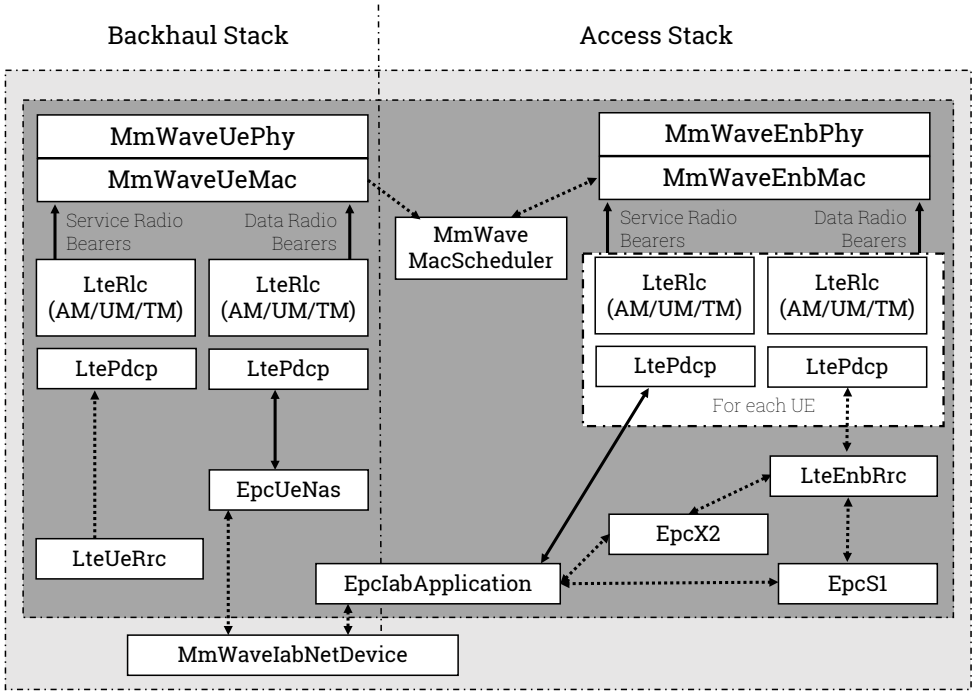
- Opportunities
  - mmWave: high bandwidth for backhaul + spatial reuse
  - In-band backhaul -> no need for multiple frequency licenses
  - Plug-and-play design – self-configuration of IAB nodes
- Challenges
  - Scalability
  - Efficient scheduling
  - Analyze cross-layer interactions

Our contributions:

- Extend ns-3 mmWave with IAB functionalities
- Evaluate end-to-end performance of IAB

IAB implementation in ns-3

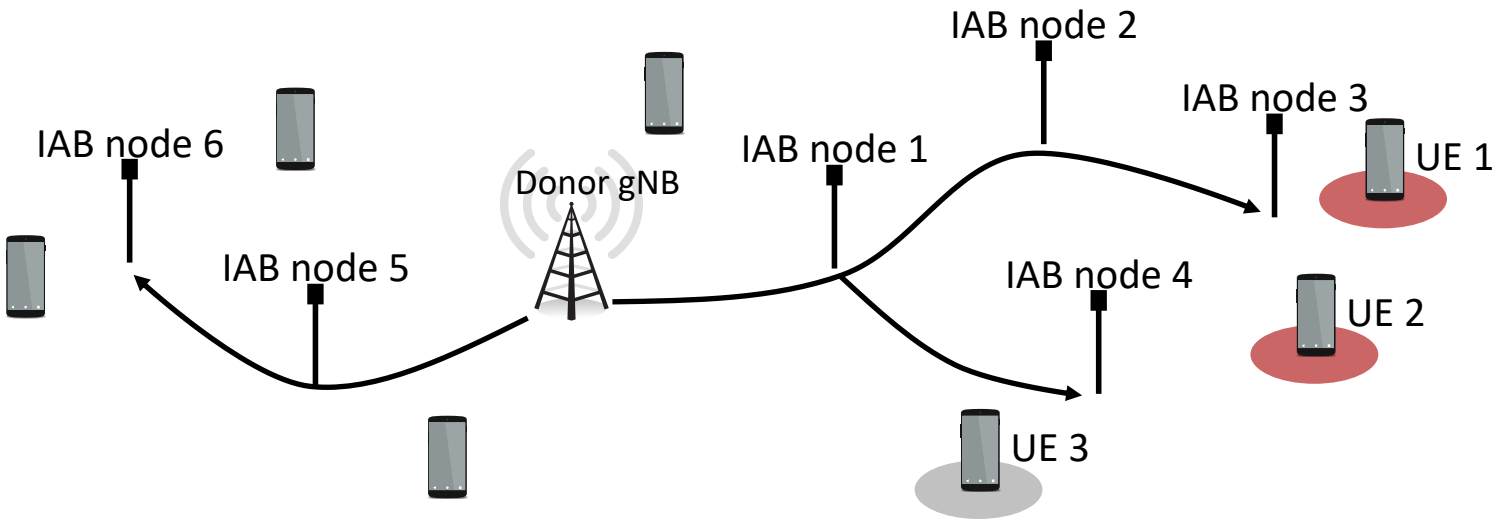
- Implement an **IAB protocol stack in ns-3**
  - New NetDevice
  - New overlay class to handle wireless backhaul
  - Similar to 3GPP proposed architecture 2b [1]
  - Work in progress: track 3GPP SI to match functionalities



[1] 3GPP, "Study on Integrated Access and Backhaul", TR 38.874 – V0.4.0 Rel. 15

Single- and multi-hop support

- Realistic control plane operations
  - Control plane for IAB nodes on wireless links
  - GTP tunnels for forwarding of control-plane-related packets
  - Autonomous access and configuration procedures
  - Routing

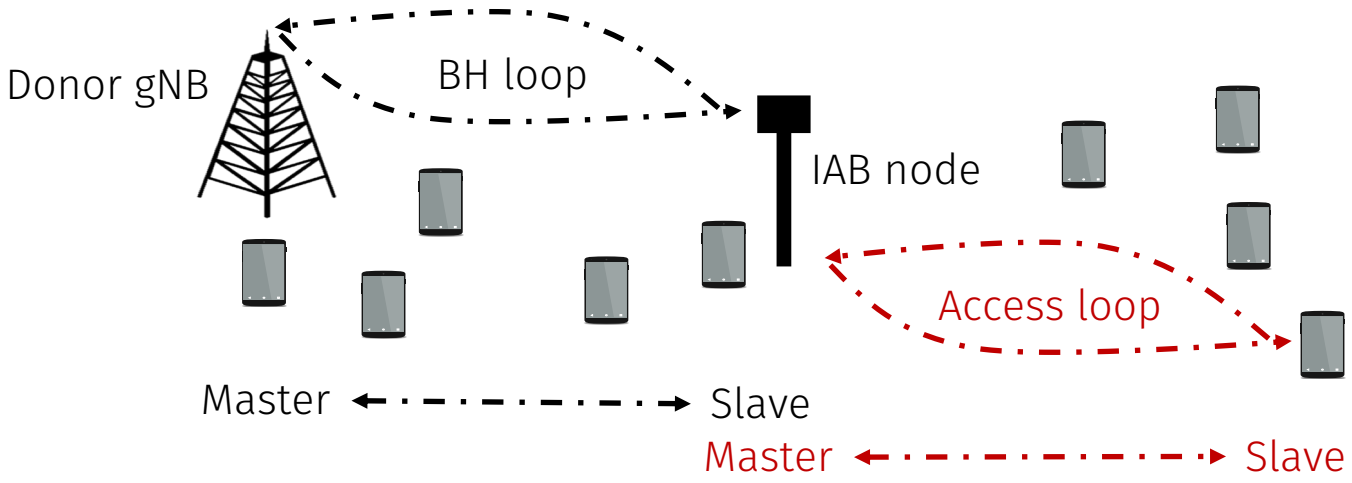


IAB Scheduler

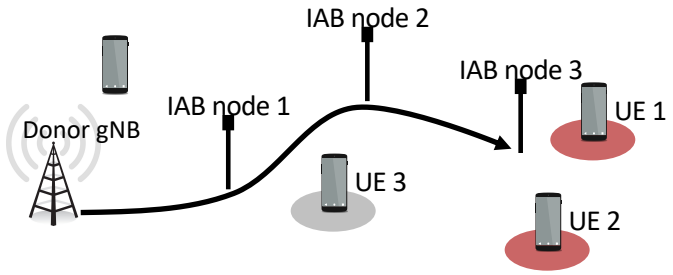
- Scheduler is *not* specified by 3GPP – room for **innovation**
- **Dynamic** scheduling: update according to traffic demand
  - In LTE, the backhaul/access partition is fixed
- Spanning tree topology
  - Scheduled access – different from WiFi mesh
  - We focus on in-band backhaul with a TDD PHY/MAC
  - Currently, we implemented TDMA multiplexing
  - Future work: exploit mmWave spatial multiplexing

Look-ahead Backhaul-aware Scheduler

- **Independent schedulers** in each node
- Backhaul aware:
  - The scheduler in the IAB **access** is **aware** of the scheduling for the **backhaul** -> mark the resources as busy
- Look-ahead:
  - Each IAB node must know in advance the scheduling of its parent
  - Dynamic: update the look-ahead according to the depth of the tree



Example



Time instant at which the scheduling decision is taken at the Donor gNB

Donor gNB	CTRL res	IAB 1	IAB 1	IAB 1	IAB 5	IAB 5	UE data	UE data	UE data	CTRL res
IAB 1	CTRL res	Reserved for BH			IAB 2	IAB 2	IAB 2	UE data	UE data	CTRL res
IAB 2	CTRL res	IAB 3	IAB 3	UE data	Reserved for BH			UE data	UE data	CTRL res
IAB 3	CTRL res	Reserved for BH		UE data	UE data	UE data	UE data	UE data	UE data	CTRL res

t = T - 4

t = T - 3

Lookahead of the node

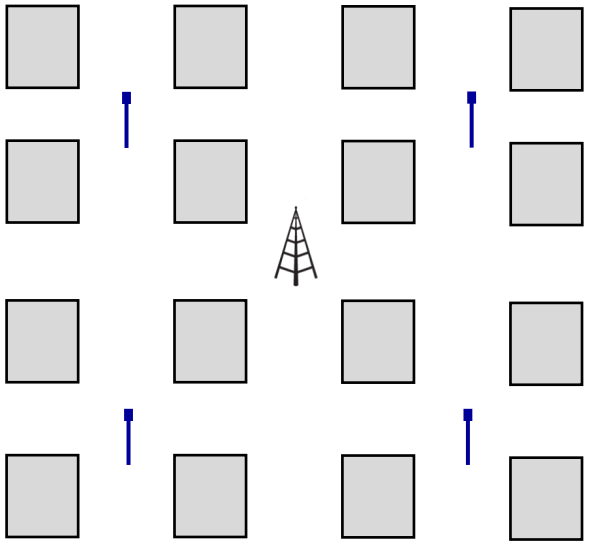
t = T - 2

t = T - 1

- Scheduling decisions for slot T
  - Assuming a delay of 1 slot for the transmission of the scheduling decision from the parent to its children

IAB Performance in grid scenario

- Preliminary evaluation: simple outdoor scenario

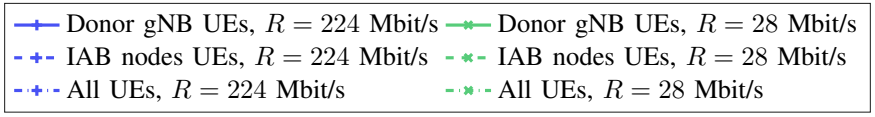


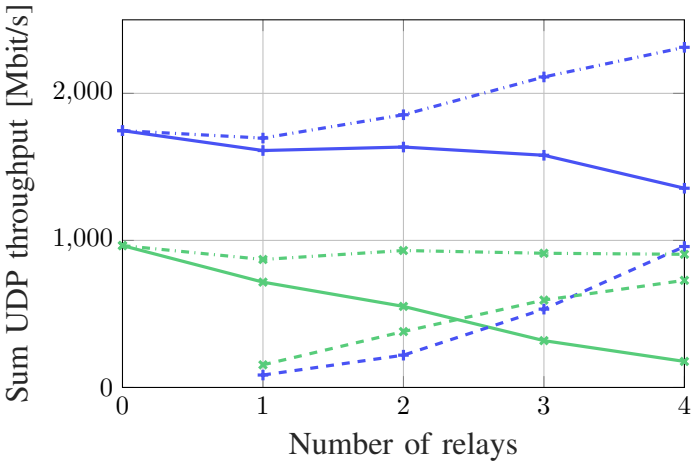
Parameter	Value
mmWave carrier frequency	28 GHz
mmWave bandwidth	1 GHz
3GPP Channel Scenario	Urban Micro
mmWave max PHY rate	3.2 Gbit/s
MAC scheduler	Round Robin
Subframe duration	1 ms
Donor gNB to remote server latency	11 ms
RLC buffer size B_{RLC} for UEs	10 MB
RLC buffer size B_{RLC} for IAB nodes	40 MB
RLC AM reordering timer	2 ms
UDP rate R	$\{28, 224\}$ Mbit/s
UDP packet size	1400 byte
Number of independent simulation runs	50

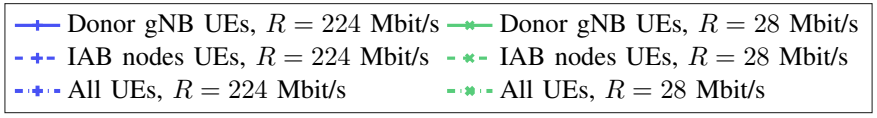
TABLE I: Simulation parameters

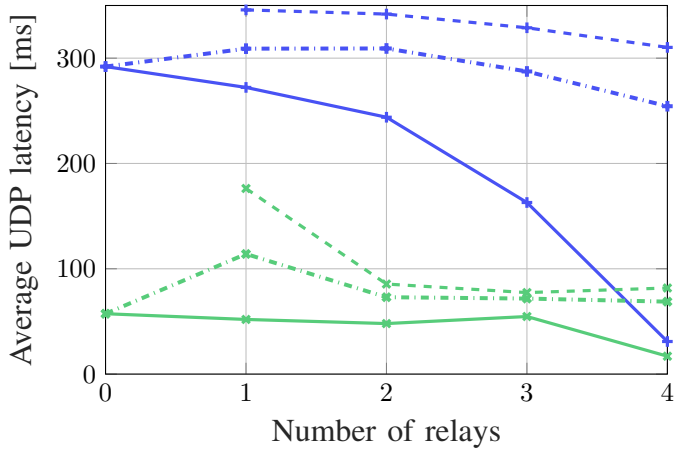
- From 0 to 4 IAB nodes
- 40 users randomly placed **outdoor**
- 3GPP channel model
- UDP traffic at rate $R \in \{28, 224\}$ Mbit/s per UE

End-to-end Performance for IAB









- Main findings:
  - For high source rate, the relays improve the UDP throughput by improving the link quality for **cell-edge users**
  - Offload the wired base station of cell-edge users -> **lower latency** for its UEs

Performance Evaluation

Main takeaways on IAB

- IAB can provide an alternative to fiber for initial ultra-dense NR deployments
- We provide a tool for **end-to-end performance** evaluation
- Key design parameters for improved end-to-end performance:
  - Scheduler
  - Multi-hop attachment strategies
  - Spatial multiplexing (to be investigated)

M. Polese, M. Giordani, A. Roy, D. Castor, M. Zorzi, "**Distributed Path Selection Strategies for Integrated Access and Backhaul at mmWaves**", *IEEE GLOBECOM*, 2018.
M. Polese, M. Giordani, A. Roy, S. Goyal, D. Castor, M. Zorzi, "**End-to-End Simulation of Integrated Access and Backhaul at mmWaves**", *IEEE CAMAD*, 2018.
https://github.com/signetlabdei/ns3-mmwave-iab

More info: mmwave.dei.unipd.it

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