3GPP TSG-RAN Meeting # 102
Edinburgh, UK, December 11 – 15, 2023

RP-233272
Agenda Item 9.1.1.9

Rel-19 Additional RAN1 Topics

Multi-Carrier Enhancements
Study on UE-side SBFD for latency-sensitive eMBB
Device-collaborative MIMO

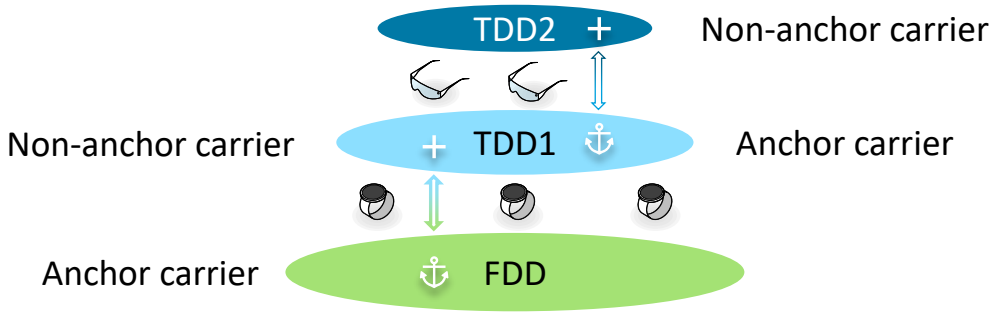
MediaTek Inc.

Multi-Carrier Enhancements

Motivation/Proposal – Agile Carrier Switching

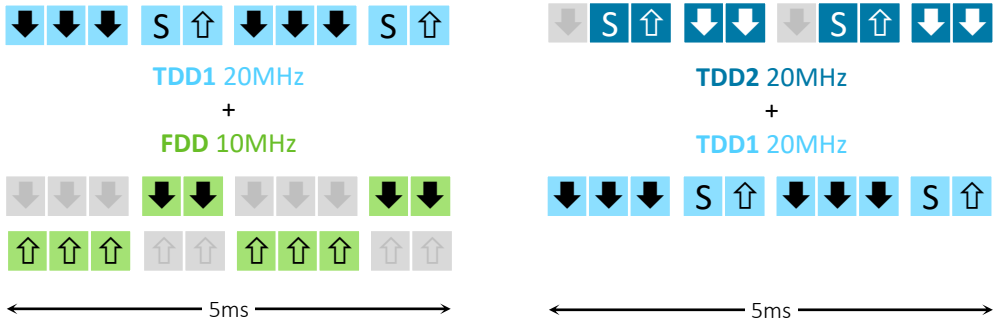
Improved performance with same UE complexity envelope

- Example: RedCap UE (no CA capability):
  - <20MHz in many FDD bands and no simultaneous DL + UL in TDD bands
  - UE cannot make full use of its simultaneous 20 MHz DL + UL capability



- Agile carrier switching allows RedCap UE to do the following (while maintaining UE complexity envelope)
  - Switch UE DL or UL to non-anchor band to allow **simultaneous cross-band UL and DL operation**
  - **More effectively utilize resources across two carriers** for UE performance

  Semi-statically preconfigured switching pattern to minimize interruption, but **L1 trigger can also help for more flexibility** in terms of switching instance



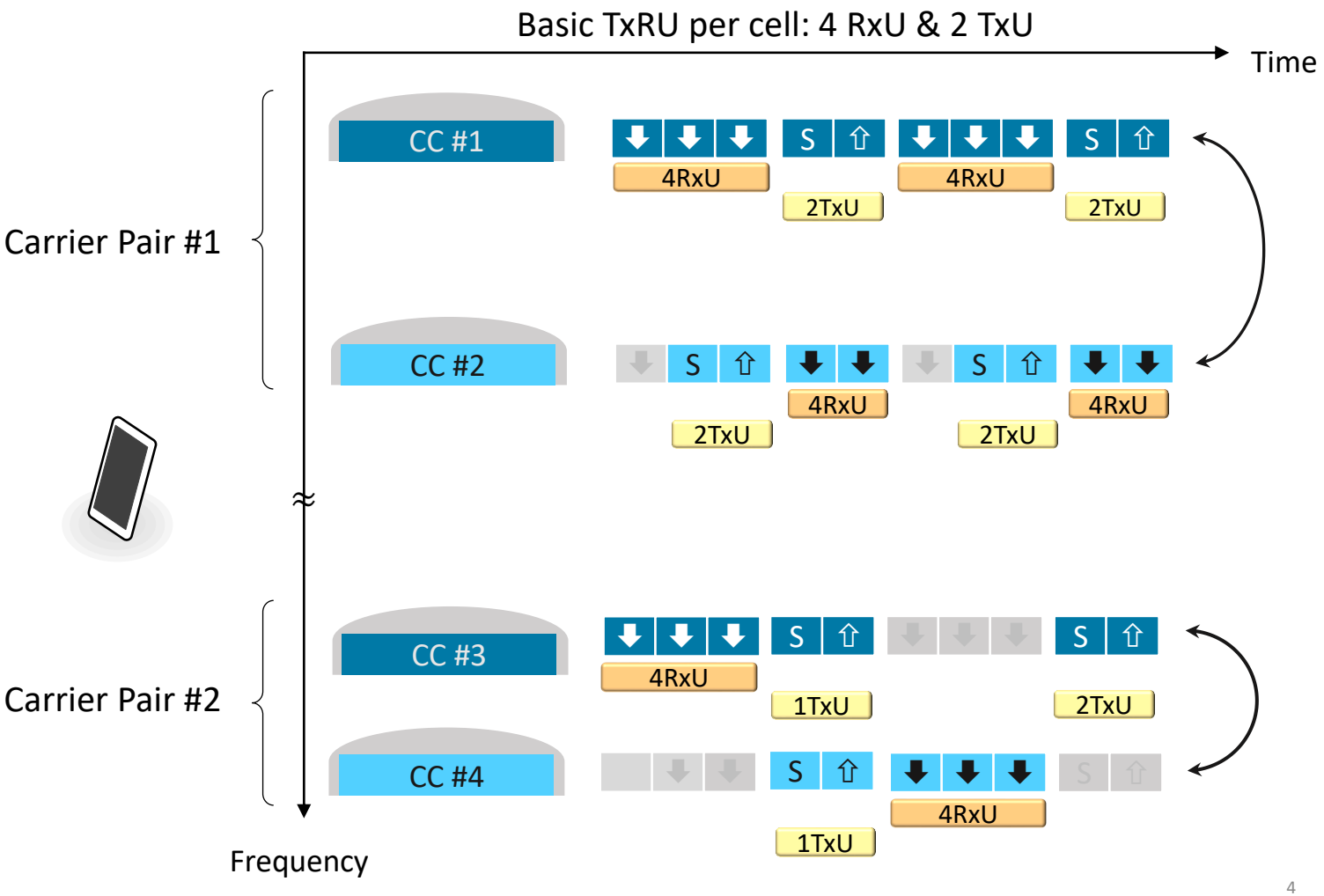
DL: 162.42Mbps (+19%)
UL: 48.41Mbps (+33%)
Fast switch: 210µs gap feasible

DL: 188.74Mbps (+38%)
UL: 57.51Mbps (+58%)
Fast switch: 210µs gap feasible

Agile Carrier Switching

Generalization to non-RedCap scenario

- **Agile carrier switching** in previous slides can be **generalized from RedCap to normal UE framework**
- **Semi-static** carrier switching by **pre-configuration**
- **No cross-pair carrier switching**



Agile Carrier Switching
Envisaged specification impact

- Baseline considerations
  - We propose to focus on the scenario where carriers of a carrier pair are co-located (single TAG)
  - Maximize the reuse of legacy UE specified behaviour for UL inter-band switching as a basis for extension to DL and UL switching
- RAN1 impacts:
  - Clarify PDCCH monitoring behaviour
  - Define whether a UE needs to maintain timing synchronization, RLM/RRM, CSI acquisition & (UL power control) over inactive DL (or UL) carrier while the UE is active on another DL (or UL) carrier
  - Define UE behaviour based on semi-static pre-configured carrier switching pattern
  - Additional L1 signaling indicating carrier switch (if dynamic switching is also considered)
  - As a second priority consider supporting HARQ cross-carrier retransmission
- RAN2 impacts: RRC signalling impacts to support carrier switch
- RAN4 impacts: Carrier switch gap and Band Pair combinations definition

Agile Carrier Switching

Benefits: User Throughput, Network Energy Saving (NES)

- Improve RedCap DL performance
  - By overcoming inherent limitations in available spectrum resources to serve the UE
  - Simulation shows 32.7% UPT gain with only 2.4% NES penalty for FTP traffic at medium load (30% ≤ RU ≤ 50%)

UPT and NES results		
	Baseline*	Agile Carrier Switch
Ave. UPT (Mbps)	45.5	60.4
UPT gain (%)	0%	**32.7%**
Ave. BS power**	214.6	219.8
NES gain %	0%	**-2.4%**

- Throughput gain can also be traded for NES gains
  - For example, NES spatial adaptation (SD) reduces number active antennas to achieve NES gain, but has 20.5% UPT penalty without agile carrier switching
  - Utilizing agile carrier switching can minimize this UE UPT impact while still enabling substantial NES gains vs Baseline
    - Simulation shows 33.5% NES gain with 3.8% UPT penalty based on both NES SD and agile carrier switching

UPT and NES results (adding NES spatial adaptation (SD))		
	NES SD (64 → 16 ports)	NES SD & Agile Carrier Switch
Ave. UPT (Mbps)	36.3	43.8
UPT gain (%)	**-20.5%**	**-3.8%**
Ave. BS power**	124.1	142.5
NES gain %	**42.2%**	**33.5%**

* 2 TDD carriers with patterns DDDUU and DDUUU and 30% RU

** 3GPP unit based on BS power consumption model in TS 38.864

Proposal

SA/CT Dependency: No

Enable cross-band switching/operation to allow non-/low-CA capable UE (such as RedCap UE) to maximise usage of its simultaneous UL and DL capabilities and available spectrum to benefit user experience

Objective I: Enable inter-band carrier switch operation (including DL and UL operating on alternate bands simultaneously) with up to two carriers in a carrier pair [RAN1, RAN2, RAN4]

- Specify the following physical layer procedures (RAN1)
  - Clarify PDCCH monitoring behaviour
  - Define whether a UE needs to maintain timing synchronization, RLM/RRM, CSI acquisition & (UL power control) over inactive DL (or UL) carrier while the UE is active on another DL (or UL) carrier in a Carrier Pair
  - Define UE behavior based on semi-static pre-configured carrier switching pattern
  - Additional L1 signaling indicating carrier switch (if dynamic switching is also considered)
  - As a <u>second</u> priority consider supporting HARQ cross-carrier retransmission

- Specify RRC signaling impacts to support carrier switch (RAN2)

- Specify band combination and switch gap for carrier switch [RAN4]

Note 1: Maximize the reuse of legacy UE behaviour for UL inter-band switching
Note 2: Focus on co-located carriers in a carrier pair (single TAG)

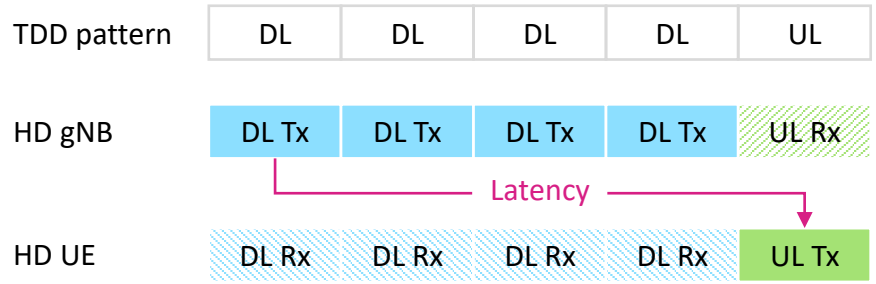
Study on UE-side SBFD for Latency-sensitive eMBB

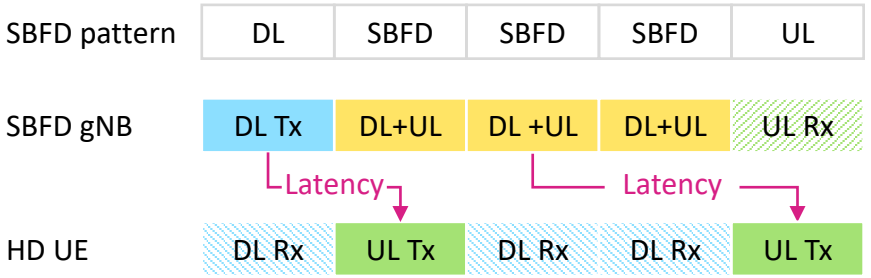
gNB-SBFD Study Item
Status update

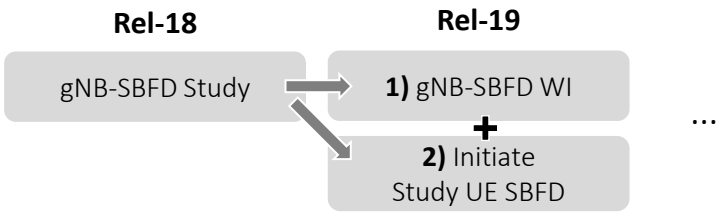
- RAN1 concluded their part of the study on gNB SBFD scheme, covering
  - Performance evaluation using SLS for different deployments (Indoor, Dense Urban & Urban Macro) for single-operator case and adjacent-channel coexistence (two operators)
  - Link-level evaluation for the possible coverage gain
- Main observations from RAN1 SI
  - gNB-SBFD provides UL throughput gain: mainly in Indoor and Dense Urban deployments
  - Negative impact of inter-UE and inter-gNB CLIs on the system performance
    - ~14% degradation in DL spectral efficiency due to inter-UE CLI
    - Any future WI on SBFD operation should prioritize handling inter-UE and inter-gNB CLIs
- RAN4 completed its study with the following main observations:
  - gNB-SBFD feasibility: Controlling self-interference to meet the 1dB receiver desensitization target is more feasible in medium range and local area gNBs
  - Reusing existing UE RF requirements is the conclusion of the study phase

UE-SBFD Study
Motivation

- **TDD** bands offer large bandwidth. However, fixed TDD UL/DL patterns result in **increased latency**, and **limited capacity and coverage**
  - This negatively impacts system capacity for latency-sensitive services
- **gNB-SBFD** full duplex alleviates the issue to <u>some</u> extent
  - However, **UE HD operation remains the latency bottleneck** due to non-simultaneous UL/DL UE operation
- **UE-SBFD would fully address these issues and:**
  - Enable FDD-like low-latency in TDD bands, to improve capacity for latency-sensitive services, particularly important for the success of XR

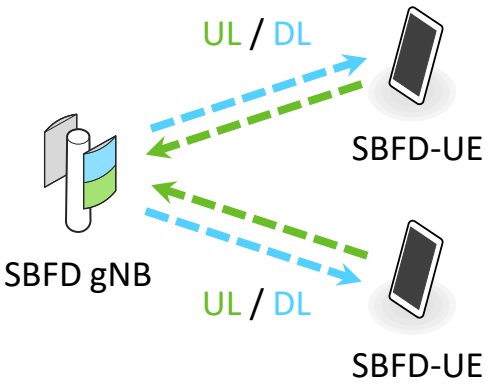


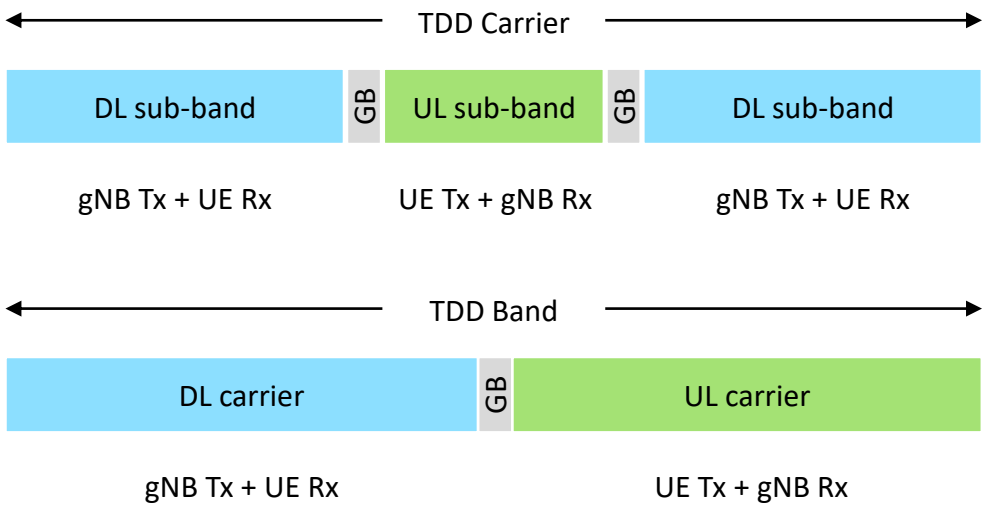




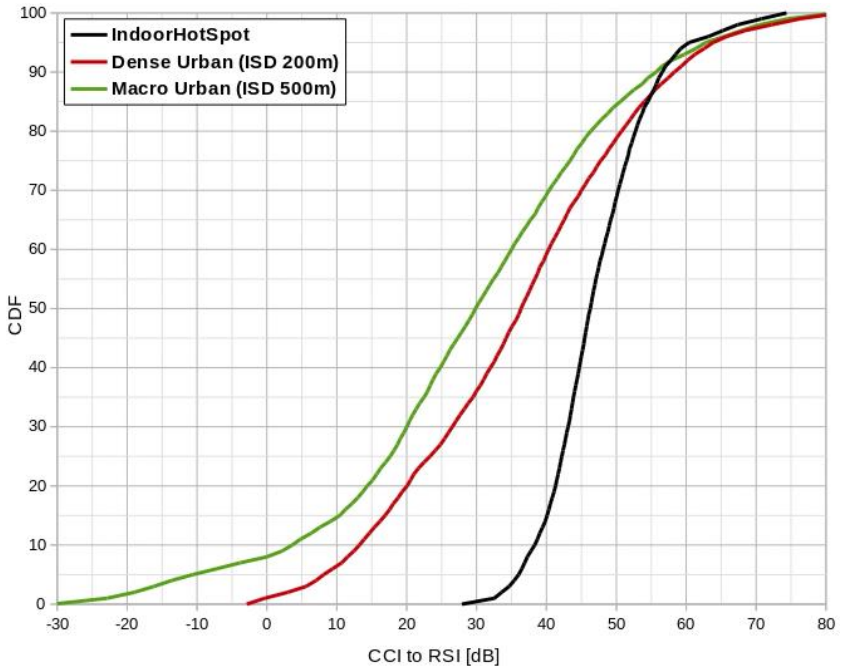
Proposal
Study full-duplex operation at UE

- Study full-duplex operation at UE
  - Non-overlapped simultaneous transmission and reception
  - Within a carrier or across different carriers (in intra-band CA)
- Investigate aspects to allow constraining UE complexity, such as
  - Level of frequency separation (if needed) between Rx and Tx sub-bands
  - Opportunistic operating conditions (e.g., UE Tx power level, inter-cell-interference level, UE Tx allocation, etc.)
  - Different device types
- Long-term objective: A feasibility study in R19 to provide a good foundation for the 6G study in R20.

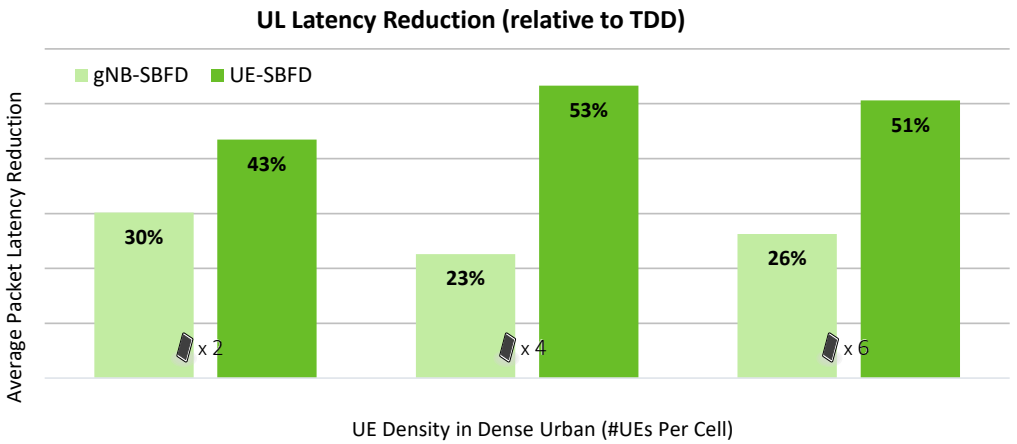


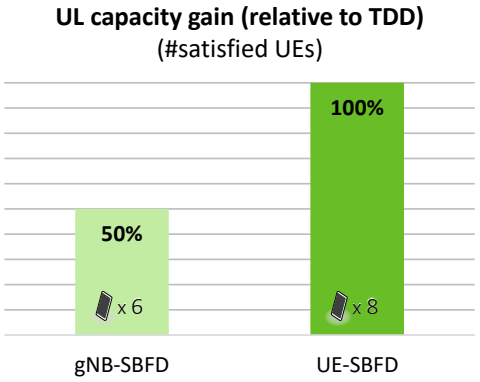


Feasibility and Performance results



CCI: inter-cell interference **RSI:** Residual self-interference





- Negligible residual self-interference relative to CCI for most of the time
- Noticeable improvements to latency
- Substantial improvements to capacity for latency-sensitive services e.g. XR

Dense Urban (200m ISD) XR Traffic (10Mbps data-rate, 30ms PDB) FR1, 4GHz frequency carrier

Proposal

SA/CT Dependency: No

Study non-overlapping full-duplex at the UE, with the following proposed detailed objectives

Objective I: Identify possible schemes for non-overlapping full-duplex UE and evaluate their feasibility and performance for the following (RAN1, RAN4);

- UE baseband and RF aspects, covering both FR1 and FR2 ranges.
- Different types of devices; smartphones, compact devices for XR, CPE, etc.
- The following types of UE configuration, with different levels of guard-band between UL and DL:
    - non-overlapped full-duplex on different subbands within a carrier.
    - non-overlapped full-duplex on different carriers (intra-band).
- Applicable deployment scenarios

Objective II: Identify potential functionality to mitigate self-interference and enable acceptable SBFD-UE complexity (RAN1, RAN4)

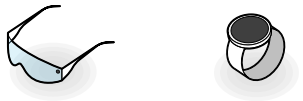
- Frequency isolation between Rx and Tx sub-bands to minimize self-interference
- Opportunistic activation of full-duplex-UE mode in favourable conditions (e.g., UE Tx power level, inter-cell-interference level, UE Tx allocation, etc.)
- Procedures and signals for self-interference cancellation training

<u>Note:</u> Coexistence and CLI handling mechanisms to be addressed in the WI on gNB-SBFD.

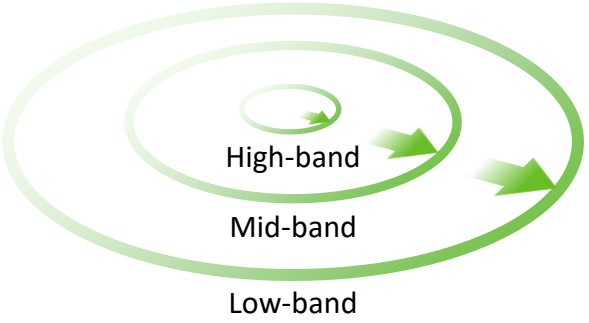
Device-collaborative MIMO

Motivation
Personal Area Network

- Issue 1: Device form-factor restrictions
  - Bottleneck of MIMO gain, due to physical limitations in the number of feasible Tx and Rx antennas



- Issue 2: Worse propagation/coverage properties in higher frequencies
  - Limit maximizing MIMO gain even in case more device antennas are feasible

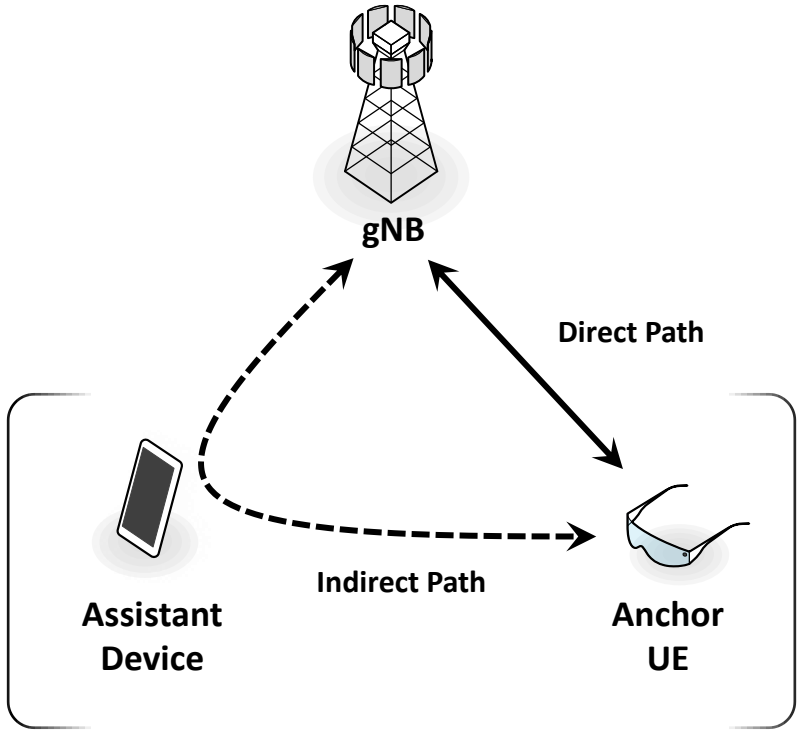


- More and more users carry a multiplicity of devices
  - incl. smartphones, tablet, wearables, etc. – a trend we expect will strengthen (e.g. XR, new form-factors)
    - These devices often operate "together" e.g. via BT tethering (voice calls, remote phone camera shutter etc.)
  - Such personal network of devices open some opportunity for greater collaboration that can address Issues 1 and 2.

The collective PHY capability of devices in close proximity can offer much greater performance than with a device alone.

Target Scenario
General

- NR should support means for low-layer collaboration between an anchor UE and an assistant device/UE to achieve high reliability/throughput, where
  - Anchor UE: typ. form-factor constrained e.g., XR glasses
  - Assistant Device: e.g., smartphone, CPE
- The anchor UE and assistant device are assumed to be in close proximity (e.g. ≤10 meters) of each other
- Use cases
  - Path combining: Use both direct and indirect paths for data transfer to achieve high throughput (via higher rank)/reliability
  - Path switching: Use either direct path or indirect path for data transfer to achieve improved reliability or power saving

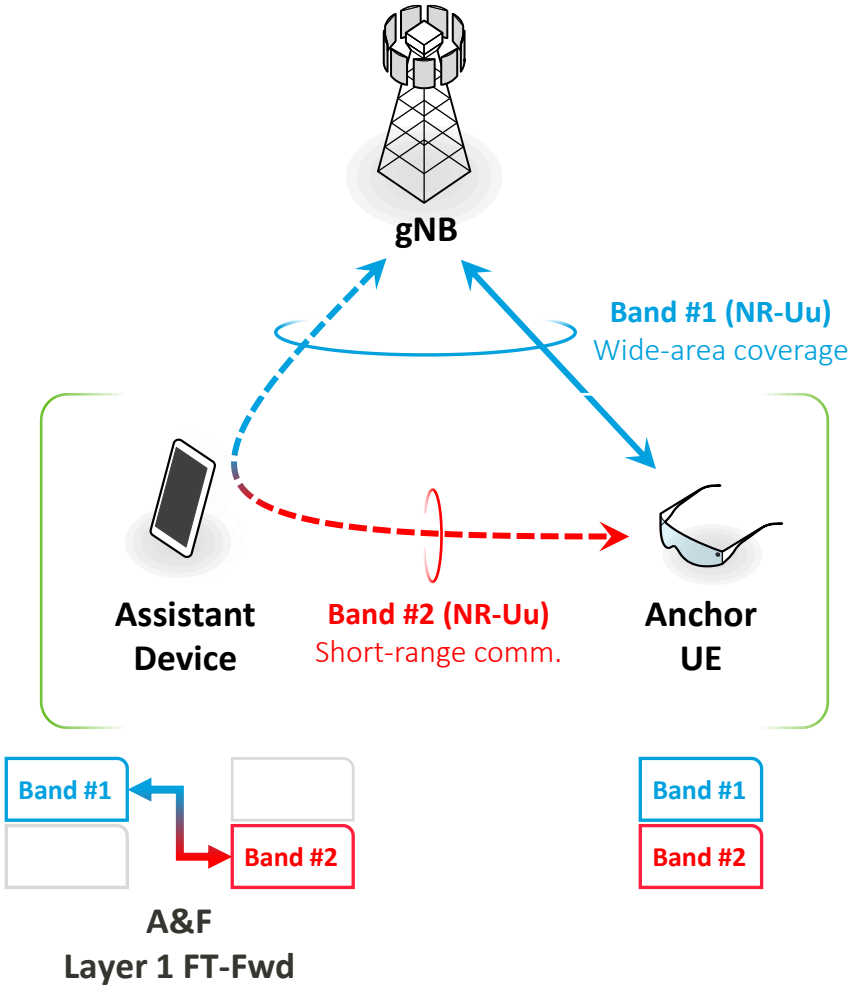


Rel-19 UE Collaboration

Proposal: Device Collaborative MIMO
Layer-1 based antenna capability aggregation

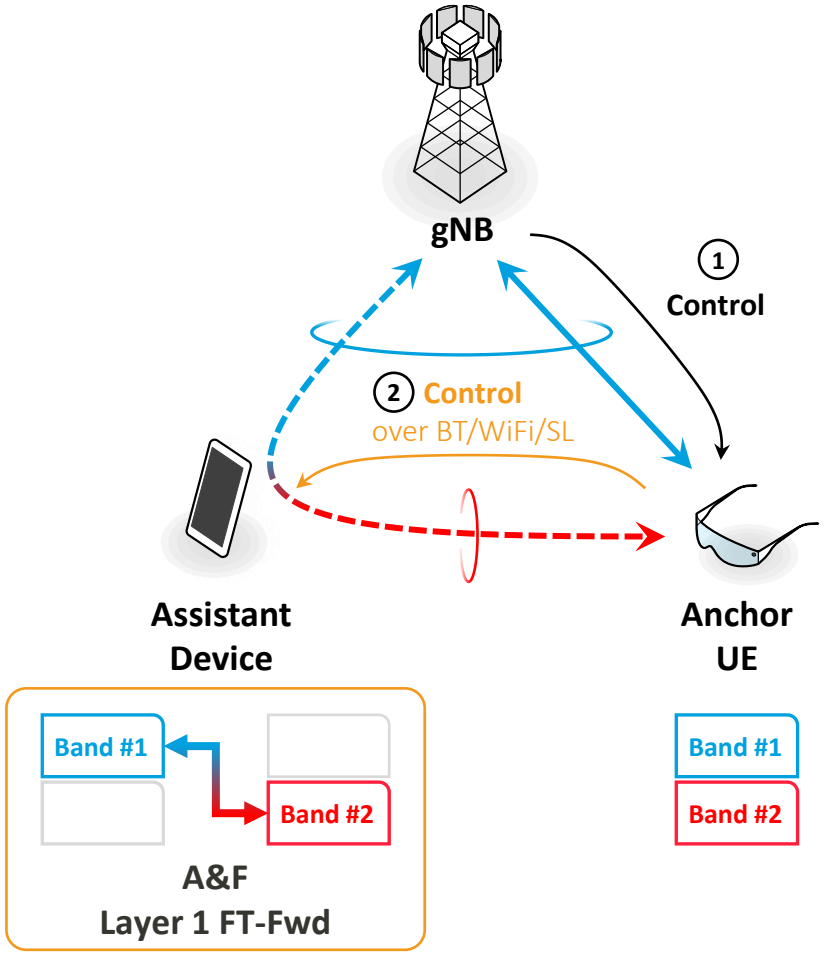
- Assistant device acts as an **external antenna panel** wirelessly connected to anchor UE
  - Performs **amplify-and-forward with frequency translation** (*Layer-1 FT-Fwd*) between Bands #1 and #2 with ~zero latency
    - Band #1: e.g., wide area coverage for gNB deployment, e.g., low-band or mid-band (2.5 or 3.5 GHz)
    - Band #2 e.g., limited geographical coverage, e.g., mid-band (4.7 or 6 GHz)
  - Transparent to the gNB (when operating as such device)
  - gNB can be informed by the anchor UE of the intention to use the "remote panel"
  - Anchor UE still controls the Layer-1 FT-Fwd behavior based on configuration from the gNB (See this slide for control)

- The gNB/Anchor UE performs data transfer:
  - **On a direct path** <> directly to/from gNB on Band #1; and
  - **On an indirect path** <> indirectly to/from gNB via the collaborative device with A&F and Layer-1 FT-Fwd between Bands #1 and #2
  - See this slide for possible operating schemes



Proposal: Device Collaborative MIMO
Collaborative device control

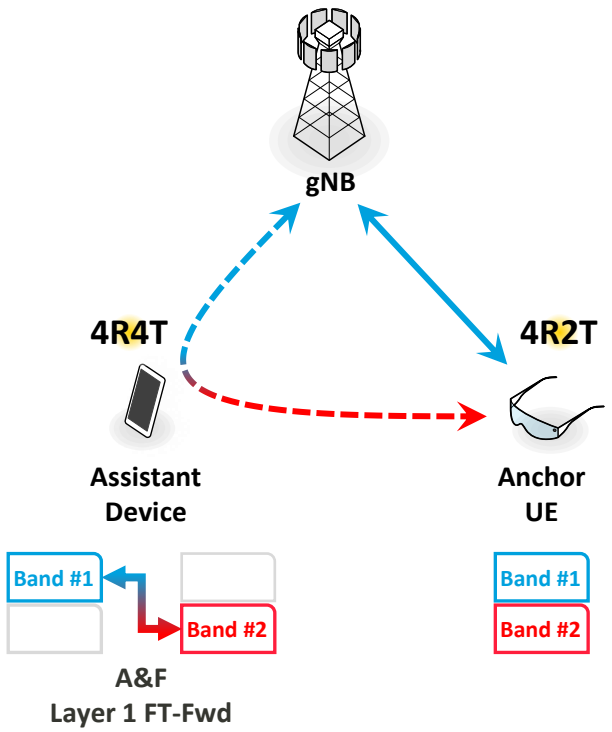
- A Control Interface between the anchor UE and the assistant device allows anchor the UE to control the **Layer-1 FT-Fwd behavior** under **constraints imposed by the gNB** (interference mitigation)
  - It operates over a paired connection (e.g., via BT, WiFi, NR Sidelink) between the anchor UE and the assistant device
  - The anchor UE provides Layer-1 FT-Fwd control information including Layer-1 FT-Fwd on/off, Band #1 configuration information, Band #2 configuration information, Tx power in Band #1, Tx power in Band #2, DL/UL split, etc.
  - The Layer-1 FT-Fwd control information is determined based on **gNB control information** (configuration/indication) including max Tx power in Band #2 (e.g. 10 dBm), candidate bands for Band #2, TDD pattern config, in order to minimize interference
  - The Layer-1 FT-Fwd control information could be specified at Stage 2 level
  - The **gNB control information** could be specified as side control information (similar to what was done for Rel-18 NCR)



Proposal: Device Collaborative MIMO

Tx/Rx schemes at the UE with aggregated antenna capability

- **Scheme #1: Path Combining**
  - Use <u>both</u> direct and indirect paths between gNB and anchor UE for data transfer with joint transmission/reception



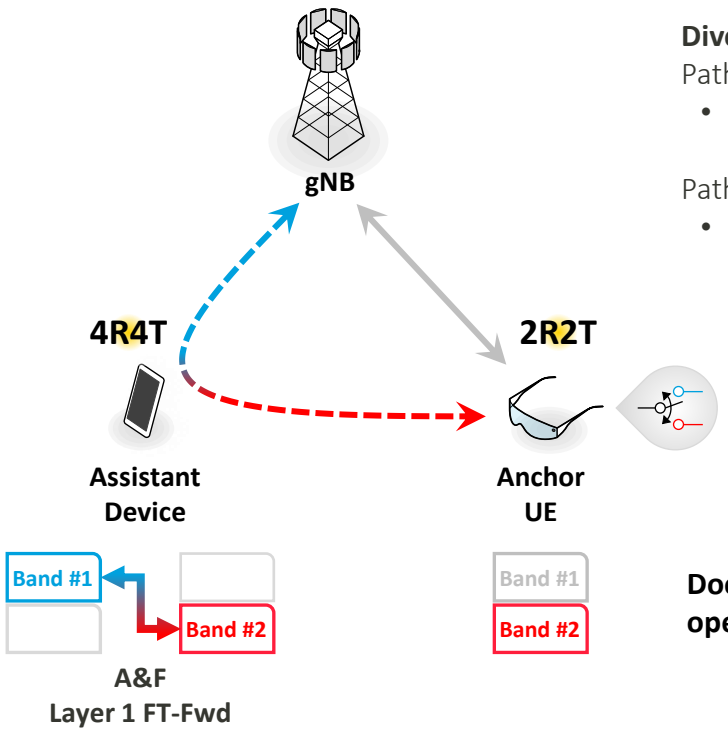
Rank Augmentation

DL: 4Rx → 4Rx + 4Rx:
- Mean DL UPT +~37%; 40% UEs with RI≥4

UL: 2Tx → 2Tx + 2Tx :
- Mean UL UPT +~51%; 90%UEs with RI>2

Requires joint Tx/Rx operation on Bands 1 and 2

- **Scheme #2: Path Selection**
  - Select <u>either</u> direct path or indirect path between gNB and anchor UE for data transfer at any one time



Diversity Augmentation

Path-selection:
- Mean DL UPT +~14%

Path-selection + Rx BF at UE:
- Mean DL UPT +~28%

Does not require joint Tx/Rx operation on Bands 1 and 2

UPT: User-perceived Tput

Proposal

SA/CT Dependency: No

Key Message: NR to support means for a UE to aggregate its own antenna capability with the antenna capability of a collaborative device in proximity in order to obtain UL/DL MIMO performance beyond the UE's own antenna capability, using Layer-1 forwarding (amplify-and-forward) with frequency-translation.

- The objective of this study is to identify and evaluate the potential mechanism(s) to support (joint) transmission/reception on a UE to/from a gNB using a direct path and an indirect path between the gNB and the UE, where
    - The direct path operates on a first frequency band (B1); and
    - The indirect path operates both on B1 between the gNB and a collaborative device, and on a second frequency band (B2) between the UE and the collaborative device; and
    - The indirect path is enabled by the collaborative device performing amplify-and-forward Layer-1 forwarding with frequency-translation (Layer-1 FT-Fwd) of signals exchanged between the gNB and the UE, translating between B1 and B2; and
    - the DL and UL performance of the UE is improved by aggregating the antenna capabilities of the UE and of the collaborative device
- The study includes the following aspects:
    - Develop an evaluation methodology to evaluate the performance gain as well as interference impact, and identify potential enhancement(s) to support this type of operation [RAN1]
    - To control the Layer 1 FT-Fwd behavior, identify the necessary control information to be transferred directly between the UE and the collaborative device, and the necessary side control information to be transferred from the gNB to the UE [RAN1]
    - Identify possible procedures/signaling to inform the gNB of the establishment/termination of collaboration with the collaborative device [RAN2, RAN1]
    - Identify potential impact to RAN4 performance requirements to support this type of operation [RAN4]
- The following scenarios and assumptions are applied to focus the direction of the study:
    - The application scenario consists of a collaborative device and a UE constrained in terms of Tx/Rx antennas
    - The UE and collaborative device are assumed to be in close proximity (e.g. ≤10 meters) of each other to strictly limit the Tx power on the B2 for both UE and collaborative device
    - The collaborative device is connected to the UE using a non-3GPP-standardized UE-device connection, or NR sidelink: establishing and managing this connection is not in scope of the Study. This connection is used by the UE to control the Layer-1 FT-Fwd behavior on the collaborative device via exchange of necessary control information.
    - The collaborative device is transparent to the gNB
    - The collaboration establishment/termination (including discovery, pairing, and unpairing) with the intermediate device is always initiated by the UE
    - B1 and B2 are FR1 licensed bands
    - The gNB shall be able to control/restrict the usage and radio operation of the Layer 1 FT-Fwd (indirectly) on first and second frequency bands, by means of side control info sent from the gNB to the UE.
- Note: No SA/CT impact are expected

Thank you!