

Motivation for new SI: Study on Full Duplex Operation for NR



Full Duplex Operation for NR

- **Motivation**

- For 5G, many of the new service types (e.g., XR service, AI based service, Self-driving Car) are characterized by dynamic variation of traffic in both DL and UL directions, requiring low latency in the packet delivery
- For 5G services, demands on the traffic load will be exploding to support various emerging use cases.
- Existing semi-static or dynamic TDD UL/DL configuration has a limit of delay in time and inter-operator interference issue. Existing FDD scheme has a limitation on the efficient frequency resource utilization for DL/UL direction
- Full duplex operation within a single carrier should be studied to achieve enhancements in the low-latency and efficient resource utilization in NR.

- **Potential categories for full duplex operation**

- “gNB Full Duplex & UE Half Duplex”, “gNB Full Duplex & UE Full Duplex”
- “Subband-wise Full Duplex”, “Spectrum Sharing Full Duplex”

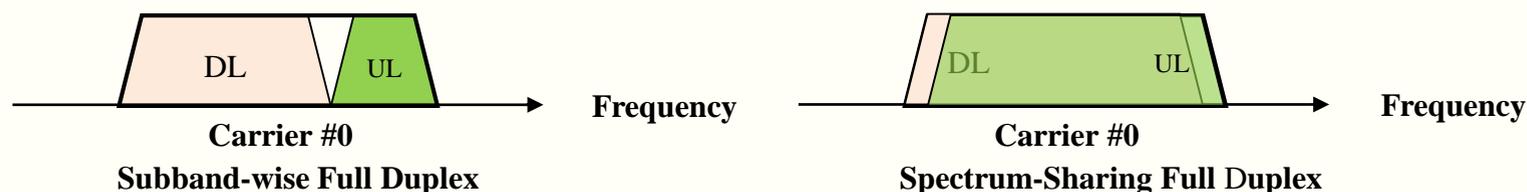
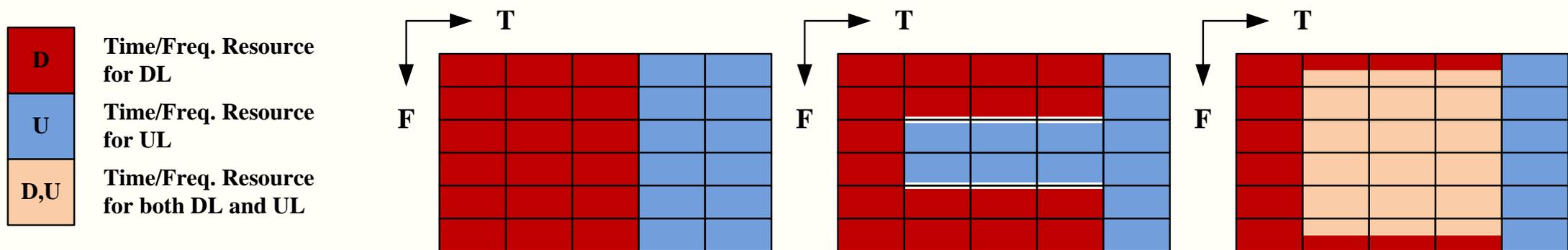


Figure 1.

Full Duplex Operation Scenarios [1/2]

- Combination of Half Duplex and Full Duplex Operation**
 - For legacy TDD operation, legacy static TDD configuration is assumed. Also, a part of time resources is designated for Half Duplex operation.
 - Based on above assumption, other part of time resources is designated for Full Duplex operation. Within the time resource, SB-FD or SS-FD can be operated.
- Interference Scenarios depending on Duplex operation**



	(a) HD ¹⁾ only	(b) HD + SB-FD ²⁾	(c) HD + SS-FD ³⁾
Self Interference	None	Subband wise emission	Subband wise emission + Inband
Cross Link Interference	None	Subband wise emission	Subband wise emission + Inband
Adjacent Carrier Interference	None (if static TDD configuration)	Not severe (if static TDD configuration)	Not severe (if static TDD configuration)

1) HD: Half Duplex
 2) SB-FD: Subband wise Full Duplex
 3) SS-FD: Spectrum-sharing Full Duplex

Figure 1.

Full Duplex Operation Scenarios [2/2]

- **Interference Handling**

- To enjoy the benefit of Full Duplex operation, interference (i.e., self-interference, Cross Link Interference, Adjacent Carrier Interference) should be handled.
- **Self Interference (SI)** [In page 5]
 - Transceiver for SI mitigation/cancelation should be applied.
- **Cross Link Interference (CLI)** [In page 6 and 11~14]
 - In SB-FD case, not only simultaneous Tx/Rx within a carrier but also mitigation of CLI can be achieved by using subband-wise resource partitioning between DL and UL. On the other hand, the performance enhancement is limited due to the subband-wise resource partitioning.
 - In SS-FD case, higher performance gain in terms of throughput enhancement and latency reduction can be expected from wider frequency resource and/or more time occasion for DL/UL transmission. But, cross link interference (esp., severe BS2BS CLI.) should be handled appropriately to prevent performance degradation.
- **Adjacent Carrier Interference (ACI)** [In page 15~17]
 - It is hard to handle ACI by tight coordination among different operator in adjacent channel.
 - Gap between UL resource (in a carrier for a operator) and DL resource (in an adjacent carrier for other operator) in frequency domain can be set to reduce a affect of ACI. [E.g, Figure 1 in page 3]

Transceiver Structure

- Structure for SI mitigation / cancellation**

Table 1. Example of Level of SI mitigation / Cancellation [dB] (based on measurement result from LG's implementation)

	For SB-FD	For SS-FD
(1) Antenna Isolation	30~35	30~35
(2) Tx/Rx Filter & Spectrum emission	33~40	
(3) RF-SIC	25~30	25~30
(4) Digital SIC	-	25~35 (Linear)
Total	95~100 (If Digital SIC is applied, further cancellation can be achieved.)	95~100 (If non-linear cancellation is applied, 5~20 dB can be further cancelled.)

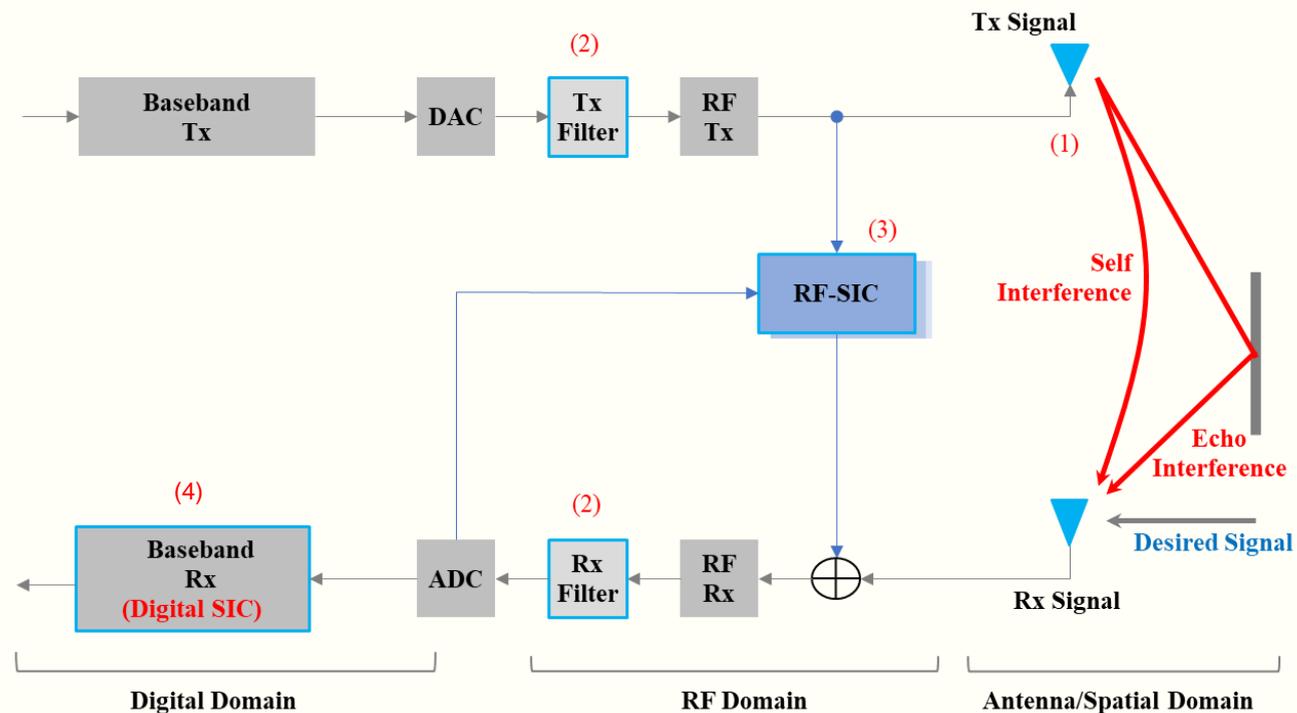
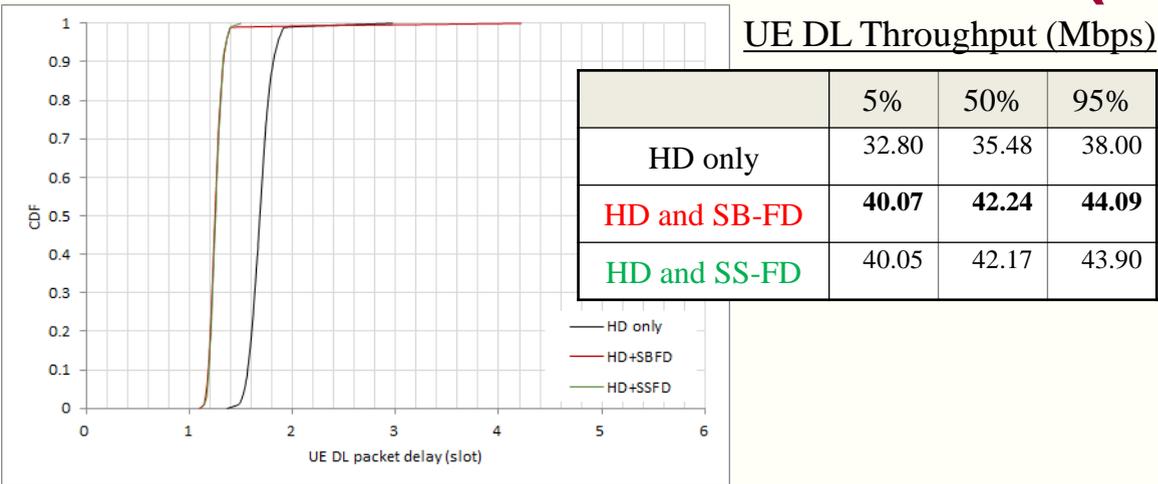


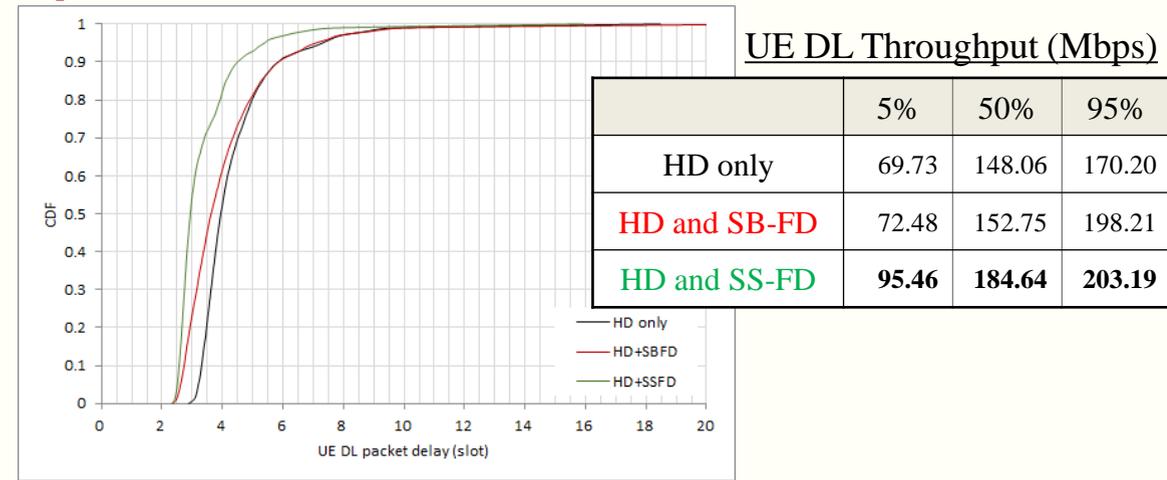
Figure 1. Example of Transceiver structure for SI mitigation /cancellation

Potential Benefit of Full Duplex operation

- Initial Evaluation Result (SLS) [Evaluation assumption in page10]

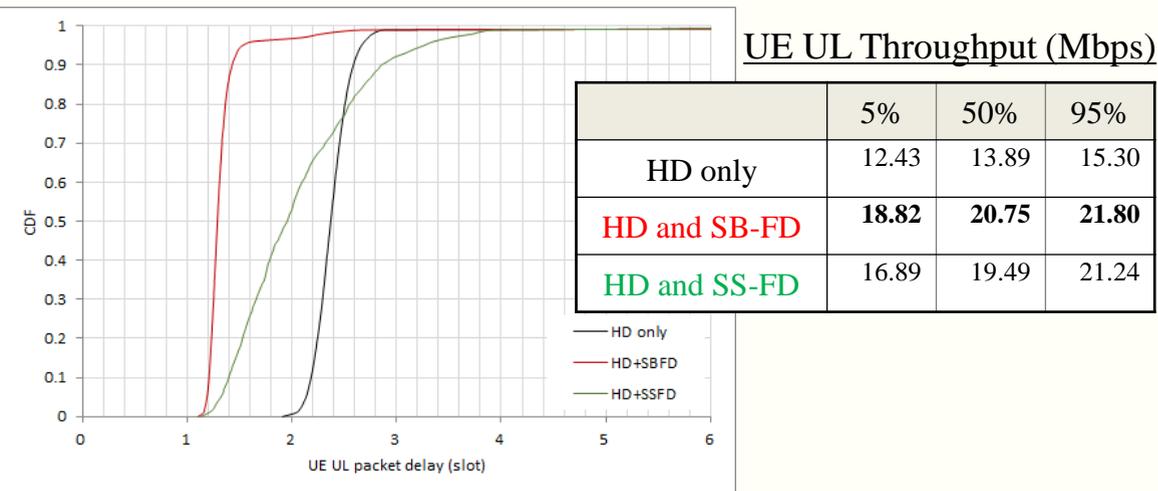


(a) Small Size of Packet

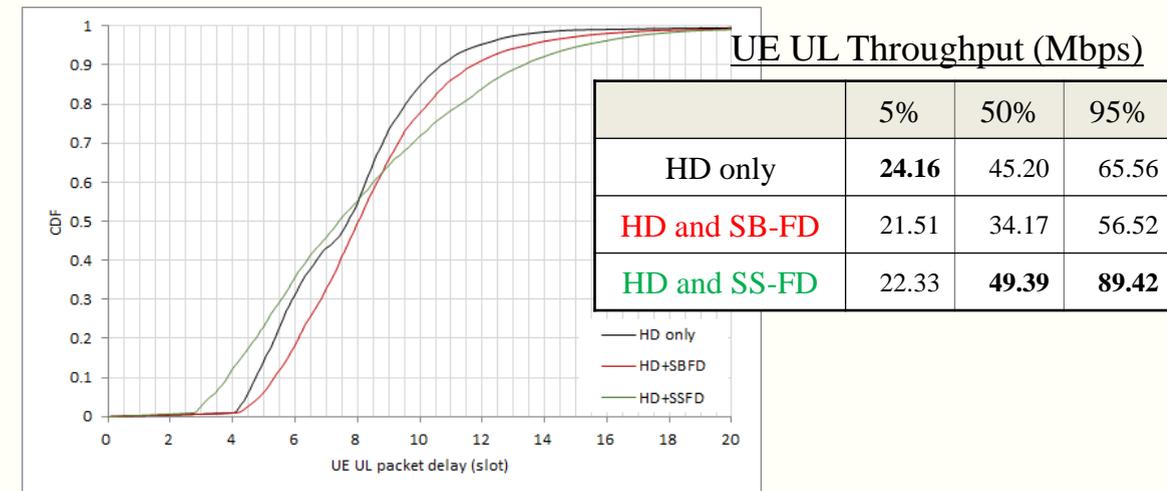


(b) Medium Size of Packet

Figure 1. Average UE packet delay and 50% UE Throughput (DL)



(a) Small Size of Packet



(b) Medium size of Packet

Figure 2. Average UE packet delay and 50% UE Throughput (UL)

- Observation:**

- It is observed that average UE Packet Delay is reduced and UE throughput is enhanced when Full Duplex is applied.

Proposed Objective [1/2]

- **Study feasibility of full Duplex operation in unpaired spectrum [RAN1, RAN4]**
 - Define/prioritize scenarios for Full Duplex operation in terms of some aspects such as:
 - Full duplex operation in gNB and/or UE
 - Frequency resource utilization (e.g., separated frequency resource in a carrier is used for DL and UL, same frequency resource in a carrier is used for simultaneous operation of both DL and UL), etc.
 - Frequency range (e.g., FR1, FR2, FR-X)
 - Deployment scenario (e.g., Rural, Urban, Indoor, Isolated)
 - Antenna configuration (e.g., Single-/multi-panel, Co-located/distributed antenna),
 - Note1: In a resource allocation perspective, full duplex operation means simultaneous TX-RX in a same carrier
 - Note2: The study may focus on Uu link in unpaired spectrum, but necessity of enhancements for other scenarios(e.g. IAB, wireless backhaul, sidelink, paired spectrum) may be considered further
 - Note3: RAN1 studies general objectives, while RAN4 confirms the feasibility

Proposed Objective [2/2]

- **Study standardization impacts and potential enhancements for the selected scenarios for full Duplex operation in unpaired spectrum such as: [RAN1]**
 - Resource allocation (e.g., BWP)
 - Interference handling (i.e., self-interference, UE-UE interference, gNB-gNB interference)
 - MIMO operation (e.g., Beam management, Reference signal, CSI measurement/report, Multi-TRP/Cell)
 - Duplex adaptation



Annex

System Level Simulation / Interference Measurement

Evaluation Assumption for SLS

• Deployment Scenario

- Carrier frequency:
 - 2GHz (Macro Layer), **3.5GHz (Micro Layer)**
- Layout: Two layers
 - Macro layer: Hex. Grid, 19 BSs
 - **Micro layer: Random drop, 3 micro cells per macro sector**
- Min. distance btw macro-to-macro: 500m
- **Min. distance btw macro-to-micro: 40m**
- **Min. distance btw micro-to-micro: 40m**
- UE distribution
 - **855 micro UEs (5 UEs per micro cell in average)**
 - **80% of indoor UEs, 20% of outdoor UEs**
 - Min. distance btw macro-to-UE: 35m
 - **Min. distance btw micro-to-UE: 10m**
- Tx power for Micro Layer:
 - 23~33dBm for SS-FD**
 - 33dBm for other cases (HD only, SB-FD)**
- Tx power for UE: **23dBm (UE)**
- Antenna configuration
 BS: (M, N, P, Mg, Ng) = (8, 8, 2, 1, 1), (dH, dV) = (0.5, 0.8) λ
 UE: (M, N, P, Mg, Ng) = (1, 1, 2, 1, 1)

• Performance Metric

- UE average DL/UL traffic delay (slot)
 - Traffic delay: Slot index (Packet transmission completion) - Slot index (Packet is generated)
 - Minimum traffic delay: 1 slot
- UE average DL/UL throughput (Mbps)
 - Average throughput = $\text{sum}(\text{Packet size/traffic delay}(n)) / N$

• Traffic model

- FTP traffic model 3
 - Type #1 (Small size of Packet)**
 - - Downlink: 10 traffics/sec/UE, **6 KB/traffic**
 - - Uplink: 10 traffics/sec/UE, **3 KB/traffic**
 - Type #2 (Medium size of Packet)**
 - - Downlink: 10 traffics/sec/UE, **60 KB/traffic**
 - - Uplink: 10 traffics/sec/UE, **30 KB/traffic**

• System Parameters

- System BW/SCS: 50MHz / 15kHz (**270RBs**)
- DL/UL resource pattern
 - HD only: **DDDUU**
 - HD + SB_FD: **DSSSU**
(**S:DL 170RB, Guard 14 PRBs, UL 86RBs**) D:U=2:1
 - HD + SS_FD: **DSSSU**
(**S:DL only 30RB, both DL and UL 240RBs**)
- HARQ
 - Min. HARQ retransmission delay: **8 slots**
- Packet dropping time
 - **30 slots** (A packet is in outage if this packet failed to be successfully received by destination receiver beyond "Packet dropping timer")
- Rank-1 (perfect CSI assumed)

• Interference

- ACIR for CLI: **43 dB**(ACIR BS-BS), **28 dB** (ACIR UE-UE)
- Residual SI for SB-FD = Tx power - **ACIR (43dB) - SIC (80dB)**
- Residual SI for SB-FD = Tx power - **SIC (80dB)**

Intra-cell UE2UE CLI¹⁾ (wideband) [1/2]

1) CLI: Cross Link Interference

• Measurement Environment

- **Deployment:** Indoor (Parking Area)
- **One gNB (Wideband-wise Spectrum Sharing Full Duplex operation** for simult. DL & UL)
BW (100MHz), Center Frequency (3.5GHz), Antenna (1Tx-1Rx), Tx power (5dBm)
- One aggressor UE (**UL Tx**) : Antenna (2Tx), Tx power (5, -5, -15, -25dBm, & No Tx), 6 candidate locations
- One victim UE (**DL Rx**): Antenna (2Rx), 4 candidate locations

• Observation

- Measured SINR (dB) of victim UE is varying depending on Tx power of aggressor UE, and distance between aggressor UE and victim UE. In many cases (e.g., lower Tx power for aggressor UE, or longer distance between victim UE and aggressor UE), intra-cell UE2UE CLI is negligible.
- It seems that the intra-cell UE2UE CLI is manageable by cross-Link Interference (CLI) mitigation schemes and network scheduling.

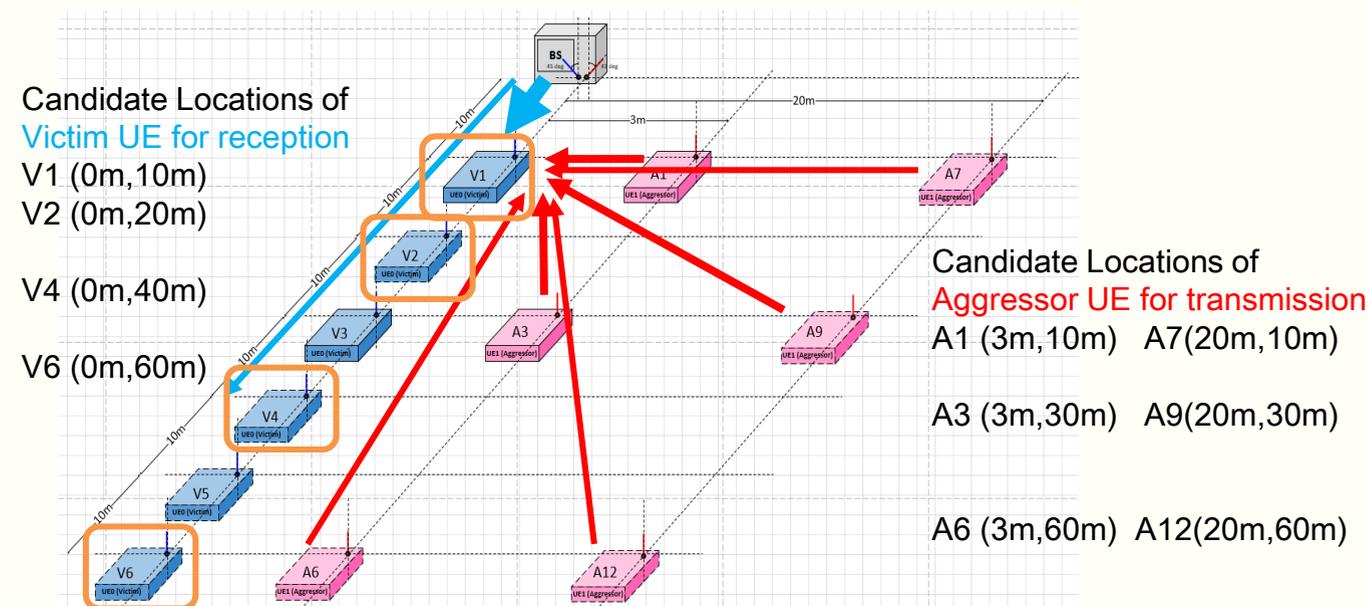


Figure 1. Deployment for Intra-cell UE2UE CLI measurement (wideband)

Inter-subband Intra-cell UE2UE CLI¹⁾ [1/2]

1) CLI: Cross Link Interference

• Measurement Environment

- **Deployment:** Indoor
- **One gNB and Two UEs** are assumed.

One gNB (SB-FD operation for simult. DL & UL): BW (100MHz), Center Frequency (3.85GHz), Antenna (1Tx-1Rx), Tx power (5dBm)

One victim UE (DL Rx): Antenna (2Rx), Subband (17.28MHz) wise Rx

One aggressor UE (UL Tx) : Antenna (2Tx), Subband (18.72MHz) wise Tx, Tx power (5, 2dBm, & No Tx)

- Two types of Tx-Rx filter (i.e., wideband, subband) are applied.

• Observation

- Measured SINR (dB) of victim UE is varying depending on Tx power of aggressor UE, and distance between aggressor UE and victim UE. In many cases (e.g., lower Tx power for aggressor UE, or longer distance between victim UE and aggressor UE), intra-cell UE2UE CLI is negligible.
- It is observed that inter-subband wise Intra-cell UE2UE CLI can affect to victim UE if two adjacent subbands are designated for aggressor UE and the victim UE (when wideband filter is applied for UE.). Similar with wideband CLI case, it seems that the intra-cell UE2UE CLI is manageable by cross-Link Interference (CLI) mitigation schemes and network scheduling.

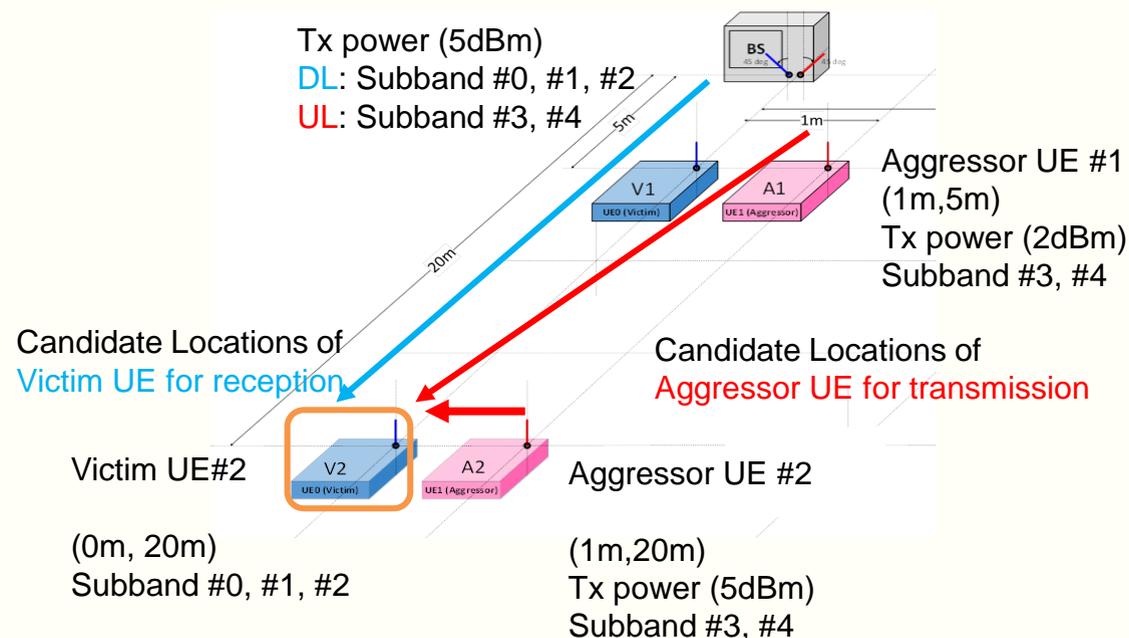
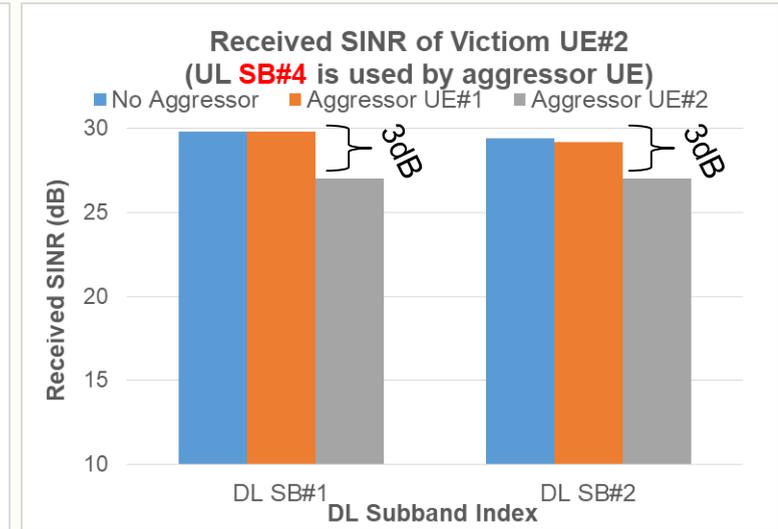
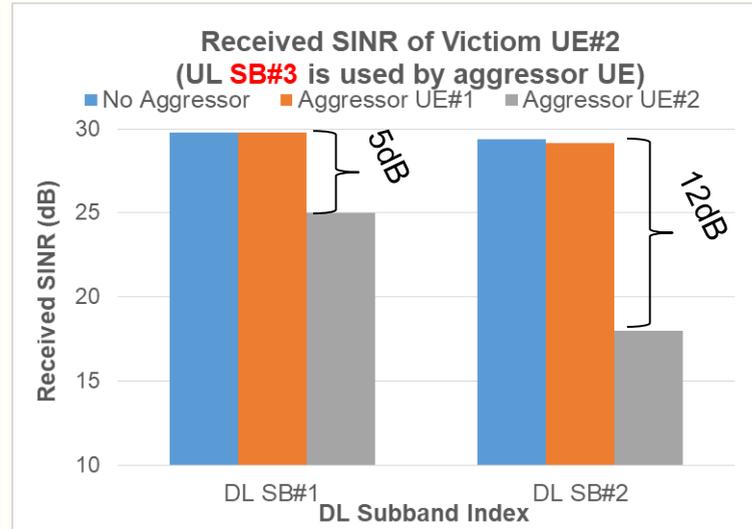
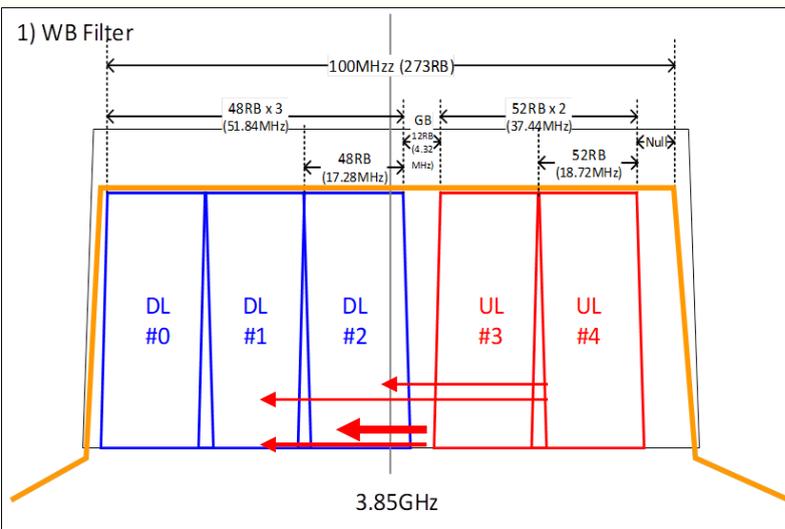


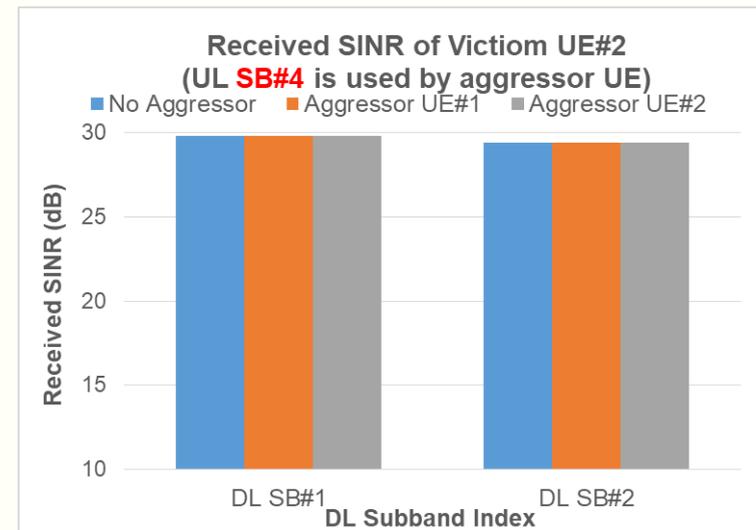
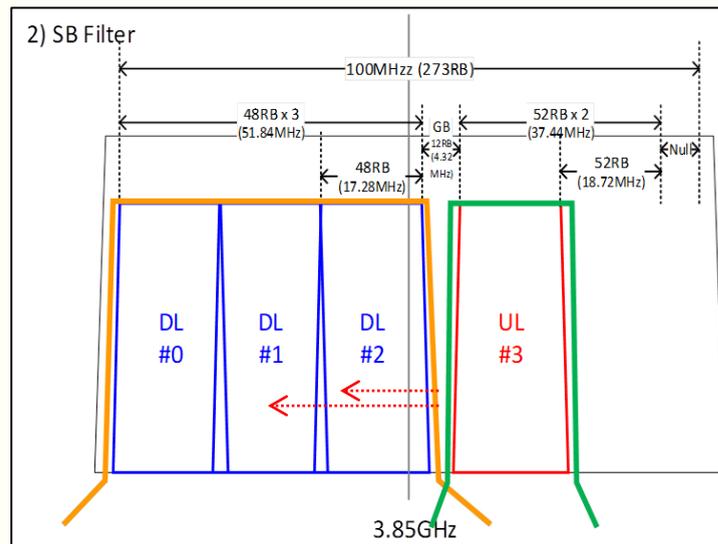
Figure 1. Deployment for Inter-subband Intra-cell UE2UE CLI measurement

Inter-subband Intra-cell UE2UE CLI [2/2]

• Measurement Result



(a) Case 1: Wideband filter is applied.



(b) Case 2: Subband filter is applied.

Figure 1. SB-FD operation scenarios and Measurement Result (Received SINR)

Wideband-wise UE2UE ACI¹⁾

1) ACI: Adjacent Cell Interference

• Measurement Environment

- **Deployment:** Indoor (Parking Area)
- **Two gNBs and two UEs are assumed**
- **One gNB (DL Tx):** Center Frequency (3.85GHz)
- **One victim UE (DL Rx):** Center Frequency (3.85GHz), Subband (20MHz) wise DL reception
- **One aggressor UE (UL Tx):** Center Frequency (3.75GHz), **Wideband-wise (100MHz)** UL Tx
- Wideband Tx-Rx filter is applied.

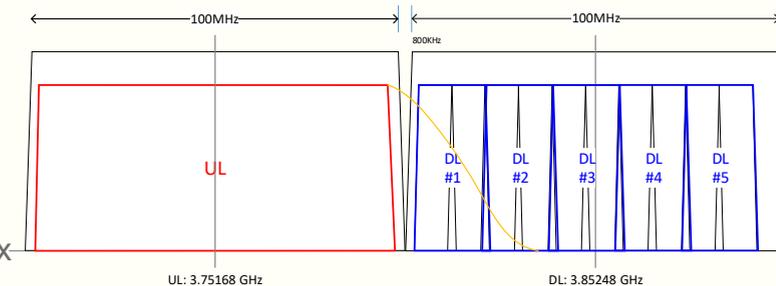


Figure 1. Adjacent Carrier Interference

• Observation

- ACI from a far UE is negligible.
- ACI from a near UE affects to received signal quality of victim UE. Power of ACI is diminished when frequency position for UL signal transmission of aggressor UE is far from the frequency position for DL signal reception of victim UE.
- It seems that the UE2UE ACI is manageable by network scheduling.

• Measurement Result

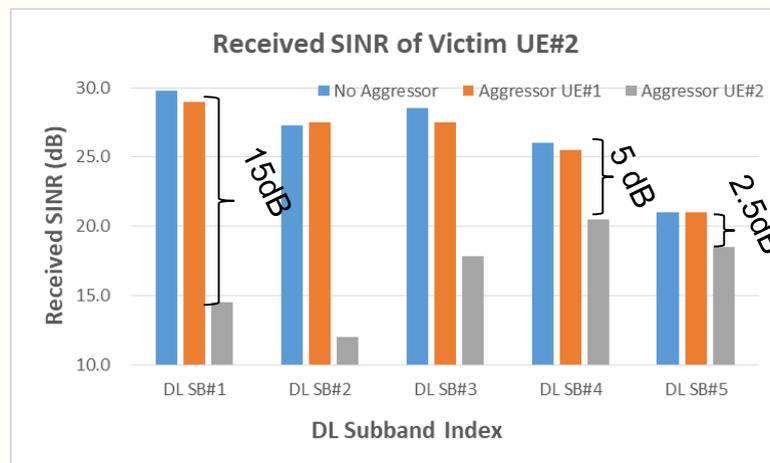


Figure 2. Measurement Result (Received SINR)

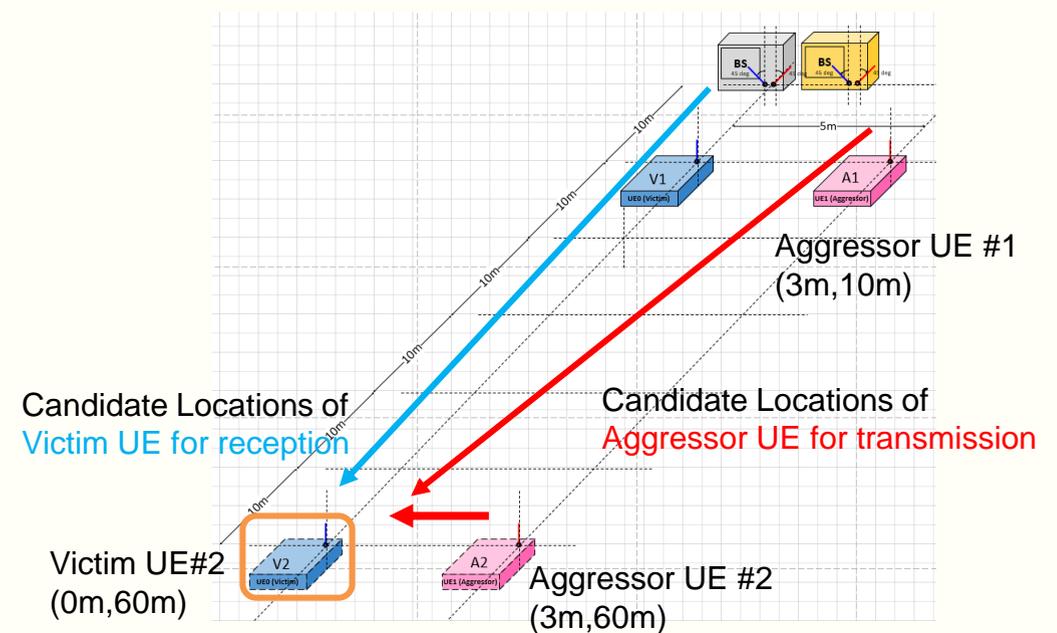


Figure 3. Deployment for Wideband-wise UE2UE ACI measurement

Subband-wise UE2UE ACI¹⁾ [1/2]

1) ACI: Adjacent Cell Interference

• Measurement Environment

- **Deployment:** Indoor
- **Two gNBs** and two UEs are assumed.
One gNB (**DL Tx**): BW (100MHz), Center Frequency: 3.85GHz, Antenna (1Tx-1Rx), Tx power (5dBm), DL subband (#0 ~ #4)
One gNB (**UL Rx**): BW (100MHz), Center Frequency: 3.75GHz
- One victim UE (**DL Rx**): Center Frequency (**3.85GHz**), Antenna (2Rx), **Subband (17.28MHz)** wise Rx
- One aggressor UE (**UL Tx**): Center Frequency (**3.75GHz**), Antenna (2Tx), **Subband (18.72MHz)** wise Tx, Tx power (5, 2dBm, No Tx)
- Two types of Tx-Rx filter (i.e., wideband, subband) are applied.

• Observation

- In case of subband resource allocation for UL, it is observed that ACI from a subband is affect to adjacent subband, but the level of ACI is negligible if UE is required to transmit UL signal without significant high Tx power in case of small cell environment.

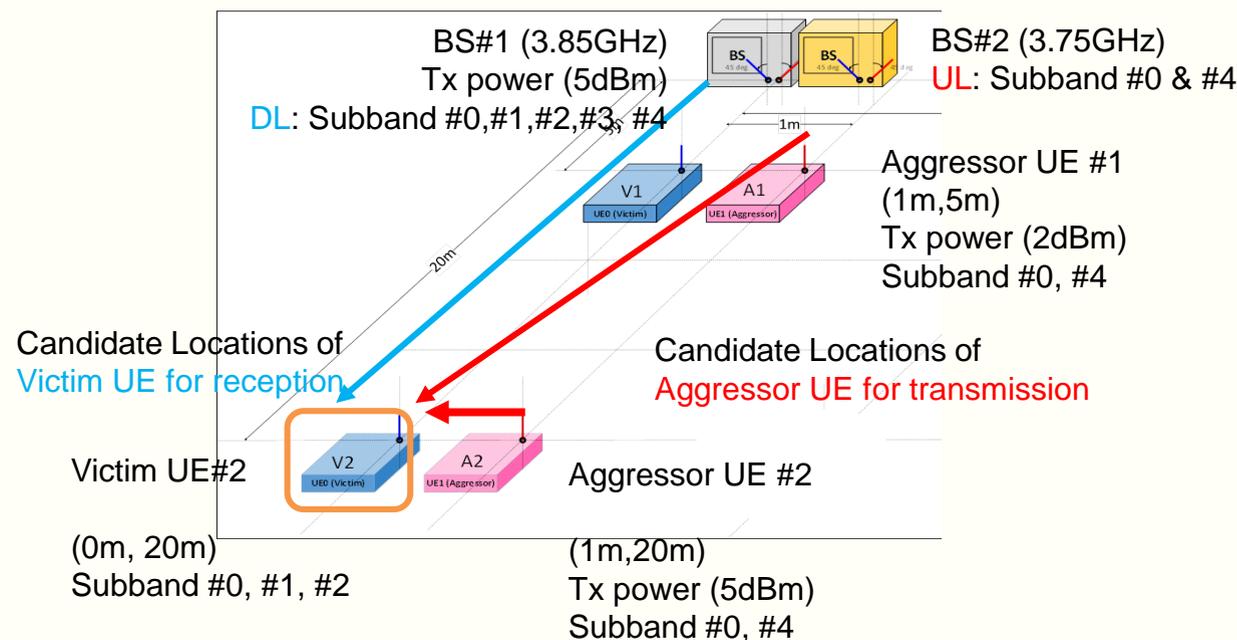
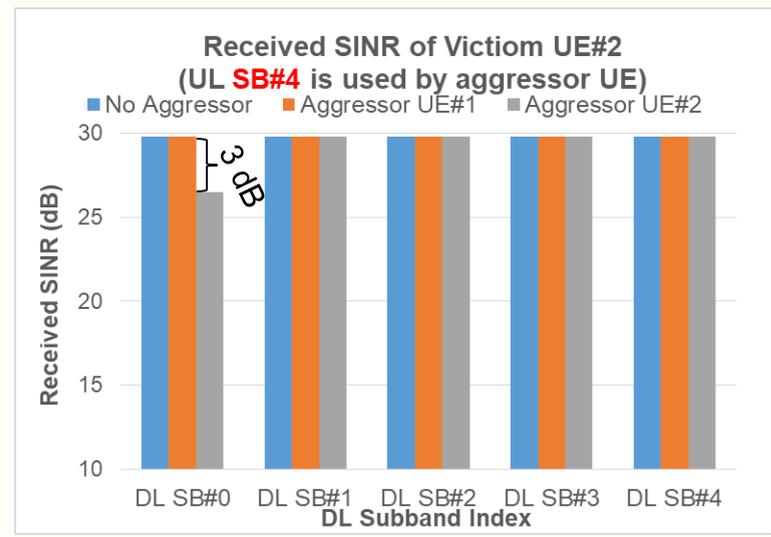
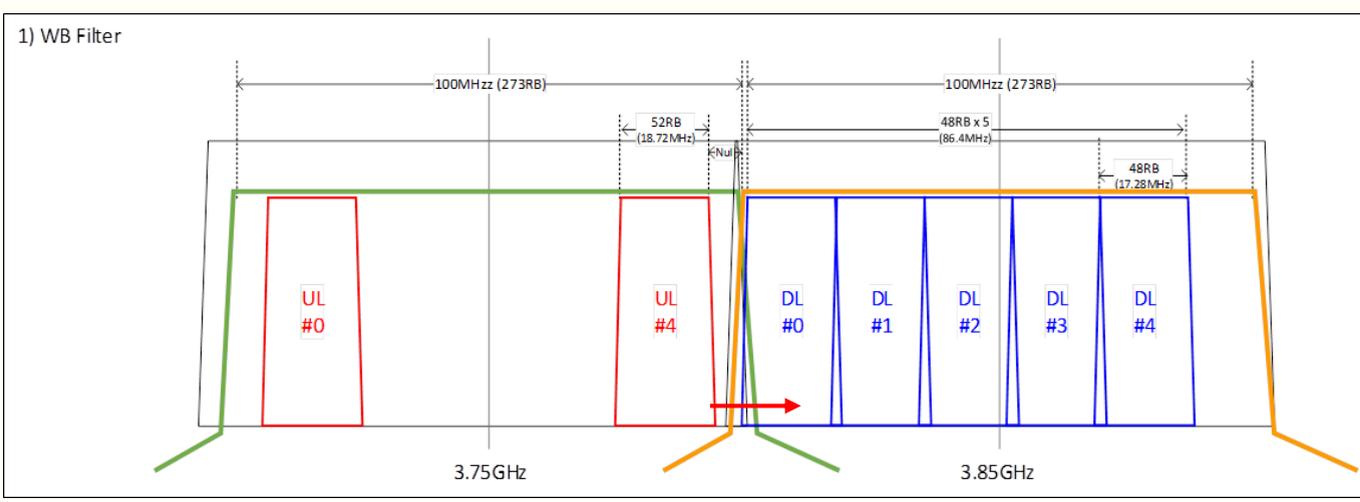


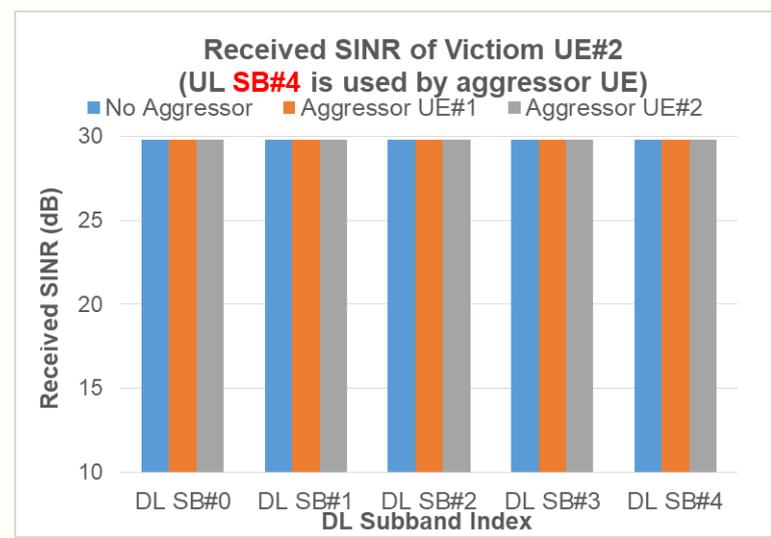
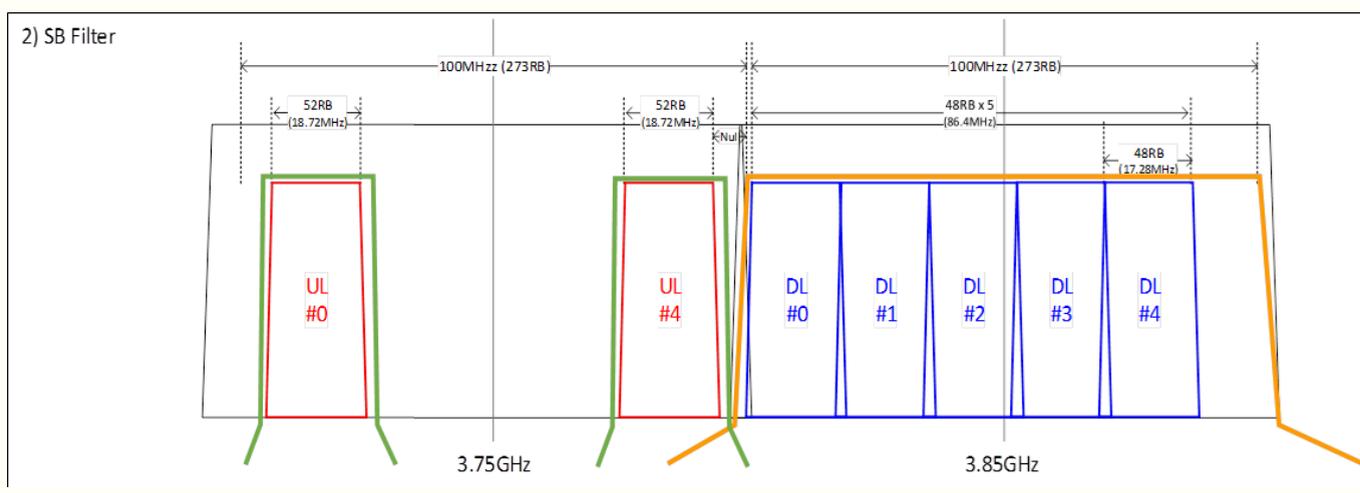
Figure 1. Deployment for Subband-wise UE2UE ACI measurement

Subband-wise UE2UE ACI [2/2]

Measurement Result



(a) Case 1: Wideband filter is applied.



(b) Case 2: Subband filter is applied.

Figure 1. Subband-wise UE2UE Adjacent Carrier Interference