



6Rx / 8Rx CPE in 5G-NR FR1-TDD

Benefit & Deployment Recommendations

Qualcomm Technologies, Inc.

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1 Introduction: 6Rx & 8Rx CPE in 5G-NR

When 5G-NR was launched, the de-facto number of CPE receiver chains (Rx) in FR1 bands was 4Rx. CPE manufacturers are looking for differentiators for their premium products to provide better user experience over others. 6Rx / 8Rx in CPEs is an option to improve both coverage and user experience. From an operator's perspective, the prime FR1 bands have limited spectrum and there is strong desire to increase network capacity. Introducing 6Rx / 8Rx in CPEs is one way to increase network capacity by improving spectral efficiency.

1.1 Motivation for more than 4Rx on CPE

There is a strong desire to increase network capacity, especially DL network capacity due to the following reasons:

- FR1 bands have limited spectrum.
- CPEs typically use DL heavy applications, like video streaming.

With the introduction of 6Rx / 8Rx in CPEs, even when supporting up to 4 layers, DL spectral efficiency can be improved due to better combining gain and better interference rejection capabilities coming from 6Rx / 8Rx over 4Rx. 6Rx / 8Rx CPEs can enable up to 6 / 8 layers on DL in the future (from UE capability perspective, 6 layers is being considered for 3GPP release 19 and 8 layers is already supported in 3GPP release 15 onwards), thereby improving spectral efficiency and hence cell capacity even further.

1.2 Practical Design Considerations

To achieve higher spectral efficiency with 6Rx / 8Rx CPEs, the antenna placements for each Rx within the CPE must be carefully designed. Design goals include as much antenna decorrelation between each pair of antennas as possible. This enables better diversity gain which in turn results in better spectral efficiency. When 6 / 8 layers on DL is available this also enables better 6 / 8-layer performance.

Antenna decorrelation is a function of physical antenna spacing in terms of multiple of wavelength and / or antenna polarization separation. Typically, few wavelengths or higher physical separation along with polarization results in good antenna decorrelation and diversity gains. Since CPEs typically have larger form factor than smartphones it is easier to accommodate 6Rx / 8Rx antennas with larger physical separation for lower antenna correlation.

Considering typical CPE form factors and dimensions, frequency bands above 1GHz are most suitable for 6Rx / 8Rx operation. Frequency bands below 1GHz will require very large physical antenna separation which may not be practical in current CPE form factor.

Another point to consider is future 6 / 8-layer support on DL; to sustain 6 / 8 layer transmissions on DL, SINR requirements are significantly large. High DL SINR is most feasible in massive MIMO (M-MIMO) networks due to beamforming gains. Typical M-MIMO networks today are mostly deployed in FR1-TDD bands which are 2.5GHz to 4.9GHz range. So, FR1-TDD band CPEs will enjoy higher spectral

efficiency from 6Rx / 8Rx due to better diversity gain / interference cancellation and up to 6 / 8-layer transmissions on DL.

1.3 3GPP Dependencies

6Rx / 8Rx CPEs supporting up to 4 layers on DL does not need any 3GPP version update beyond release 15. Optionally, starting with 3GPP release 17, CPEs can inform the network that it can support SRS Antenna Switching with more than 4Rx antennas. Even without the release 17 feature, CPEs can implement 6Rx / 8Rx transparently to the network. From physical layer support, 3GPP release 15 and beyond supports 8 layers on DL which means that if radio conditions are not optimum for 8 layers, DL transmissions can fall back to less than 8 layers, including 6 layers. But explicit UE capability signaling for maximum 6-layer support on DL is being considered for future 3GPP release 19. Up to 3GPP release 18, UE capability signaling supports maximum 2 layers, 4 layers or 8 layers.

2 4Rx vs 6Rx vs 8Rx CPE: How do they compare?

The primary difference between 4Rx and 6Rx / 8Rx CPEs is on the DL. UL for both CPEs can either be 1Tx (typically UL SISO or PC3 CPE) or 2Tx (typically UL MIMO or either PC2 or PC1.5 CPE). So, we do not expect any difference in UL performance between 4Rx and 6Rx / 8Rx CPEs. One exception being 6Rx / 8Rx CPEs with Tx antenna switching diversity can mitigate the effects of physical external blocking on one or more antennas better than 4Rx CPEs with the same feature. Another exception is better SRS performance if 6Rx / 8Rx CPEs use 3GPP release 17 SRS antenna switching with more than 4Rx antennas feature.

On DL, 4Rx CPEs can support up to 4 layers and benefit from diversity gain and interference rejection gains due to 4Rx antennas whereas 6Rx / 8Rx CPEs currently support up to 4 layers (6 / 8-layer support in future) can experience higher spectral efficiency, better diversity gain and interference rejection gains due to higher number of receive chains along with interference cancellation algorithms like MMSE-IRC (Minimum Mean Square Error – Interference Rejection Combiner). With future 6 / 8-layer support, 6Rx / 8Rx CPEs can get up to 1.5 / 2.0 times higher peak DL throughput than 4Rx CPEs respectively.

Description	4Rx CPE	6Rx CPE	8Rx CPE
Number of DL Rx chains	4	6	8
Number of DL SU-MIMO layers	Up to 4 layers	Up to 4 layers (today); Up to 6 layers (future beyond 3GPP release 18)	Up to 4 layers (today); Up to 8 layers pending gNB support
Peak DL Throughput	1x	Up to 1.5x higher with future 6 layers	Up to 2.0x higher with 8 layers
UL Performance	No difference with respect to 6Rx / 8Rx without UL antenna switching diversity	Can improve UL performance if 6Rx uses UL antenna switching diversity to mitigate	Can improve UL performance if 8Rx uses UL antenna switching diversity to mitigate

		physical blocking of antennas	physical blocking of antennas
SRS Performance	Same as 6Rx or worse if 3GPP Rel 17 SRS antenna switching more than 4Rx antennas enabled	Same as 4Rx or better if 3GPP Rel 17 SRS antenna switching more than 4Rx antennas enabled	Same as 4Rx or better if 3GPP Rel 17 SRS antenna switching more than 4Rx antennas enabled

Figure 2-1 4Rx vs 6Rx vs 8Rx CPE Comparison

2.1 Which channels benefit from more than 4 receivers in CPE?

6Rx / 8Rx in CPEs should benefit all channels on DL and optionally SRS performance on UL if 3GPP release 17 SRS antenna switching more than 4Rx antennas is enabled. Apart from the obvious PDSCH channel benefits of higher SPEF due to higher number of SU-MIMO layers, better diversity gains and better interference rejection, 6Rx / 8Rx result in more robust DL control channel performance (PDCCH) due to better diversity gain and interference rejection. This benefit will be more evident in networks with a single broadcast beam systems (broad beam equates to higher interference for broadcast control channel). We expect higher improvement for cell-edge DL performance where interference is likely higher than cell-center.

3 Device and Infrastructure Requirement

3.1 CPE Capability Requirement

Assuming network supports up to 4-layer SU-MIMO on DL, 6Rx / 8Rx implementation in CPE can be transparent to the network and unless specified otherwise, it is assumed that UE supports 4-layer SU-MIMO. If network supports more than 4-layer SU-MIMO on DL, then explicit CPE-support indication is used as part of the capability message to inform gNB of its capability. The UE-capability indications defined in 3GPP to standardize the process are listed below:

- CPE must be able to convey maximum SU-MIMO layers on DL per CC (*maxNumberMIMO-LayersPDSCH*). Up to release 18, only 2, 4 and 8 layers are defined in 3GPP for DL. For future releases, this information element would likely be updated to include 6 layers as well.
- Optionally, CPE can support UL Tx Antenna Switching Diversity across all 6 / 8 antennas to improve UL performance due to reduction in probability of localized physical object blocking the active Tx antenna.
- Optionally, if CPE supports release 17 SRS Antenna switching for more than 4Rx, then UE must be able to convey the same to the gNB (*srs-AntennaSwitchingBeyond4RX-r17*).
- If above is true, then CPE must be able to also convey a combination of supported xTyRs. (*supportedSRS-TxPortSwitchBeyond4Rx-r17* {*t1r1*, *t2r2*, *t1r2*, *t4r4*, *t2r4*, *t1r4*, *t2r6*, *t1r6*, *t4r8*, *t2r8*, *t1r8*})

3.2 gNB Infrastructure Requirement

6Rx / 8Rx implementation in the CPE is transparent to the gNB. DL will improve due to multiple receivers at CPE independent of whether gNB has knowledge of the number of CPE receiver antennas. Depending on UE-capability signaling, gNB may optionally support 3GPP release 17 SRS antenna switching beyond 4Rx in the future for further improved channel estimation. Upon receipt of UE-capability-message, gNB may decide to configure the CPE appropriately, otherwise legacy SRS antenna switching over 4 antennas will always be functional.

4 Network Simulations: 4Rx vs 6Rx vs 8Rx

To estimate realistic benefit of 6Rx / 8Rx in CPEs against a baseline of current 4Rx CPE ecosystem, system simulations were done for both types of 4-layer SU-MIMO and 6 / 8-layer SU-MIMO, with real world urban / suburban site deployment, spectrum scenario and CPE user distribution.

Six sets of comparative results as outlined below are discussed in the subsequent sections:

- All 4Rx UE's who are capable up to 4-layer SU-MIMO [Reference Baseline – 4Rx, 4L].
- All 6Rx UE's who are capable up to 4-layer SU-MIMO [6Rx, 4L].
- All 8Rx UE's who are capable up to 4-layer SU-MIMO [8Rx, 4L].
- All 6Rx UE's who are capable up to 6-layer SU-MIMO [6Rx, 6L].
- All 8Rx UE's who are capable up to 6-layer SU-MIMO [8Rx, 8L].
- All 8Rx UE's who are capable up to 8-layer SU-MIMO [8Rx, 8L].

Coverage, user experience and network capacity metrics are compared.

The first set of scenarios [4Rx-4L, 6Rx-4L & 8Rx-4L] represent today's network configuration where gNB supports up to 4L SU-MIMO. The next two sets of scenarios [6Rx-6L, 8Rx-6L & 8Rx-8L] represent future network configuration when gNBs will support up to 6L / 8L SU-MIMO.

The assumptions we used for these simulations as well as the comparative results are presented in the following sections.

4.1 Simulation Assumptions

The simulations were performed for a cluster in a tier-1 global city, mix of urban and suburban morphologies with realistic site deployment and the following high-level details:

- 346 km² cluster, Urban/Suburban Morphology, 75 Macro Sites, 2.6 km average inter-site distance
- Indoor CPEs deployed near deep indoor (27.3dB average building penetration loss)
- Average 10 active CPEs per sector [full buffer application]
- PC1.5 UL Tx Power, 7dBi peak CPE antenna gain
- 3.7 GHz (n77) band, 100MHz BW, 30kHz SCS, 64TRX, 192AE M-MIMO, Up to 256QAM, 4 or 6 or 8L DL SU-MIMO, 7DSUU TDD

4.2 User Experience Benefits: Near-Cell Deep Indoor CPE

In this section, we discuss the CPE throughput gains when using 6Rx / 8Rx CPE over 4Rx CPE for CPEs which are in near-cell radio conditions.

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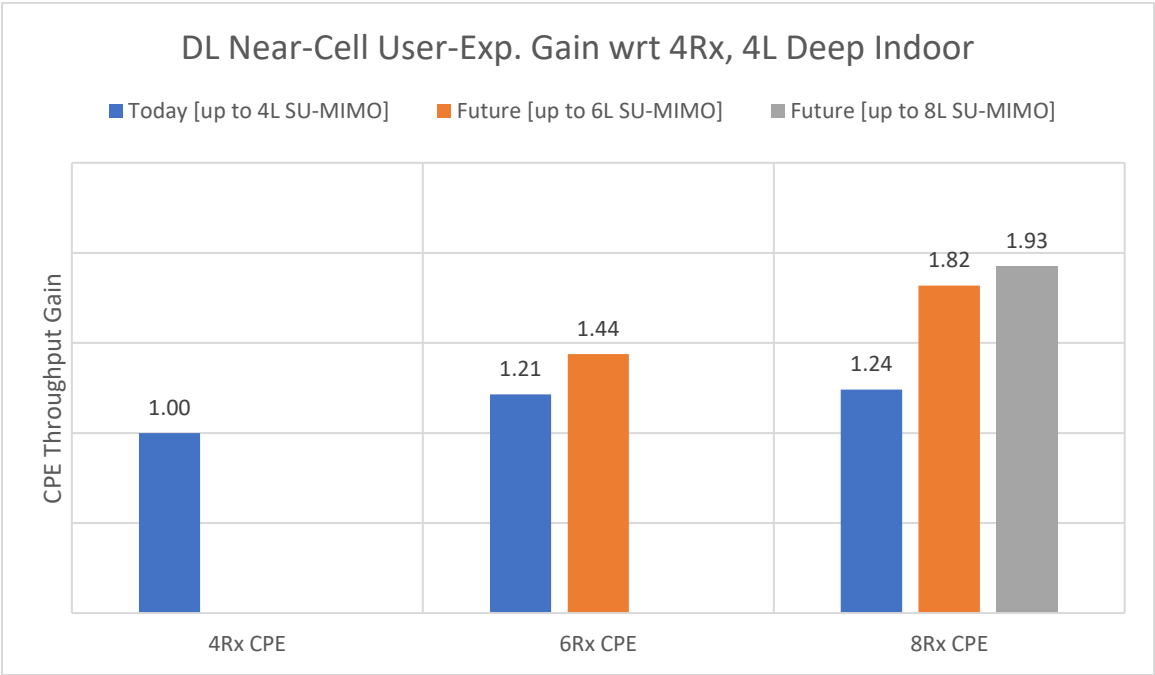


Figure 4-1 Near-Cell DL Throughput

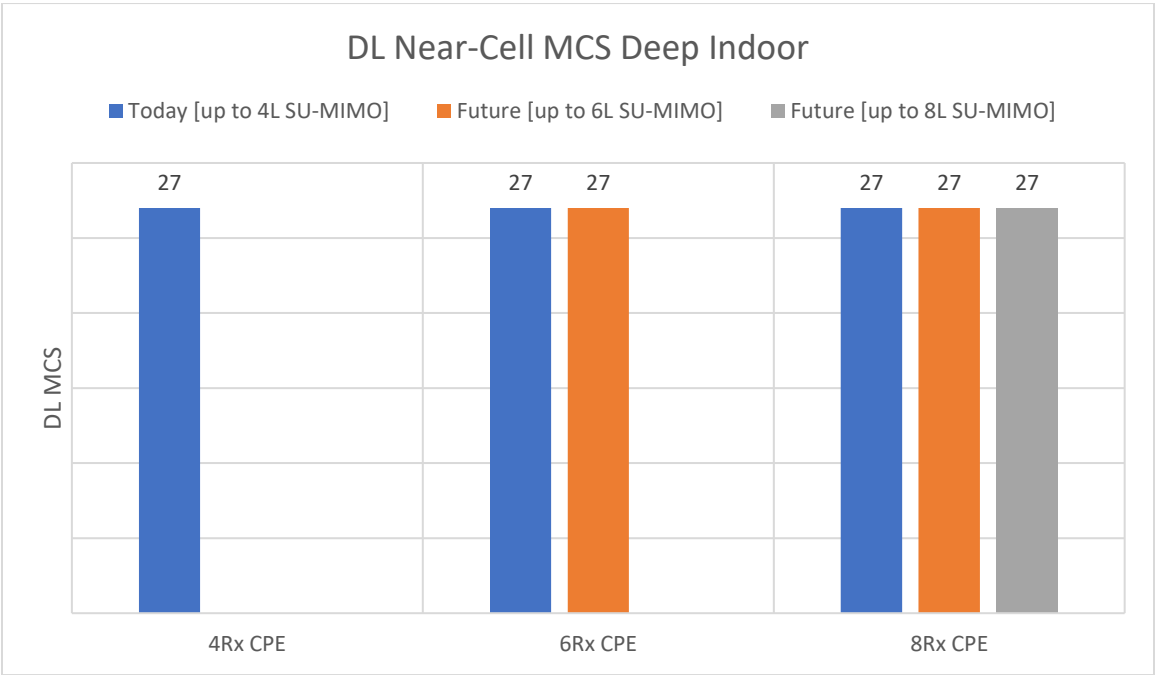


Figure 4-2 Near-Cell DL MCS

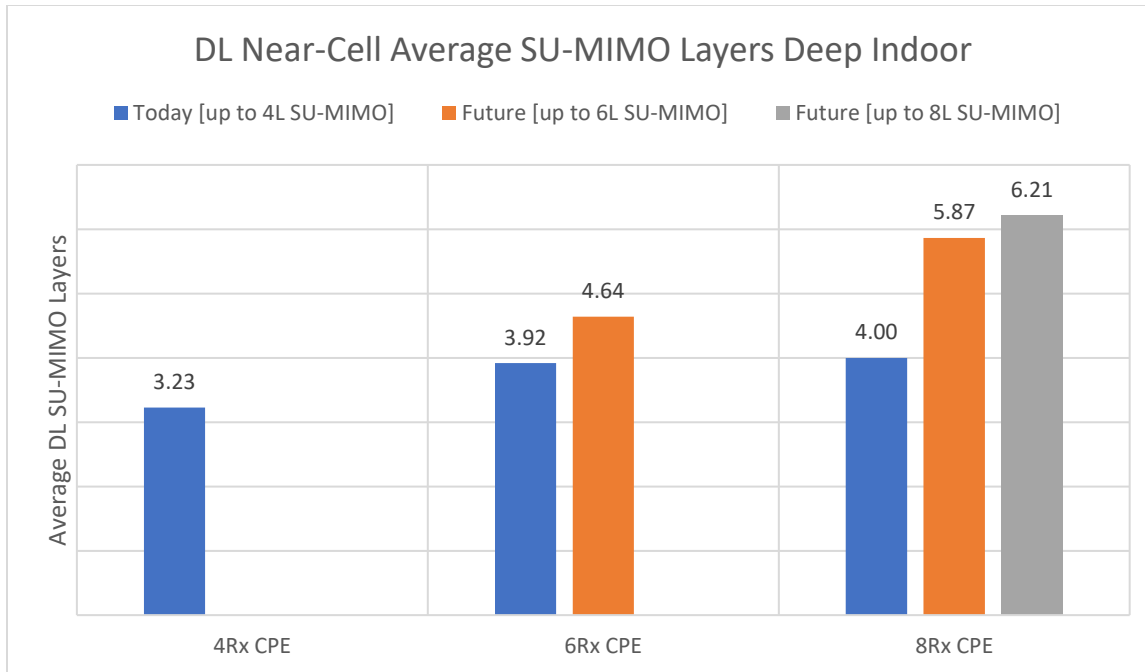


Figure 4-3 Near-Cell Average DL SU-MIMO Layers

Figure 4-1 Near-Cell DL Throughput shows the near-cell user throughputs for all scenarios. Near-cell here represents the top 5th percentile radio condition, not necessarily the highest SINR condition. At near-cell, due to higher number of receive chains over 4Rx CPEs, 6Rx / 8Rx CPEs show up to 21% / 24% respectively higher DL throughput when network supports up to 4L SU-MIMO. Since at near cell, highest MCS is achieved [**Figure 4-2 Near-Cell DL MCS**], benefit primarily stems from higher rank / SU-MIMO layers achieved [**Figure 4-3 Near-Cell Average DL SU-MIMO Layers**] over 4Rx CPEs due to more Rx paths. When going from 6Rx-4L / 8Rx-4L to 6Rx-6L / 8Rx-6L / 8Rx-8L, additional improvement seen at near-cell due to peak 6-layer / 8-layer SU-MIMO, which brings the overall gain for 6Rx-6L / 8Rx-6L / 8Rx-8L to 44% / 82% / 93% respectively over 4Rx-4L. Note that this simulation assumes max 256QAM modulation on DL. If 1024QAM modulation is supported in DL, we would expect incrementally higher gain for 6Rx/4L 6Rx-6L / 8Rx-6L / 8Rx-8L CPE over 4Rx/4L CPE at near cell due to higher SINR, higher probability of 1024QAM with 6Rx / 8Rx.

4.3 User Experience Benefits: Mid-Cell Deep Indoor CPE

In this section, we discuss the CPE throughput gains when using 6Rx / 8Rx CPE over 4Rx CPE for CPE's which are in mid-cell radio conditions.

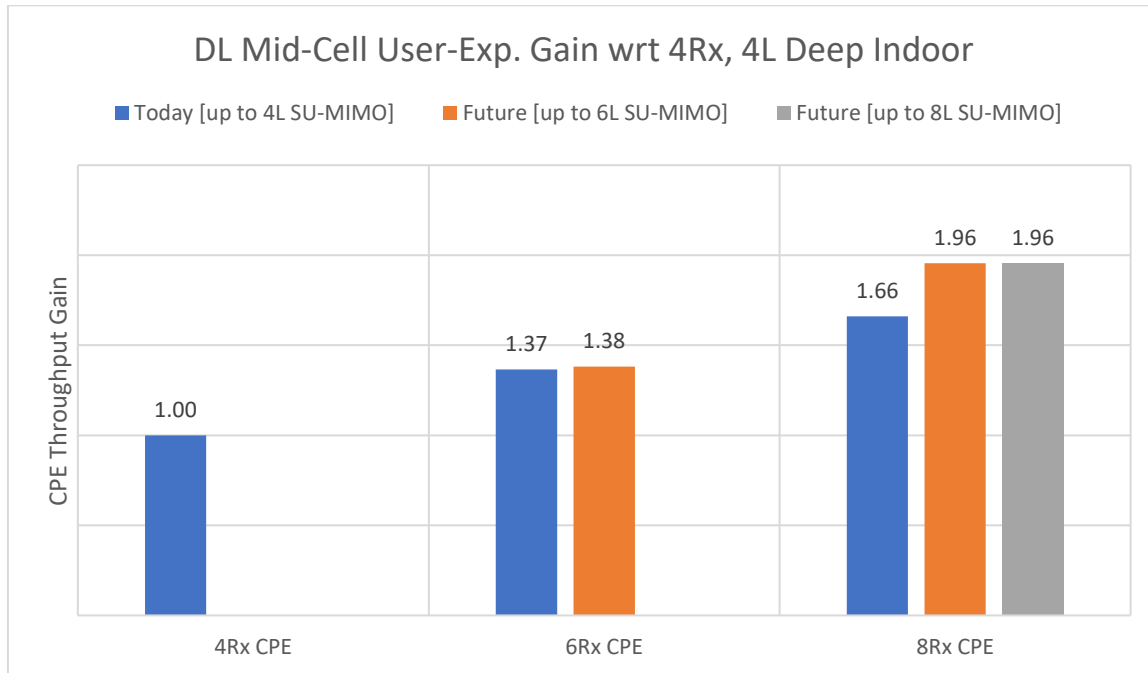


Figure 4-4 Mid-Cell DL Throughput

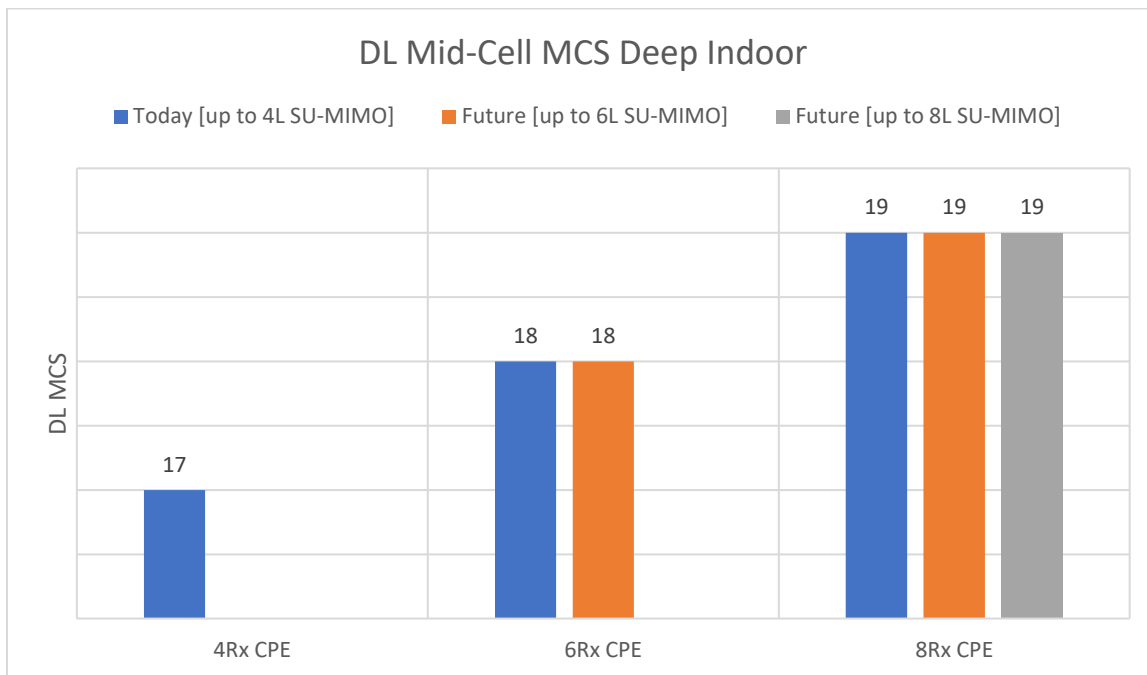


Figure 4-5 Mid-Cell DL MCS

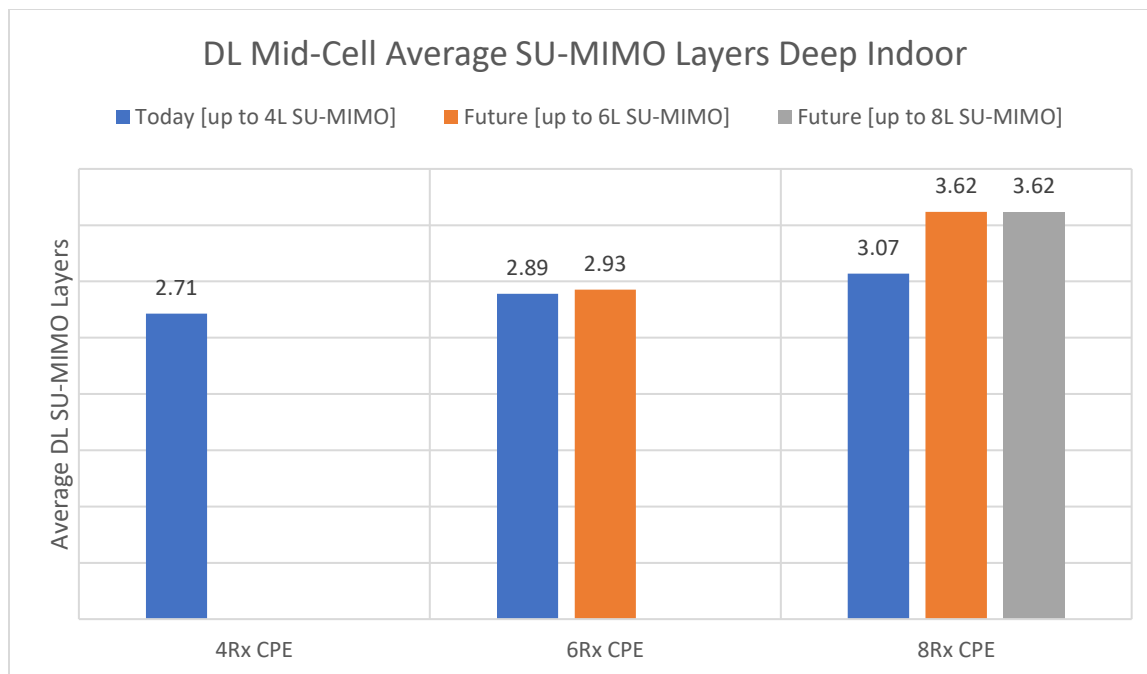


Figure 4-6 Mid-Cell Average DL SU-MIMO Layers

Figure 4-4 Mid-Cell DL Throughput above shows the mid-cell user throughputs for all scenarios. Mid-cell here represents the median radio condition. At mid-cell, due to higher number of receive chains over 4Rx CPEs, 6Rx / 8Rx CPEs show up to 37% / 66% respectively higher DL throughput when network supports up to 4L SU-MIMO. This benefit primarily stems from better diversity gain and interference rejection associated with higher Rx which results in higher MCS [**Figure 4-5 Mid-Cell DL MCS**] and higher rank / SU-MIMO layers [**Figure 4-6 Mid-Cell Average DL SU-MIMO Layers**]. 6Rx-6L performs like 6Rx-4L at mid-cell since number of SU-MIMO layers with 6Rx at mid-cell radio conditions does not exceed 4L. However, 8Rx-6L & 8Rx-8L show additional improvement seen at mid-cell since 8Rx at mid-cell radio conditions enable higher MCS and SU-MIMO layers for CPEs. This brings the overall gain for 8Rx-6L / 8Rx-8L to 96% over 4Rx-4L. Note that gains both 8Rx-6L and 8Rx-8L is 96% since 8Rx at mid-cell radio conditions did exceed 6L SU-MIMO for CPEs.

4.4 User Experience Benefits: Cell-Edge Deep Indoor CPE

In this section, we discuss the CPE throughput gains when using 6Rx / 8Rx CPE over 4Rx CPE for CPEs which are in cell-edge radio conditions.

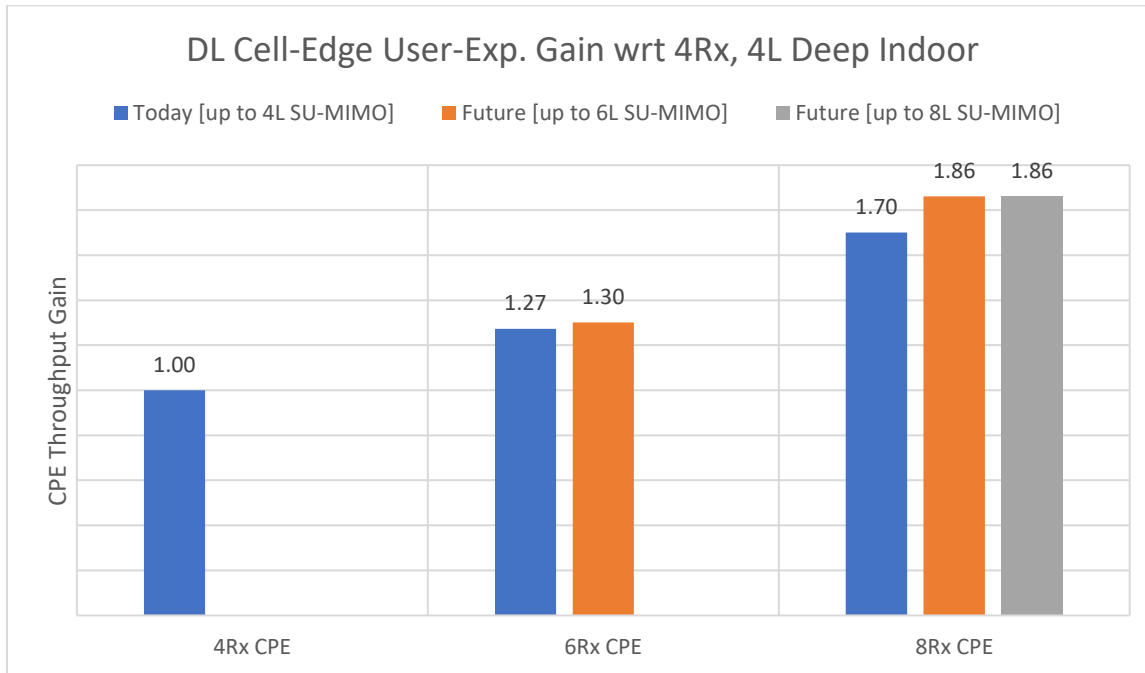


Figure 4-7 Cell-Edge DL Throughput

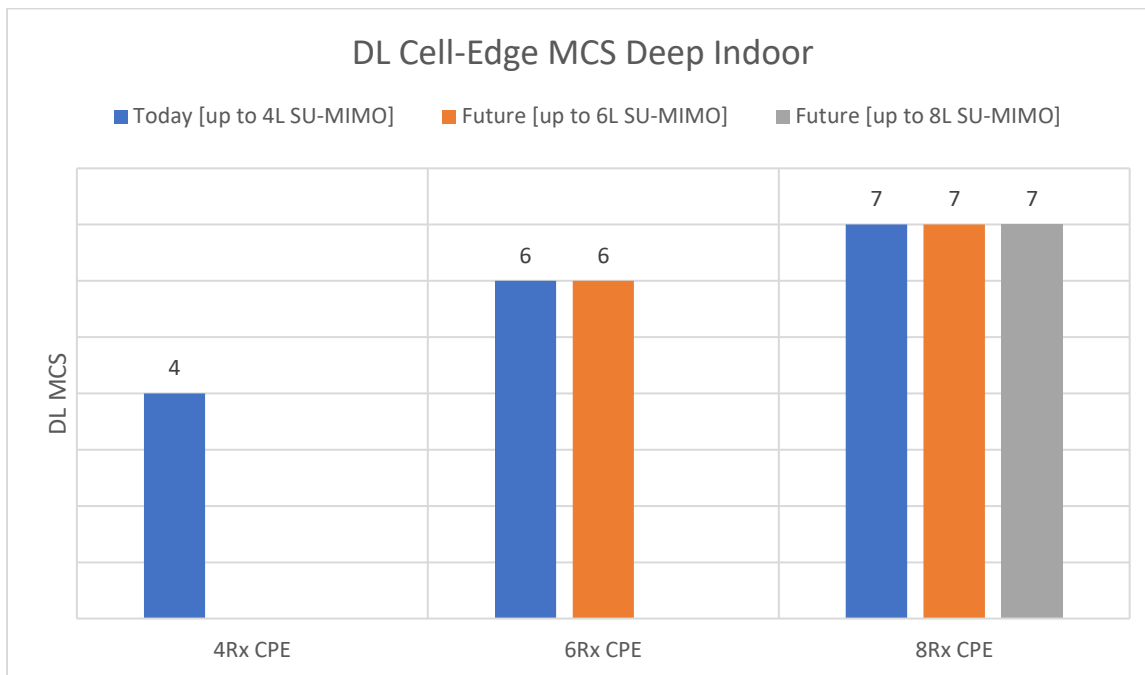


Figure 4-8 Cell-Edge DL MCS

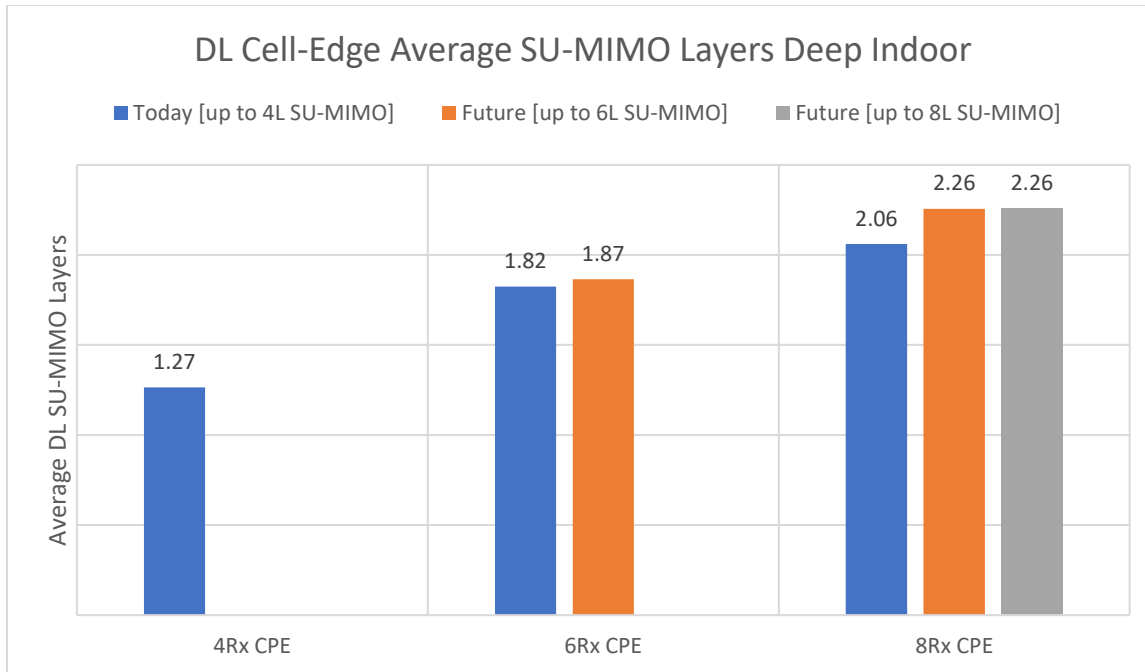


Figure 4-9 Cell-Edge Average DL SU-MIMO Layers

Figure 4-7 Cell-Edge DL Throughput above shows the cell-edge user throughputs for all scenarios. Cell-Edge here represents the worst 5th percentile radio condition, not necessarily the lowest SINR condition. At cell-edge, due to higher number of receive chains over 4Rx CPEs, 6Rx / 8Rx CPEs show up to 27% / 70% respectively higher DL throughput which can be recognized as DL coverage improvement. This benefit primarily stems from better diversity gain and interference rejection associated with higher Rx which results in higher MCS [**Figure 4-8 Cell-Edge DL MCS**] and higher rank / SU-MIMO layers [**Figure 4-9 Cell-Edge Average DL SU-MIMO Layers**]. 6Rx-6L performs like 6Rx-4L at cell-edge since number of SU-MIMO layers with 6Rx at cell-edge radio conditions does not exceed 2L. However, 8Rx-6L & 8Rx-8L show additional improvement seen at cell-edge since 8Rx at cell-edge radio conditions enable higher MCS and SU-MIMO layers for CPEs. This brings the overall gain for 8Rx-6L / 8Rx-8L to 86% over 4Rx-4L. Note that gains both 8Rx-6L and 8Rx-8L is 86% since 8Rx at cell-edge radio conditions did exceed 6L SU-MIMO for CPEs.

4.5 Coverage Benefits: Deep Indoor CPE Deployment

This section quantifies the coverage benefits of using 6Rx / 8Rx CPE over 4Rx CPE when CPEs are deployed deep indoor. Coverage here is defined as percentage of CPEs which get higher than 1Gbps DL CPE throughput. The numbers here are based on the simulation case study cluster assumed for a typical urban to suburban morphology.

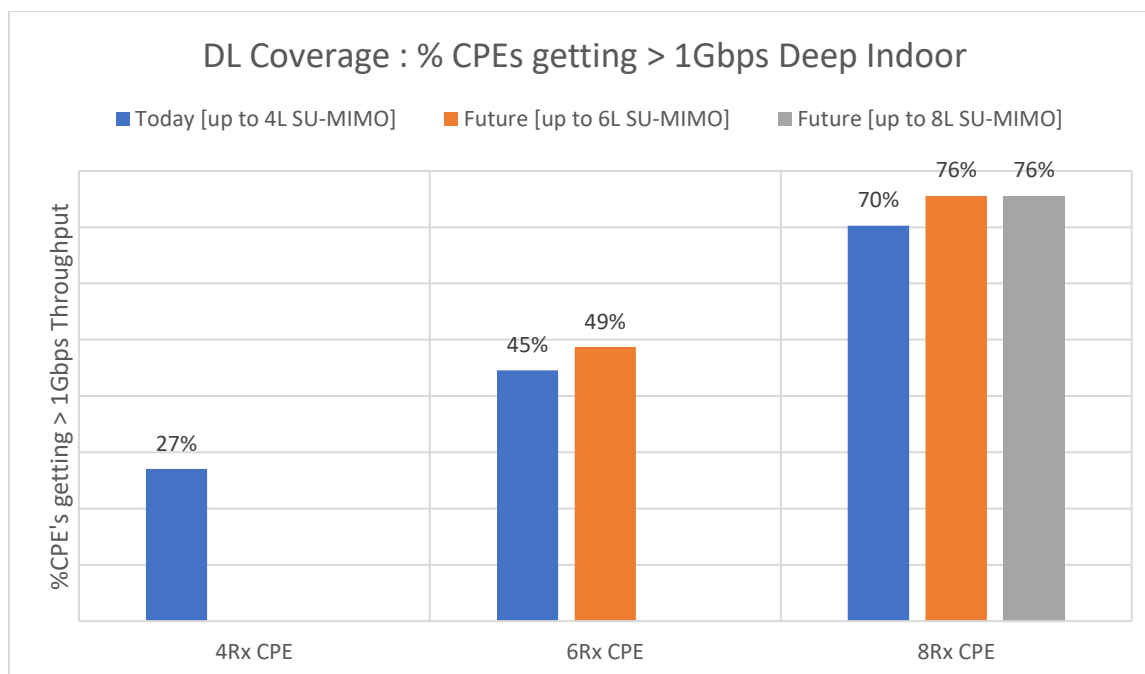


Figure 4-10 DL Coverage: % CPEs getting >1Gbps

Figure 4-10 DL Coverage: % CPEs getting >1Gbps above shows the percentage of CPEs which get higher than 1Gbps as a single user throughput. This would qualify a CPE placed in a household to get target data rate. When targeting 1Gbps service with up to 4L SU-MIMO network support, 6Rx and 8Rx CPEs will cover additional users over 4Rx CPE coverage [18% to 43% percent points higher coverage respectively]. The benefit primarily stems from better diversity gain and interference rejection associated with higher Rx. With 6L and 8L SU-MIMO network support, incrementally higher coverage achieved with 6Rx and 8Rx CPEs since few users likely to get slightly higher MCS and layers due to addition receivers.

4.6 Network Capacity Benefits: Deep Indoor CPE Deployment

This section quantifies the cell capacity benefits of using 6Rx / 8Rx CPE over 4Rx CPE when CPEs are deployed deep indoor. Cell capacity here is defined average cell throughput which factors in user / CPE throughputs at all different radio conditions in the cell.

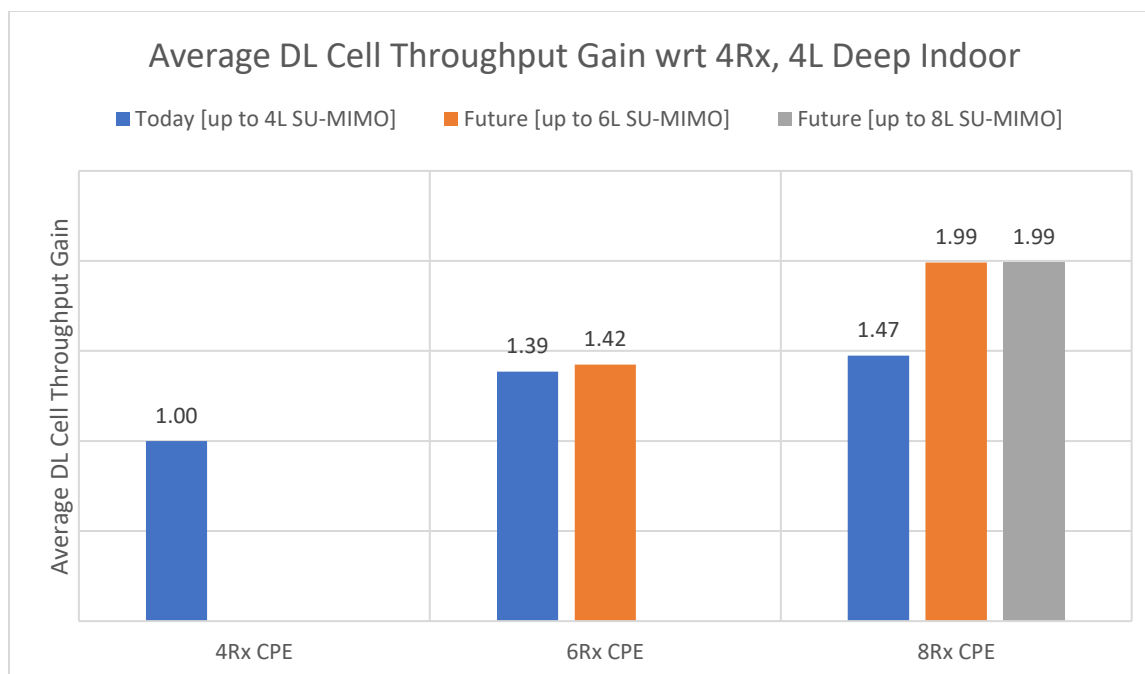


Figure 4-11 DL Cell Capacity

Figure 4-11 DL Cell Capacity above shows the average DL cell throughput assuming 100% UE penetration for each type. with up to 4L SU-MIMO network support, 6Rx-4L / 8Rx-4L brings about 39% and 47% higher DL cell capacity respectively due better SPEF. With 6L and 8L SU-MIMO network support, cell capacity incrementally improves to 42% higher for 6Rx-6L and improves to 99% higher for 8Rx-6L and 8Rx-8L CPEs. UL cell capacity is not impacted since number of Rx in CPE pertains to DL performance only.

5 Deployment Recommendations

6Rx / 8Rx in CPEs will provide superior DL data rates which in turn improves DL cell capacity. Cell level benefits is a function of 6Rx / 8Rx CPE penetration ratio. Many popular CPE applications are DL heavy applications and will benefit from 6Rx / 8Rx. The benefit stems from better receiver diversity gain and better interference rejection which in turn improves SINR and SPEF. Most FR1 bands above 1GHz will benefit from 6Rx / 8Rx in CPEs. Due to larger wavelength and antenna size, antenna spacing requirement FR1 bands below 1GHz will be challenging to implement 6Rx / 8Rx in today's CPE form factor / dimensions. Expedite deployment of 6Rx / 8Rx in CPEs in FR1 bands above 1GHz, followed by roll-out of 6-layer / 8-layer SU-MIMO on DL in the network, especially for M-MIMO networks where high SINR required for 6-layers / 8-layers is achievable.

6 Conclusion

6Rx / 8Rx in CPEs improves downlink coverage and will sustain higher data-rates for all users. It is suitable for superior user-experience which requires higher data-burst rate and faster service time (lower latency). The higher the penetration of 6Rx / 8Rx CPEs in the network, the higher is the

downlink network capacity. The benefits improve further with the introduction of 1024QAM and future 6-layer / 8-layer SU-MIMO on DL. In addition to DL enhancements, availability of 6 / 8 antennas at CPE will provide future opportunities for UL coverage and capacity enhancement features like analog beamforming and/or coherent UL MIMO which will also benefit UL depending on deployment scenario.

We recommend faster and aggressive adoption of 6Rx / 8Rx CPE, to improve coverage, capacity, and user-experience.

References

3GPP TS 38.211 NR; Physical channels and modulation
3GPP TS 38.212 NR; Multiplexing and channel coding
3GPP TS 38.214 NR; Physical layer procedures for data
3GPP TS 38.306 NR; User Equipment (UE) radio access capabilities
3GPP TS 38.311 NR; Radio Resource Control (RRC) protocol specification

Abbreviations

3GPP – 3rd Generation Project Partnership (www.3gpp.org)
CPE – Customer Premise Equipment
FDD – Frequency Division Duplexing
gNB – 5G NR NodeB (the 5G NR base station)
MCS – Modulation and Coding Scheme
MMSE-IRC – Minimum Mean Square Error - Interference Rejection Combiner
PDCCH – Physical Downlink Control Channel
PDSCH – Physical Downlink Shared Channel
RRC – Radio Resource Control
SPEF – Spectral Efficiency
SRS – Sounding Reference Signal
SU-MIMO – Single User Multiple Input Multiple Output
TDD – Time Division Duplexing
UE – User Equipment (CPE, cellphone, cellular IoT device, ...)

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