3GPP TSG RAN Rel-19 Workshop
Taipei, June 15-16, 2023

RWS-230207

# MIMO enhancements in Rel-19

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# Overview

## Key enhancement areas in 5G-Adv in Rel-19

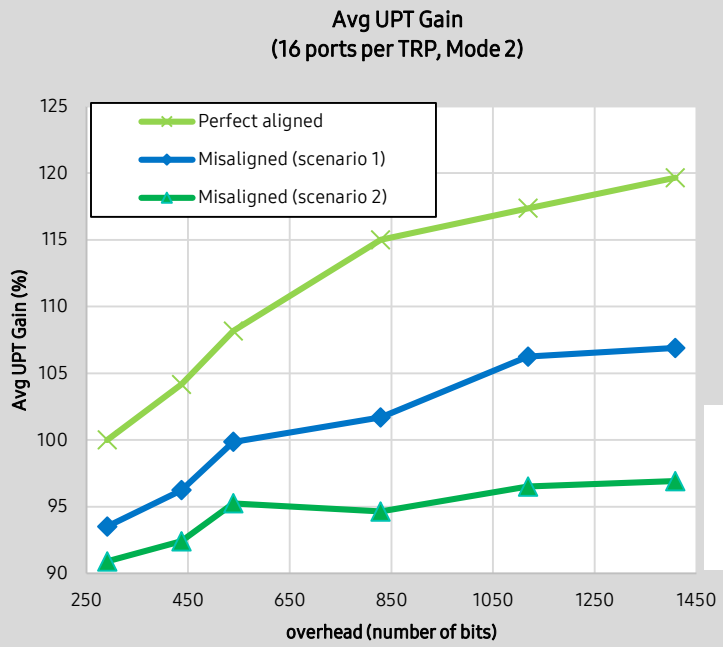
- Multi-TRP enhancement for more challenging and realistic deployment scenarios (e.g. inter-site, non-ideal backhaul and synchronization, higher speed)
- Fast adaptation and low overhead beam management for FR2 multi-beam operation (FR2)
- Further enhanced UL MIMO targeting FWA/CPE

| | Rel-15 | Rel-16 | Rel-17 | Rel-18 | Rel-19 |
|---|---|---|---|---|---|
| Multi-TRP | - Spec-transparent NCJT & CJT (no spec support) | - Multi-TRP SDM based PDSCH (for eMBB)<br>- Multi-TRP PDSCH repetition (for URLLC) | - Multi-TRP PDCCH/PUCCH/PUSCH repetition<br>- Inter-cell, HST scenario support | - CJT based PDSCH<br>- Two TAs (timing advances) for multi-DCI multi-TRP | |
| CSI | - Type I CSI (low resolution)<br>- single/multi-panel codebook<br>- Type II CSI (high resolution)<br>- L1-RSRP reporting | - eType-II: Type-II with low overhead & rank 3 and 4<br>- L1-SINR reporting | - NCJT CSI<br>- FeType-II: Type-II with partial reciprocity by long-term channel property in FDD band<br>- Group-based beam reporting | - Type-II CSI for CJT<br>- Type-II for UE with med/high velocity<br>- Time domain channel property (TDCP) reporting | |
| FR2 Beam | - Basic beam management (BM) for each channel/signal<br>- PCell BFR | - Low-latency/overhead BM (simultaneous activate/deactivate)<br>- SCell BFR | - Unified TCI framework<br>- Per-TRP BFR | - Unified TCI framework extension to multi-TRP use case | |
| UL MIMO | - CB (Codebook) based PUSCH<br>- NCB (Non-codebook) based PUSCH<br>- SRS (<= 4 ports, <= 4T4R for AS) | - Low PAPR RS<br>- UL full-power TX | - SRS: flexible AP triggering, <= 4T8R for AS, Capacity/Coverage Enh.) | - STx2P (simultaneous transmission by 2 panels)<br>- DMRS, SRS, TPMI for UL 8TX | |

# Multi-TRP enhancement: motivation 1

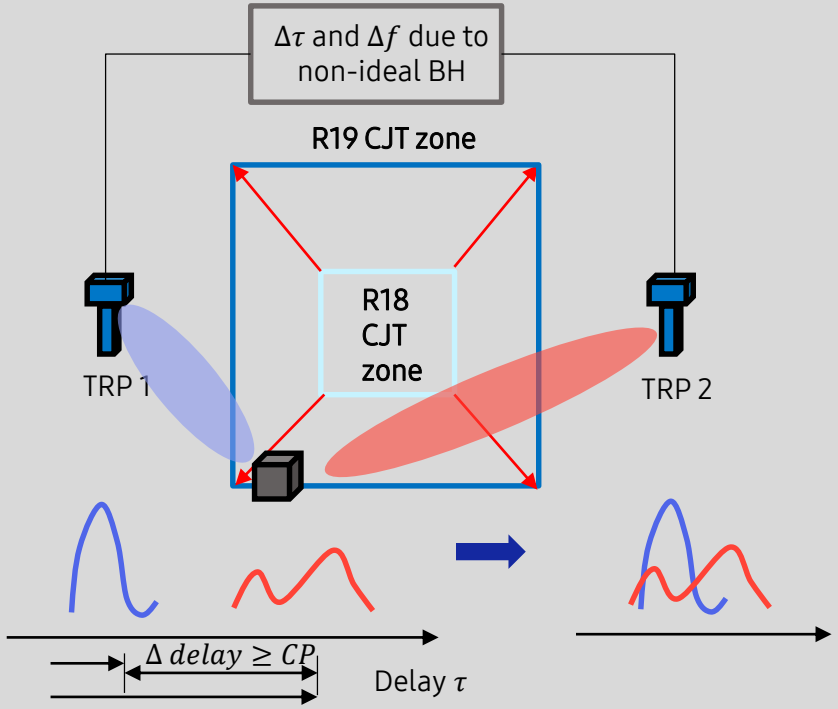
## Motivations for CJT enhancements

- Rel-18 targets intra-site CJT ("ideal" sync and backhaul), restricting applicable deployment scenarios
  - Extending applicable deployment scenarios for CJT is key to large system throughput gain
- Rel-18 supports up to 2 QCLs for CJT measurements while Rel-18 Type-II CJT codebook supports up to 4 TRPs
  - Per-TRP QCL benefits UE measurements for non-collocated TRPs
- Impairments such as inter-TRP phase/delay and frequency offsets are present especially for inter-site M-TRP, causing large throughput degradation
  - Requiring inter-TRP delay/phase/frequency calibration
  - Also requiring inter-TRP DL/UL calibration for TDD CJT
- Implementation-based inter-TRP calibration is challenging
  - Limited knowledge of inter-TRP misalignment on network side




Scenario 1: offset = delay spread

Scenario 2: offset = 3x delay spread



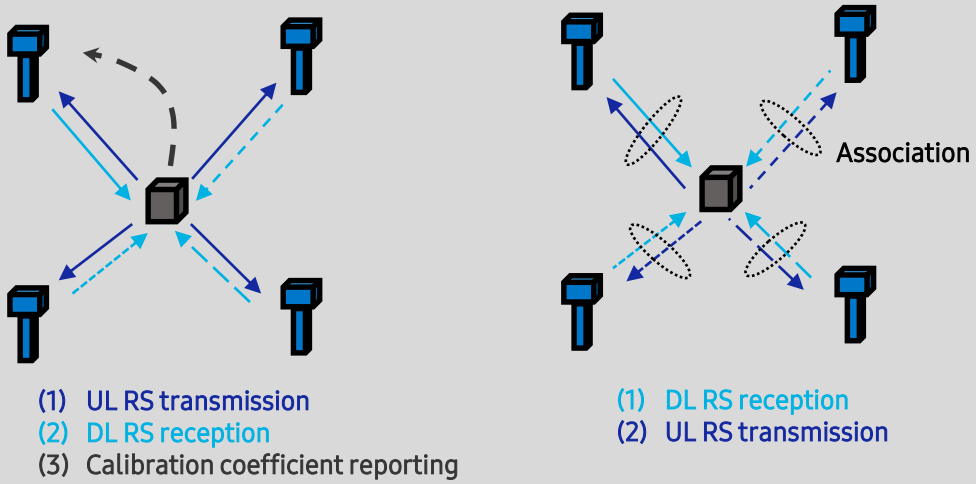
# Multi-TRP enhancement: UE-assisted M-TRP calibration

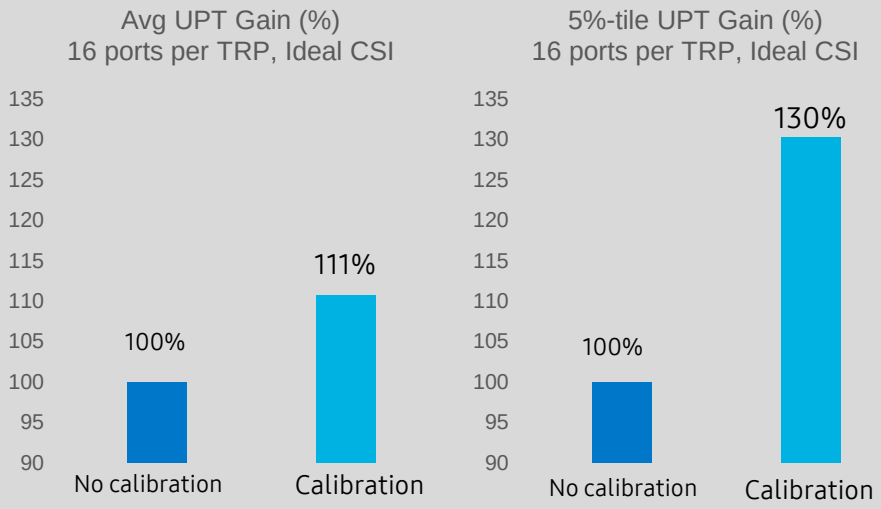
## Reporting/measurement for UE-assisted M-TRP calibration, targeting FDD/TDD

- UE measures DL-RS and reports calibration-assisting information to the network
- Examples: inter-TRP delay/phase and residual frequency offsets, inter-TRP DL/UL calibration correction

## Support up to 4 QCLs to further aid measurements for inter-site CJT

- One QCL per TRP
- Also facilitating association between DL- and UL-RSs for TDD calibration




UE-assisted calibration: TDD

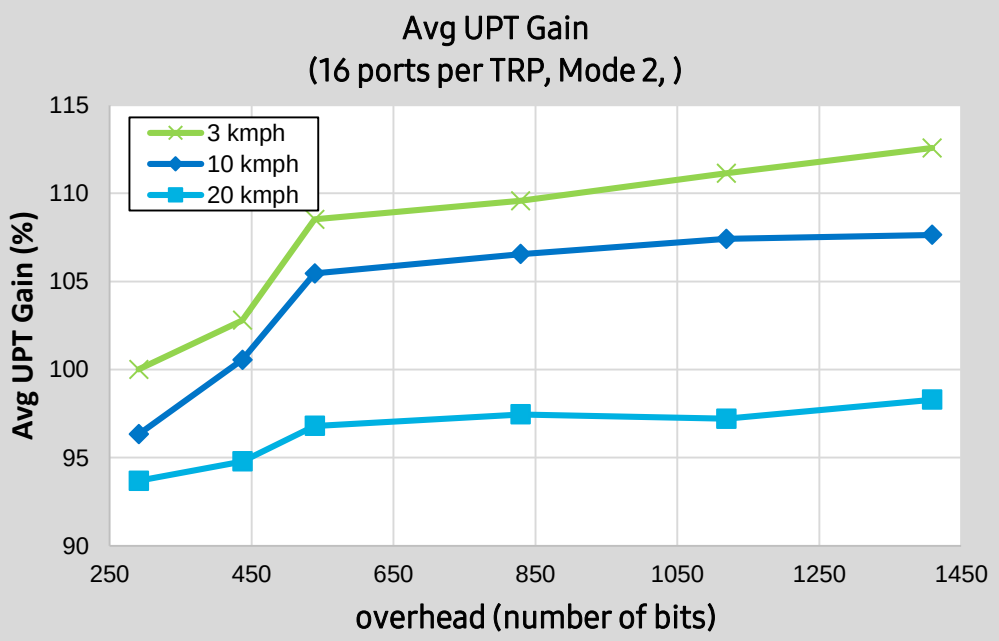
# Multi-TRP enhancement: motivation 2

**Considering CJT coverage, medium/high-speed should be seriously considered**

- Average UPT performance of 10-20 km/h UEs degrades 15% over 3km/h performance

**For FR2, Rel-18 introduces M-TRP enhancements that results in more asymmetry between DL and UL**

- Simultaneous UL TX over two panels
- Two TCI fields potentially corresponding to two different TCI states and/or two different channels




CJT Performance: impact of UE speed



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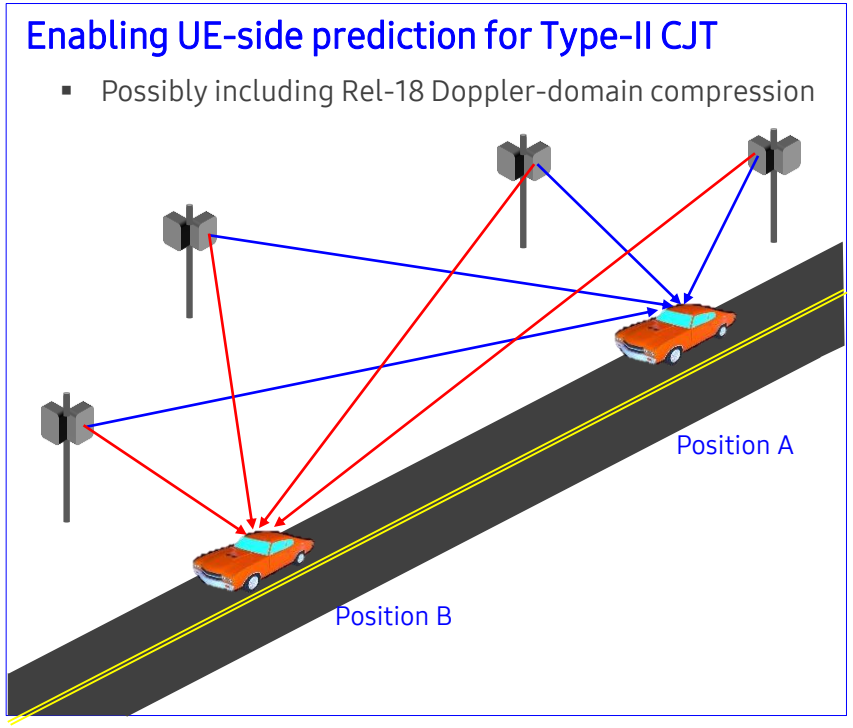
# Multi-TRP enhancement: High-speed and FR2 with asymmetric DL/UL

## Support UE-side prediction for Type-II CJT codebook

- Reusing UE-side prediction framework from Rel-18 Type-II Doppler codebook
- Possibly including Rel-18 Doppler-domain compression, if justified
- Improved throughput for med/high mobility UEs

## Added flexibility for FR2 with asymmetric DL/UL

- Extension of Rel-18 2TA designed for multi-DCI M-TRP to single-DCI-based M-TRP
- UL/PUCCH-based beam failure report (multiple UL beam based failure control)



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# Multi-beam (FR2) enhancement: motivation

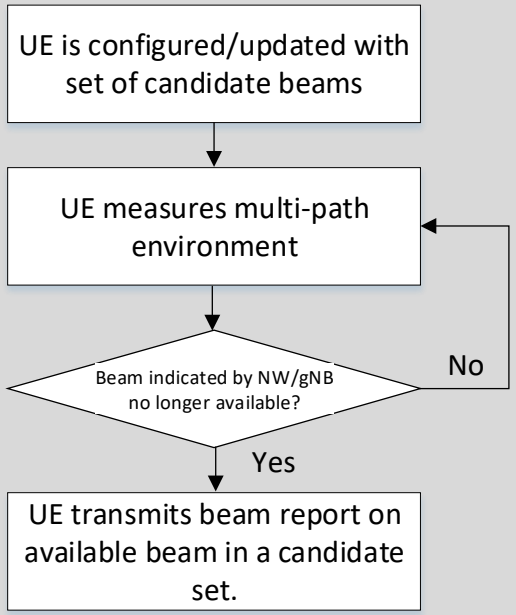
**Although NR specs have made provision for FR2, it remains challenging for deployments with mobile (medium/high-speed) UEs and/or outdoor cellular environments**

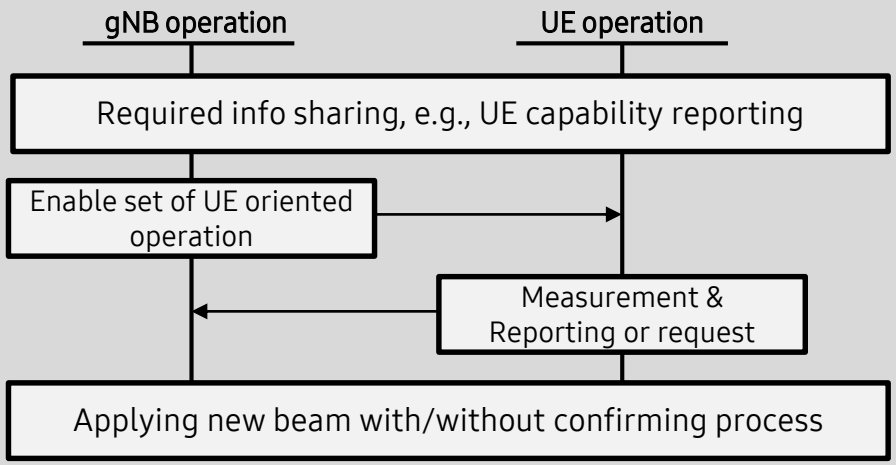
**Network-controlled measurement and reporting incur high latency and/or signaling overhead especially for high-speed UEs**

- In most cases UE knows better when to perform beam switch and/or reporting, i.e. event-based

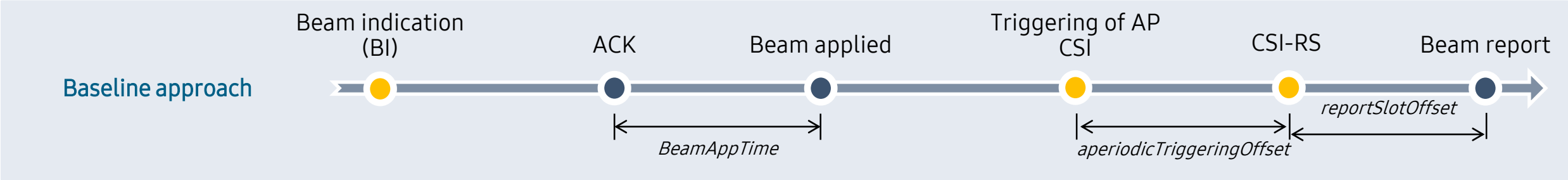
**UE-initiated/event-based beam management will enhance FR2 operations for mobile scenarios**

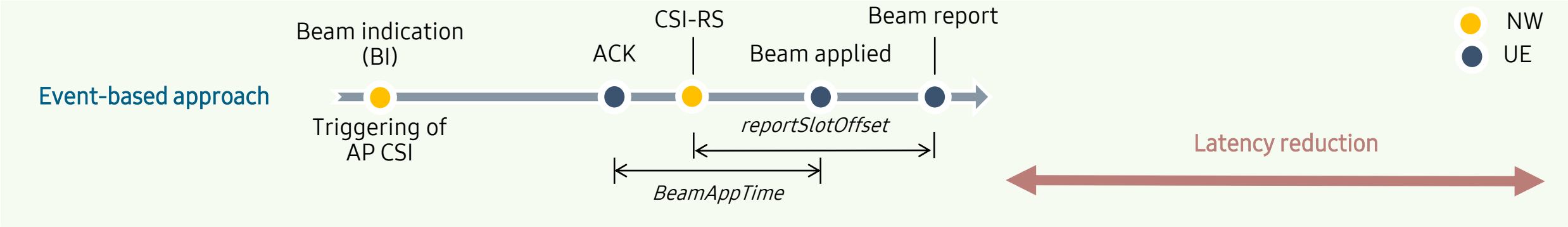
- Reduced latency: circumventing NW trigger/request
- Reduced overhead: reporting only when it's truly needed
- Reduced outage (beam failure, radio link loss): minimize chance for late actions from the network due to lack of knowledge
- Improved FR2 coverage



# Multi-beam (FR2) enhancement: event-based reporting



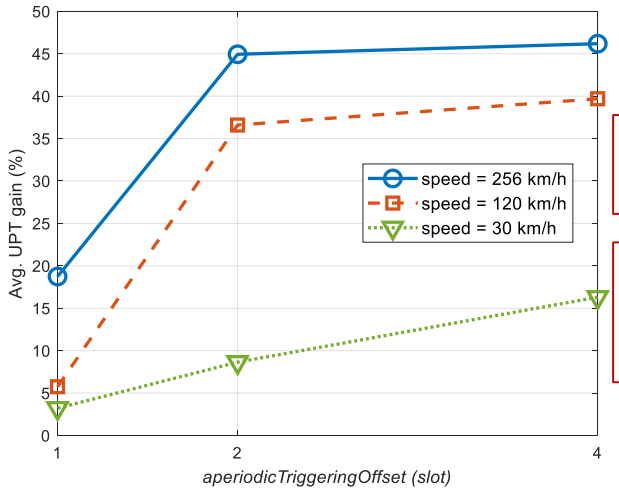

**Beam indication triggers CSI-RS measurement/beam reporting**

- Beam tracking right after beam indication
- Circumventing network triggering of aperiodic beam reporting
- Based on Rel-17/18 unified TCI

**Latency reduction**

- No dedicated time offset between triggering and transmitting CSI-RS

Evaluation results




Event-based over baseline

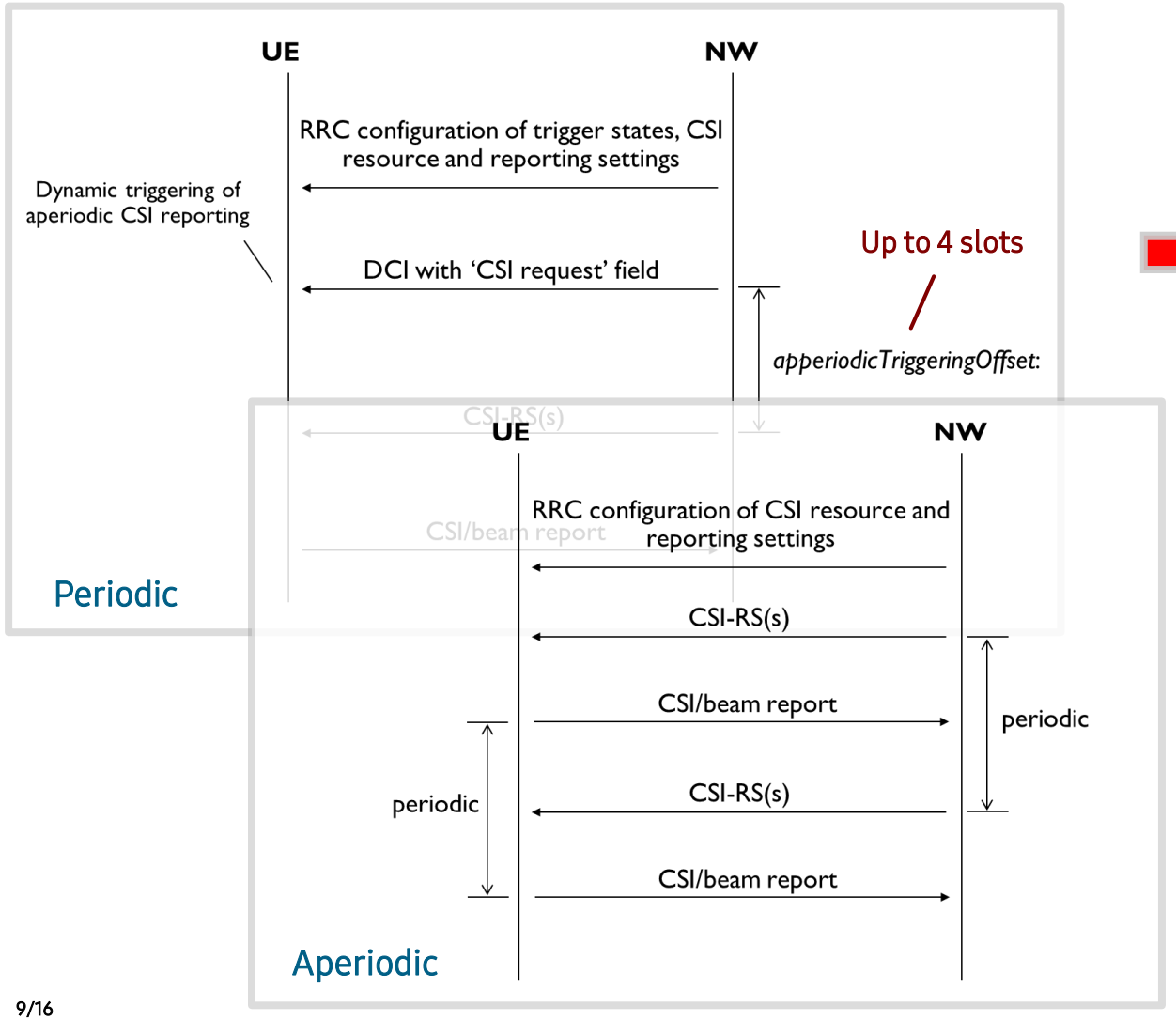
With increase in UE moving speed, avg. UPT gain increases

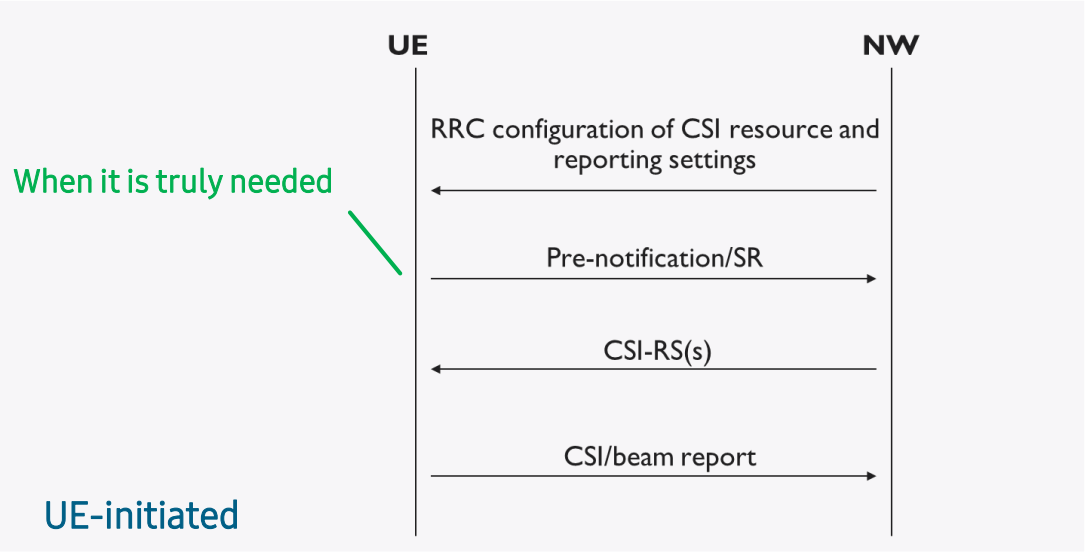
With increase in offset between CSI triggering and measurement, avg. UPT gain increases

High-speed train

# Multi-beam (FR2) enhancement: UE-initiated reporting

Large overhead/latency reduction especially for HST (e.g., ~250 km/h) at FR2

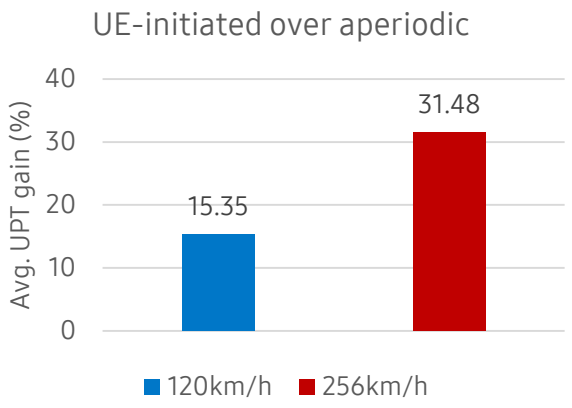



## Evaluation results

| Parameters | Values |
|---|---|
| SCS | 120 kHz |
| BW | 100 MHz |
| Number of PRBs | 66 |
| Distance between RRHs | 200 m |
| UE Speed | 120, 256 km/h |
| Number of beams per RRH | 64 |
| Number of active UEs | 1024 |

High-speed train



# Multi-beam (FR2) enhancement: predictive beam management

**For high-speed scenarios requiring fast beam switching, latency and overhead are competing goals**

- Faster beam switching (minimizing latency) incurs large overhead
- Slower beam switching (minimizing overhead) results in beam failure

**However, beam switch trajectory is often predictable**

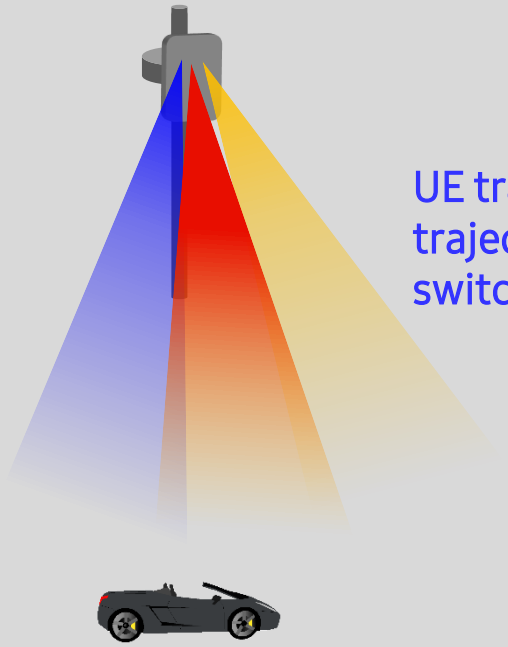
- Examples: vehicular (highways), high-speed train: railways

**Predictive beam indication**

- Beam indication using TCI-group signaling representing beam switching trajectory
- Based on the streamlined Rel-17 and Rel-18 unified TCI
- Faster beam indication (from prediction) with greatly reduced (PDCCH) overhead

**Predictive beam measurement/reporting**

- Reporting of best beam sequence based on beam trajectory
- Faster beam reporting (from prediction) with greatly reduced (PUS/CCH) overhead



UE traveling on predictable trajectory → predictable beam switching behavior

| | | | | | | |
|---|---|---|---|---|---|---|
| TCI $State_0$ | $T_0$ | TCI $State_1$ | $T_1$ | ------- | TCI $State_{N-1}$ | $T_{N-1}$ |

Beam Indication of N TCI states with activation time for each

A UE receives a beam indication with a TCI state and an activation time (T).

↓

At activation time T, UE applies TCI State.

# Further enhanced UL for FWA/CPE: motivation

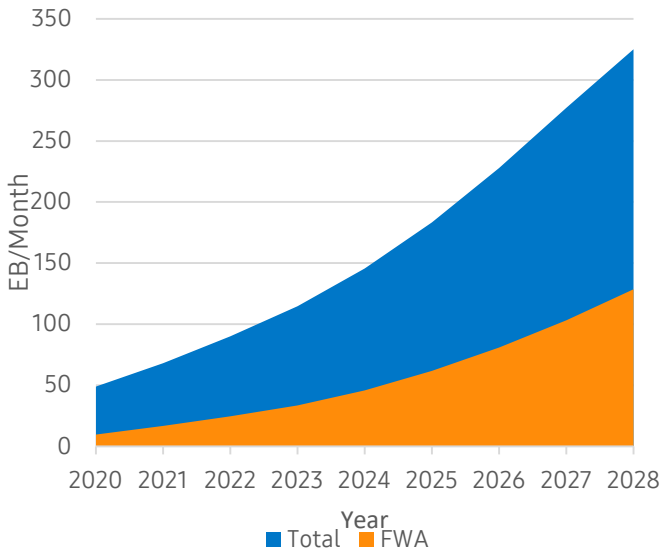
**FWA/CPE is a key use-case in 5G and constitutes 40% of traffic of 5G in 2028** [Ericsson report]

**70% of FWA/CPE are for indoor and mostly used for DL-heavy traffic** [GSA report]

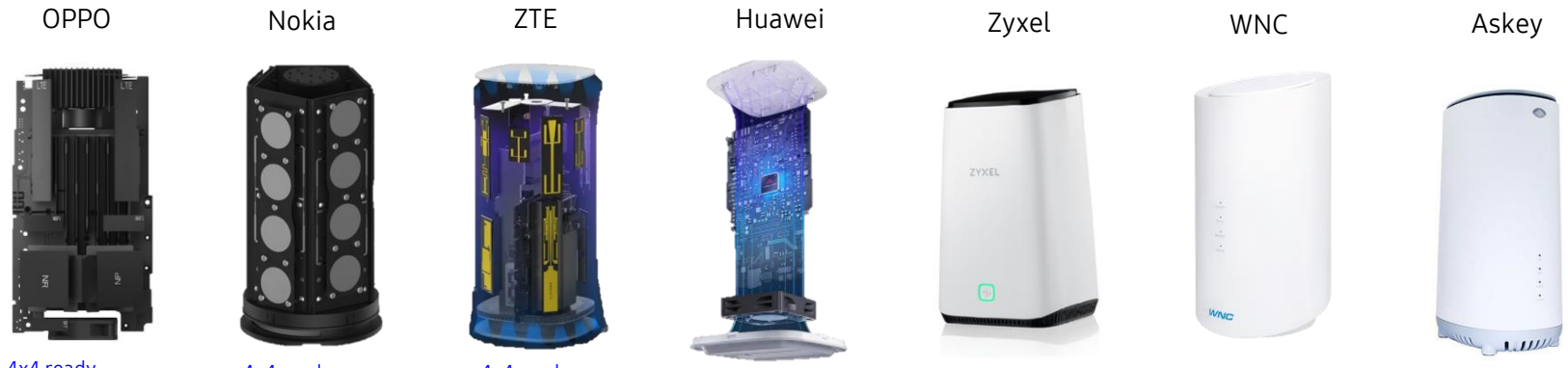
## UL MIMO potential for FWA/CPE:

- Form factor is suitable for larger antenna architecture: 8Tx UL MIMO for FR1
- Capability is suitable for UL sensitive services such as AR/VR (20x), online meeting (2-3x)
- Advanced UL MIMO precoding (up to 8 layers) is expected to perform well since channel is quasi-static yet rich in scattering

FWA traffic expectation




Current major product lines



| OPPO | Nokia | ZTE | Huawei | Zyxel | WNC | Askey |
|---|---|---|---|---|---|---|
| 4x4 ready<br>8 antennas for FR1<br>2 panel for FR2 | 4x4 ready<br>20 antennas for FR1<br>No FR2 | 4x4 ready<br>8 antennas for FR1<br>2 panel FR2 | 4x4 ready<br>4 antennas for FR1<br>No FR2 | 4x4 ready<br>4 antennas for FR1<br>No FR2 | 4x4 ready<br>8 antennas for FR1<br>No FR2 | 4x4 ready |



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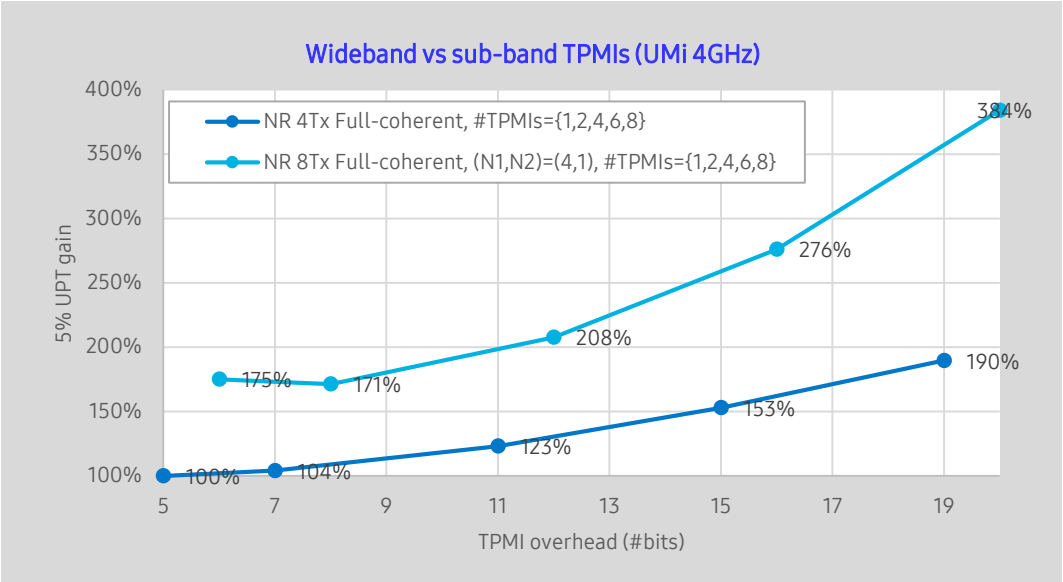
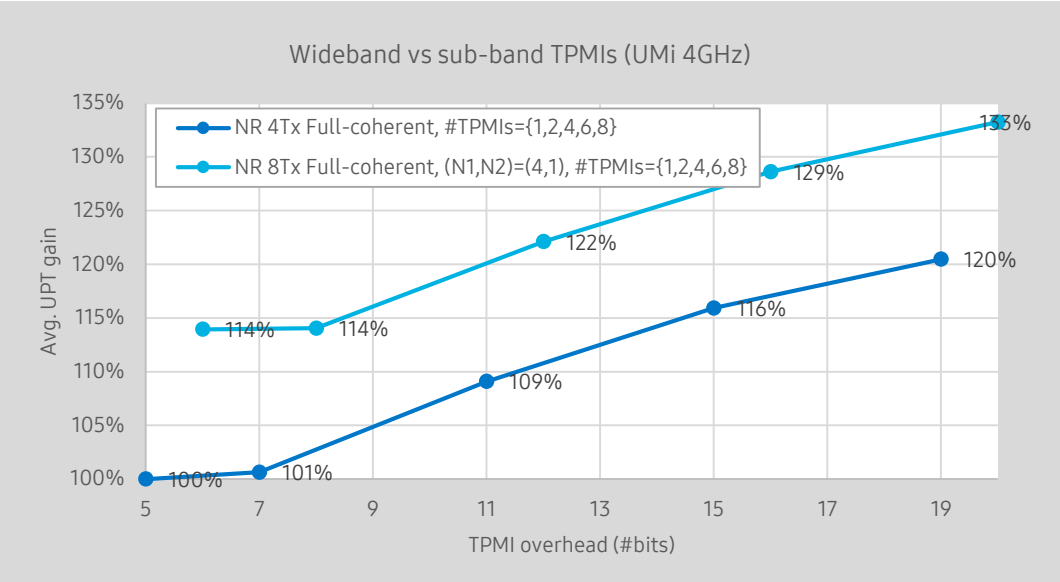
# Further enhanced UL for FWA/CPE: UL sub-band precoding

## UL sub-band codebook-based precoding for FDD:

- Sub-band TPMI based on dual-stage codebooks targeting 4Tx and higher
  - Dual-stage 8Tx UL codebook is already supported in Rel-18, but …
  - Dual-stage 4Tx UL codebook needs additional spec support
- Two-part UL DCI (analogous to sidelink):
  - Part 1: Fixed TPMI payload
  - Part 2: Variable sub-band TPMI payload depending on UL resource allocation



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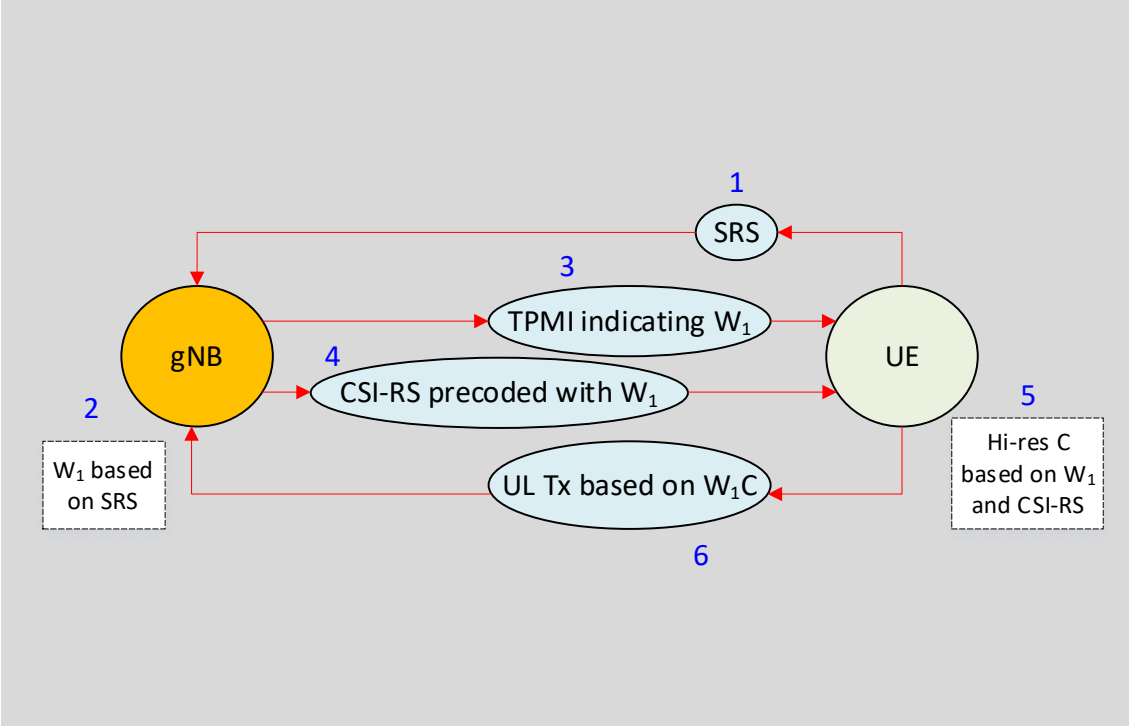
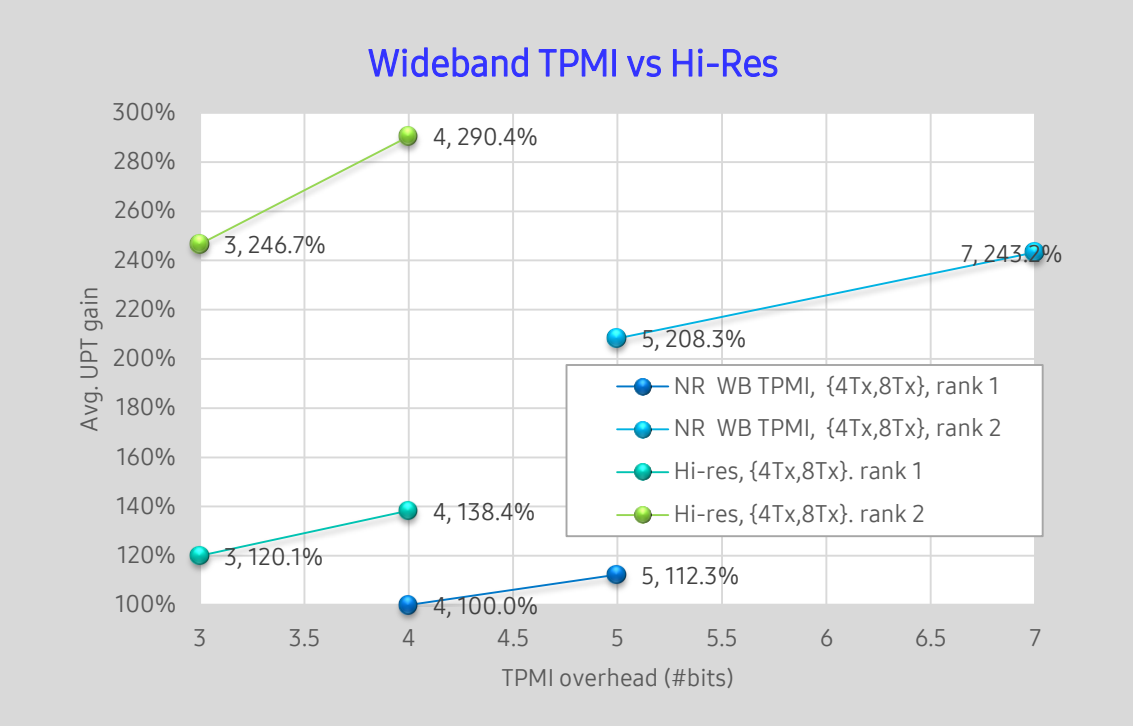
# Further enhanced UL for FWA/CPE: UL hi-res precoding

## UL high-resolution precoding for TDD

- Unquantized performance analogous to Type-II DL codebook can be achieved in UL, if UE-side DL/UL reciprocity is feasible, with the same payload as wideband TPMI
- Utilizing $W_1$ part of dual-stage codebook
- Vastly superior to Rel-15 UL non-codebook-based transmission



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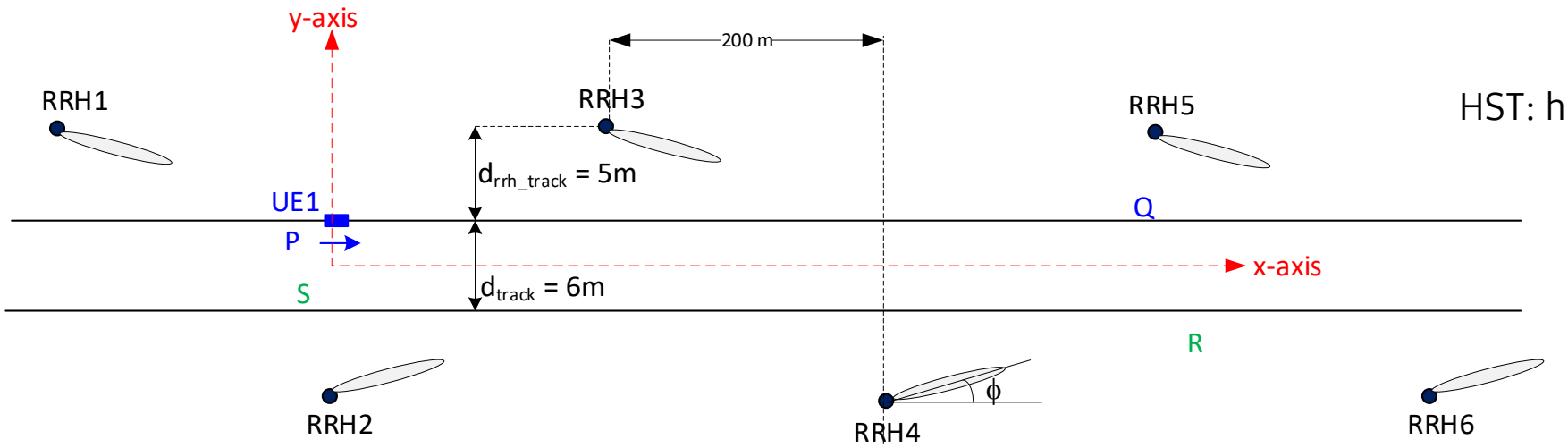
# Conclusion

## Driving factors: high network capacity via expanded M-TRP deployment, outage-free low overhead/latency FR2 operation for mobile, ultra-high UL data rate and coverage for FWA/CPE

- UE-assisted inter-TRP calibration measurement and reporting to circumvent impairments due to non-ideal backhaul and synchronization – both for TDD and FDD, targeting FR1
- Extending Rel-18 Type-II CJT codebook for high/medium-speed with UE-side prediction – targeting FR1
- UE-initiated/event-based beam reporting and switching – targeting FR2, based on Rel-17/18 unified TCI (*)
- Predictive beam indication and reporting – targeting FR2, based on Rel-17/18 unified TCI (*)
- High-resolution and frequency-selective UL precoding – targeting FR1 and FWA/CPE use case
- Miscellaneous: 2TA support for S-DCI M-TRP, UL-based BFR – targeting FR2

(*) Also applicable for/with AI/ML-based beam management

# Appendix: HST setup for UE-initiated/event-based




- Simulation parameters are based on TR38.802/913
- UE moves horizontally, either to the left or right
- At a given time, UE receives PDSCH only from one RRH



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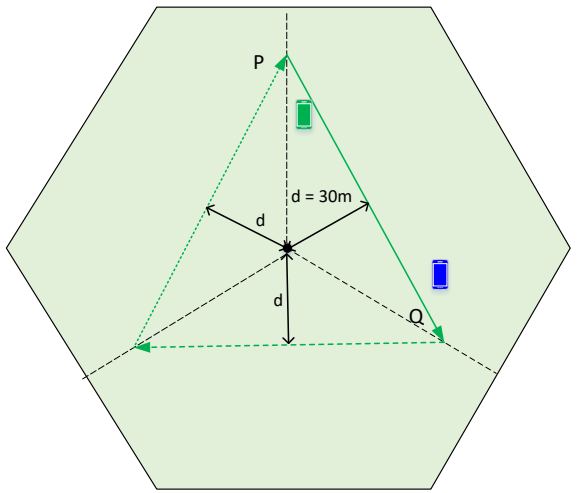
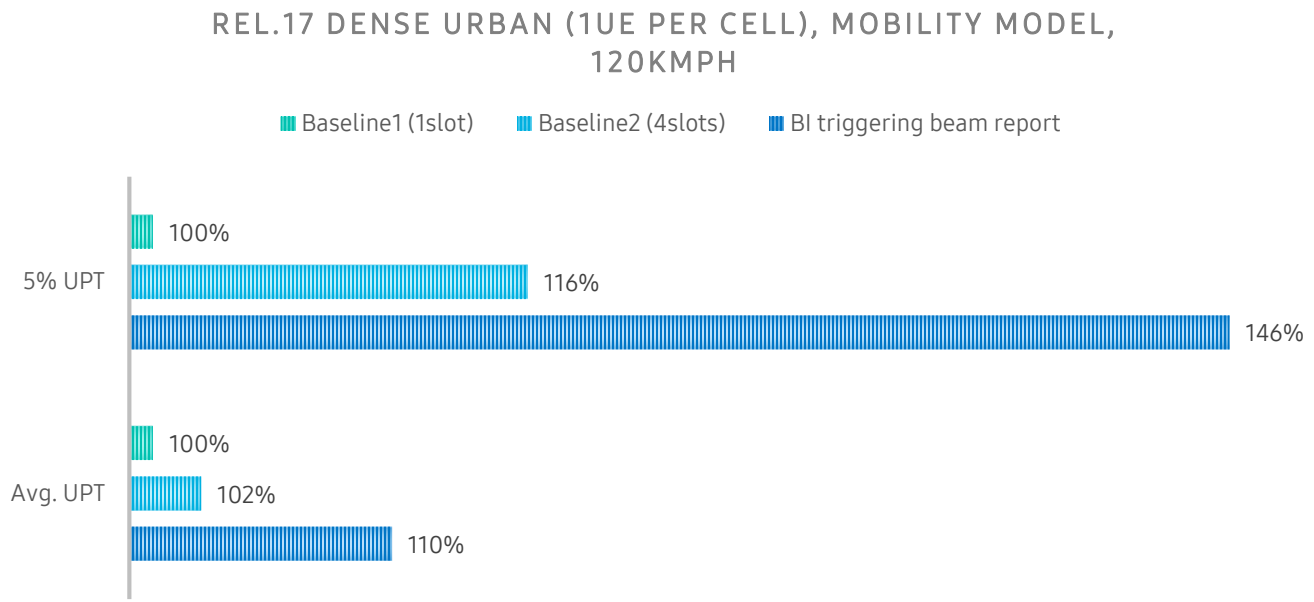
# Appendix: additional results on event-based beam reporting

- Rel-17 Dense Urban model for beam management, used to emulate highway scenario
- UE moves along one of the trajectories on the triangle

- **Observation**: Up to 10% and 45% gain in average and cell-edge throughputs, respectively (due to latency reduction)




**Baseline1**: DL-DCI (carrying BI) → UL-DCI (triggering beam report)
→ gap = 1 slot

**Baseline2**: BI → ACK → UL-DCI (triggering beam report)
→ gap = 4 slots

**BI (beam indication) triggering** beam report
→ gap = 0



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