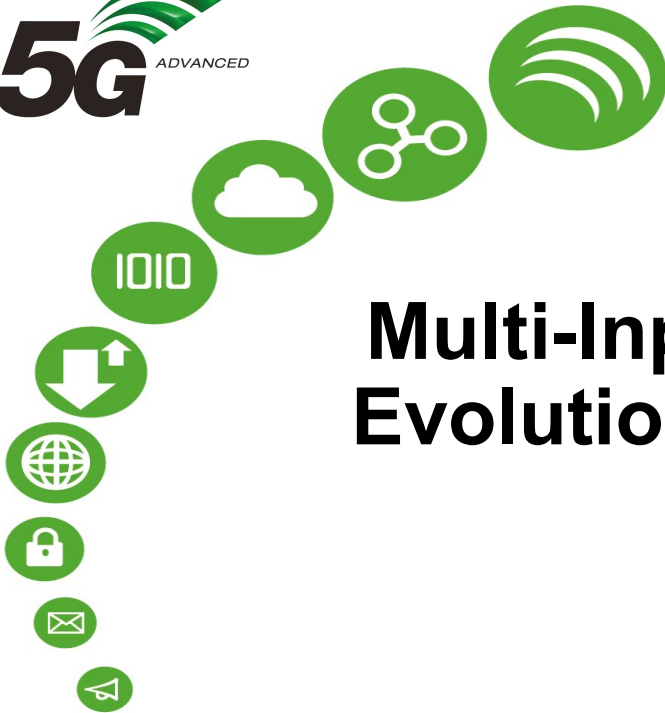




Multi-Input Multi-Output (MIMO) Evolution: Toward Unlocking 6G Potential

Dr. Eko Onggosanusi
Senior Director, Samsung
June 12, 2026

Overview

- 📶 Reimagining MIMO for 6G: new challenges
- 📶 Mid-band spectrum for 6G:
 - Opportunities and challenges
- 📶 AI-powered Semantic Channel State Information (CSI) Compression
- 📶 Distributed MIMO
 - Use cases beyond traditional communications
- 📶 Reviving mmWave with High-Capacity Architecture

Reimagining MIMO | New 6G challenges

New media/app

3D Interactive Streaming

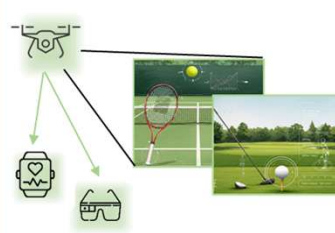


New terminals/devices

Guide and Memory Aid



GenAI Life Coaching



New service

ISAC (Security, Care)



Common denominator:

- Low latency
- High-rate and bursty data traffic
- Ubiquitous connectivity

Scenario-driven but avoid fragmentation

- Single framework multi-capability
- Coverage vs capacity



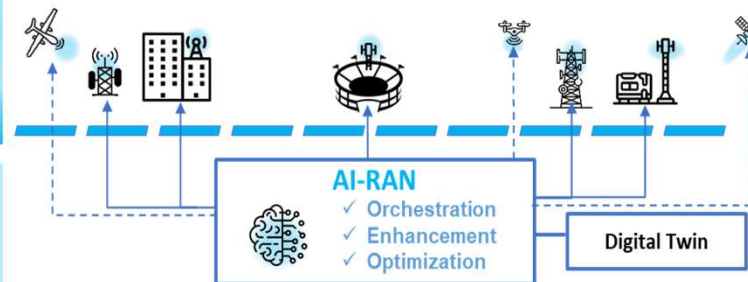
Robots & Physical AI
Query & remote control (DL)
Bursty small rate
Sensing data uploading for off-device processing (UL)
Bursty variable rate



AR glasses
Voice Query (UL)
Bursty small rate
Cont. video uploading (UL)
Bursty variable rate
Display on glasses (DL)

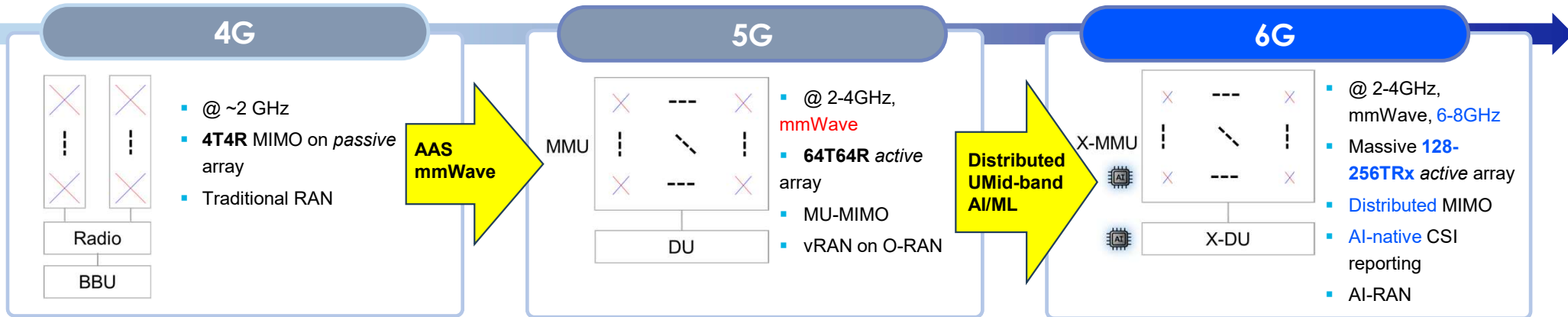


6G AI Smartphone
Multi-modal Query (UL)
Bursty high rate
Multi-modal response (DL)
Bursty high rate
3D video streaming (DL)



AR: Augmented Reality
DL/UL: Downlink/Uplink
ISAC: Integrated Sensing and Communication
RAN: Radio Access Network

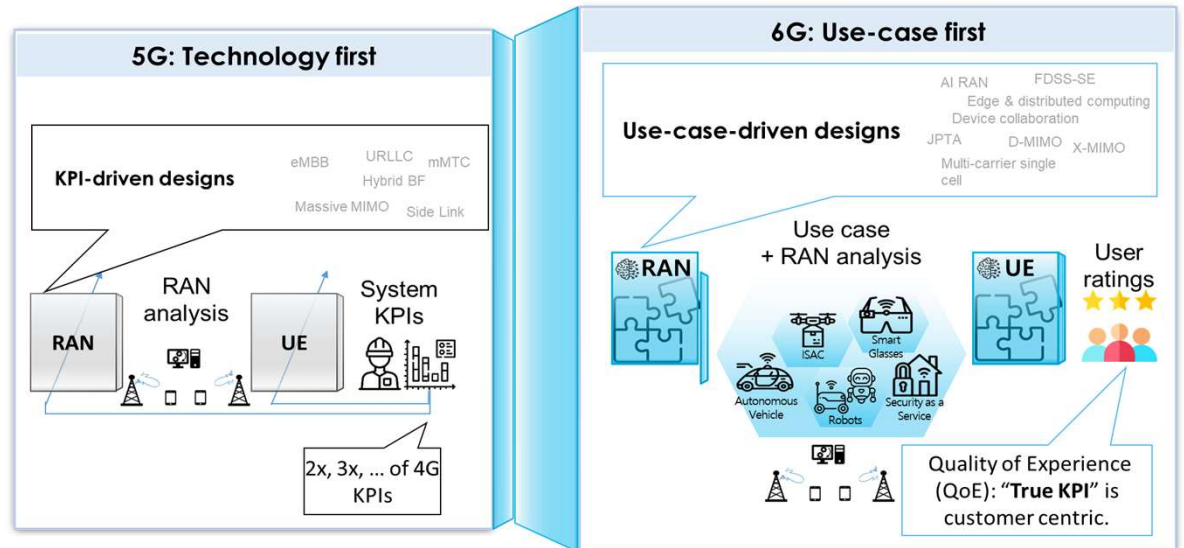
MIMO Evolution | 4G → 5G → 6G



Revolution-driven Evolution:

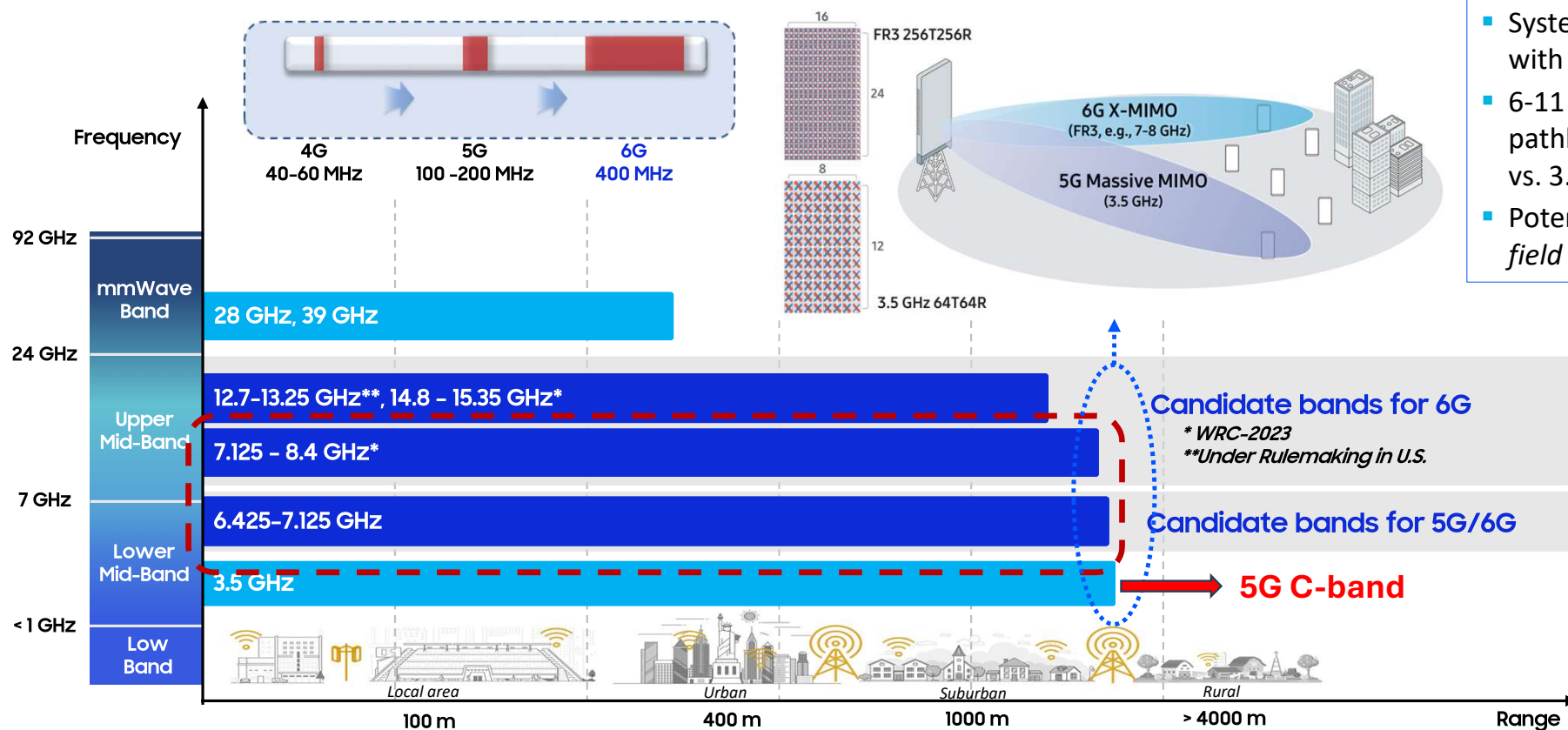
- 🌿 New RF and antenna array technology
- 🌿 New spectrum
- 🌿 New network architecture
- 🌿 Paradigm shift

AAS: Active Antenna System
 CSI: Channel State Information
 CSI-RS: CSI Reference Signal (DL measurement)
 KPI: Key Performance Index
 O-RAN: Open-RAN
 SRS: Sounding RS (UL measurement)
 UE: User Equipment (terminal)
 UMid-band: Upper mid-band
 vRAN: virtualized RAN



Upper Mid-band for 6G | Opportunities and challenges

Bandwidth per operator: 4G 40-60 MHz → 5G 100-200 MHz → **6G 400 MHz**



Main Challenges

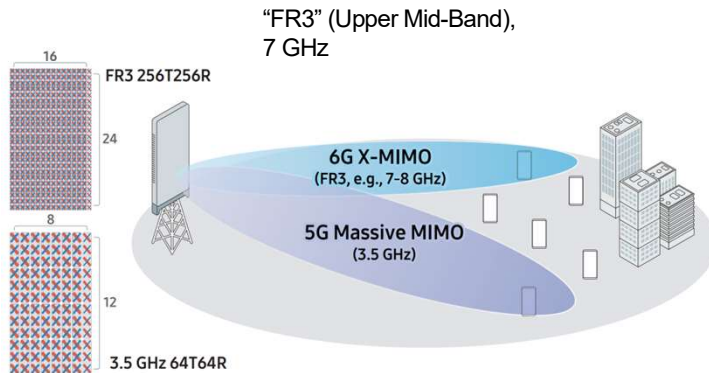
- System overhead with 256TRx
- 6-11 dB extra pathloss @ 7GHz vs. 3.5GHz
- Potential *near-field* effect

Upper Mid-band 6G MIMO | Single-Node Outdoor Test Bed

Comparable coverage with C-band despite path-loss challenges at upper mid-band

🌿 Single Node (single TRP)

Upper Mid-band MIMO (X-MIMO)



Design targets

- Comparable coverage as C-band with beamforming (90% downlink coverage of 5G C-band)
- More capacity with higher-order spatial multiplexing (~2.5x average user spectral efficiency)
- Up to 400MHz carrier bandwidth

“FR3” (Upper-Mid-Band) Test setup for outdoor test (Seoul, Korea)



C-band (terrestrial): 3.7-4.2GHz (FCC)
MMU: memory management unit
NLOS: non Line-of-Sight
TRP: Transmit-Receive Point

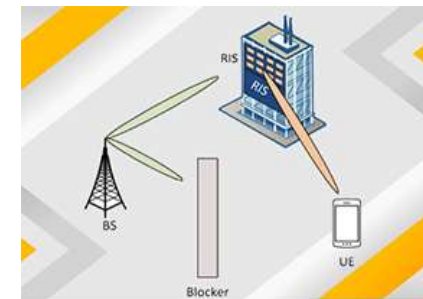
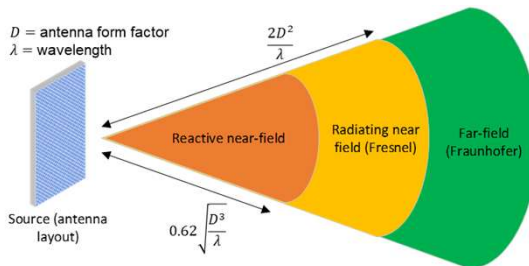
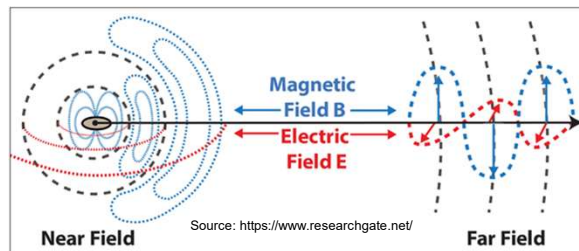
3D view for X-MMU installed on A-Tower rooftop

Achieved 1.68 Gbps Downlink Peak Throughput
w/ 256QAM & 4-layer (NLOS)

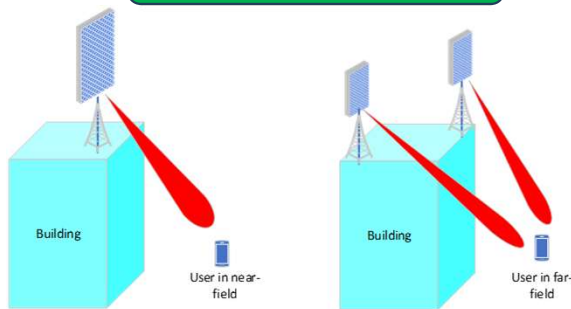
Upper Mid-band 6G MIMO | When Near-Field (Fresnel) Effect Manifests

Near field (NF) effect: spherical wavefront (vs planar in far-field) + decoupling of E and B fields

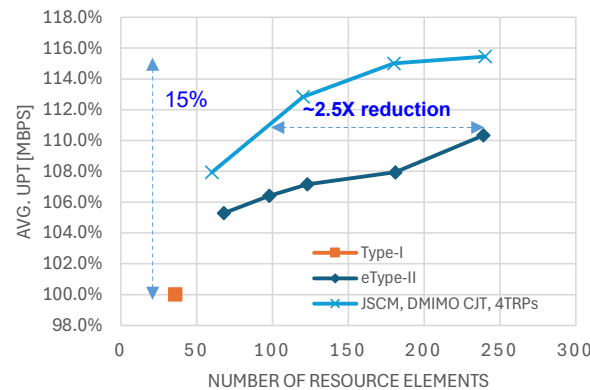
- Proximity to 'large-sized' antenna array relative to Rayleigh distance $2D^2/\lambda$
- Deployment site reuse of C-band for upper mid-band



Direction 1: Distributed MIMO (D-MIMO)

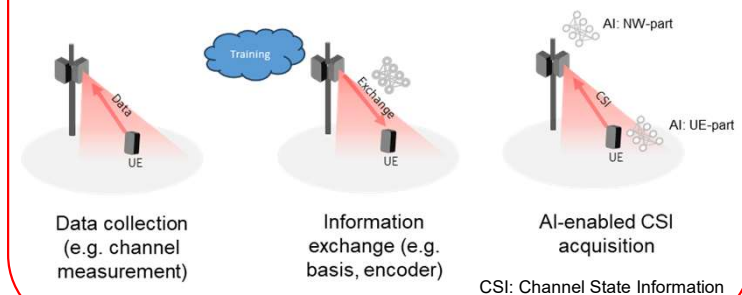


7GHZ, URBAN MACRO 200M ISD, 768TXRU -> 128PORTS, RANK-1: NEAR-FIELD

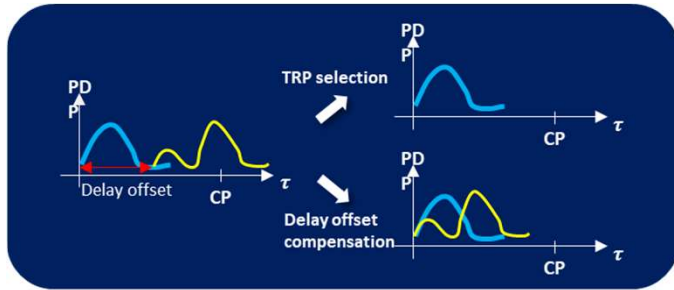


Source: Samsung, to be presented in RAN1

Direction 2: AI-enabled (scenario-driven) CSI acquisition



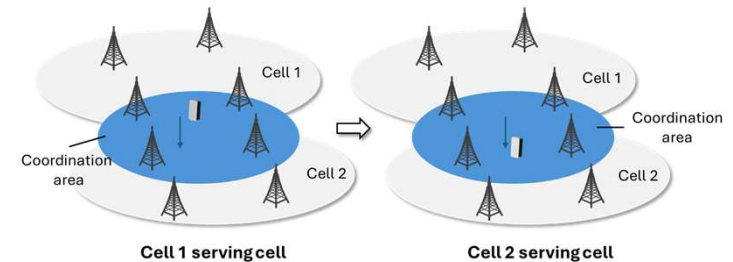
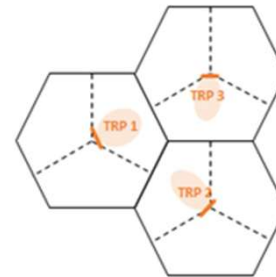
Distributed MIMO | Overcoming Deficient Point-to-Point Channel Rank



Source: 3GPP RAN1, Samsung, R1-2400728, R1-2402460

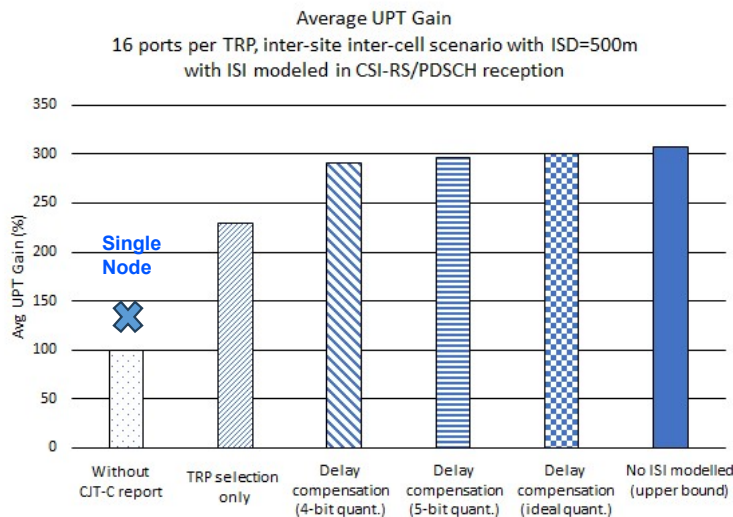
Key Ingredients:

- Multi-Node Channel State Information (CSI)
- Inter-Node (inter-TRP) calibration (delay, frequency offsets)



Value proposition:

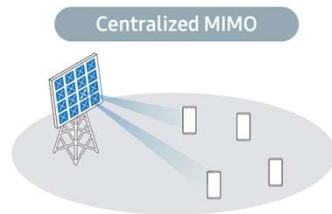
- Both capacity and coverage boost
- Spatial multiplexing gain for rank-deficient channels
- Seamless "cell-free" experience



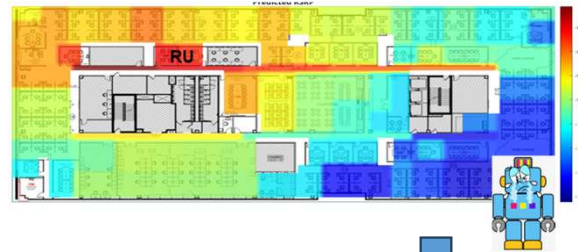
CJT-C: Coherent Joint Transmission Calibration
TRP: Transmit Receive Point
UPT: User Perceived Throughput

Distributed MIMO | Overcoming Indoor Robotics Blindspot

Robotics requires *reliable low-latency* communication link *anywhere*



RSRP heatmap for centralized MIMO (SRA-SMI office)



20dB coverage boost + 3x capacity boost



RSRP heatmap for D-MIMO (SRA-SMI office)



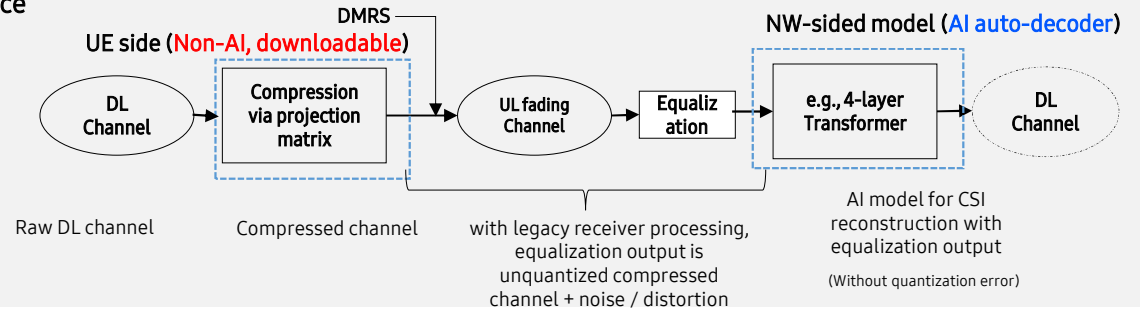
SRA-SMI: Samsung Research America – Standards and Mobility Innovation

Channel State Information (CSI) | AI-based Semantic Compression

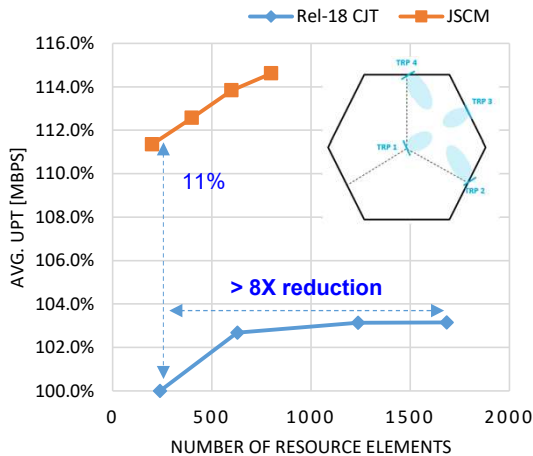
Joint Source Channel-Coding Modulation (JSCM):

- Network-side auto-decoder → no inter-vendor collaboration
- Greatly reduced UL overhead
- Lower UE complexity & processing latency
- Future-proof to new scenarios

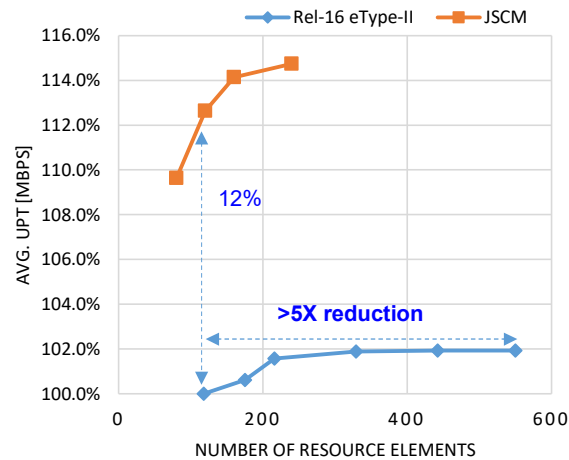
Inference



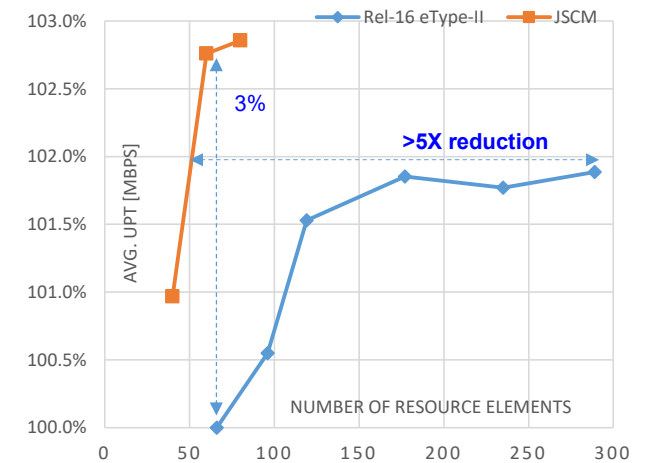
DMIMO, NTRP=4, 8 PORTS/TRP, RMA, MAXRANK2, SU



STRP, 64 PORTS, UMA, MAXRANK2, SU



STRP, 64 PORTS, UMA, MAXRANK1, MU



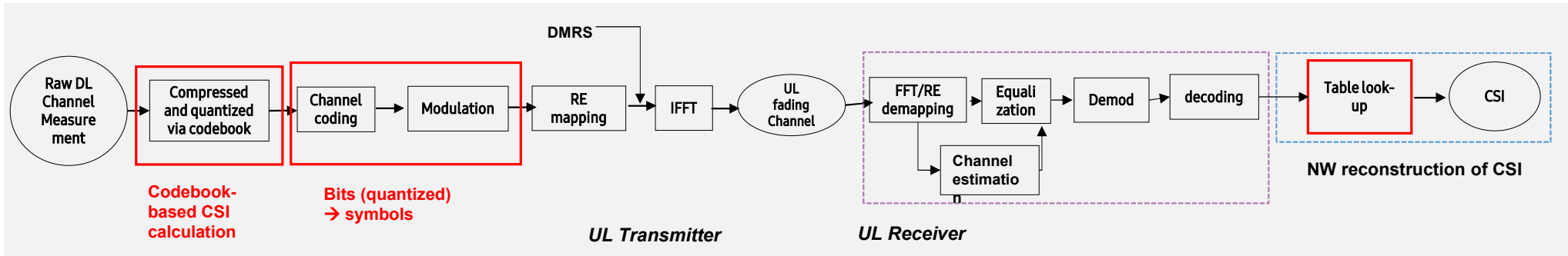
Source: 3GPP RAN1, Samsung, R1-2605065

(*) JSCM: Joint Source Channel Coding Modulation

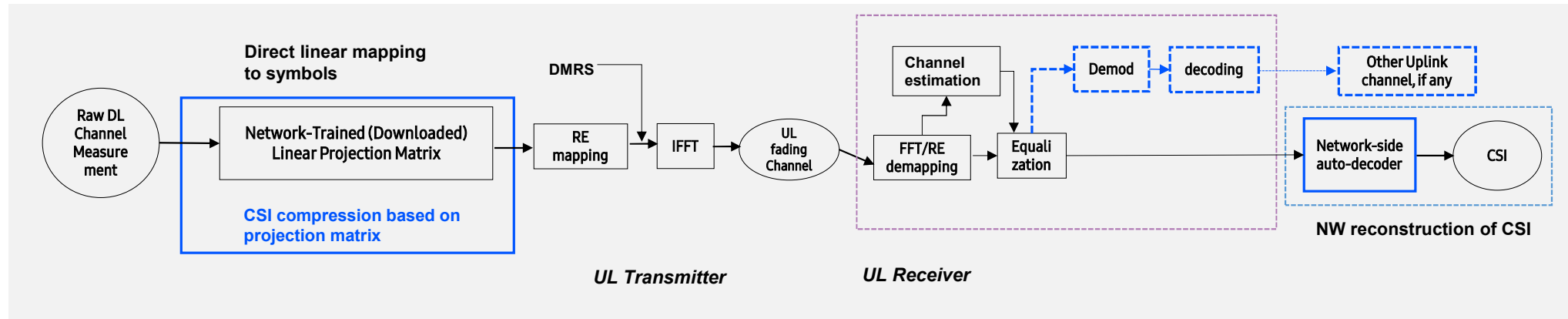
Source: Samsung

Channel State Information (CSI) | AI-based Semantic Compression

Non-AI Codebook-based CSI feedback



JSCM CSI Compression with Projection Matrix (auto-encoder at UE is not required)



(*) JSCM: Joint Source Channel Coding Modulation

JSCM CSI Feedback | Proof of Concept (PoC) Demo

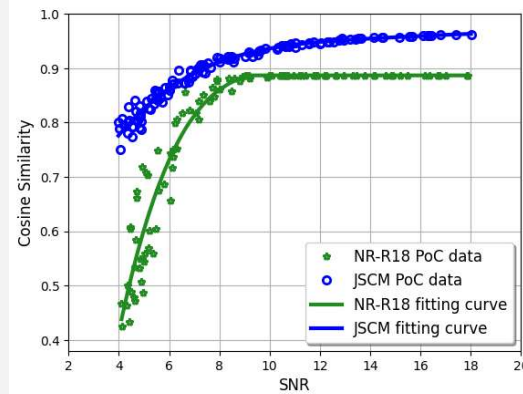
PoC Demo Scenario



Offline trained model

- **8T4R Channel** @ 2.56 GHz with 30kHz SCS and 52 RBs.
- **PUCCH**: 3RB and 1 OFDM symbol, 4-layer transformer

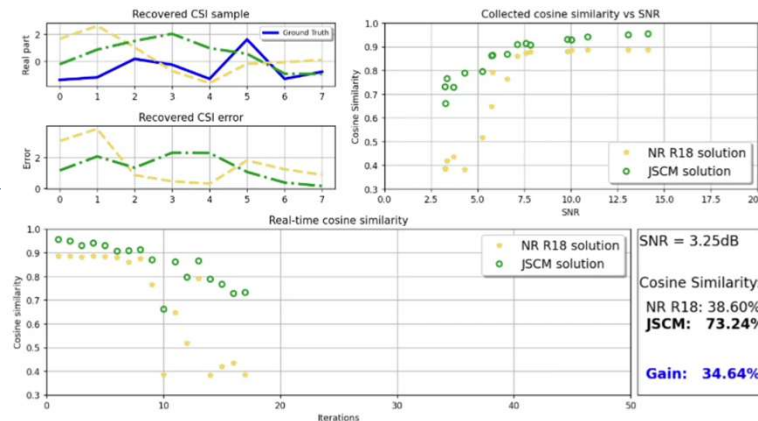
Indoor Test Results



- **>8 % higher cosine similarity (+20% higher)** than NR Type-I CSI
- **Relieved cliff-effect @ low SNR**

- Offline trained model followed by real-time live end-to-end CSI feedback
- Demonstrated **>8% CSI accuracy improvement & >3 dB cliff-effect relief over 5G AI-based CSI**

Live demo results



JSCM: Joint Source Channel Coding Modulation
PUCCH: Physical Uplink Control Channel
RB: resource block (12 SCSs)
SCS: sub-carrier spacing

Integrated Sensing and Communication | ISAC D-MIMO Fusion

Geometry Diversity

Single-TRP Scenario (One Transmitter)

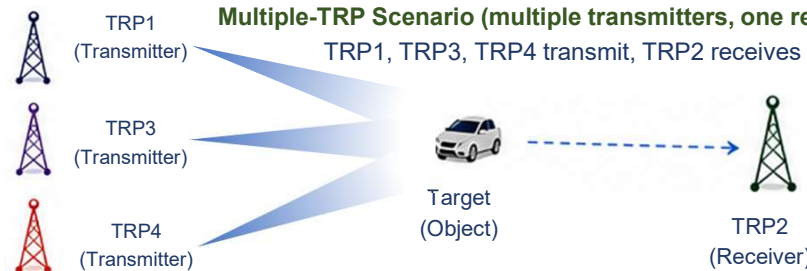
TRP1 transmits, TRP2 receives



- Low SINR
- Low detection probability
- Higher missed detection

Multiple-TRP Scenario (multiple transmitters, one receiver)

TRP1, TRP3, TRP4 transmit, TRP2 receives



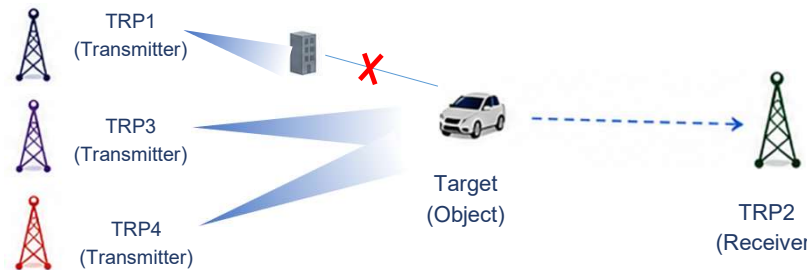
Improves:

- ✓ Received SINR
- ✓ Accuracy
- ✓ Observability

Coverage & Blockage Robustness



- Blockage /NLOS
- Lost sensing path
- Tracking interruption



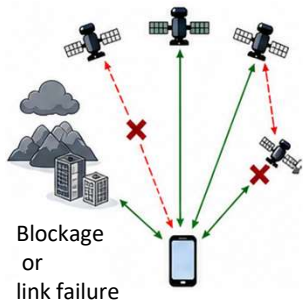
Enables:

- ✓ Multiple sensing paths
- ✓ Continuous tracking amidst blockage



Non-Terrestrial Networks (NTN) | Multi-Satellite and D-MIMO

Robustness and Higher Throughput



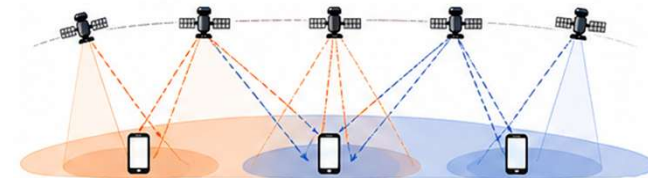
- **Motivation:** robustness against blockage, atmospheric effect, link failure
- **Enabler:**
 - Multiple satellites
 - Fast and reliable inter-satellite and feeder links



- **D-MIMO-based NTN:**
 - Joint transmission and coordinated scheduling
 - Intelligent beam management
 - Inter-satellite calibration

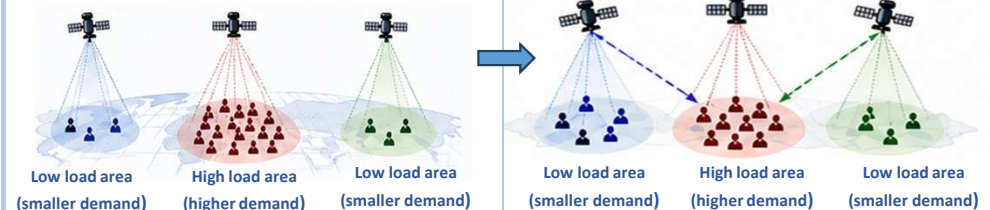
- ✓ Uninterrupted link connection
- ✓ Higher reliability
- ✓ Higher throughput

Seamless Coverage



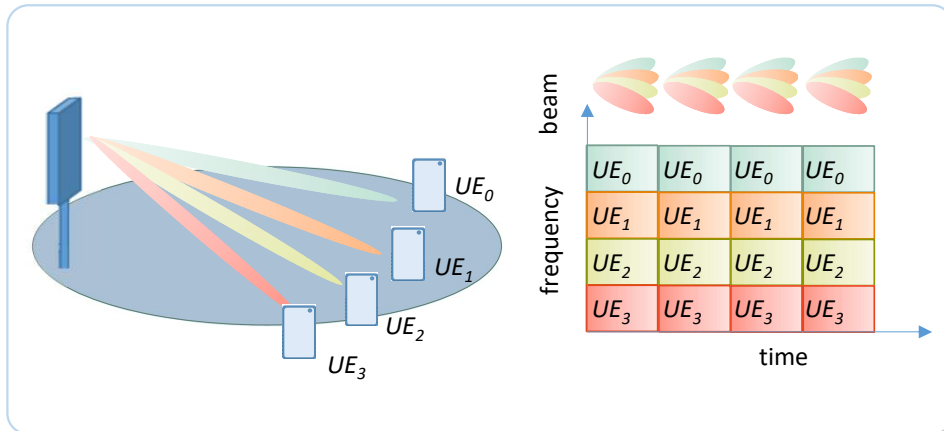
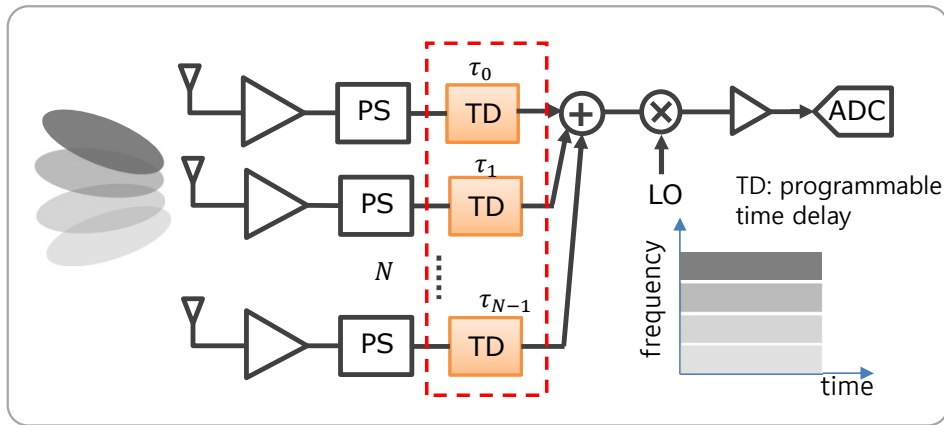
- (1) Connect to Satellite A
- (2) Connect to both Satellite A and B
- (3) Connect to Satellite B

Capacity & Load Balancing



- ✓ Higher system capacity
- ✓ Better QoS
- ✓ Scalability to support more users and services

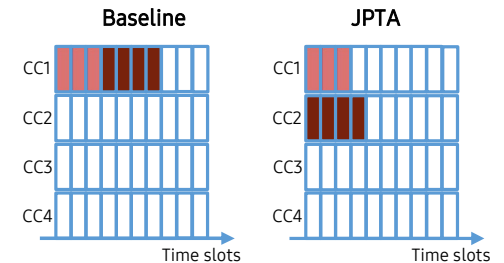
Reviving mmWave | Need for Capacity, Speed, and Efficiency



- Multiplex **analog** beams in **time and frequency**
- Faster **DL beam training**
- Increased **UL coverage**
- Greatly increased DL and UL **multiplexing capacity**
- Multi-panel/TRP benefits with **one panel**

28GHz, 400MHz UE BW Cat1
(CPE), Urban Macro LOS

UL capacity gain: 4.4x mean UPT,
7.3x 5%-tile UPT



Mean reading time (s)	Baseline				4-beam JPTA			
	UPT (Mbps)		RU (%)	Packet drop ratio (%)	UPT (Mbps)		RU (%)	Packet drop ratio
	Average	5%-tile			Average	5%-tile		
0.03	1105.2	537.1	8.9	0	1154.2	646.5	9.0	0
0.007	500.8	65.9	38.7	0.1	794.1	272.1	40.1	0
0.005	197.7	17.2	50.7	5.3	588.4	126.3	56.6	0
0.004	93.7	20.4	55.0	16.9	411.7	32.3	68.3	0.9

Concluding Remarks | MIMO Evolution

📶 Idea (3G HSPA) → Advanced Feature (4G) → Core Feature (5G) → Core Enabler (6G)

📶 Role of paradigm shift and RF/hardware/antenna innovation

📶 6G MIMO as Core Enabler – no longer in isolation:

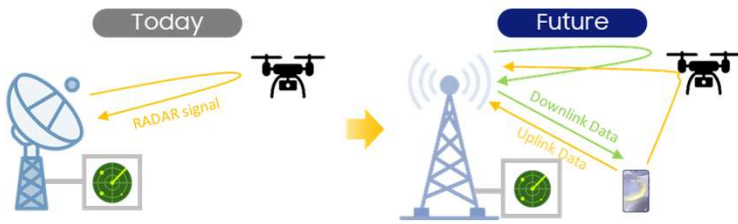
- New mid-band spectrum + 5G mmWave
- AI/Machine learning
- Distributed collaborative architecture
- Enabling new innovative use cases for capacity and coverage

Thank You!

Integrated Sensing and Communication | New Opportunity

ISAC: Key **enabling technology** for diversifying the use cases of future telecommunication systems

Adding advanced sensing to traditional telecom networks



Enabling Technologies & Use Cases

- AI and signal processing for sensing inference
- Intelligent scheduling for resource allocation
- Sensing signal for sensing resolution and range
- Multi-sensor fusion (Camera+RF) for enhanced sensing



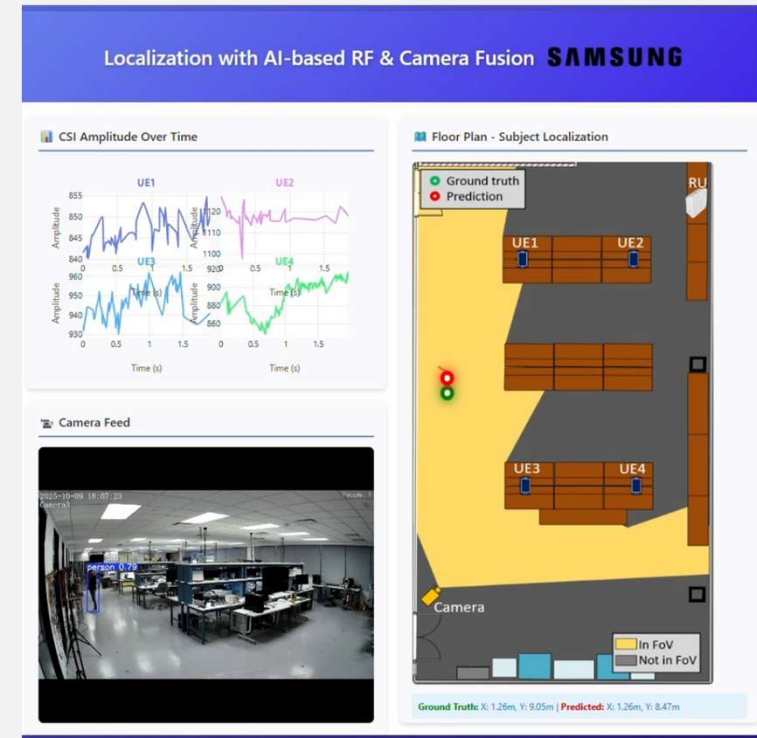
Drone detection and tracking



Home intrusion detection



Vehicular tracking



RF complements vision: Seamlessly takes over tracking when target moves out of camera field-of-view

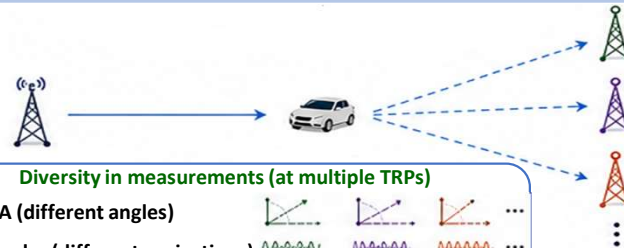
ISAC | The Need for Multi-Node Solution (multi-node Rx)

Geometry Diversity



Single measurement at TRP 2

- One AoA
- One Doppler
- One Delay



Diversity in measurements (at multiple TRPs)

- AoA (different angles)
- Doppler (different projections)
- Delay (different paths)

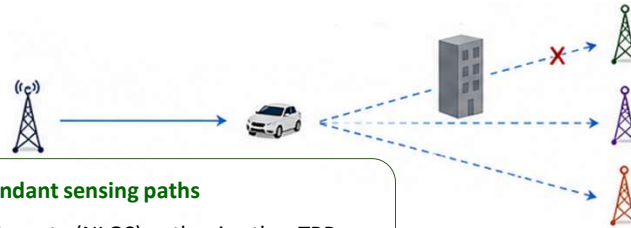
Improves:

- ✓ Position accuracy (joint estimation)
- ✓ Velocity estimation
- ✓ Ambiguity resolution
- ✓ Better parameter observability

Coverage & Blockage Robustness



- Blockage /NLOS
- Lost sensing path
- Tracking interruption



Redundant sensing paths

- Alternate (NLOS) paths vis other TRPs
- Maintained detection and tracking

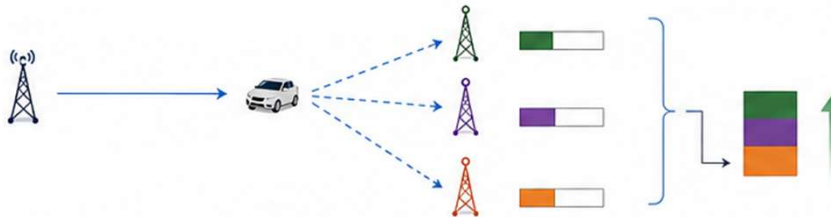
Ensures:

- ✓ Redundant sensing paths
- ✓ Higher detection prob.
- ✓ Continuous tracking even with blockage

SNR & Detection Gain



- Low SNR
- Low detection probability (P_d)
- Higher miss detection



Leads to:

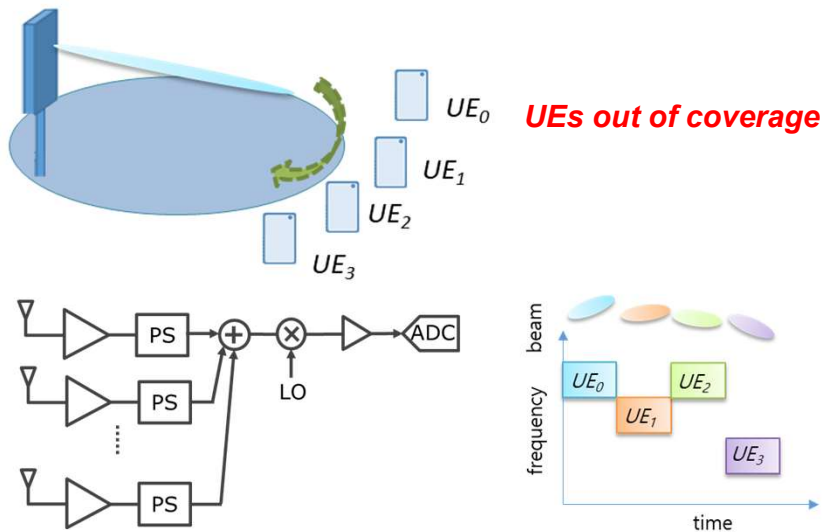
- ✓ Higher received power
- ✓ Better detection Prob.
- ✓ Lower miss detection

Reviving mmWave | Need for Capacity, Speed, and Efficiency

Joint Phase-Time Array (JPTA): creating sub-band analog beams

5G Single Wideband Analog Beam

- + Simple and efficient architecture
- Phase shifter in time domain $\rightarrow$ one beam/band



6G JPTA Sub-Band Analog Beams

- + Freq. dependent beamforming
- Difficult to implement low loss "ns" delay lines

