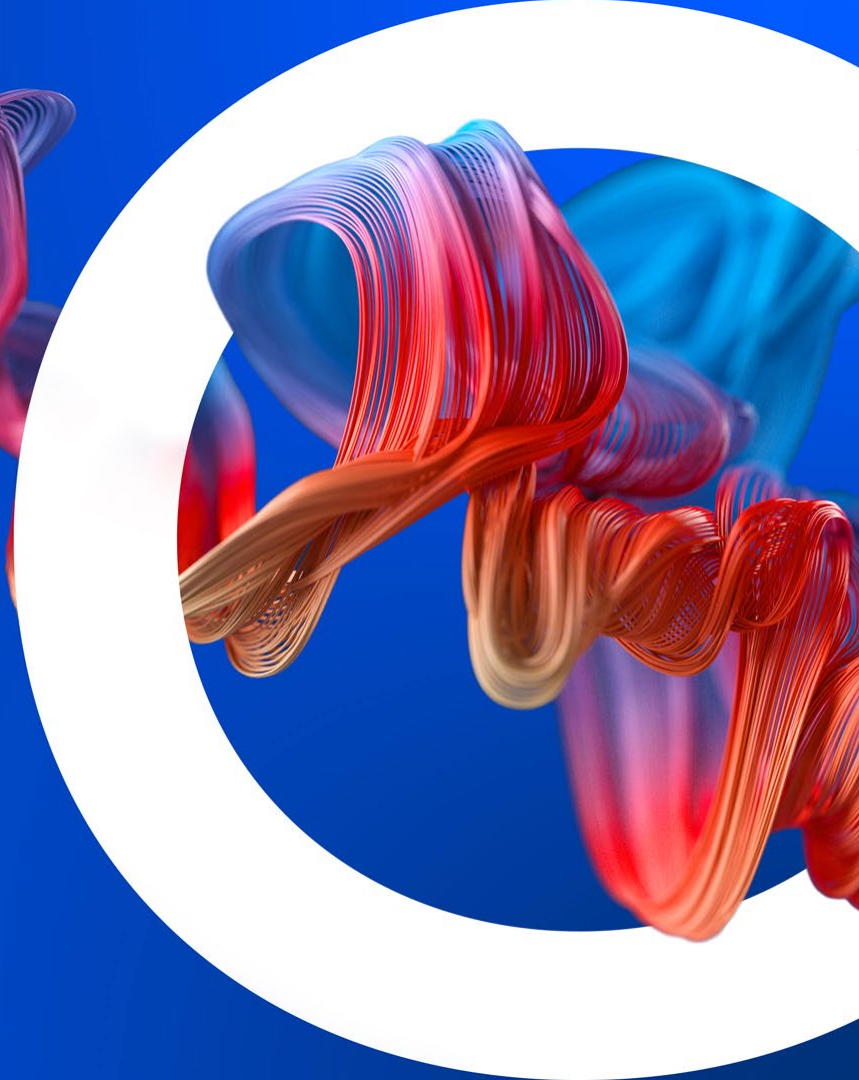
6G Standardization and the role of AI/ML on physical layer specifications

Dick Carrillo Melgarejo

2025



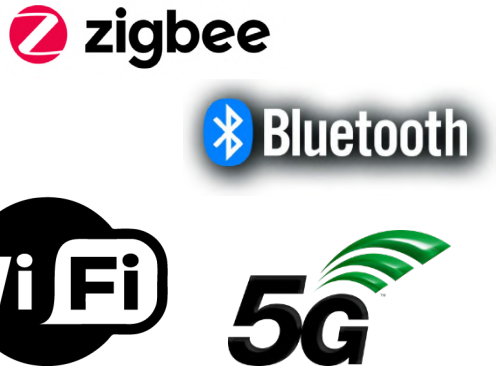
Agenda

1. **Insights on Standardization and the role of 3GPP**
2. 6G vision into action: timeline and strategic day one focus
3. How AI is shaping the current RAN standardization

Standards in our daily lives

Food standards

Data protection standards

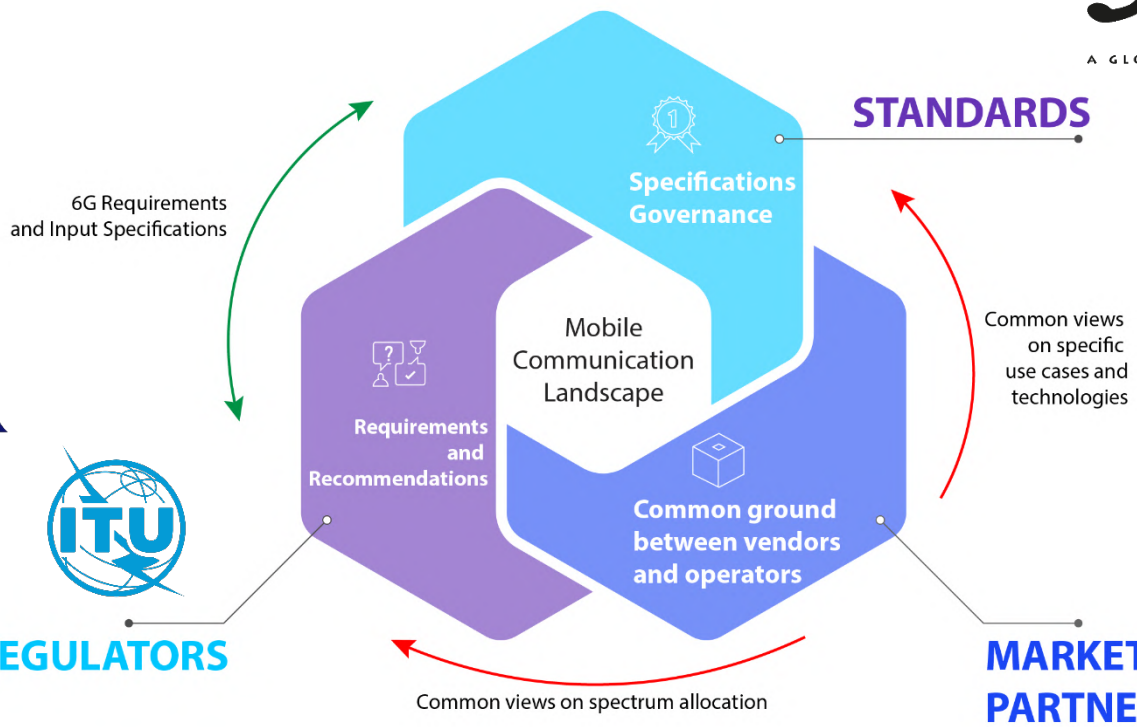


Wireless communications standards

International electrotechnical standards

Agile projects and project Management standards

3GPP and mobile communication landscape



Global Mobile Suppliers Association (GSA)
Global System for Mobile Communications Association (GSMA)

Organizations involved in 3GPP

The aspects involving creation, maintenance, adoption, and dissemination are roles done by standards development organizations (SDOs).

3GPP™

A GLOBAL INITIATIVE

3GPP Organizational Partners

- ✓ ARIB (The Association of Radio Industries and Businesses) –Japan
- ✓ TSDSI (Telecommunications Standards Development Society, India) –India
- ✓ ATIS (The Alliance for Telecommunications Industry Solutions) –USA
- ✓ CCSA (China Communications Standards Association) –China
- ✓ ETSI (The European Telecommunications Standards Institute) –Europe
- ✓ TTA (Telecommunications Technology Association) –Korea
- ✓ TTC (Telecommunication Technology Committee) –Japan

How 3GPP works?

- Participants (companies, not individuals representatives)
  - All major telecommunication companies-operators, vendors, service providers.
  - Ministries, Regulators and government agencies actively engaged.
  - Vertical industry representatives.

- Way of working:
  - Face-to-face meetings
  - Pro-activity and contributions.
  - Agreements by consensus (no body says “no”)

- Outcomes
  - Study items, work items,
  - Releases every 15 to 24 months with fixed time-lines
  - Coordinated work plan
  - External liaison activity with SDOs, industry bodies, projects.

3GPP, RAN and RAN1

3GPP develops 5G (NR) specifications

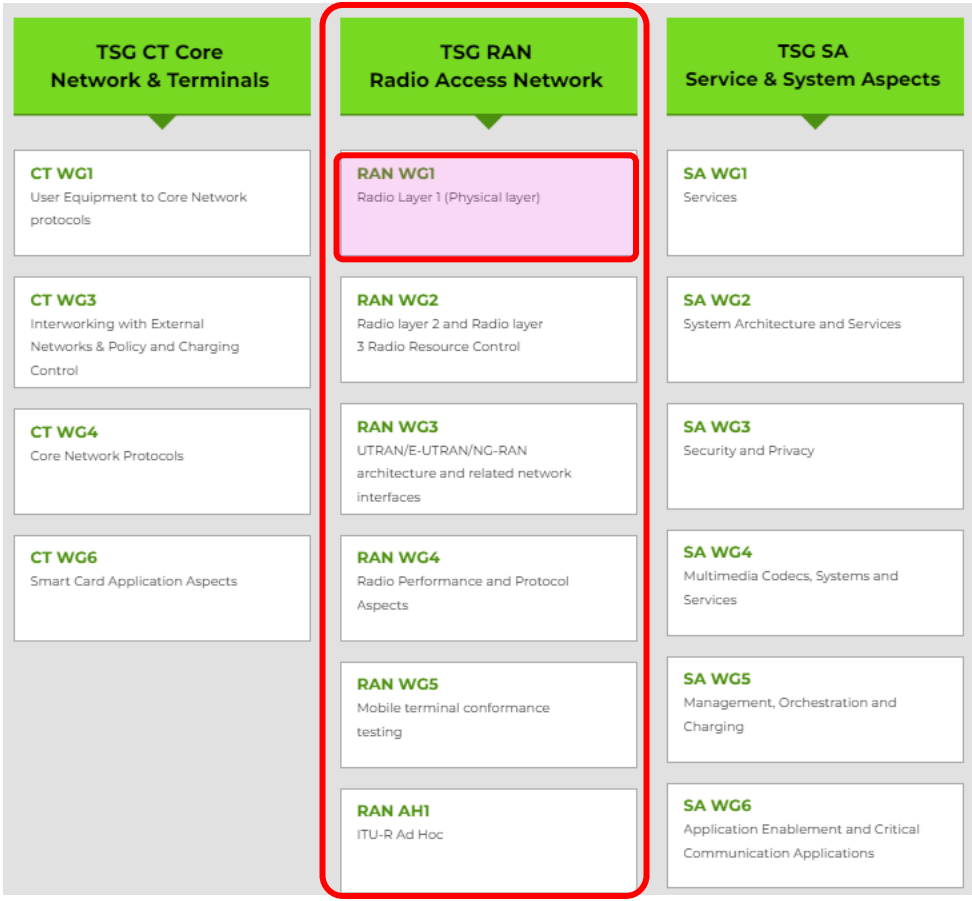
3GPP consists of 3 Technical Specification Groups

- TSG RAN defines manages the radio interface between the UE and the network and radio network internal interfaces

RAN WG1 takes care of the Physical Layer

- NR specs/reports: 38.xxx
  - https://www.3gpp.org/dynareport?code=38-series.htm
- TS: Technical Specification
  - NR-related specs numbered 38.100 - 38.599
  - E.g. RAN1 specs: 38.2xx, RAN2 specs 38.3xx, …
  - Products are developed based on specs
- TR: Technical Report
  - NR-related TRs numbered TR38.700 upwards
  - Study Item reports and modelling documents. Not specifications for product development

3GPP consists of 3 Technical Specification Groups



www.3gpp.org

3GPP, RAN and RAN1

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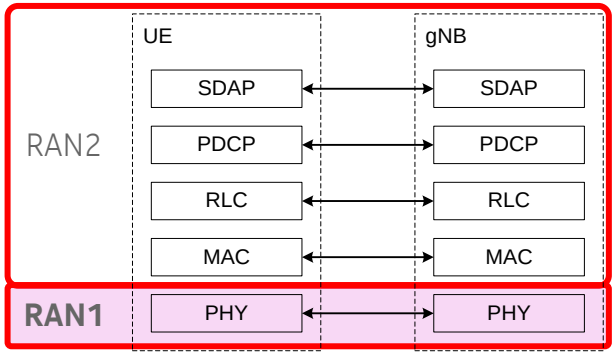


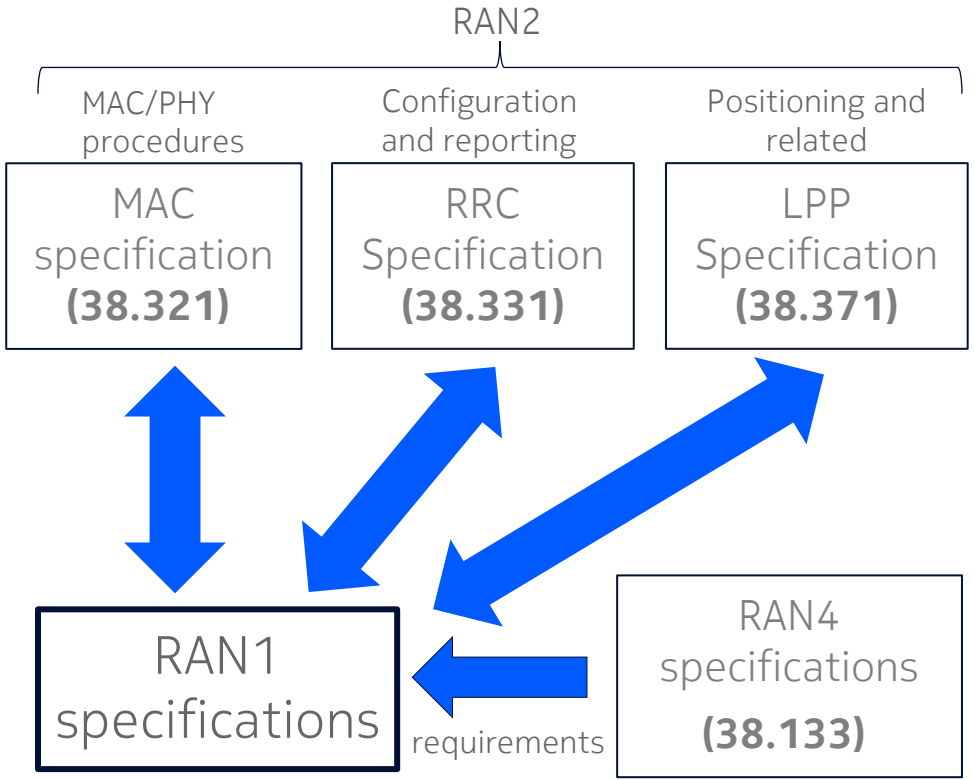
Radio interface protocol stack (user plane)

RAN1-maintained NR specifications

38.201	NR; Physical layer; General description
38.202	NR; Services provided by the physical layer
38.211	**NR; Physical channels and modulation**
38.212	**NR; Multiplexing and channel coding**
38.213	**NR; Physical layer procedures for control**
38.214	**NR; Physical layer procedures for data**
38.215	**NR; Physical layer measurements**

RAN1 Specification Connection to other WGs' Specifications

- RRC protocol (38.331) is used to configure the parameters to RAN1 specified functionality.
- RRC configures also the L2 protocol layers
- RAN4 defines frequency bands and operational and performance requirements relevant for most L1 functionalities.
  - UE requirements spec (38.133)
- For many functionalities, L1 and MAC work hand-in-glove.
- Bottom-line: specification of most features are scattered across different specs.



3GPP Releases

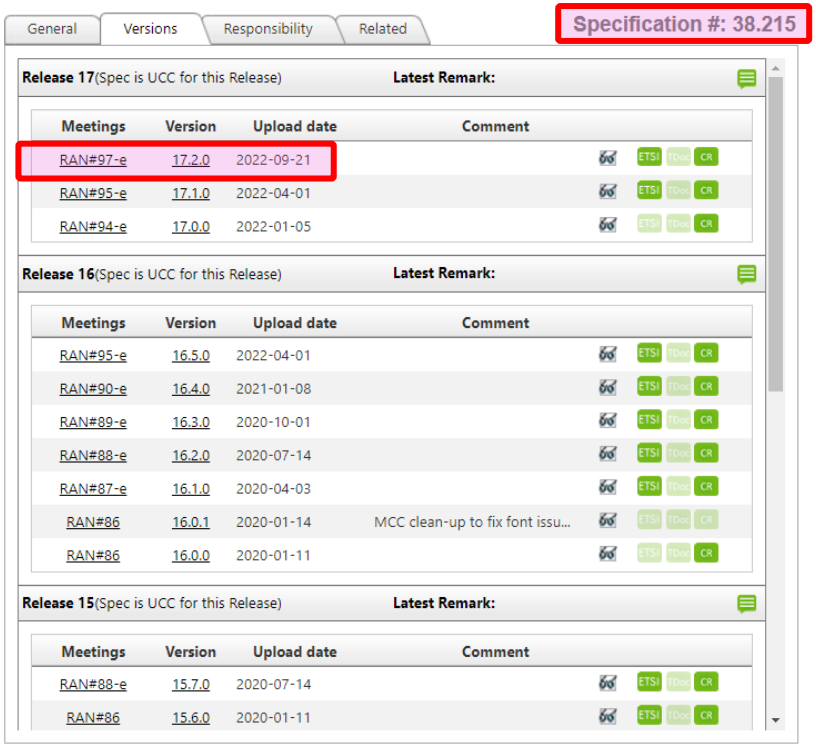
New features and generations are introduced in releases

Specification numbering scheme

- TS 38.215 version 17.2.0 is a
  - 17: means that it is a Rel-17 specification.
  - 2: means that it is a 3rd (0, 1, 2) technical iteration of that release.
  - 0: means that it has no trivial (editorial, formatting etc.) fixes.
- Rel N functionality is always included in Rel N+1
- Version M functionality is (practically) always included in version M+1 of the spec

Some landmark 3GPP Releases

- Release 3: First UMTS release (3G), 25.xxx specs
- Release 5/6: High Speed Packet Access (3.5G)
- Release 8: First LTE release (4G), 36.xx specs
- Release 10: LTE-Advanced ('True 4G', 4G+)
- Release 15: First NR release (5G), 38.xxx specs
- Release 18: First 5G-Advanced release
- Release 19: second phase of 5G-Advanced release
- Release 20: enhancing the current capabilities of 5G



What happens in a 3GPP RAN WG meeting ?

A RAN WG meeting in summary

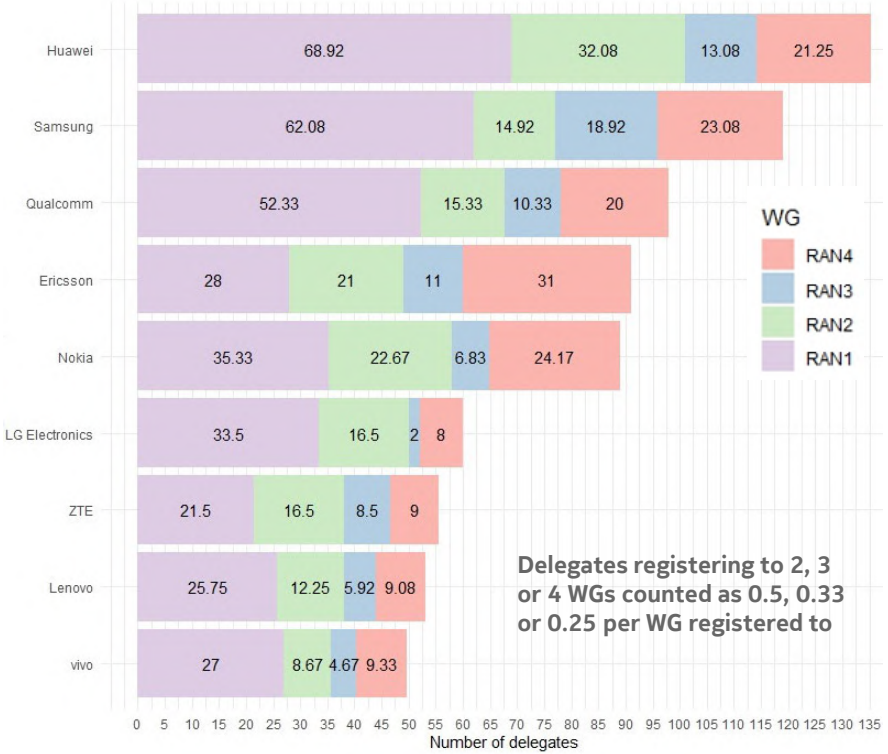
- In preparation: Companies prepare a set of Tdocs (temporary documents) and submit by deadline
- In meeting: Delegates debate submitted proposals
- Agreements come out
  - For ongoing release: A set of agreements furthering the work
  - End-of-release feature: introducing CRs with new spec. text.
  - For closed releases: Agreed Change Requests (CRs)

A lot of TDocs by participating companies → 3GPP Fog → **Agreements**

Discussions are organized around Work and Study Items

- Each Tdoc is attributed to an agenda item relating to a particular WI/SI.

Example: Delegates registered to Nov/2022 RAN1/2/3/4 meetings



A typical RAN1 meeting schedule, a 5-day meeting

3 parallel “online” sessions with full decision-making power
2 parallel “offline” sessions doing preparatory work

RAN1#123, Nov/2025
918 delegates registered face-2-face
353 delegates registered for online
1302 Tdocs EoM

RAN1#123 Online Session Schedule — Lone Star Ballroom B | Dallas Ballroom B | Seminar Theater

	Monday			Tuesday			Wednesday			Thursday			Friday		
08:30 ~ 10:30 (120 min)	RAN1#123 commences at 09:00 on Monday Agenda items 1, 2, 3, 4, 5 Maintenance 8.3			6GR Channel coding (40) Evaluation (40) Overall (40)	R19 UE features (120)	AI 8 (60) . 8.8 R20 Coverage (60)	6GR Overall (40) Waveform (40) Channel coding (40)	AI 8 (120) MIMO (60) NES (60)	R19 UE features (120)	6GR Waveform (60) Overall (40)	AI 8 (120) AI/ML (40) NTN-NR (40) NTN-IoT (40)	R20 Coverage (60) R20 ISAC (60)	6GR Energy (40) Channel coding (40) Evaluation (40)	R20 NR-NTN (120)	R20 A-IoT (120)
Morning coffee break: 10:30 ~ 11:00															
11:00 ~ 13:00 (120 min)	Maintenance (70) . 8.3 . 8.6 6GR (50) Overall (50)			6GR AI/ML (70) Waveform (50)	AI 8 (120) NTN-NR (40) NTN-IoT (40) AI/ML (40)	AI 8 (30) . 8.4 R20 A-IoT (90)	6GR Modulation (40) AI/ML (80)	AI 6,7 (60) R20 NR-NTN (60)	AI 8 (30) . 8.4 R20 A-IoT (90)	6GR AI/ML (40) Channel coding (40) Energy(40)	R20 MIMO (120)	R20 A-IoT (120)	Sweep AI 8 6GR **Short break: 13:00-13:30** **Resume at 13:30**		
Lunch break: 13:00 ~ 14:30															
14:30 ~ 16:30 (120 min)	6GR Energy (80) Frame structure (40)	AI 6, 7 (60) AI 8 (60) MIMO (30) NES (30)	AI 8 (60) . 8.8 R20 Coverage (60)	6GR Energy (80) Frame structure (40)	R20 MIMO (60) R20 NR-NTN (60)	R20 ISAC (60) R20 A-IoT (60)	UE features wrap up 6GR Energy (80) Frame structure (40)	NR-NTN (60) R20 MIMO (60)	R20 ISAC (60) (60) R20 Coverage (60)	AI 8 (120)	R20 NR-NTN (60) AI 8 (60)	AI 8 (60) . 8.8 R20 ISAC (60)	Any other open issues . Session reports . etc.		
Afternoon coffee break: 16:30 ~ 17:00															
17:00 ~ 19:30 (150 min)	6GR (150) Waveform (50) Modulation (50) Energy (50)	R20 AI/ML (50) R20 NTN (50) R20 MIMO (50)	R20 A-IoT (100) R20 ISAC (50)	6GR (150) Channel coding(50) Modulation (50) Evaluation (50)	AI 6, 7 (60) R20 AI/ML (90)	R20 A-IoT (150)	6GR (90) Evaluations (90)	R20 AI/ML (90)	R20 A-IoT (90)	6GR Frame structure (40) Modulation (50) Evaluation (60)	R20 AI/ML (150)	R20 A-IoT (150)	**RAN1#123 expected to close at 14:30**		
All sessions end at 19:45 – no exceptions															

RAN1#123 Offline Session Schedule — Lone Star Ballroom A4 | City View 8

	Monday		Tuesday		Wednesday		Thursday		Friday	
08:30 ~ 10:30 (120 min)			Xiaodong (120) 6GR Overall (60) AI/ML (60)	Hiroki (120) AI 8.4 (30) R20 A-IoT (60) AI 8.8 (30)	Xiaodong (120) 6GR Modulation (60) AI/ML (60)	Sorour(40) R20 NR-NTN (40) Hiroki (80) R20 A-IoT (80)	Sorour (60) R20 MIMO (60) Xiaodong (60) 6GR AI/ML (60)	Hiroki (120) R20 A-IoT (120)		
Morning coffee break: 10:30 ~ 11:00										
11:00 ~ 13:00 (120 min)	Xiaodong (120) 6GR Overall (60) Frame structure (60)	Hiroki R20 A-IoT (40) Xiaodong (80) 6GR Energy (80)	Xiaodong (120) 6GR Waveform (60) Energy (60)	Hiroki (40) R20 ISAC (40) Sorour (80) R20 MIMO (40) R20 NR-NTN (40)	Xiaodong (120) 6GR Frame structure (40) Energy (80)	Hiroki (80) R20 Coverage (40) R20 ISAC (40) Sorour(40) R20 MIMO (40)	Xiaodong (80) 6GR Energy (80) Hiroki (40) R20 ISAC (40)	Sorour (120) R20 NR-NTN (60) R20 AI/ML (60)		
Lunch break: 13:00 ~ 14:30										
14:30 ~ 16:30 (120 min)	Xiaodong (120) 6GR Waveform (60) Modulation (60)	Sorour (60) R20 AI/ML (60) Hiroki (60) R20 A-IoT (60)	Xiaodong (120) 6GR Frame structure (40) Channele coding (80)	Hiroki (40) R20 Coverage (40) Sorour (80) R20 AI/ML (80)	Xiaodong (120) 6GR Overall (40) . TR skeleton (40) Evaluation (80)	Sorour (120) R20 AI/ML (60) TBD (60) [AI 8 (60) / R20 NTN (60)]	Xiaodong (120) 6GR AI/ML (40) Modulation (40) Frame structure (40)	Hiroki (120) R20 A-IoT (120)	To be assigned by Sorour To be assigned by Hiroki	
Afternoon coffee break: 16:30 ~ 17:00										
17:00 ~ 19:30 (150 min)	Hiroki (40) ISAC (40) Xiaodong (110) 6GR Evaluation (60) Channel coding (50)	Sorour (90) R20 NTN (40) R20 MIMO (50) Hiroki (60) R20 Coverage (60)	Xiaodong (150) 6GR AI/ML (50) Overall (50) Waveform (50)	Xiaodong (150) 6GR Modulation (50) Frame structure(50) TBD (50) [UE features, if necessary]	Xiaodong (90) 6GR Waveform (90)	Xiaodong (90) 6GR Channel coding (50) Overall (40)	Xiaodong (150) 6GR Evaluation (90) Waveform (60)	Xiaodong (150) 6GR Energy (90) Overall (60)		
All sessions end at 19:45 – no exceptions										

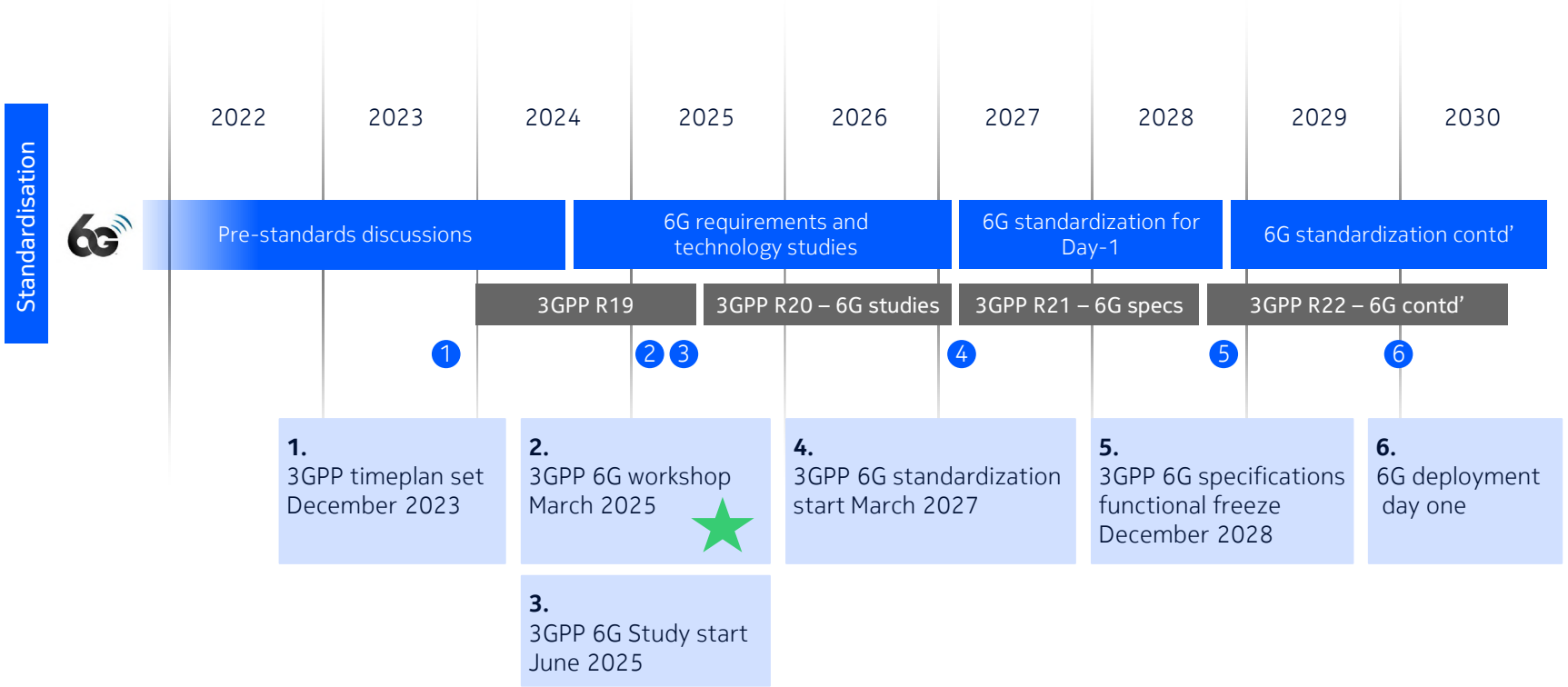
Agenda

1. Insights on Standardization and the role of 3GPP
2. **6G vision into action: timeline and strategic day one focus**
3. How AI is shaping the current RAN standardization

From research to standardization, the journey towards 6G vision has reached a pivotal milestone

6G will come with Rel-21

Commercialization will start Q4 2029



What will 6G bring on day one / Rel-21 ?

Performance elevation: Setting a new benchmark to meet future demands efficiently

Scalability & monetization: A platform that supports new use cases, applications, and revenue models

Ensuring **environmental responsibility** and **built-in cybersecurity and resiliency**

Technology enabler examples

AI native framework

Environmental sustainability framework

Programmable networks and API native

Extreme mMIMO on existing grid

A single architecture and smooth migration

Non-Terrestrial Networks

Agenda

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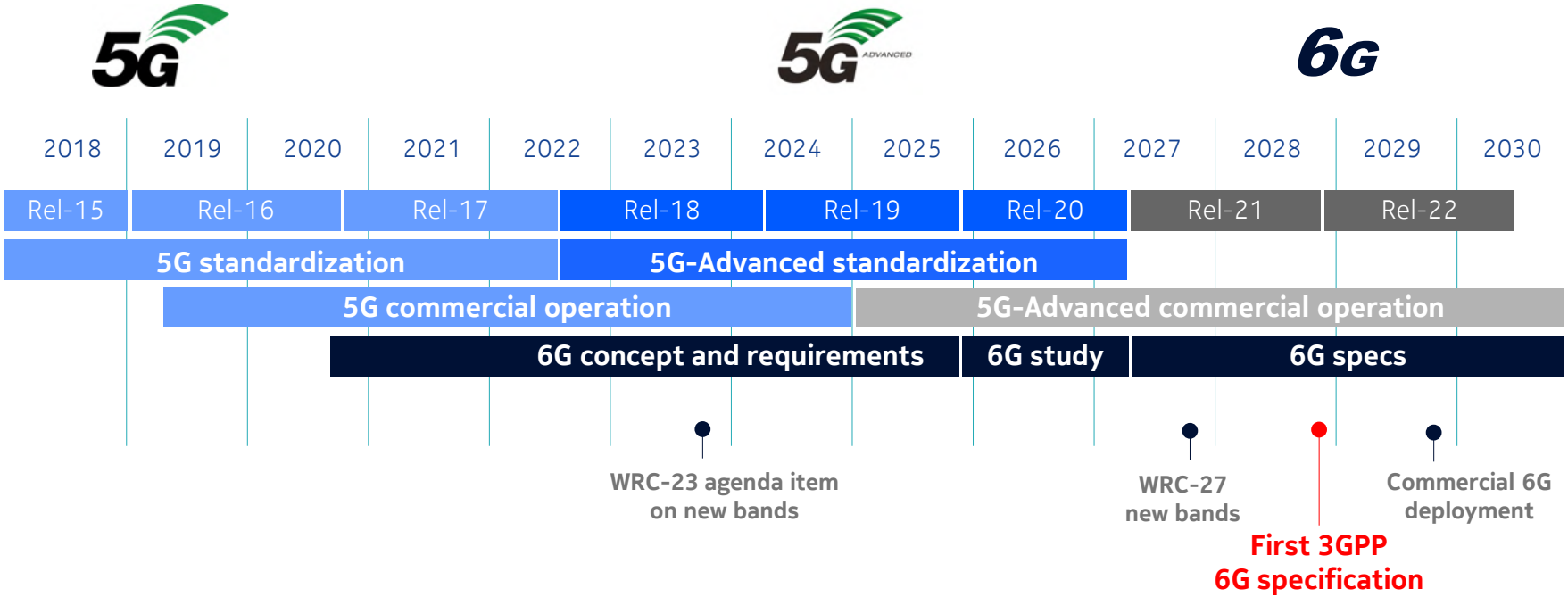
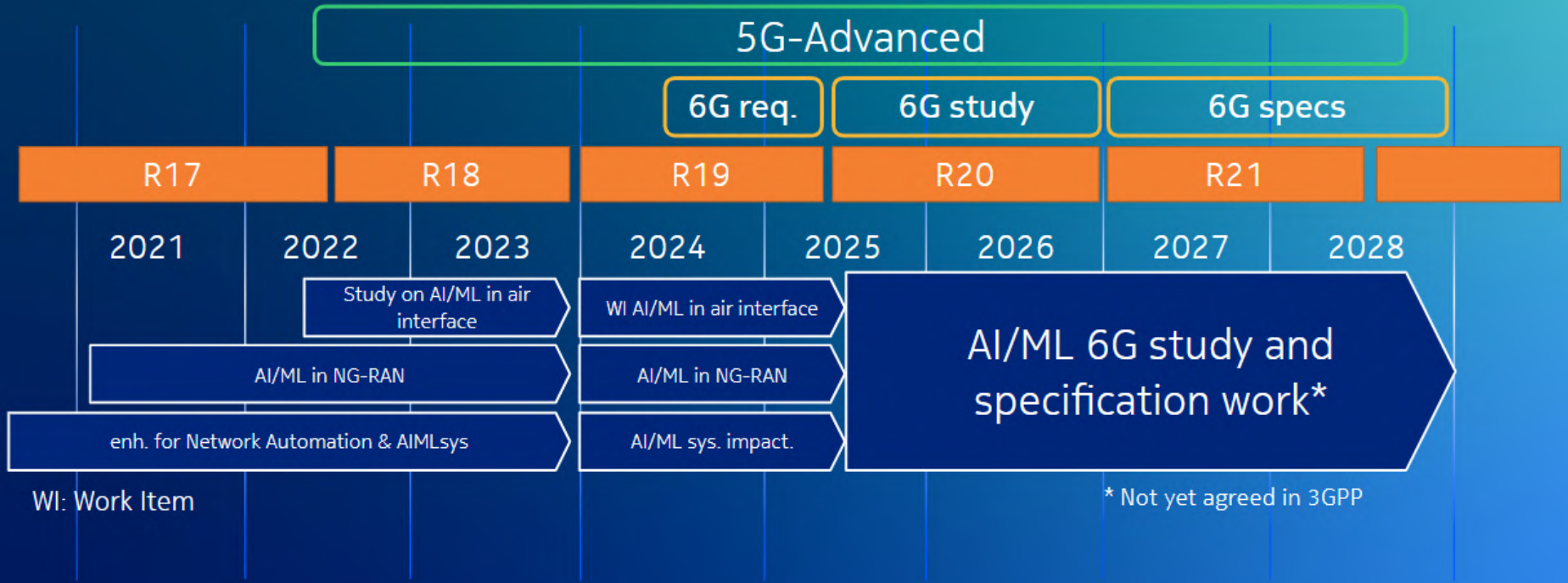
6G , 5G, and 5G-Advanced Timeline



AI/ML timeline in Standardization

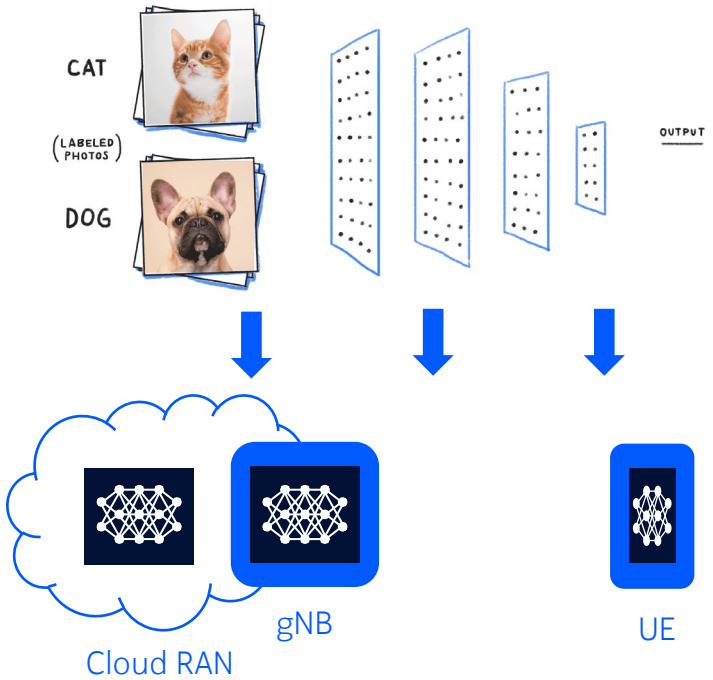


AIMLsys: system support for AI/ML-based services

AI in Wireless

Exploit recent advances in artificial intelligence and machine learning to disrupt how we design, implement, and optimize wireless communication systems

- Enhance performance or reduce complexity
- Bespoke solutions for different environments and traffic with minimal custom standards



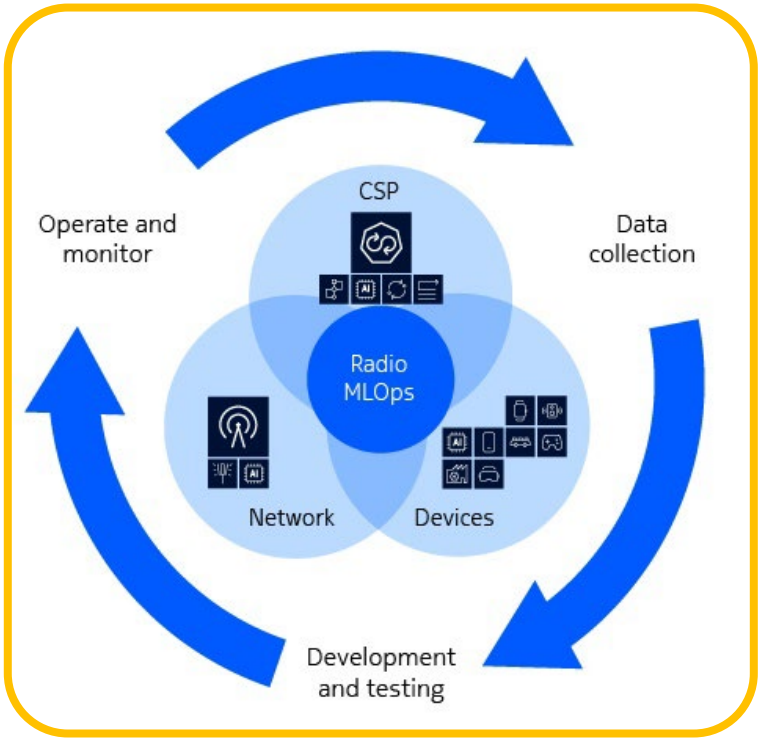
Will AI/ML revolutionize wireless communications?

Not a single component in 5G have been designed by AI.

Radio AI/ML framework – UE ML functionality management

RAN1 | RAN2 | RAN4 | RAN5 | 3GPP A GLOBAL INITIATIVE

- **Operate and monitor (LCM)**
  - UE ML capability exchange
  - Configuration, activation/de-activation/switching
  - Performance monitoring
- **Data collection**
  - Training data
  - Performance monitoring data
  - Inference data
- **Development and testing**
  - Minimum performance requirements
  - Core requirements
  - Post-deployment testing



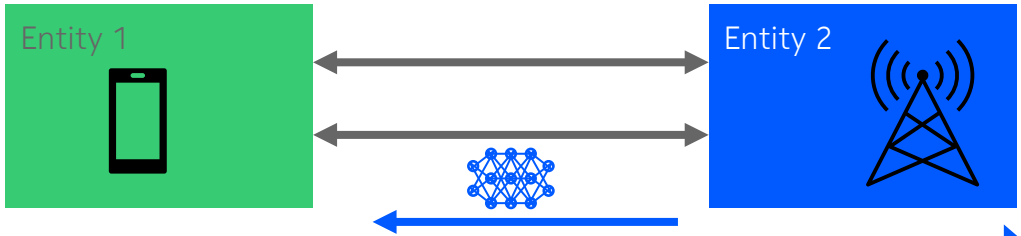
AI/ML over the air interface

Identifying various levels of collaboration

Level X

Level Y

Level Z



5G-Advanced is the key steppingstone towards AI-Native in 6G

5G: First steps

- Proprietary AI/ML solutions
- Standardized features for Network Automation

5G-Advanced: Standardized enhancements for AI/ML

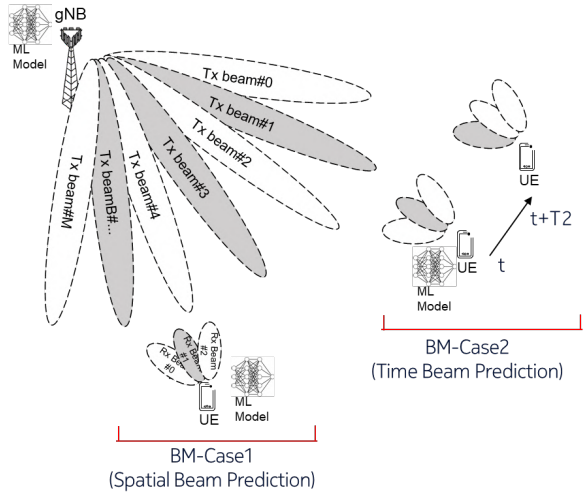
- Use cases and general framework
- Enhancements for data collection and automation
- Generic support for AI/ML

6G: AI-native system

- AI enabled network design and Deployment
- AI/ML integrated in all network domains and layers
- Trusted AI/ML

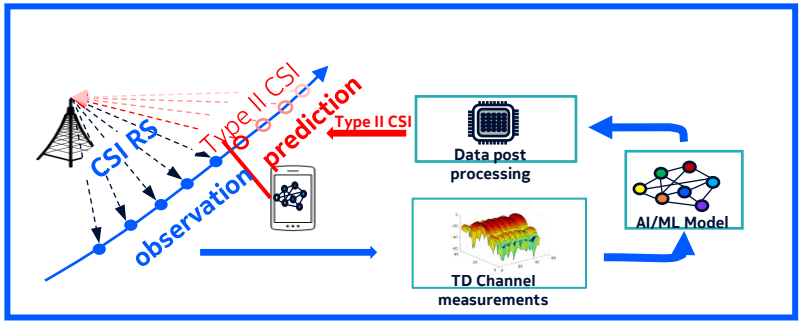
From measurement prediction to optimal beam selection

AIML beam prediction (Rel-18 SI / Rel-19 WI)



- Leveraging offline trained NNs to predict the best beam(s) based on a limited set of measurements
- Lower overheads and reduced latency
- Main optimization targets:
  - DL Tx beam prediction

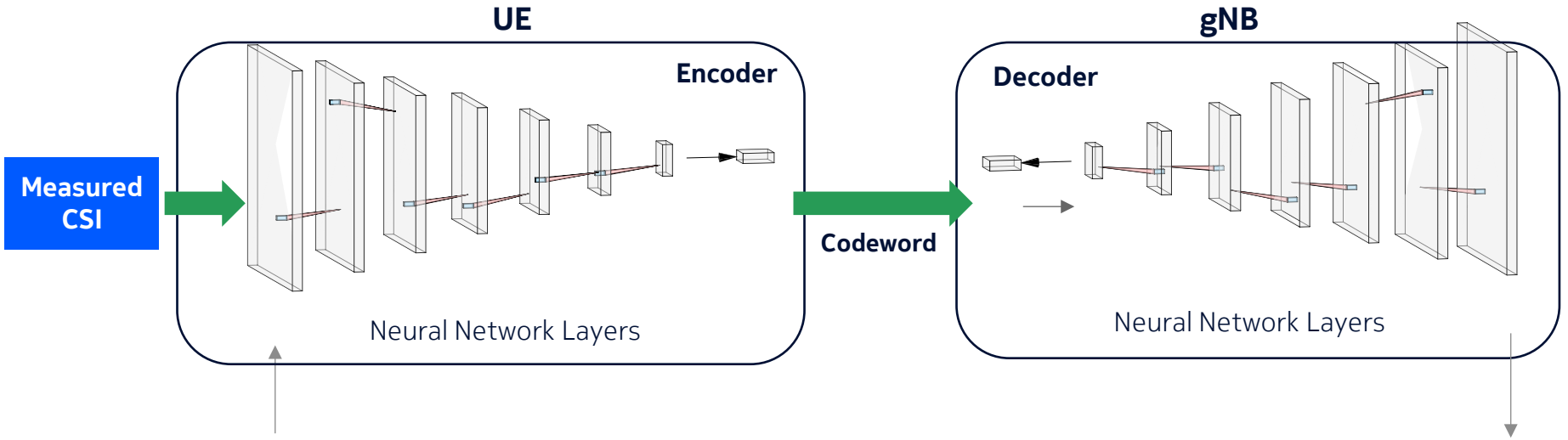
AIML CSI prediction (Rel-18 SI/Rel-19 WI)



- Support for one-sided model deployment e.g.,
  - **UE-side models** that observe the radio channel over multiple time instances at multiple UE locations
  - **Inference** of legacy Type II CSI feedback predicted ahead by one to a few time instances
  - **ML models** varying from low complexity LSTM models to extensive transformer models
- Motivation: **overcome channel aging**, especially for sensitive downlink transmission modes
- Goal: accurate predicted channel information improving **mean and cell edge spectral efficiency**
- Focusing mostly on supervised learning
- Support for suitable **pilot signal configurations**, **performance monitoring,** and **data collection** for AI/ML models

CSI Compression - Lossy Compression and Recovery with ML

AIML CSI Compression (Rel-18 SI / Rel-20 WI)

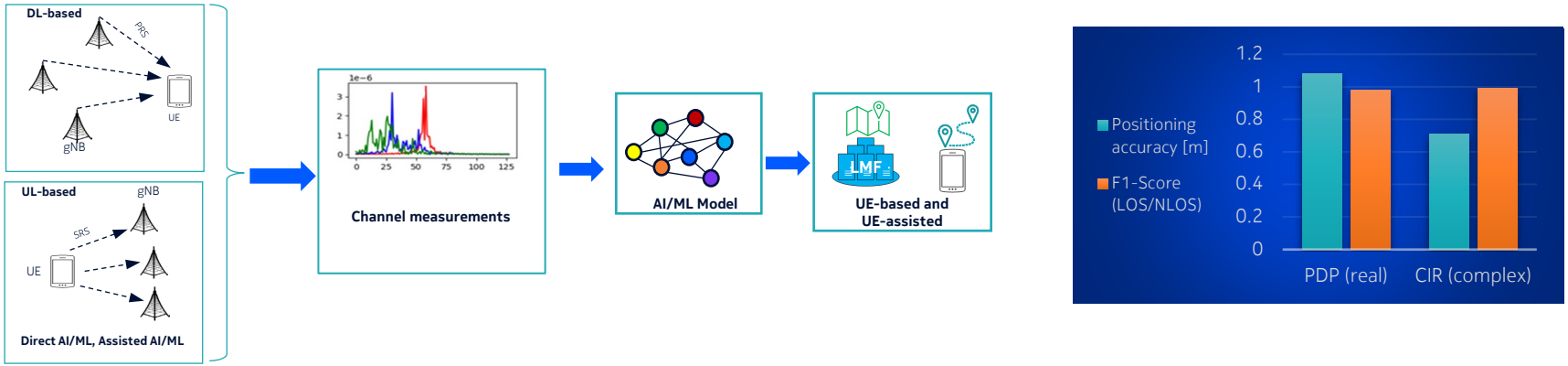


CSI: Channel State Information

Aim: throughput gain for a fixed feedback overhead/ Reduce feedback overhead for a fixed throughput

AI/ML Positioning

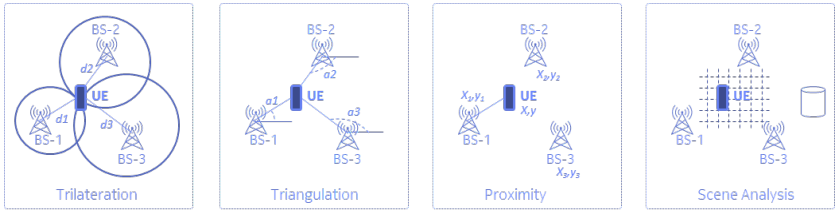
AI/ML Positioning (Rel-18 SI / Rel-19 WI)



- Supporting for one-sided model deployment e.g.,
  - **UE-side models** that estimate UE location directly or an intermediate feature (e.g., LOS/NLOS, timing info, PDP, CIR)
  - **gNB-side models** that estimate intermediate feature
  - **LMF-side models** that estimate UE location
- Motivation: **higher positioning accuracy**, especially in NLOS conditions, **reduced complexity/overhead**, e.g., less TRP measurements
- Focusing mostly on the supervised learning
- Support for **performance monitoring** and **data collection** for AI/ML models

Why AIML Positioning?

Positioning: Legacy (Rel16->Rel-18)



Non-ML approaches:
Positioning methods: Time, angle, phase-based measurements such as CPP (Carrier phase positioning), A-GNSS, OTDOA (Observed Time Difference of Arrival), E-CID (Enhanced Cell-ID), Barometric, WLAN/BT based

Study in Rel-18: AIML Positioning

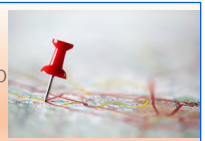
NLOS multipath channel (a) Direct path is attenuated but detectable (b) Direct path is completely blocked or non-detectable

Positioning enhancement in heavy NLOS conditions

1. Classical approaches to positioning such as time of arrival, angle of arrival methods typically rely on direct path characteristics between the transmitter and the receiver of the refence signal used for positioning. Mostly limited to LOS scenarios but poor performance in NLOS scenarios.
2. New positioning requirements for applications such as industrial IoT, asset tracking, V2X, extended reality.
3. Much more data to process: Due to the availability of huge volume of counters / UE reported measurements
4. Computational advances: GPUs, CPU, NPU, parallelism, memory …

AI/ML Positioning

- Leveraging AI/ML models to estimate the UE positio
- Purpose: Improve accuracy

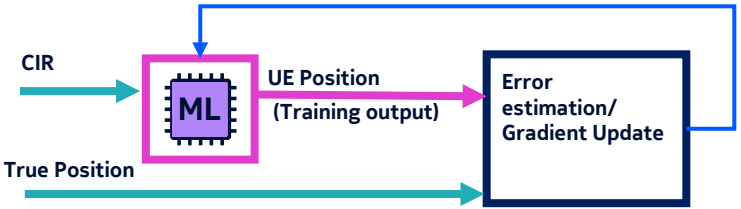


Rel-18 SI: RP-221348.zip

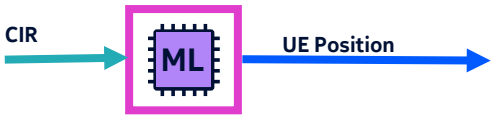
Rel-18 (AIML Positioning)

Training and Inference phase

Direct AIML Positioning (Training Phase)

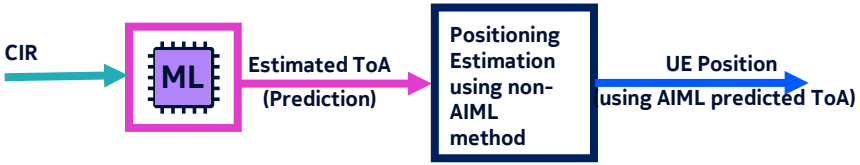


Direct AIML Positioning (Inference Phase)



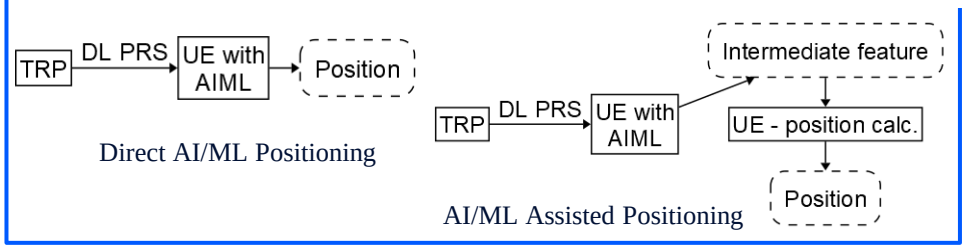
AIML Assisted Positioning (Training Phase)

AIML Assisted Positioning (Inference Phase)

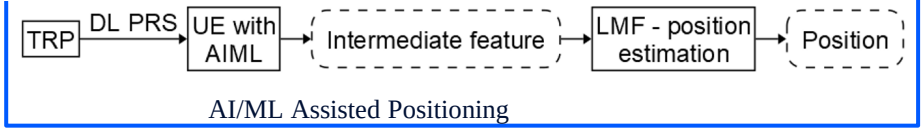


Rel-18 (Use cases in AI/ML Positioning)

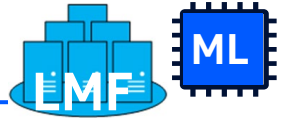
Case 1: UE-based positioning with UE-side model, direct AI/ML or AI/ML assisted positioning

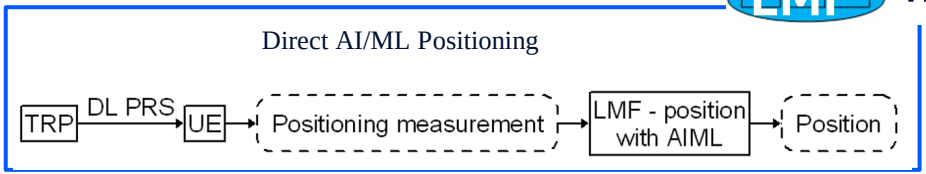


Case 2a: UE-assisted/LMF-based positioning with UE-side model, AI/ML assisted positioning

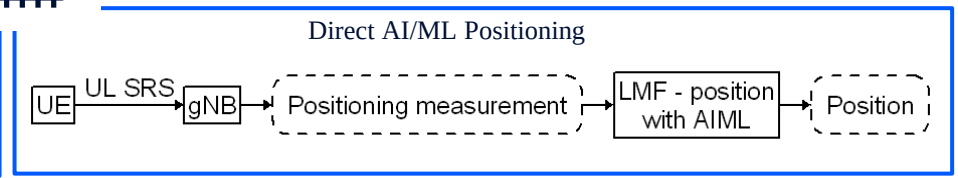


Case 2b: UE-assisted/LMF-based positioning with LMF-side model, direct AI/ML positioning

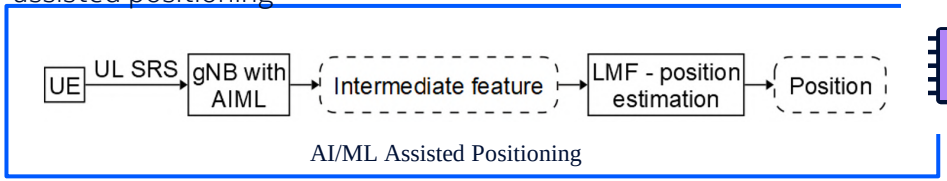


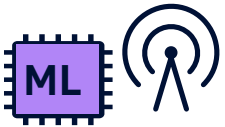


Case 3b: NG-RAN node assisted positioning with LMF-side model, direct AI/ML positioning



Case 3a: NG-RAN node assisted positioning with gNB-side model, AI/ML assisted positioning





Rel-18 (AIML Positioning)

Evaluations results (Performance KPIs)

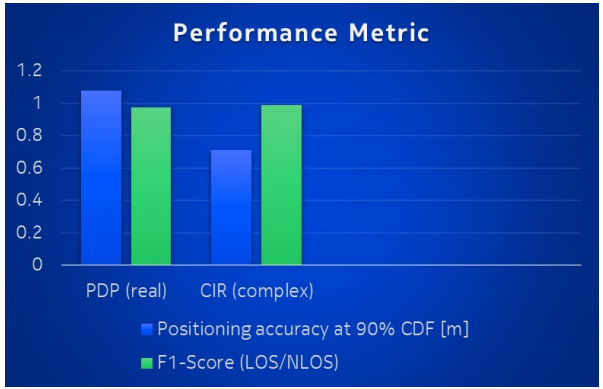
Direct AIML Positioning: Positioning accuracy at 90% CDF [meters]

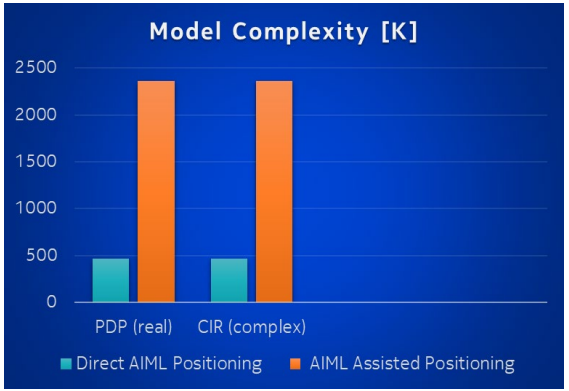
AIML Assisted Positioning: F1-score (Performance KPI for LOS/NLOS)

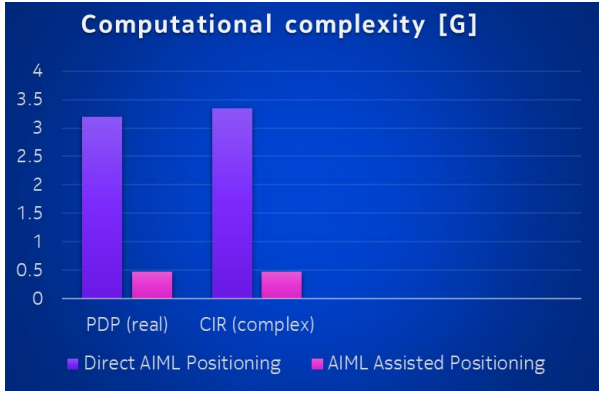
The F1-score is a metric commonly used in machine learning to assess the performance of a classification model, especially when dealing with imbalanced datasets. It combines precision and recall into a single value, providing a balanced measure of a model's effectiveness.

Model complexity: The number of parameters in a model is a key factor in determining its capacity to learn from data and its overall complexity.

Computational complexity: The computational complexity of an AI/ML model is often measured in terms of FLOPS (Floating Point Operations Per Second). The FLOPS metric provides an indication of the model's computational requirements, particularly during the inference phase.





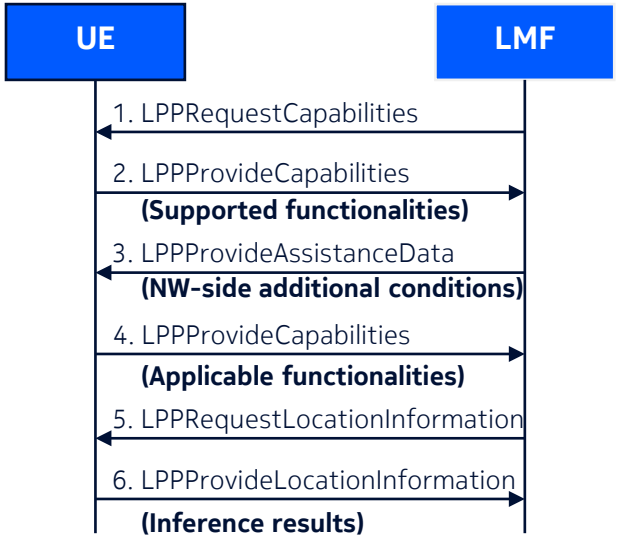


Nokia, R1-2307242

Rel-19

High-level procedures for AI/ML positioning

- **Step 1:** LMF may request the UE to report the supported functionalities at the UE side by LPP request capabilities message.
- **Step 2:** UE sends LPP provide capabilities message to LMF with the supported functionalities at the UE side.
- **Step 3:** LMF sends the LPP provide assistance data message (which may contain network side additional condition).
- **Step 4:** UE reports the applicable functionality to the LMF by the LPP provide capabilities message.
- **Step 5:** The LMF requests the inferred location information using the LPP request location information message.
- **Step 6:** UE reports the inferred location using LPP provide location information message.



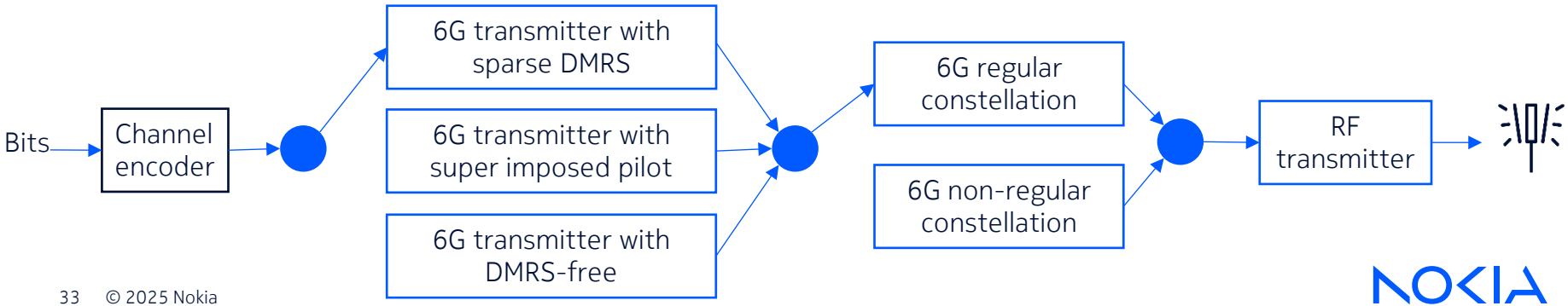
Stage2 and Stage3 specs are still under discussion in Rel-19

AI/ML in 6G

- RAN1 working group started to discuss potential 6G AI/ML use cases since August/2025 (3GPP RAN1#122 meeting).
- 48 companies contributing actively.
- More than 1000 pages contributed on this agenda item.
- Most popular use cases:
  - Reference signal overhead reduction (DMRS, CSI-RS),
  - Inter-Cell/M-TRP DL Tx beam prediction and management,
  - AI-based none-linearity handling at transmitter or receiver,

DMRS design with AI receiver

AI Transmitter configuration based on Company contributions in current 6G AIML discussion

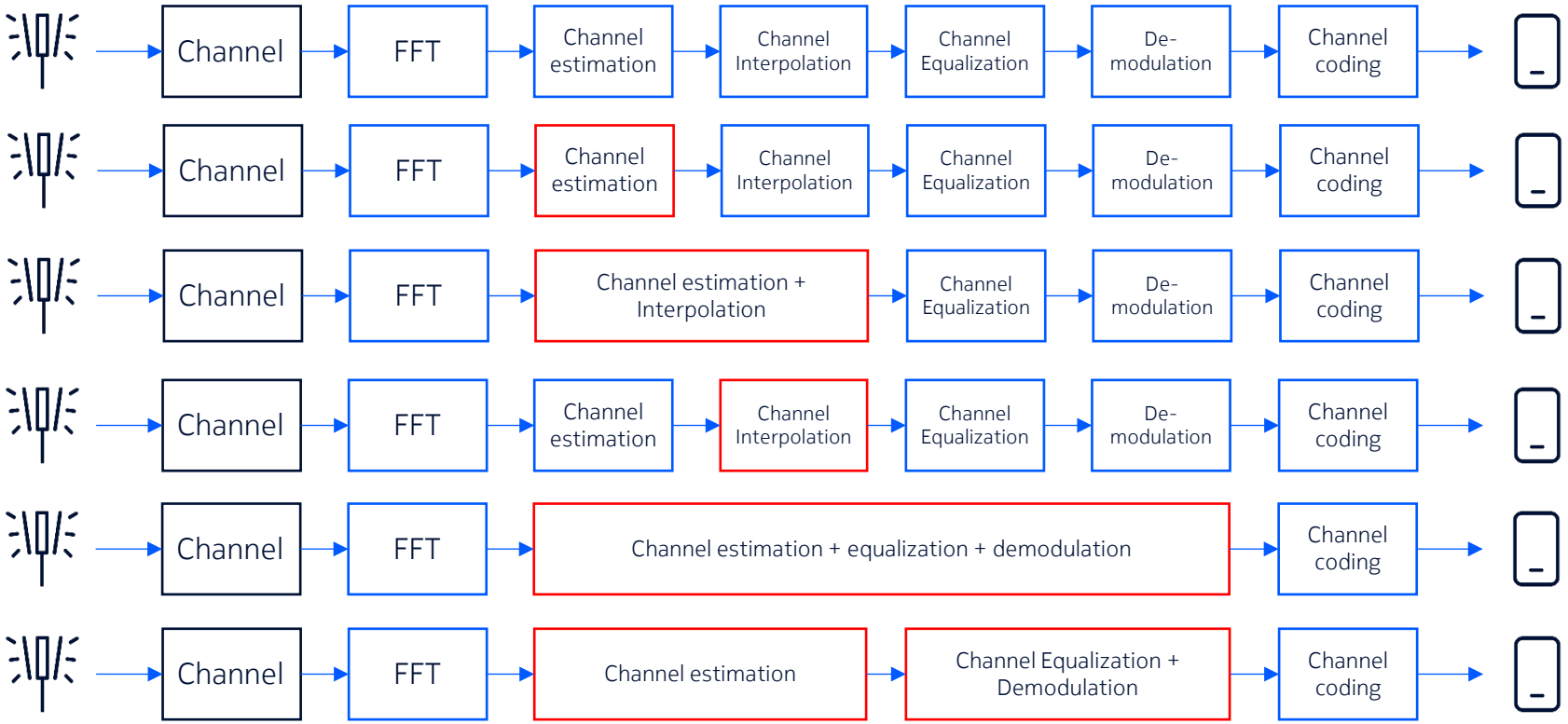


Legacy block

AIML block

DMRS design with AI receiver

AI Receivers based on Company contribution in current 6G AIML discussion in 3GPP RAN1#123 meeting



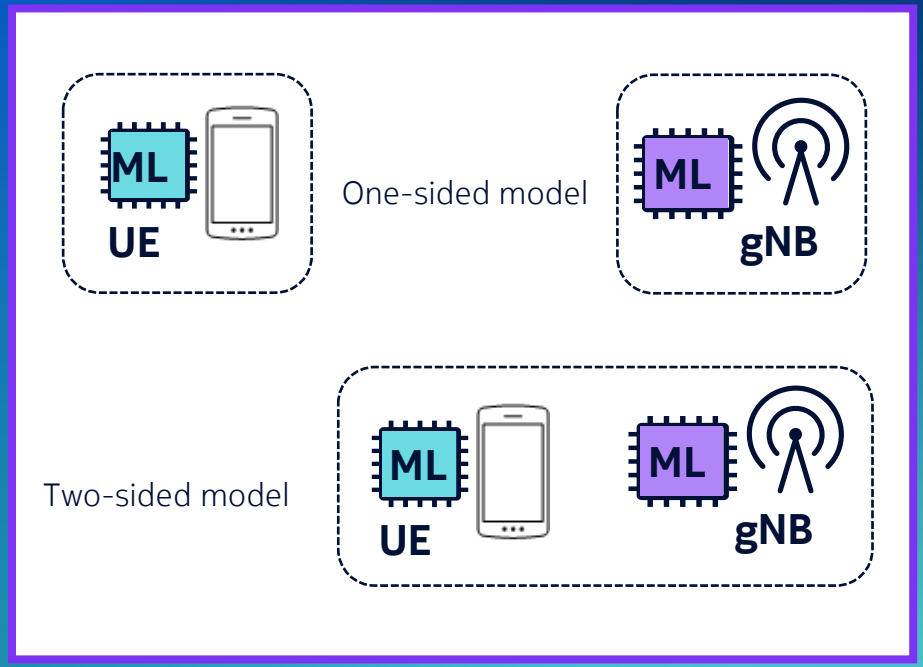
Section summary: How AI/ML is shaping the radio interface?

AI/ML Radio framework: life cycle management of UE functionalities (inference, monitoring, data collection).

5G-Advanced standardized use cases: beam management, CSI prediction, and Positioning.

6G studies are raising new use cases: Reference signal overhead reduction.

Potential use cases for AIML 6G

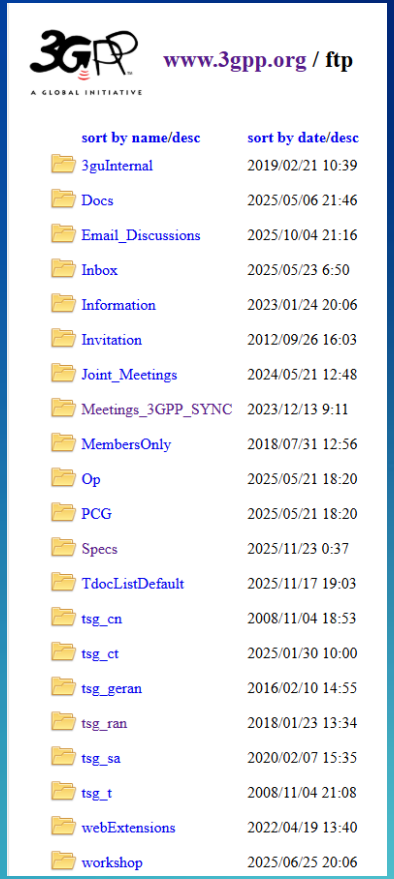


Suggestion to remark

Navigate the 3GPP ftp server

https://www.3gpp.org/ftp/

It is free and updated permanently with latest company's contributions and standardization specifications




NOKIA