E2E System View and Architecture from Chinese perspective

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Outline

Challenge 1: The existing business approaches bottleneck

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- **The development of 5G has not met expectations on revenue growth/monitization;**
- **The growth of data traffic tends to be flat or even downward;**
- **To keep sustainable development of the ecosystem, 6G needs to create new values.**

Growth

Traffic

Voice dominated traffic

Revenue

Mobile data explosion

Time
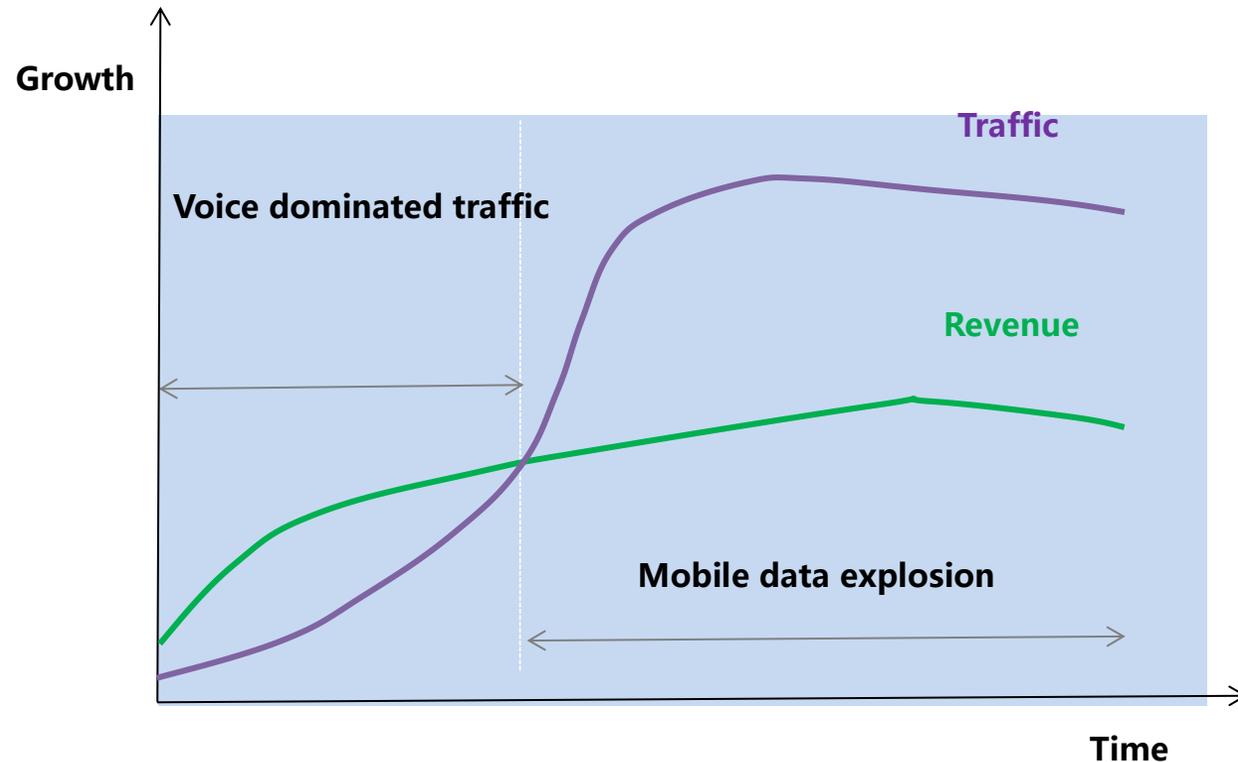
☐ **Focus 1: How to cultivate emerging businesses**

① **New service: immersive communication...**

② **New device: AR/VR, intelligent robot...**

☐ **Focus 2: How to increase value for existing businesses**

① **How can traditional communication services (voice, data) tap new value?**

② **How can vertical applications break through the bottleneck of commercialization?**

Challenge 2: Differentiated Scenarios demands very diverse Requirements

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The future scenarios will be more diversified, differentiated and fragmented, and the network needs fast and low cost deployment for customerized and personalized use cases.

Typical scenario 1: Agent communication

The demands for 6G:
◇6G needs to address the challenges faced by agents, such as **computing power, data, and task collaboration**.

Typical scenario 2: Low-altitude economy

The demands for 6G:
◇Integrating sensing and communication can construct a **cost-effective, efficient and high-precision network**.
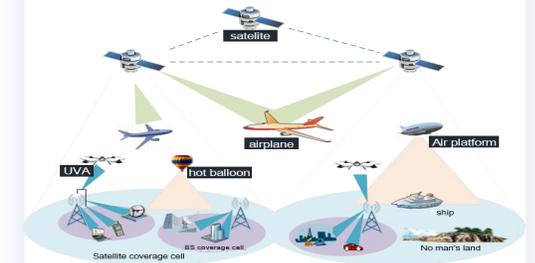
Typical scenario 3: Immersive communication

The demands for 6G:
◇It needs a **higher network performance**, as well as terminals that are **lightweight, intelligent, low-cost and have long battery life**.

Typical scenario 4: Space-air-ground Integrated Network

The demands for 6G:
◇It needs to achieve **tight coupling** between satellites and the ground to realize the goal of "strengthening the sky with the ground."

An improved adaptability to the scenarios is crucial to the 6G network

Challenge 3: Bottleneck of Air Interface Performance

Larger gap in experienced data rate between cell center and cell edge , between UL and DL.
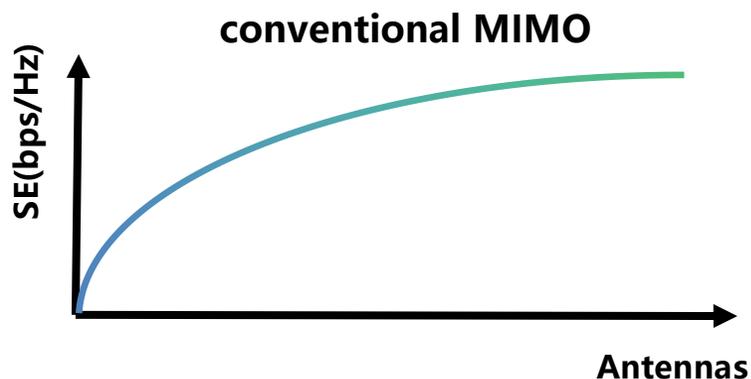
The conventional MIMO suffers from limited resources on a single site.

Limited Performance

- Limits: AAU size, power consumption, cost, antenna number, limited Tx power
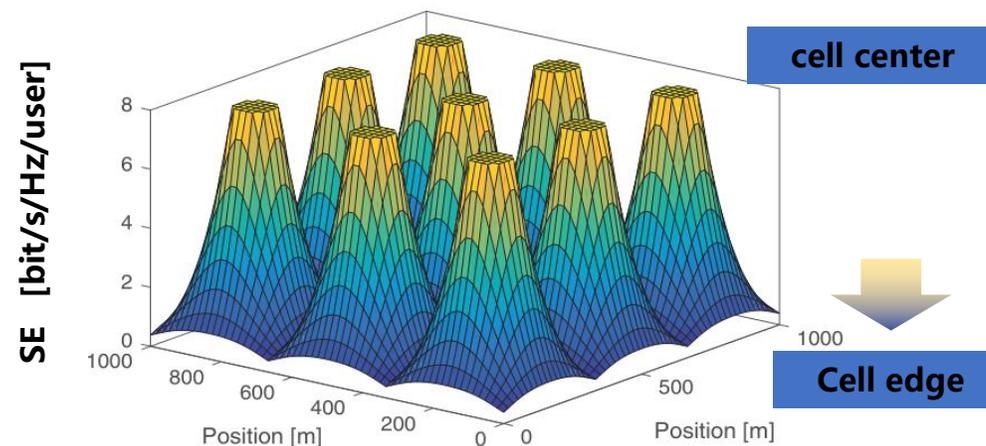
Capacity

Tx Power

$$C = B \sum_{n=1}^{N} \log_2(1 + \frac{P}{\sum_i I_i + N})$$

limited antennas   Interference limited

conventional MIMO

(SE(bps/Hz) vs Antennas graph)

Unbalanced Perforamnce

- Unbalanced User experience: **good at cell center, bad at cell edge due to interference; good at DL, bad at UL due to limted Tx power and hardware of UE**

(SE [bit/s/Hz/user] vs Position [m] 3D graph)

cell center

Cell edge

Uncoordianted MIMO degrades the cell edge performance

Challenge 4: Learning from 5G

6G should address the major challenges faced by 5G networks: high costs, high energy consumption, and complex O&M.

High cost

➤ **Redundant Construction:** Dedicated equipment is deployed in a **siloed manner** for different scenarios.

➤ **Network Utilization**: Network devices are typically **configured at full capacity**, while the actual service load follows the 80-20 rule and exhibits tidal effects, leading to idle and wasted hardware processing capabilities.

High Energy Consumption

➤ **Technology Introduction:** Broadband, Massive MIMO,etc., lead to significant energy consumption;

➤ **Equipment Form:** The **limitations of the current base station structural design** result in high idle energy consumption, which to some extent restricts the energy-saving effects of 5G networks.

Complex O&M

➤ **Management Approach: Post fault handling** results in slow response speed and high labor costs;

➤ **Technical Means:** Current AI decision-making has a lag which **leads to suboptimal outcomes.**

Outline

1   **The Challenges Faced by Ecosystem**

2   **Innovative Design for 6G Network**

       ➢ **Air Interface**

       ➢ **System Architecture**

3   **Summary**

Unified system design for all scenarios

It needs to design a resilient and efficient 6G system with a mechanism adapts to multiple scenarios.

Different functions for different subsystems

Differentiated network requirements

- Efficiency promotion
- Network simplification
- Zero-outage network

Differentiated service requirements

AI needs	AI		Computing
Sensing needs	Sensing		Positioning
low-latency needs	Deterministic communication		Ultra-low latency
large-traffic needs	Immersive communication		AI Agents

······

Common requirements

Communication   Ubiquitous Connectivity   Massive Connectivity   Security

Immersive subsystem
- Func a
- Func b

HRLLC subsystem
- Func X
- Func Y
- Func Z

Sensing subsystem
- Func ①
- Func ②

Common functions
- Func 1
- Func 2
- Func 3

······

Innovations for 6G Networks

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Challenges faced by Eocsystem

Strategic perspectives
6G needs to explore new business models

New Scenario Requirements
more diversified, differentiated and fragmented

Performance Challenges
large difference between center and edge, UL/DL

5G Pain Points
high costs, high energy consumption, and complex O&M

Key Technologies

Coordinated massive MIMO：balanced performance for UL/DL, cell edge/cell center

Coordinated Multiple bands：decoupled UL/DL, CP/UP on different bands(Low/middle/High)

Cooperative Sensing：low-cost ubiquitous communication and sensing network

6G Network Architecture: SBA based, future-oriented, Data as a Service, Computing integrated, AI native, on demand orchestration

Autonomous Network: digital twin network and native AI enables "0 fault, 0 interruption, 0 wait"

Cordinated massive MIMO: Balanced performance

Tech.

signal   Interference
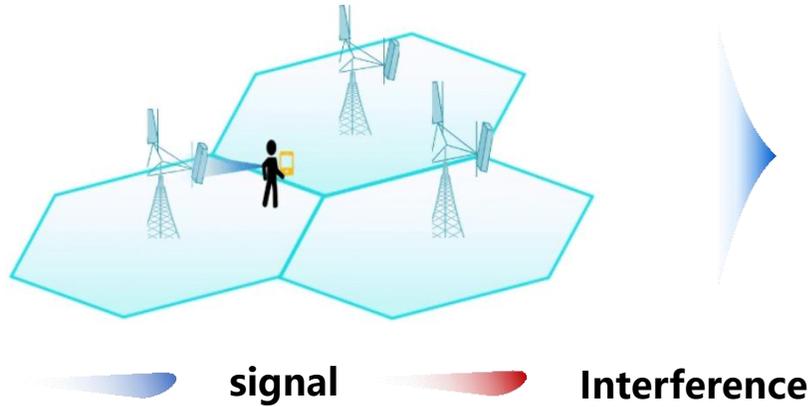
Coordinated MIMO:

- User centric transmision and multiple sites coordination for seamless user experience

Effect

Break the limits of single site

$$\text{Rate} = \sum_{r=1}^{Low\ rank} B\log_2(1 + \frac{S}{I + N})$$

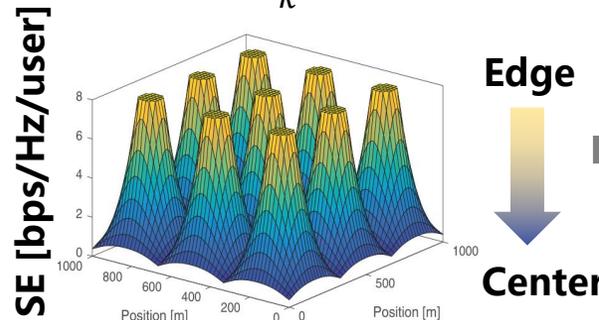**Conventional MIMO**

$$\text{Rate} = \sum_{r=1}^{High\ rank} B\log_2(1 + \frac{\sum_i S_i}{N})$$

C-MIMO

Seamless user experience

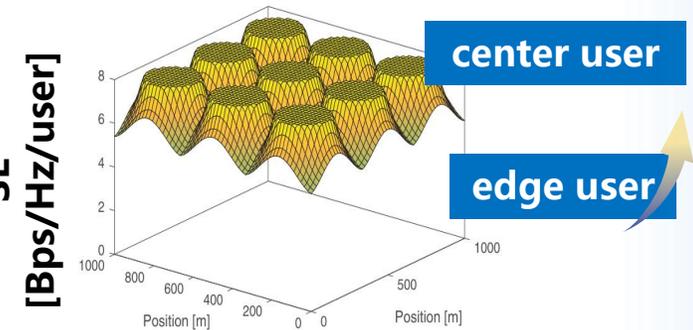$$\max \sum_k R_k$$

SE [bps/Hz/user]

Conventional MIMO

Edge → Center

$$\max \min_k R_k$$

SE [Bps/Hz/user]

center user

edge user

C-MIMO

AI powered massive MIMO

Benefit from its strong capabilities of feature extraction, training inference, and complex algorithm solving, AI empowers massive MIMO in future networks.

1. How to achieve low cost in high-dimensional channel acquisition

High dimensional → Low dimensional

- Identifying **interference and noise characteristics**, and channel **correlation**, enabling accurate channel **estimation and prediction**.
- Mining channel features, enabling **low-cost compression** feedback.
-

Feature mining
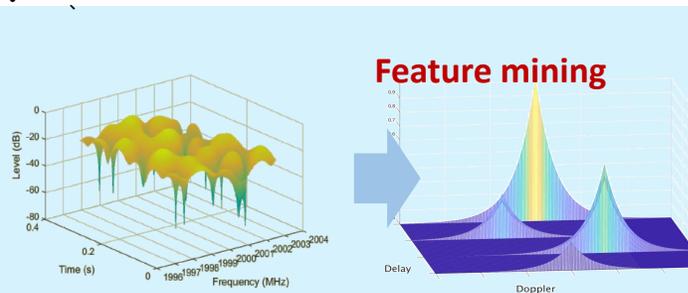
Feature extraction

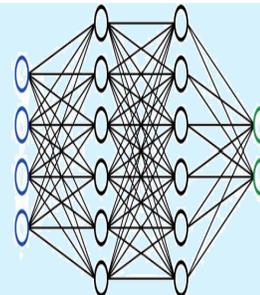**Improve channel precision**

2. How to perform real-time & accurate computation on high-dimensional matrices

Large scale → Small scale

- Learning single/multi-user MIMO precoding matrix
- Transform **complex matrix operations** into **low-cost AI inference**

$$H = U\Lambda V$$
$$H = U\Lambda U^H$$
$$W = H^{-1}$$
$$W = H^\dagger$$
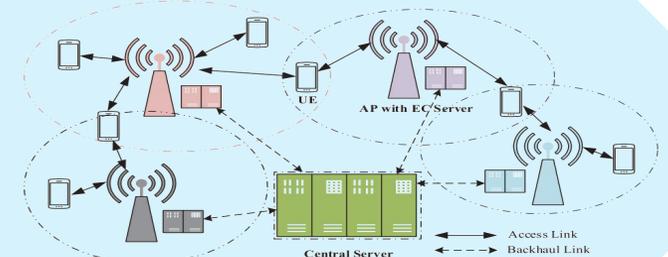$$\sum_{i=1}^{M} H_i^H \cdot H_i$$

Real-time inference

Improve computing efficiency

3. How to dynamically schedule in complex large-scale networks

Complex → Simple

- Learning **multi-cell MIMO precoding** matrix
- Interference cancellation and multi-cell coordinated scheduling algorithm
-

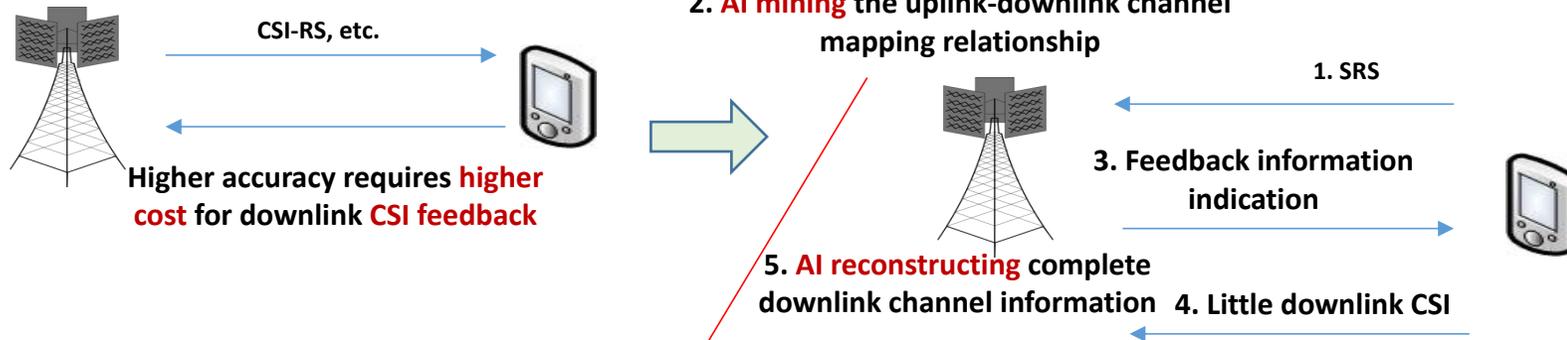**Complex algorithm solving**

Solve application challenges

AI

Empower

Example 1: AI-based Low-cost Uplink Feedback

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Solution approach

Traditional

CSI-RS, etc.

Higher accuracy requires higher cost for downlink CSI feedback

AI

2. AI mining the uplink-downlink channel mapping relationship

1. SRS

3. Feedback information indication

5. AI reconstructing complete downlink channel information **4. Little downlink CSI**
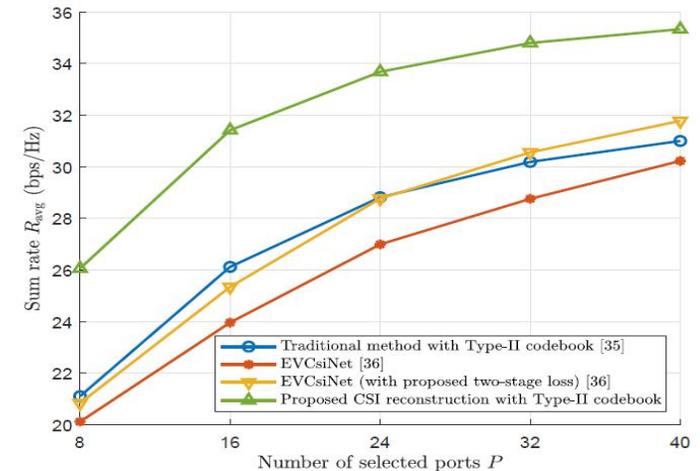
Mining the uplink-downlink differences in the angle-delay domain

Computing the uplink sparse channel

Angle $f_1(\tau_1)$ $f_3(\tau_3)$ $f_2(\tau_2)$ Delay

AI inference for downlink feedback information

$f_2(\tau_2)$ Delay

☐ **The correlation between uplink and downlink in the angle-delay domain is stronger than in other domains,** and there is less channel information with large differences.

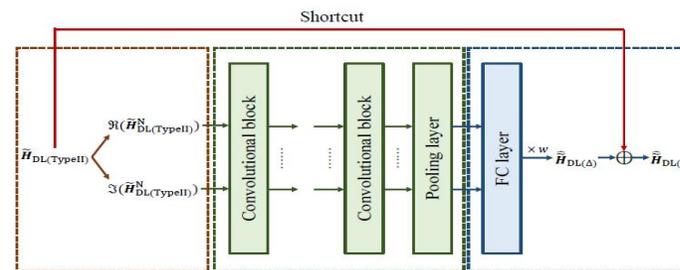☐ Users provide on-demand downlink CSI feedback, reducing overhead and improving accuracy.

AI fitting-based reconstruction

☐ **Based on the strong fitting ability of AI residual networks,** only a small amount of downlink/uplink CSI is required to reconstruct the complete downlink channel.

Shortcut

$\widetilde{H}_{\text{DL(TypeII)}}$ → $\Re(\widetilde{H}^N_{\text{DL(TypeII)}})$ / $\Im(\widetilde{H}^N_{\text{DL(TypeII)}})$ → Convolutional block ⋯ Convolutional block → Pooling layer → FC layer ×w $\widetilde{H}_{\text{DL}(\Delta)}$ ⊕ $\widetilde{H}_{\text{DL(p)}}$

Performance evaluation

(Plot: Sum rate R_{avg} (bps/Hz) vs Number of selected ports P)

Legend:
- Traditional method with Type-II codebook [35]
- EVCsiNet [36]
- EVCsiNet (with proposed two-stage loss) [36]
- Proposed CSI reconstruction with Type-II codebook

With the same spectral efficiency, feedback overhead is reduced by approximately 50%

Example 2: AI-enabled MIMO Precoding

Solution approach

Traditional
- MMSE
- Greedy
- ...

AI
- CNN
- Attention
- GNN
- ...

- ■ **Traditional model: high complexity** $O(n^3)$

- ➤ Complex matrix operations: matrix inversion, SVD, etc.
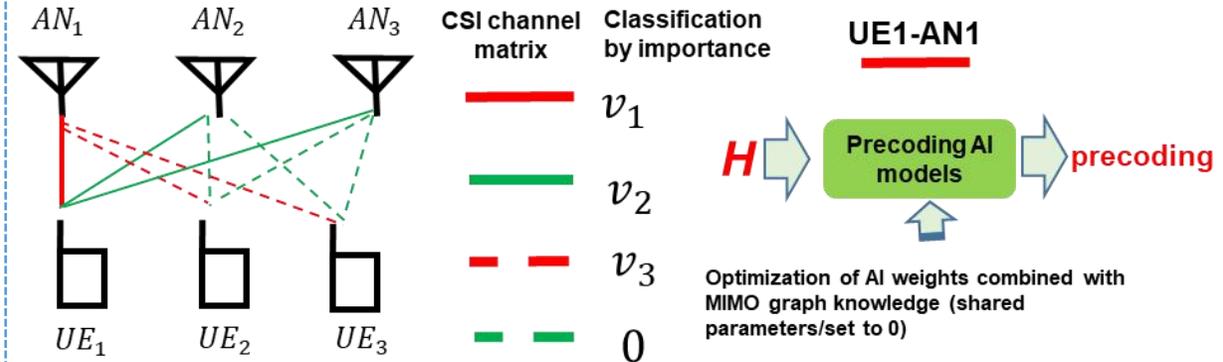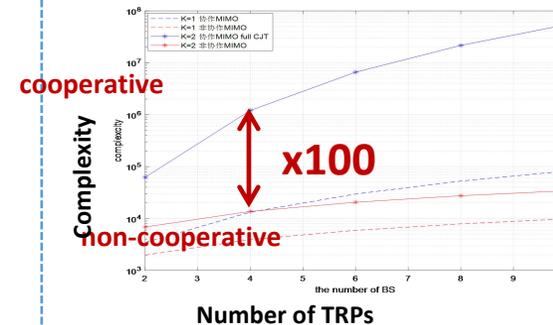- ➤ Extensive iterative operations: user pairing, etc.

- ■ AI solves complex operations through real-time efficient inference $O(n)$ while causing **high training overhead**.

- ■ To address high-dimensional MIMO matrix, a **real-time precoding algorithm** that integrates communication knowledge with AI is proposed
  - ➤ Significantly reduce training complexity and further decrease inference complexity

AI Real-time precoding based on MIMO graph connectivity

Optimization of AI weights combined with MIMO graph knowledge (shared parameters/set to 0)

Performance evaluation
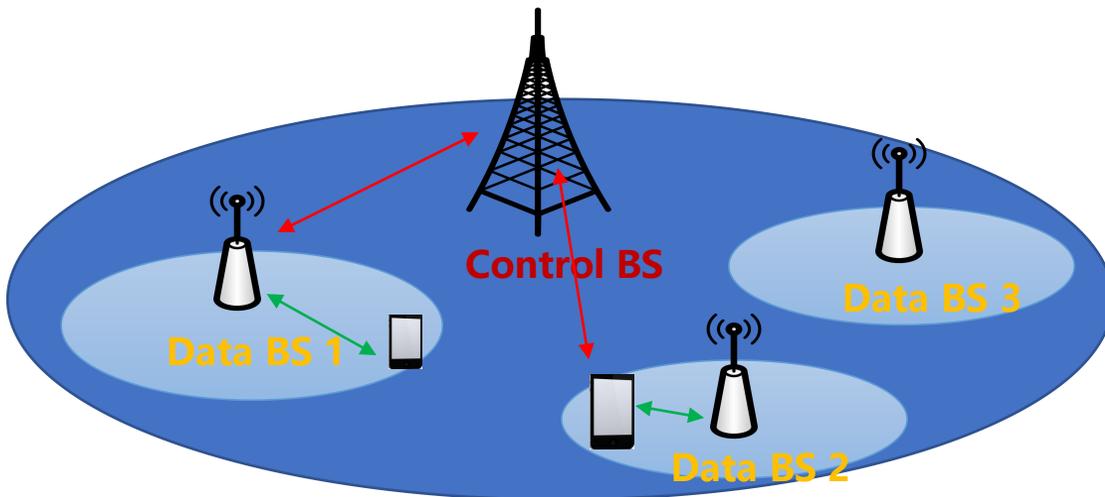

cooperative

x100

non-cooperative

Number of TRPs

- ☐ **Computational complexity**: $O(n^3)$ → $O(n)$
  - – When n =100, the complexity of the traditional method is 10^6 and the complexity of the proposed scheme is 10^2
- ☐ **AI inference time**: **Reduced by more than 50%:**
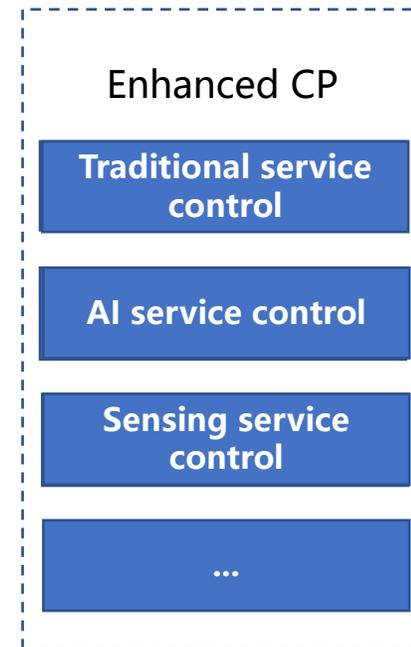
Coordinated Multi-Band for Green Network

Low-frequency control BS provides wide-area unified signaling coverage to ensure reliable connection
High-frequency data BS provides high-capacity data transmission and dynamic on-demand services

- **Decoupling of control and data link**

  - **Control link:** always on, e.g. 700MHz, provides unified signaling coverage for larger area

  - **Data link:** Dynamic on/off, e.g. Sub-6GHz, 6GHz, mmWave, THz, VLC etc.

Multi band+Multi capability

Low-frequency control BS	High-frequency data BS
Enhanced CP	Enhanced UP + data plane
Traditional service control	Traditional service data transmission
AI service control	AI service data transmission
Sensing service control	Sensing service data transmission
...	...

Control BS

Data BS 1

Data BS 2

Data BS 3

Tech.

Tx ↔ Rx

Isolation

Tx/Rx Sharing

Tx/Rx sharing

Tx/Rx sharing
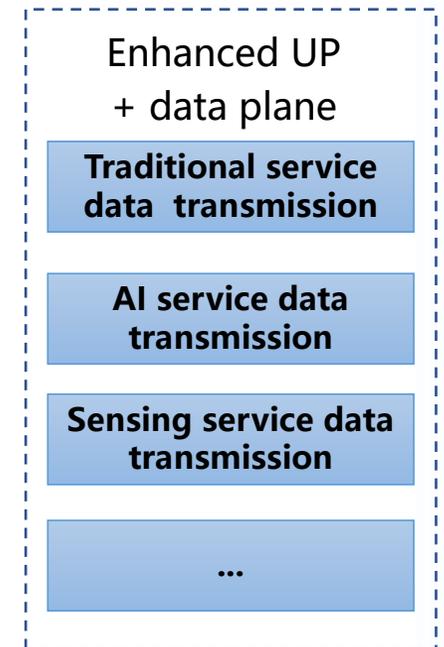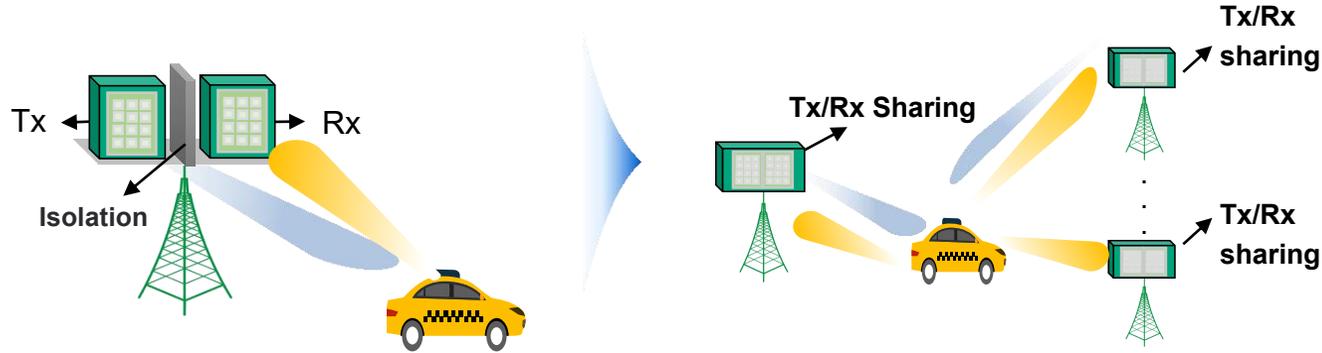
Cooperative sensing:

-leveraging multi-node cooperation and intelligently integrating multidimensional information, to improve sensing accuracy

Effect

Break the limits of single site

Cooperation sensing accuracy

$$\frac{1}{\mathbf{CRLB}_{m,n}(R, v, \theta)} = \frac{1}{\mathbf{CRLB}_{1,1}(R, v, \theta)} \times mn \times \gamma \times G(R_{m,n}, \ v_{m,n}, \ \theta_{m,n})$$

More available paths

Better collaboration gains

Stronger scattering intensity

Improve positioning accuracy
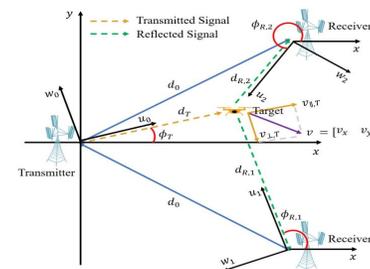
In drone and vehicle sensing scenarios, multi-node fusion improves positioning accuracy by **2x** with 95% probability.

Outline

6G enables X as a Service (XaaS)

6G will be beyond communication, which integrates the communication with sensing, computing, AI, big data and security in a native way, and creat more pipes for operator and achieves XaaS.
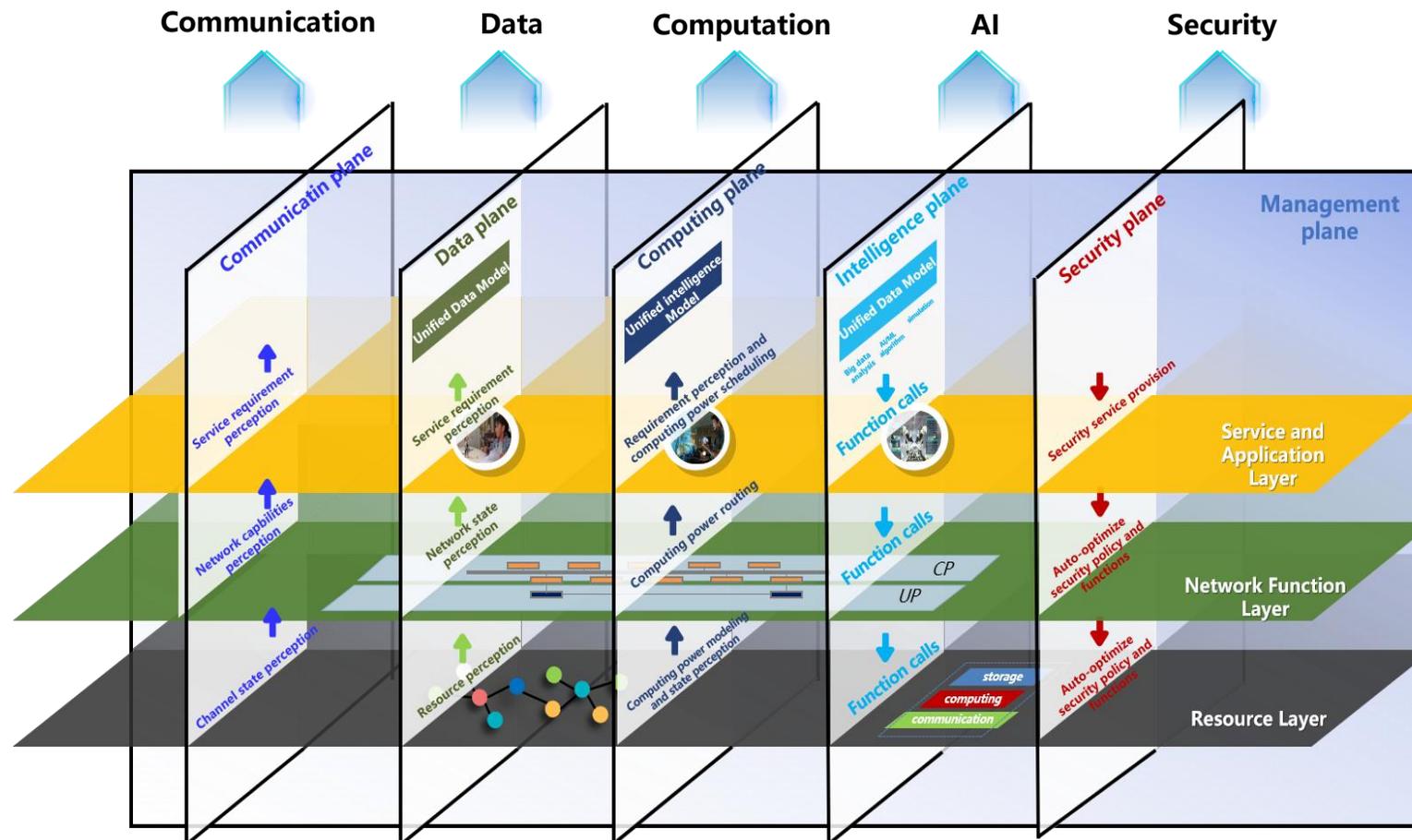
New capabilities introduction

- **Data Plane:** Manage network data and provide data services

- **Computing Plane:** native computing design, management of computing and computing services

- **Intelligence Plane:** The design of native AI provides a full-life AI service operating environment

- **Security Plane:** Native security design, provide security as a service

Potential solution: Service-based system architecture

Service based architecture realizes revolution of network architecture, 6G expands service region and key element, to establish the network as a platform
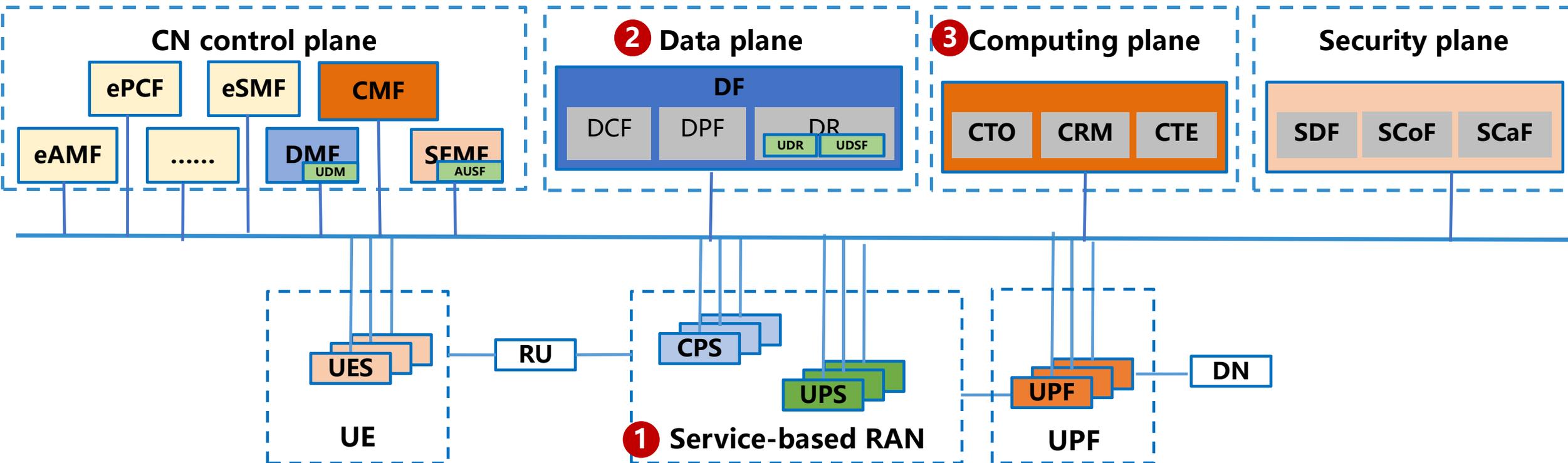
SBA brings profound changes to 5G network architecture.
6G will inherit the core concept of SBA and realize Holistic SBA

SBA-RAN

RAN capability exposure is the fundamental feature of service-based RAN, but the function orchastrating and integrating on-demand is its core value

phase 1: service-based interface to facilitate the RAN capability exposure

Option 1: Partially service-based N2
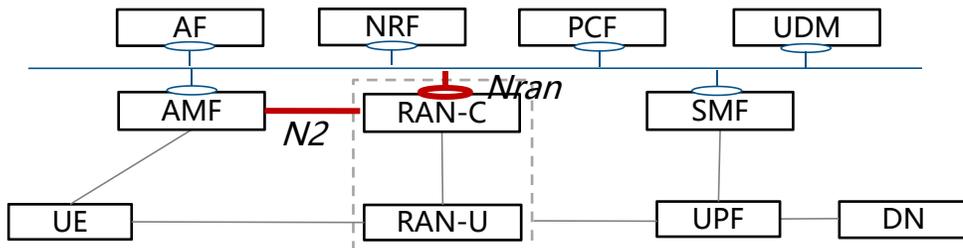
Option 2: Fully service-based N2
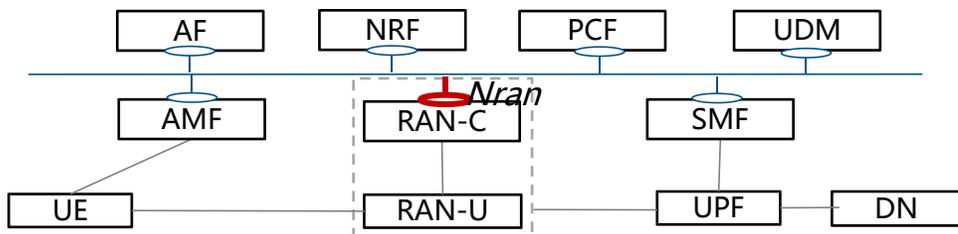
phase 2: service-based functions, enabling on-demand orchestration
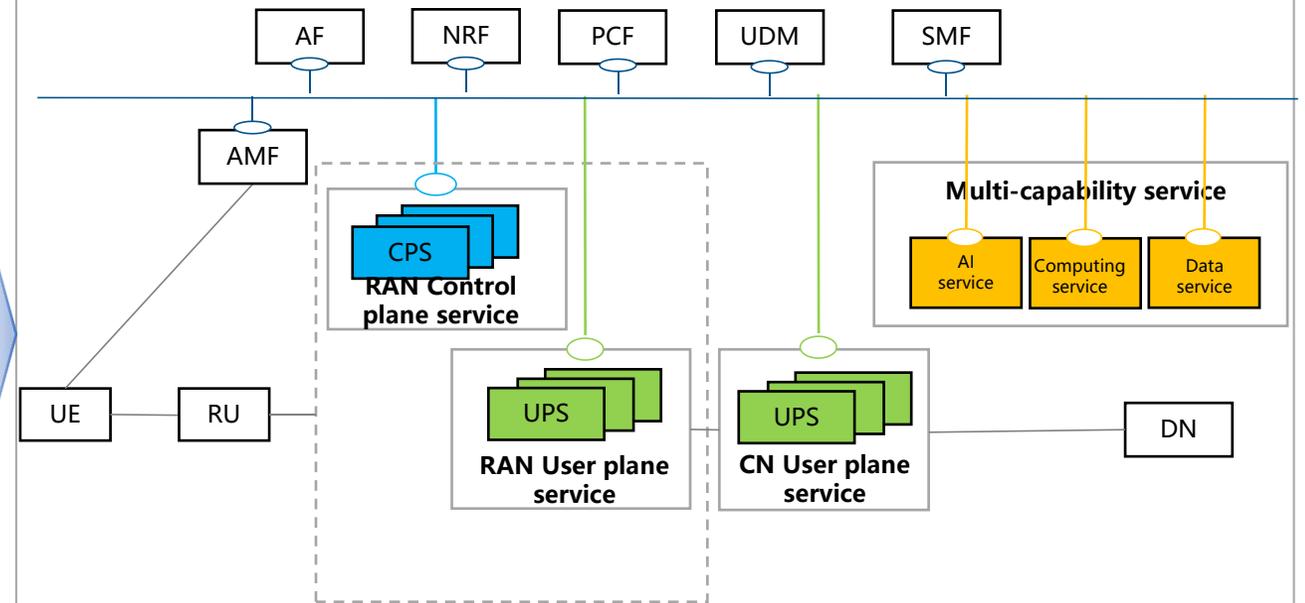
Data Plane Design

New data requirements drive 6G to design a data management system with new functionalities to support **data collection, transmission, processing, storage and exposure**

Motivation

- **AI data collection from UE:** provide full controllability and full visibility of data collection for UE-side model training
- **ISAC:** support large amount of sensing data transmission and processing
- **Network Digital Twin**: NF directly provides information/data to support digital twin generation

New mechanisms

- Introduce a new data service mechanism including
  - ✓ Data Handling Function
  - ✓ Data Processing Function
  - ✓ Data Storage Function
- Enhance the existing NFs to support a new service of data collection
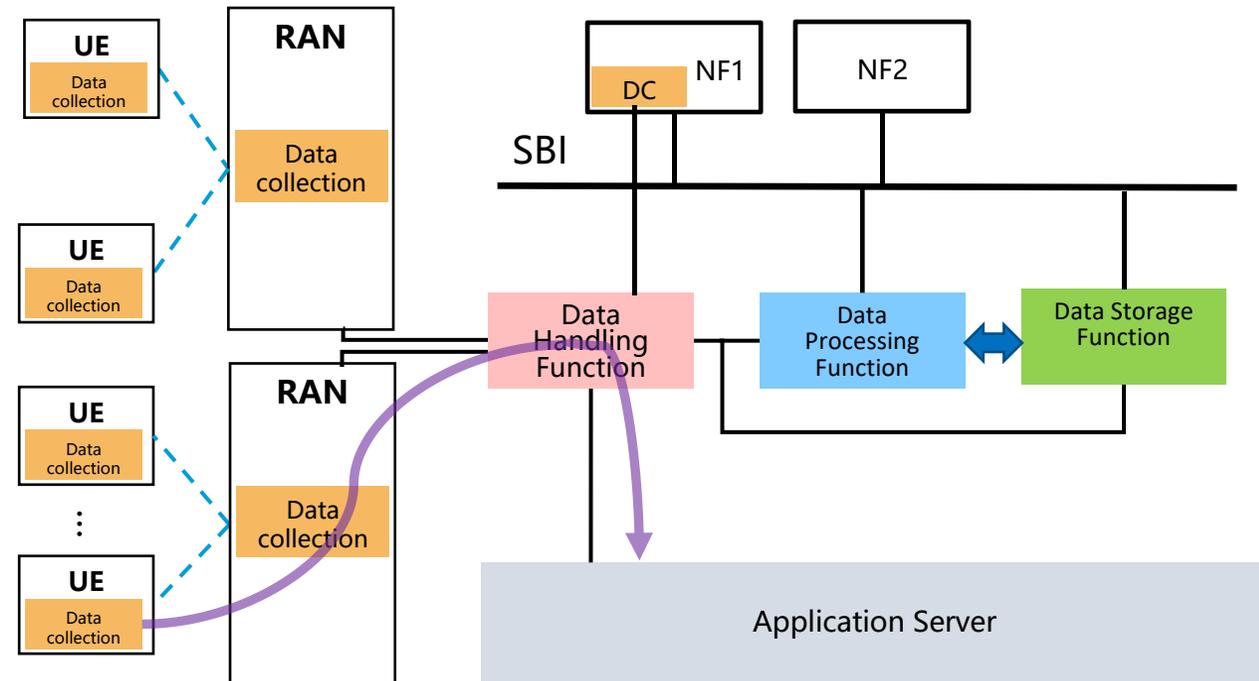
Computing Plane Design

To support scenarios like immersive communication and AI inference, the 6G core network proposes to enhance coordination between computing and communication

New requirements

- **Network services shift** from communication connection-oriented to computation task-oriented.
- **Guaranteed E2E QoS**, e.g., rate, latency, reliability for communication, and computing types, response time, FLOPs for computing.
- **E2E computing control**, across terminal, edge, and cloud.

New mechanisms

1) **New computing control function:**
- Management of computing tasks
- Computing resource state awareness
- Generation of computing offloading polices

2) **NAS re-design:** support the creation and connection of computing sessions for UE.
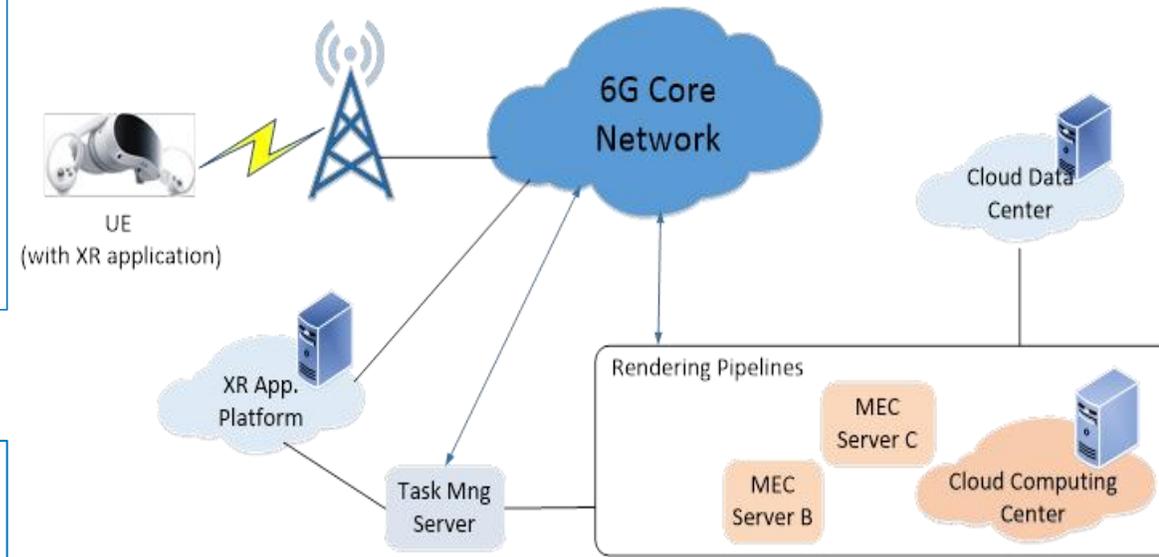
Computing and Communication Coordination for XR Rendering

Network as a Platform and capabilities exposure

Network as a platform and network capability exposure facilitate the innovative service and application, and help the monitization of the network

Multidimensional information services

Superpowered transportation   Synsensory interconnection   Holographic interaction   metaverse   Intelligent interaction   precision medicine   Intelligent industry

Usage scenarios

Network capabilities exposure

Communication   **Sensing**   **data**   **Computing**   **AI**   **Security**

Multiple atomic services

Logical function layer

| Control Plane | User Plane | Data Plane | Computing Plane | Security Plane |

Joint orchestration and management

Digital twin

IDC   IDC   AI IDC

Device

mmW   Sub-6G   THz   Fiber network   IDC

Physical infra

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Autonomous Network: Vision and Objective

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China Mobile

Scenarios are becoming more diversified, and the scale of networks as well as the complexity of O&M are growing exponentially. Advanced autonomous networks have become the essential path for operators to tackle the challenges.

6G Network Objectives

2030

self-intelligence

intelligence

digitization

L5 Fully Autonomous Network

L5 Fully Autonomous network
Automatic implementation, rules adapt to changes
Automatic iteration, network changes with business

L4 Advanced Autonomous network
Automatic realization, rules combined with AI, continuous learning and rapid iteration

L3 Conditional Autonomous network
Automatic implementation, decoupling of rules and functions, and flexible configuration on demand

L2 Partially Autonomous network
Automatic realization, the program solidifies the expert rules, and the flow can be automatically scheduled

virtualization **L1 Auxiliary operation realization**
Online record Assisted manual implementation

L0 Manual operation and maintenance
Offline manual implementation

Native AI & Digital Twin

Self-configuration → Self-optimization → Self-healing → Self-evolution

0 wait

0 touch

0 fault

⸱⸱⸱⸱ Network Autonomy   ⸱⸱⸱⸱ Intelligent OAM   ⸱⸱⸱⸱ Robust Self-healing

Concept of DTN

Digital twin network (DTN) builds a virtual network environment to simulate the network behavors and performance of a procedure, function or the whole network, realizes low-cost pre-verification in the full life-cycle of network.

Technical Features

- Data Generation
- Accurate modeling
- Orchestration and control
- Pre-validation

Improve strategy accuracy

Model Network as a "white-box"

Integrated management and control

Policy pre-validation Reduce trial-and-error costs

Value of DTN
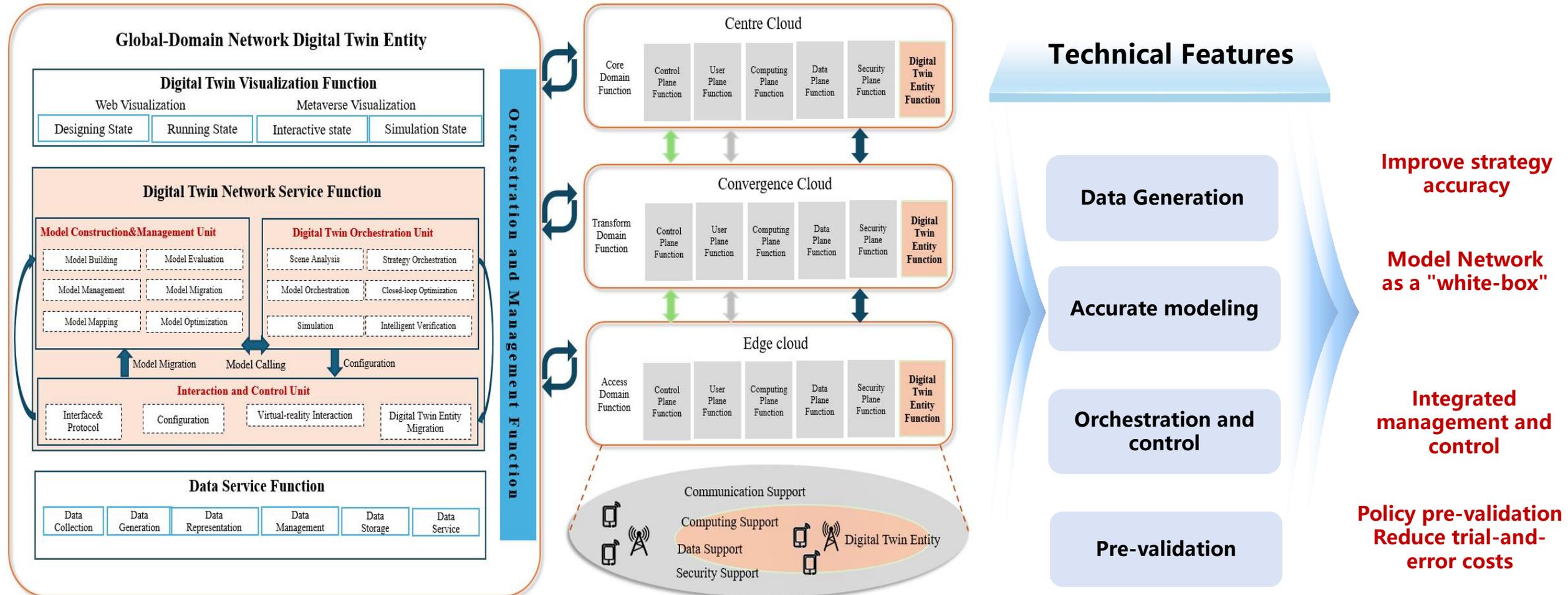
DTN enables **intelligent strategies, efficient innovation, and low trial-and-error cost**, addressing challenges in efficiency, risk, and cost.
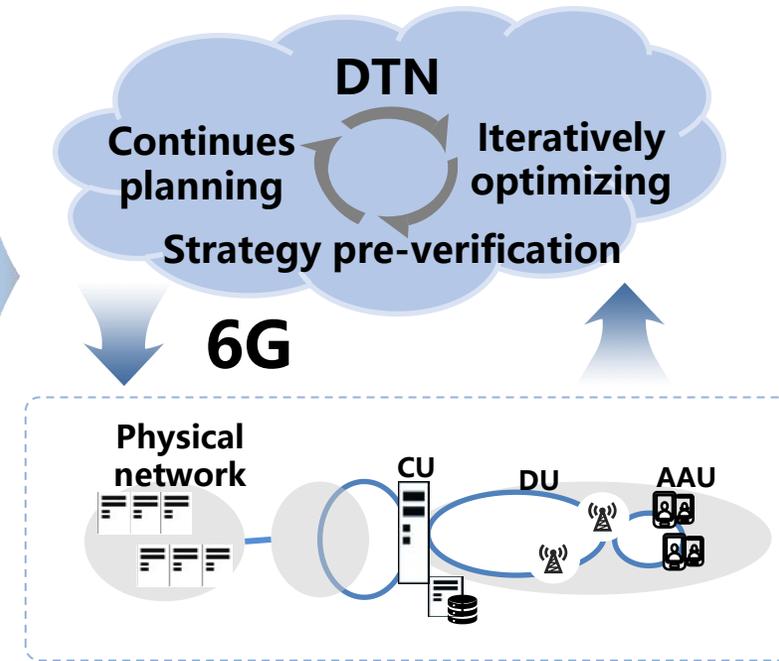
3 critital challenges

Efficiency
- Low-accuracy and high-latency under manual operations.

Risk
- Unpredictable failures in network upgrades and innovations.

Cost
- Trial-and-error costs and labor costs.

Plannin g

Constructing

Operatin g

5G

CU

DU

AAU

Optimizing ......

DTN

Continues planning

Iteratively optimizing

Strategy pre-verification

6G

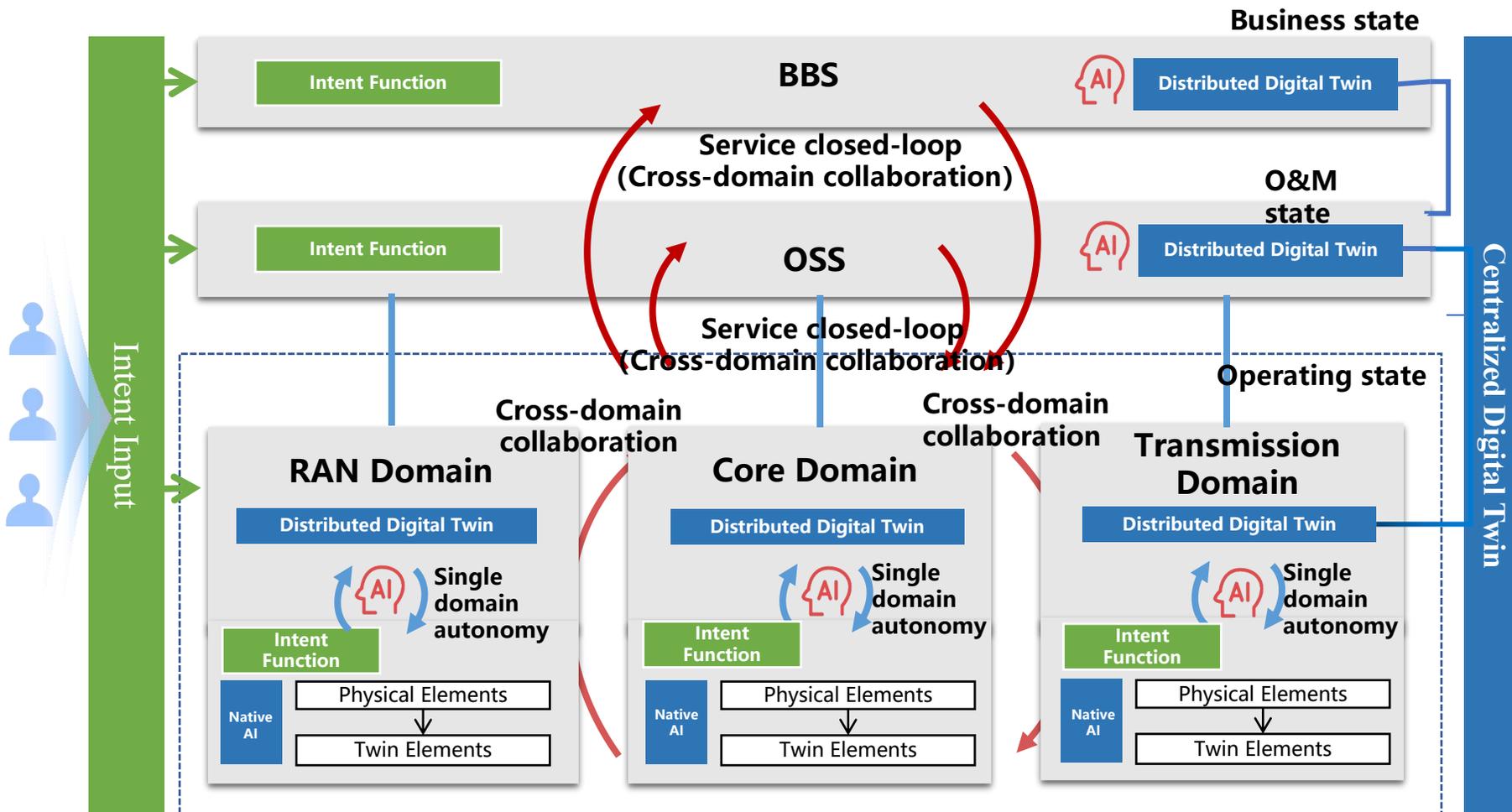Physical network

CU

DU

AAU
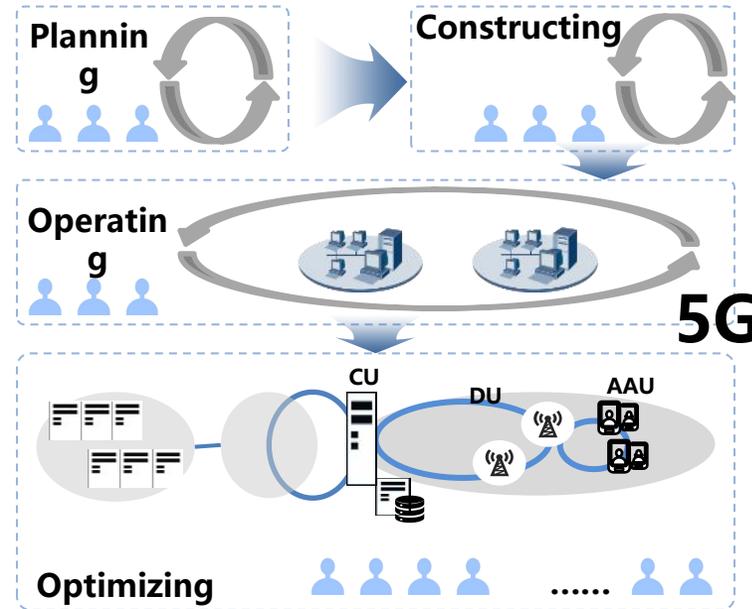
Intelligent strategies   efficient innovation   low trial-and-error cost

3 Core values of DTN

Framework of 6G Autonomous Network

Digital twin and Native AI can greatly contribute to high-level network autonomy for self-configuration, self-healing, self-optimization, and self-evolution in network Operating, O&M and Business States.

Business state

Intent Input

Intent Function

BBS

Distributed Digital Twin

Service closed-loop
(Cross-domain collaboration)

O&M state

Intent Function

OSS

Distributed Digital Twin

Service closed-loop
(Cross-domain collaboration)

Operating state

Cross-domain collaboration

Cross-domain collaboration

RAN Domain

Distributed Digital Twin

Single domain autonomy

Intent Function

Native AI

Physical Elements
↓
Twin Elements

Core Domain

Distributed Digital Twin

Single domain autonomy

Intent Function

Native AI

Physical Elements
↓
Twin Elements

Transmission Domain

Distributed Digital Twin

Single domain autonomy

Intent Function

Native AI

Physical Elements
↓
Twin Elements

Centralized Digital Twin

Centralized&Distributed Deployment

Deploying digital twin, native AI, and intent-driven function in architecture.

Cross-domain collaboration & Single domain autonomy

Achieving network autonomy in different domains and closed-loop control.

Multi-States Autonomy

Achieving automatic intent parsing, network orchestration, and management.

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Outline

Summary

- The existing business model approaches bottleneck, **6G needs to create new values.**

- **Multi-band and multi-site collaboration** are key to fill the gap in experienced data rate between cell center and cell edge , between UL and DL.

- **Cooperative sensing** helps to build a low-cost, accurate and ubiquitous sensing network.

- The 6G system architecture design should be based on **SBA, future-oriented, AI-native, Data as a Service and computing-integrated**.

- **Platformed network** is the key to monetizing network capabilities for diverse scenarios.

- **Digital twin network and native AI** enables a autonomous 6G network.

Thank you!