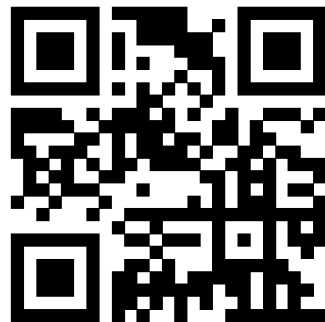# Edge Computing Empowered Tactile Internet for Human Digital Twin: Visions and Case Study

Hao Xiang, Kun Wu, Jiayuan Chen, Changyan Yi, Jun Cai, Dusit Niyato, and

Xuemin (Sherman) Shen

Edge Empowered TI (ECoTI) for HDT

Tactile Internet (TI): TI can transmit **human skills** through networks and can provide **multisensory haptic feedbacks**, enabling users to interact with objects more intuitively

| Challenges of TI for HDT	ECoTI Solution
Frequent service interruptions due to limited network resources	• Support **large-scale data collections, real-time processing and analysis** for TI; • Employ **distributed and collaborative** approaches to optimize resources allocations
Inefficiency and vulnerability when facing with heavy traffics, inducing delays and inconsistencies in feedbacks across different data modalities	• Analyze and process data **near the data sources and terminals**
Cannot support physical and virtual entities' **seamlessly data exchange and synchronization**	• **Modelling dimension**: **Manage, analyze, mine and integrate** collected multi-source data; • **Service dimension**: Utilize **lightweight AI** to provide desired functions and services

• Hao Xiang, Kun Wu, **Jiayuan Chen**, Changyan Yi, Jun Cai, Dusit Niyato and Xuemin Shen, "Edge Computing Empowered Tactile Internet for Human Digital Twin: Visions and Case Study," *https://arxiv.org/abs/2304.07454*, 2023.

System Architecture of ECoTI for HDT
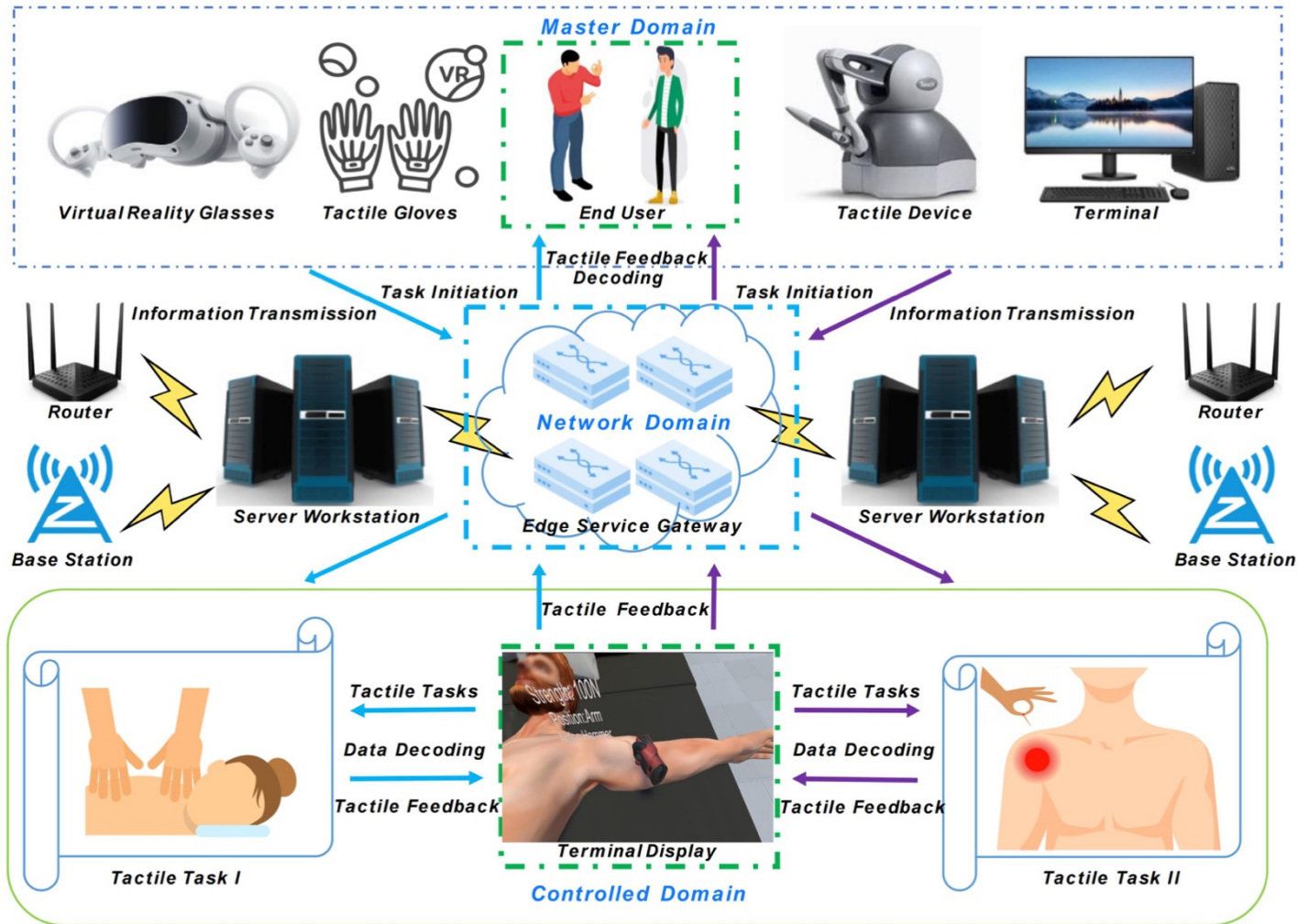
Master Domain: PTs with various haptic sensors, display devices and terminals, etc. **initiating human skills**

Network Domain: Support **bi-directional communications** between the master and controlled domains

Controlled Domain: **Execute actions** from the master domain, and the VTs **generate the feedbacks**
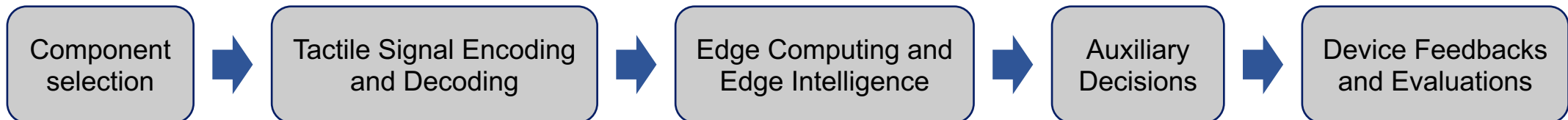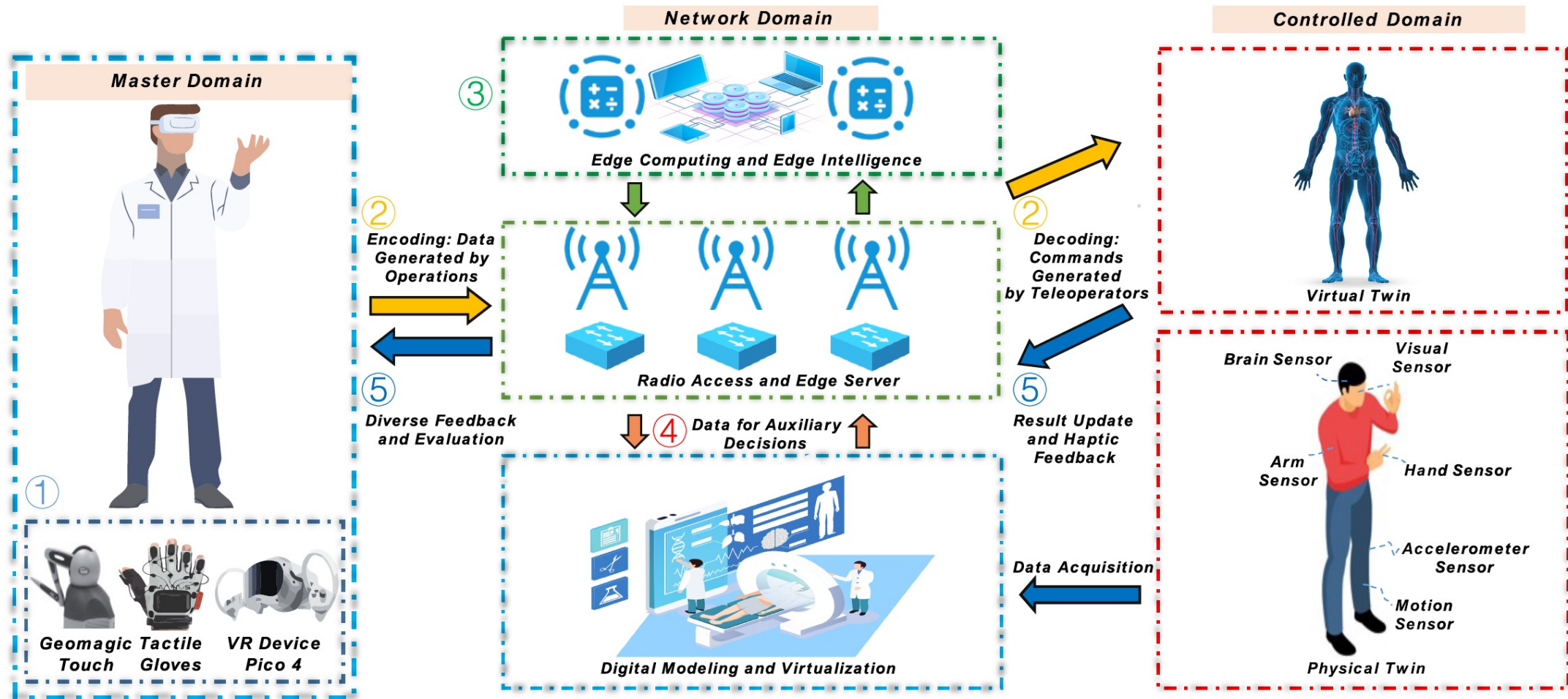
Design Requirements of ECoTI

- **Strong interactions** between Physical and Virtual Twins

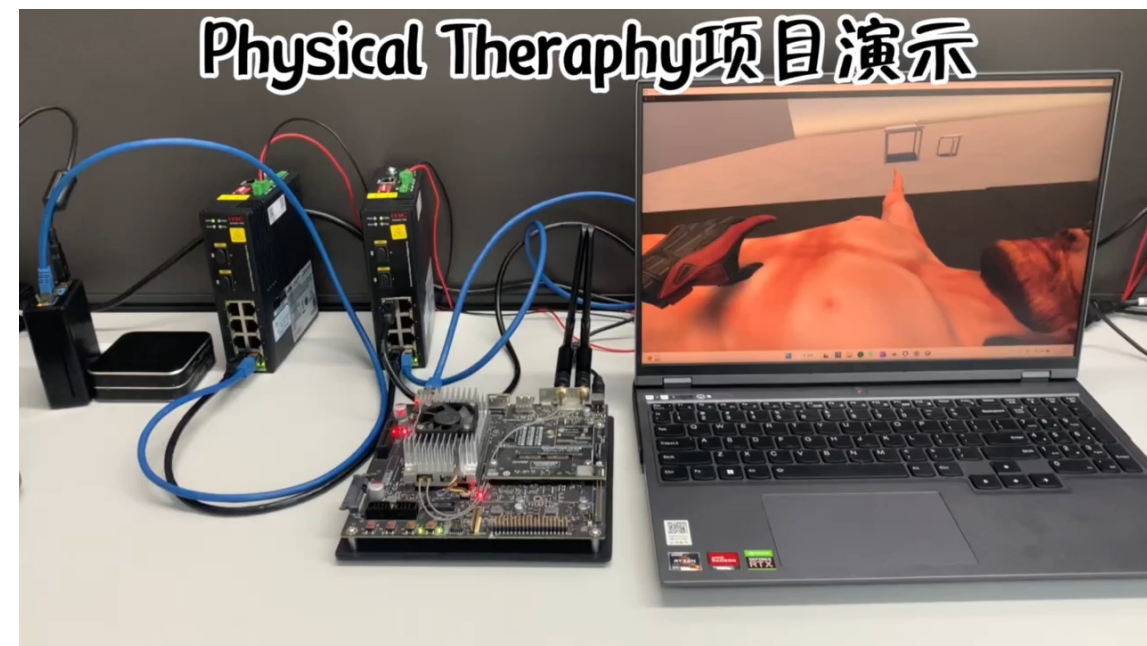| Features	Requirements
Strong interactions during mobility	Ubiquitous mobility and pervasive connectivity
Feedbacks involve **complex and multimodal information**	Real-time communication and computation with feedbacks
Data are **human-related and highly sensitive**	Privacy preserving and security with ethics and morality

- **Extremely Immersive** Quality of Experience

| Features	Requirements
Interactive effects in the design of prototypes	High fidelity virtual modeling
Multimodal data is the fuel of ECoTI for HDT	Multimodal data analysis
ECoTI for HDT is a **human-centric system**	Integration of subjective and objective evaluations

Key Steps and Core Guidelines

Network Domain

③ Edge Computing and Edge Intelligence

Controlled Domain

Virtual Twin

② Encoding: Data Generated by Operations

② Decoding: Commands Generated by Teleoperators

Radio Access and Edge Server

⑤ Diverse Feedback and Evaluation

⑤ Result Update and Haptic Feedback

④ Data for Auxiliary Decisions

Master Domain

① Geomagic Touch   Tactile Gloves   VR Device Pico 4

Digital Modeling and Virtualization

Data Acquisition

Brain Sensor   Visual Sensor   Arm Sensor   Hand Sensor   Accelerometer Sensor   Motion Sensor

Physical Twin

| Component selection | → | Tactile Signal Encoding and Decoding | → | Edge Computing and Edge Intelligence | → | Auxiliary Decisions | → | Device Feedbacks and Evaluations |

Experimental Testbed

ECoTI for HDT in Physical Therapy:

- Master domain is an agent therapist, the controlled domain is a patient, and the network domain provides both transmission and computing services.
- A virtual body is digitally constructed for mapping the patient (i.e., a PT) based on the perceived user data. TI enables the therapist to provide tactile therapy actions and videos to the patient, allowing him/her to conduct high-density and highly interactive physical operations (such as hitting and massaging) according to different situations.
- The platform also feeds back treatment operations to the patient, letting them to experience immersive and vivid therapies.

Preliminary Results

Objective Evaluation (Delay)
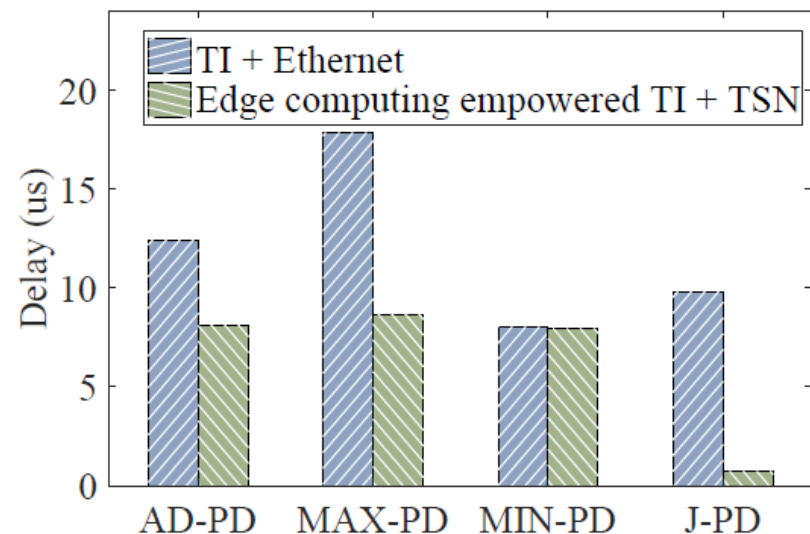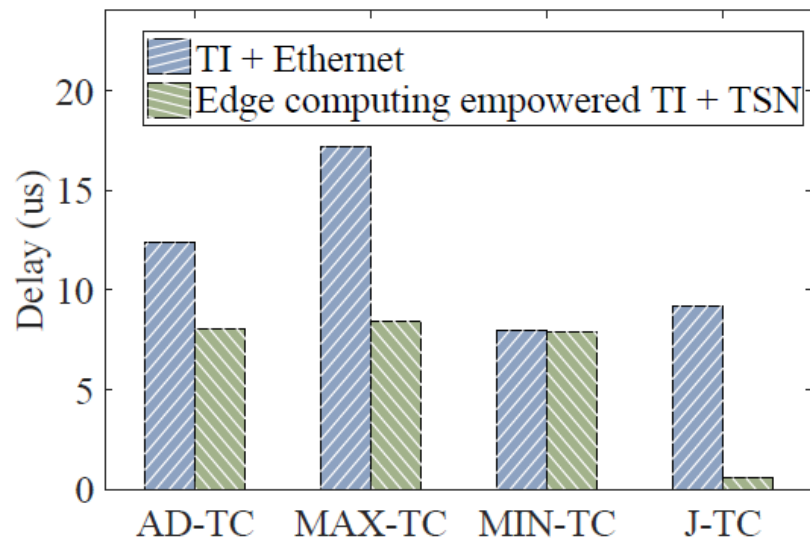
Subjective Evaluation (User QoE)

Framework	Video stream	Tactile feedback	Sync.
TI + Ethernet	Choppy	Inaccurate	Jitter
Edge computing empowered TI + TSN	Fluent	Responsive	Efficient