Networking Architecture and Key Supporting Technologies for Human Digital Twin in Personalized Healthcare: A Comprehensive Survey

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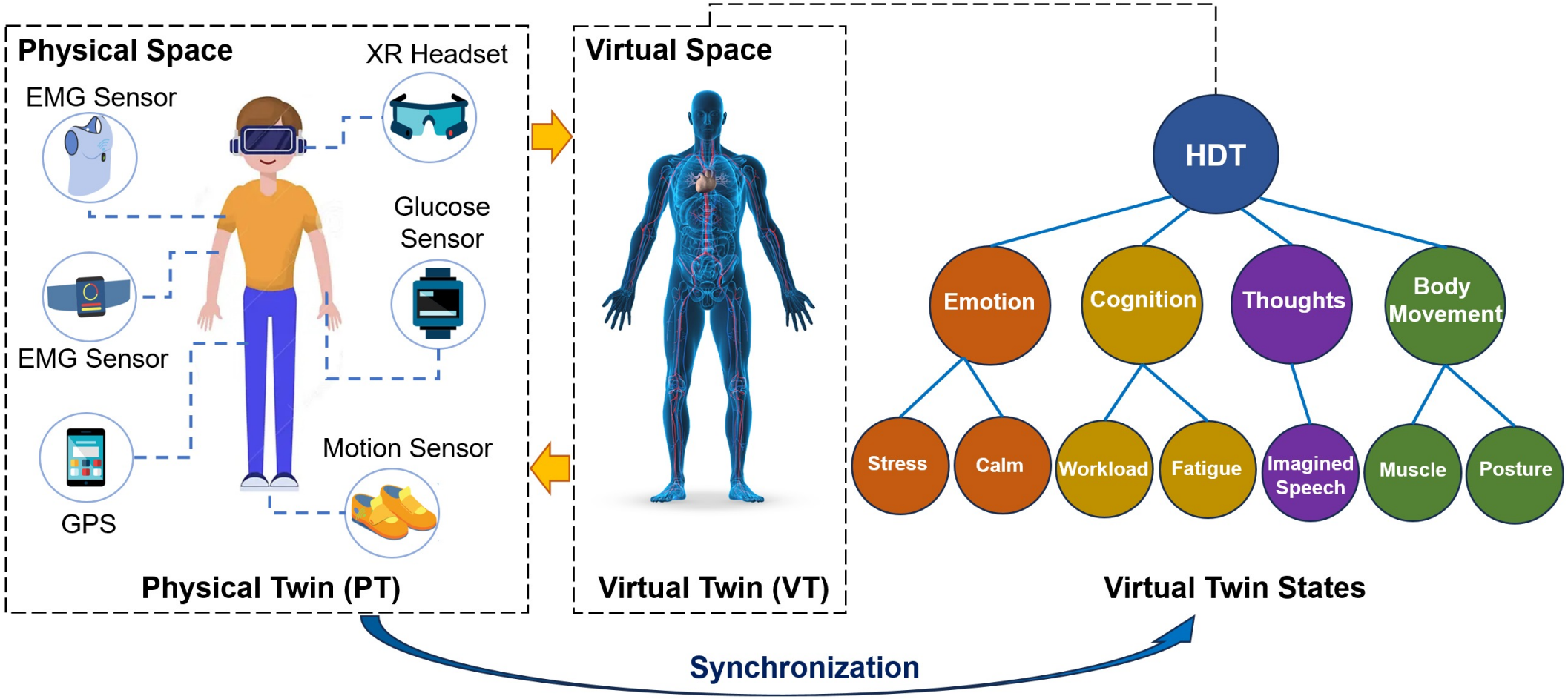
https://ieeexplore.ieee.org/document/10238695

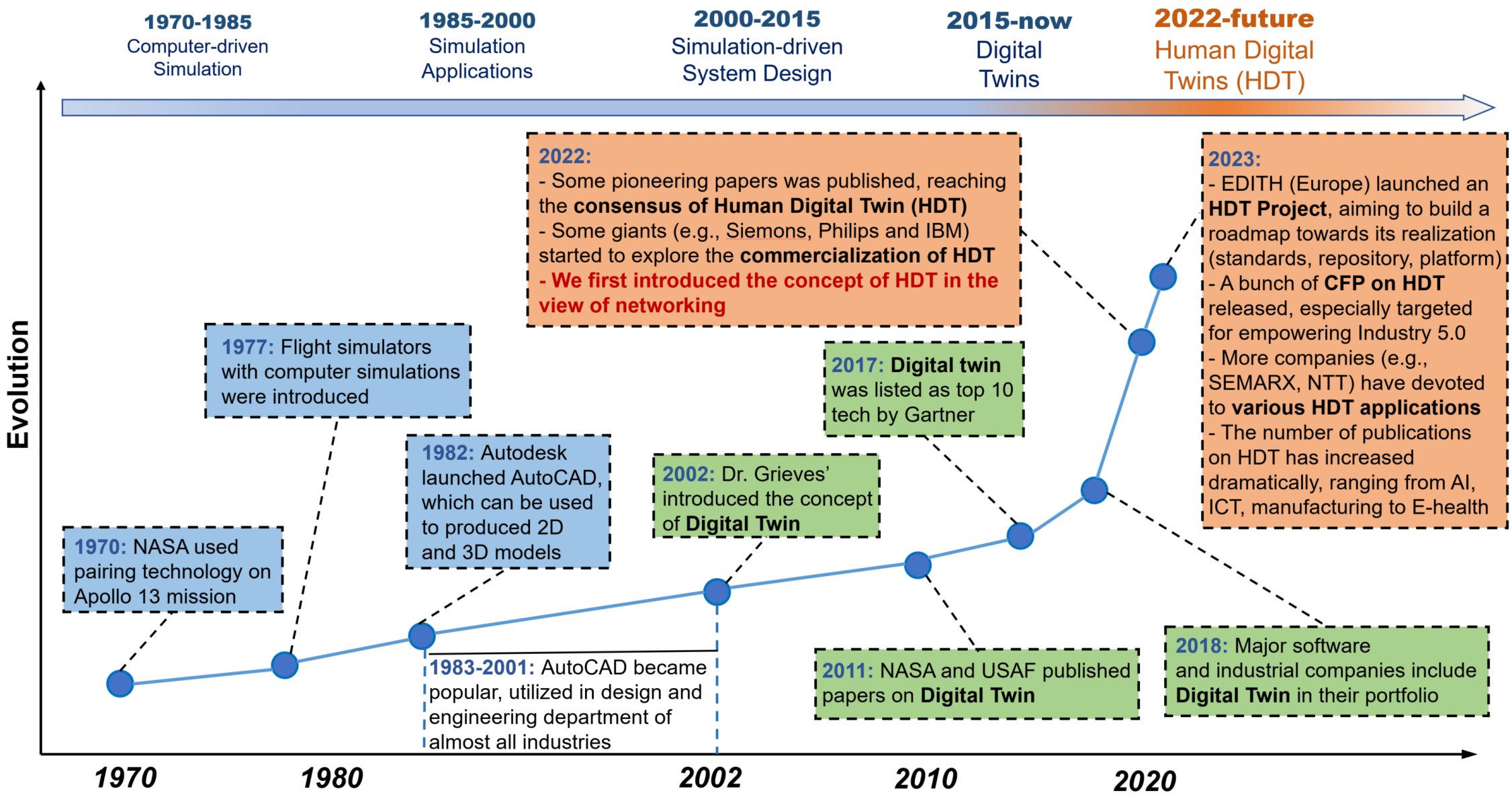
Human Digital Twin (HDT): Concept



Human Digital Twin (HDT): HDT characterizes **the replication of individual human body in the virtual/digital space** while **reflecting its physical status both psychologically and physiologically in real time**

- Samuel D. Okegbile, Jun Cai, **Changyan Yi** and Dusit Niyato, "Human Digital Twin for Personalized Healthcare: Vision, Architecture and Future Directions," *IEEE Network*, 2022.

HDT is Forthcoming



HDT in Personalized Healthcare

Continuous Health Monitoring

Proactive Diagnosis

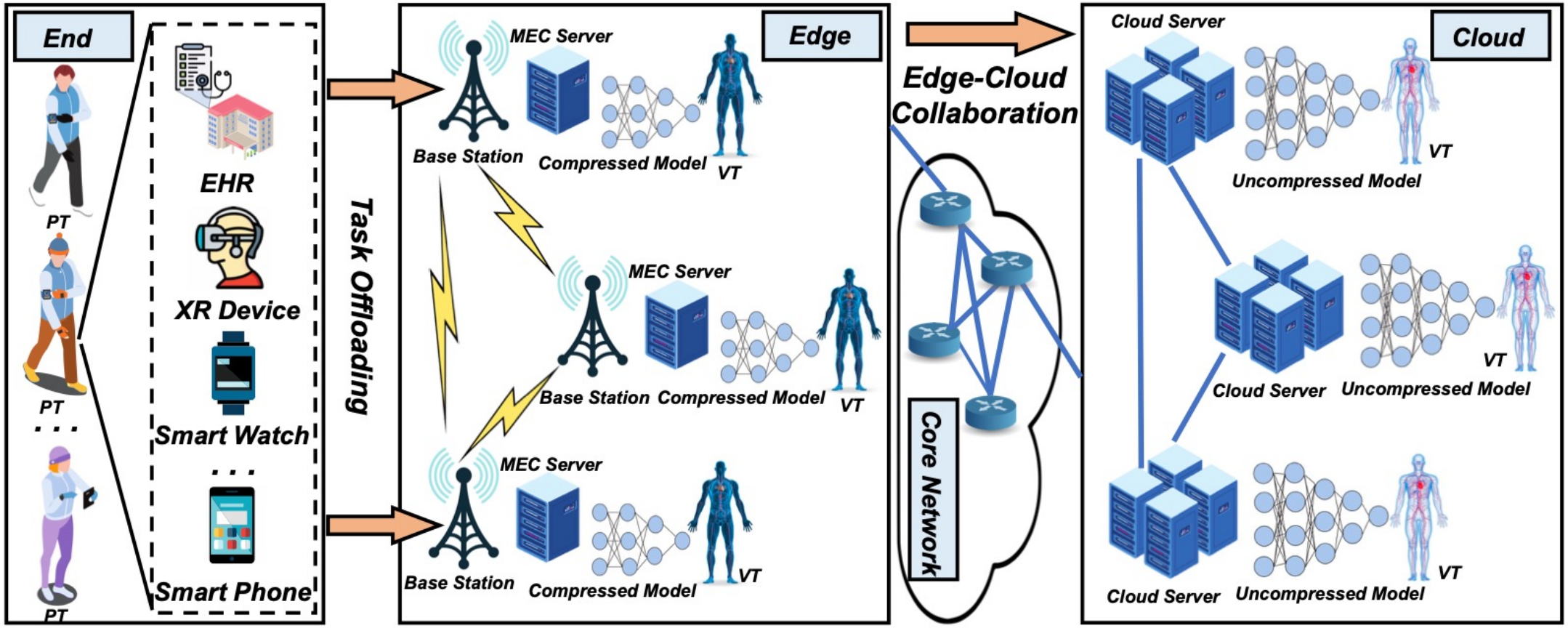
Personalized Prescription

Providing **one-fits-one treatment approach,** eliminating unnecessary side effects and high cost of conventional one-size-fits-all approaches

Preparatory Surgery

Customized Rehabilitation

HDT on the Network Edge



Fast Responsive and Low Latency

Distributed Computation

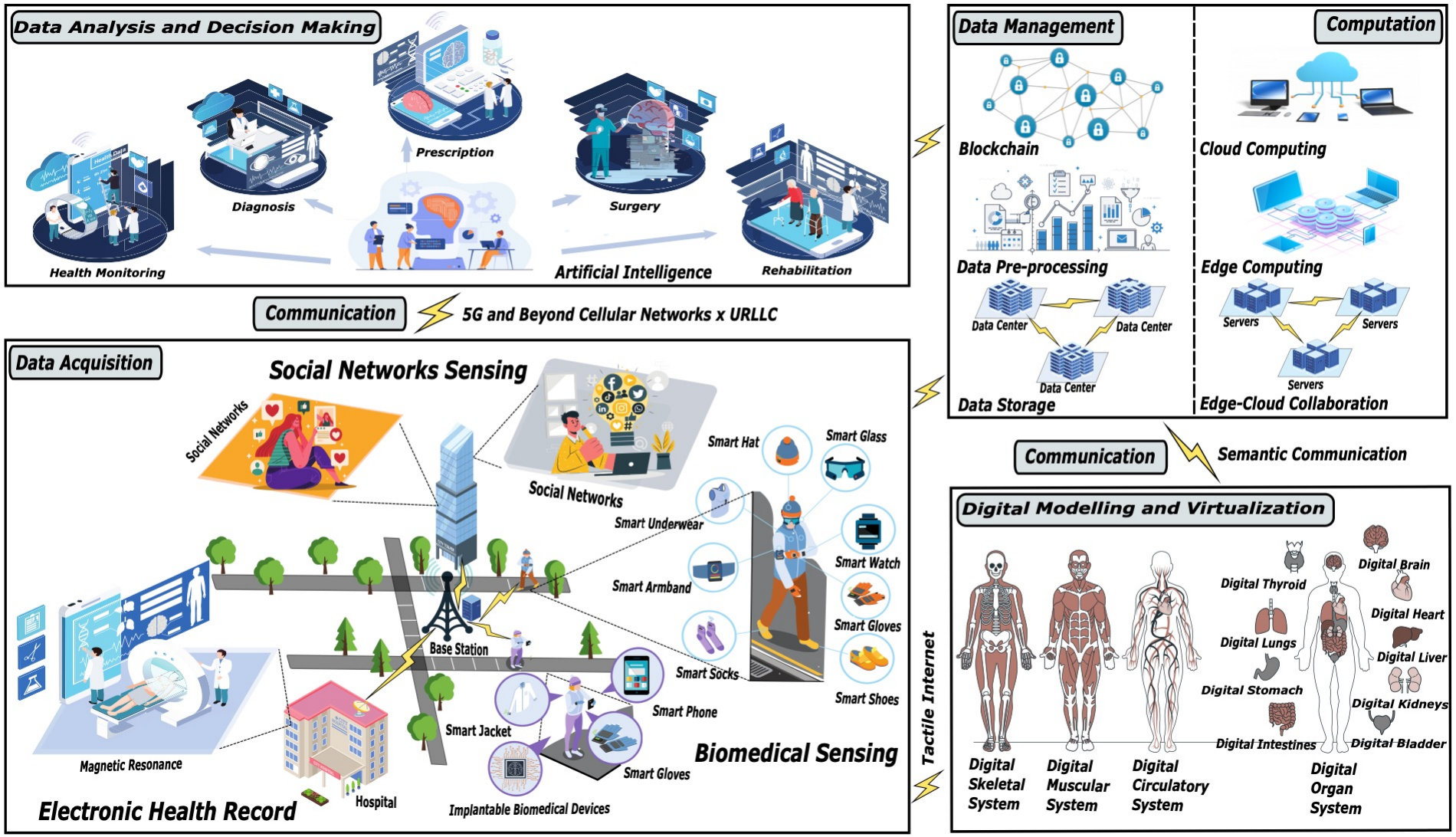
High Bandwidth Efficiency

High Reliability and Robustness

HDT vs Traditional DT

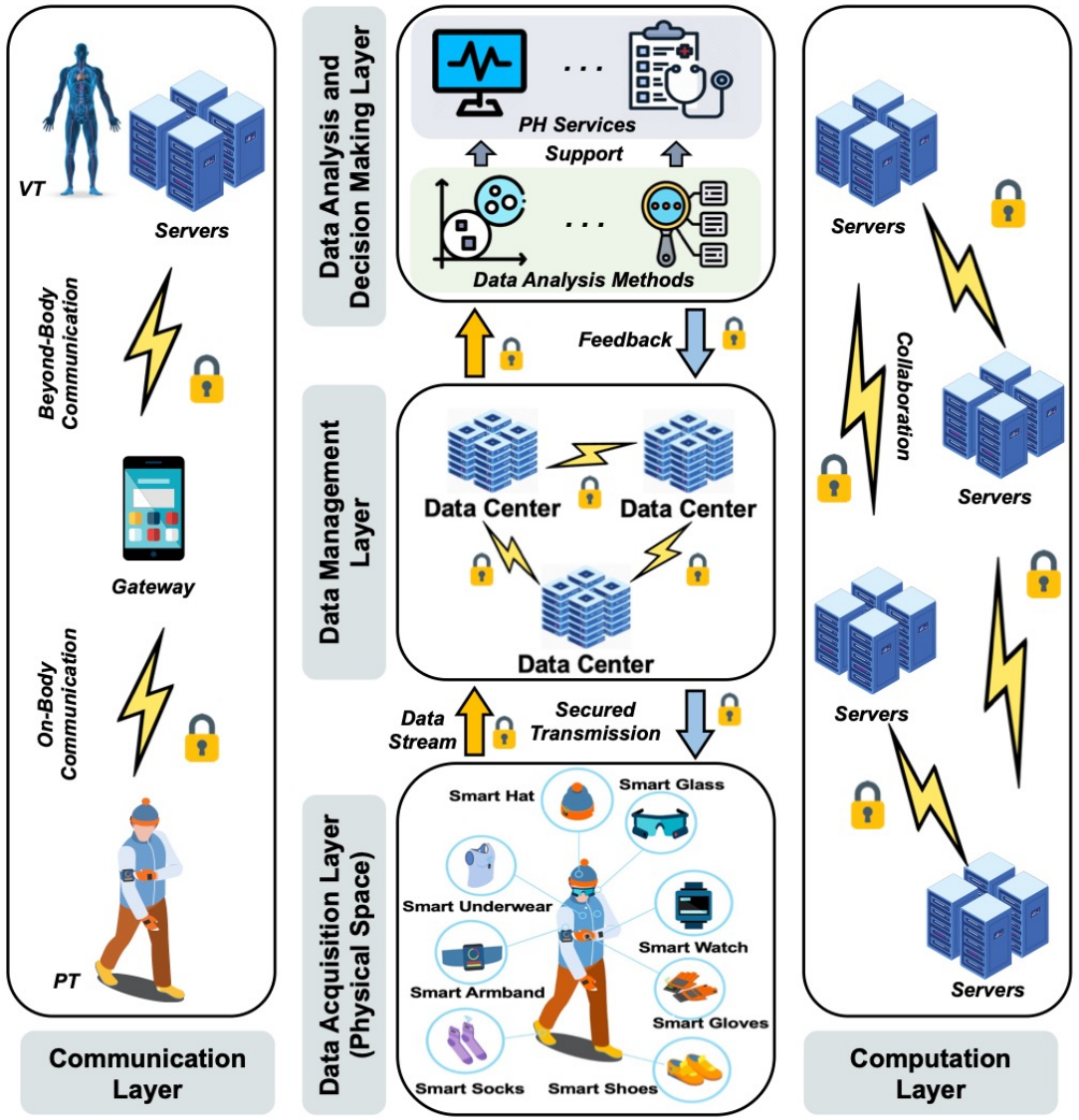
Key Features	Traditional DT	HDT
Emotion and Psychology	Lack of emotions and psychology	Human beings are living entities. Hence, their emotions and psychology can be affected by external factors or physiological states
Behavioral Rules	The behavioral rules of similar machines are almost predetermined and similar	Human external behaviors depend on individual subjective consciousness and internal behaviors, affected by multi-source and complex factors
Ethical Consideration	Limited or no ethical considerations	HDT can lead to healthcare inequality between developed and developing countries. Besides, it is not clear whether patients should be authorized to access some information about their own.
Data Complexity	Mostly structured and homogeneous	Mostly heterogeneous and unstructured. Correlation also exists between each individual and external data such as environmental and social media data
Mobility	Mostly fixed with no or limited mobility	Highly mobile with very complicated mobility patterns

Framework of HDT



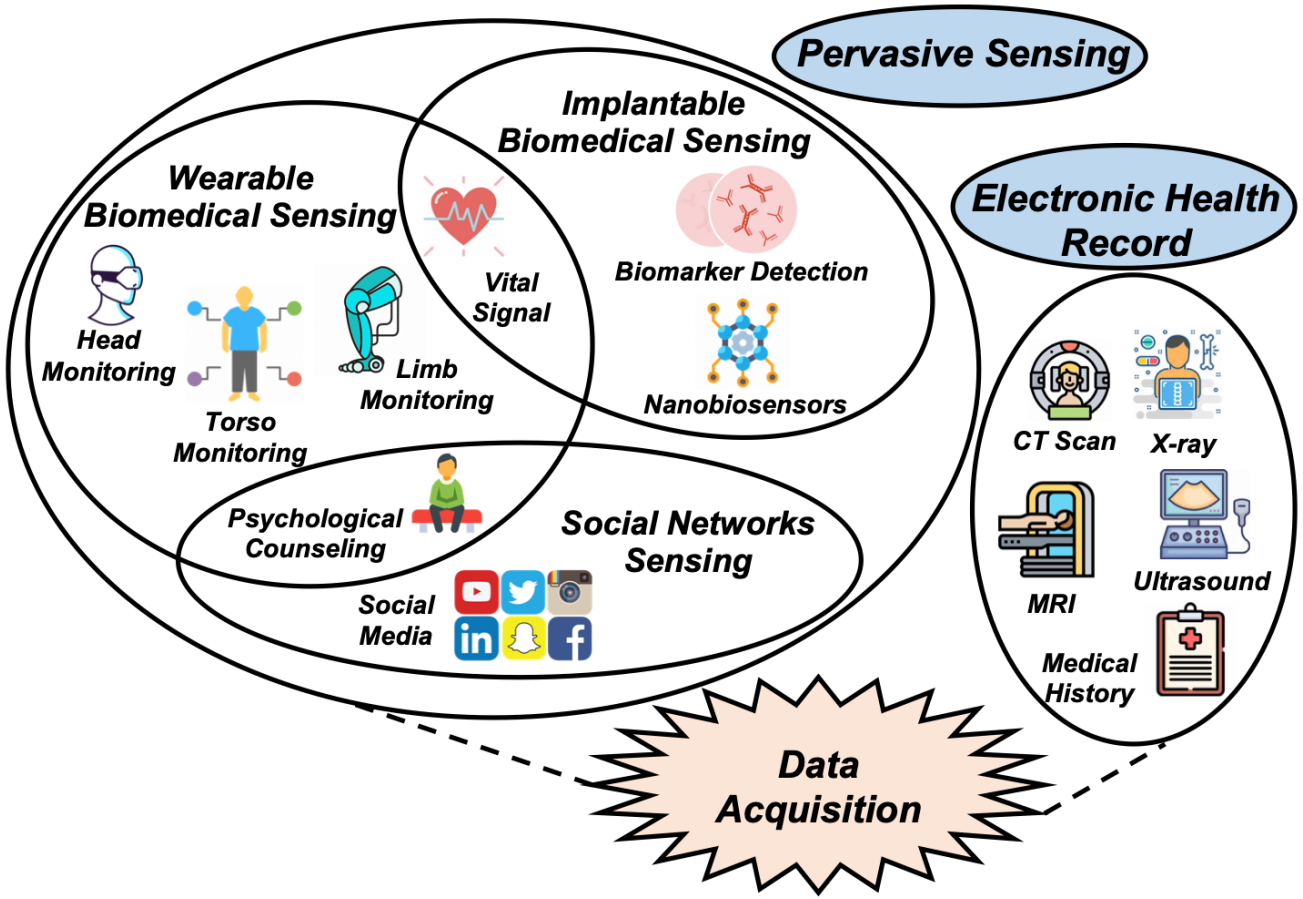
- **Jiayuan Chen**, Changyan Yi, Samuel D. Okegbile, Jun Cai and Xuemin Shen, "Networking Architecture and Key Supporting Technologies for Human Digital Twin in Personalized Healthcare: A Comprehensive Survey," *IEEE Communications Surveys and Tutorials*, 2023.

Architecture and Key Requirements of HDT



- Sophisticated and High-Quality Data
- Extreme Ultra-Reliable and Low-Latency Communication (xURLLC)
- Ultra-Low Round-Trip Time (RTT)
- Data Privacy, Security and Integrity
- Huge Data Storage
- Advanced Computing Power
- AI-Driven Analytics

Data Acquisition in HDT



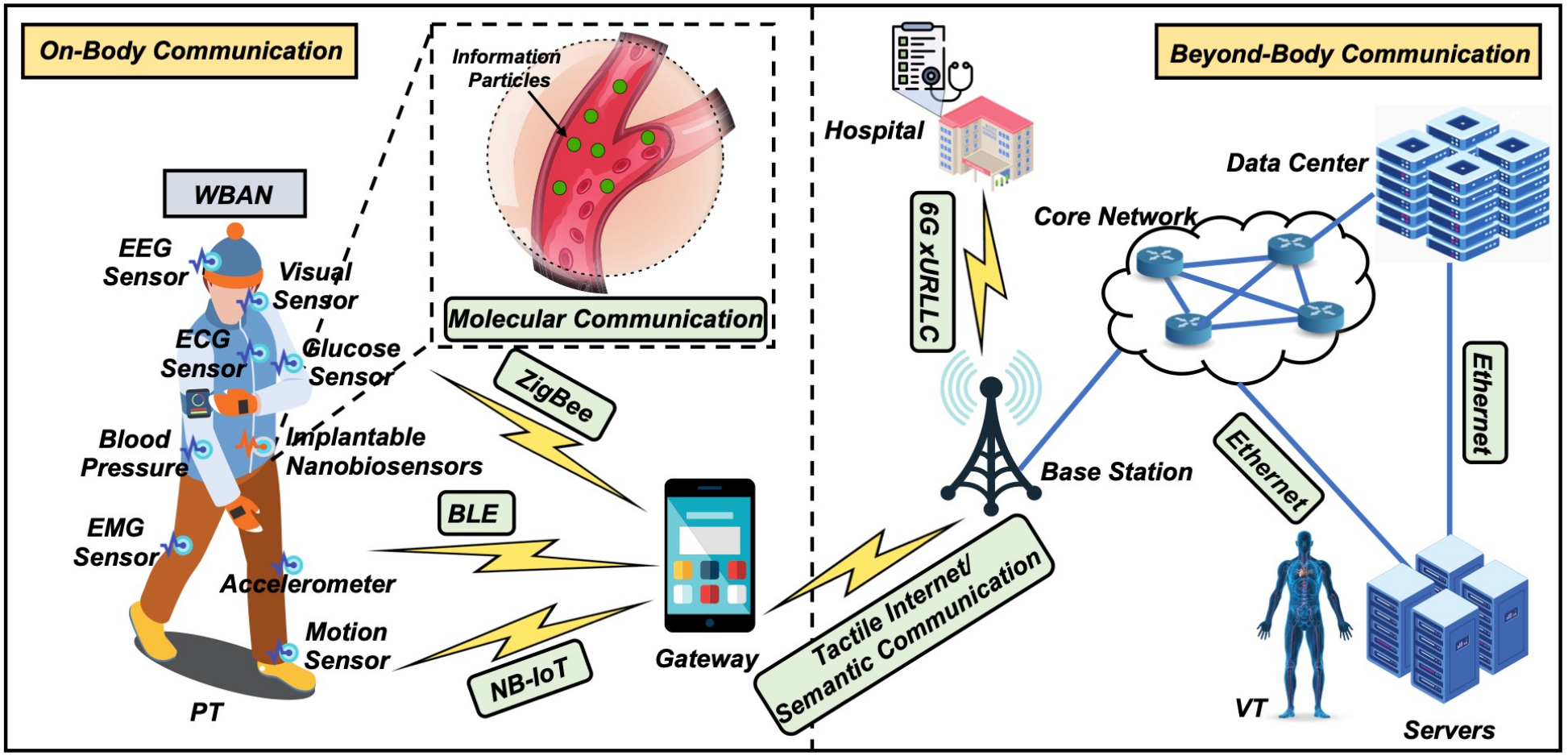
Data acquisition in HDT requires massive diverse devices to collect physiological, psychological and social data for precisely mapping the PT to its VT

Real-time

Fine-grained

Unification and Integration

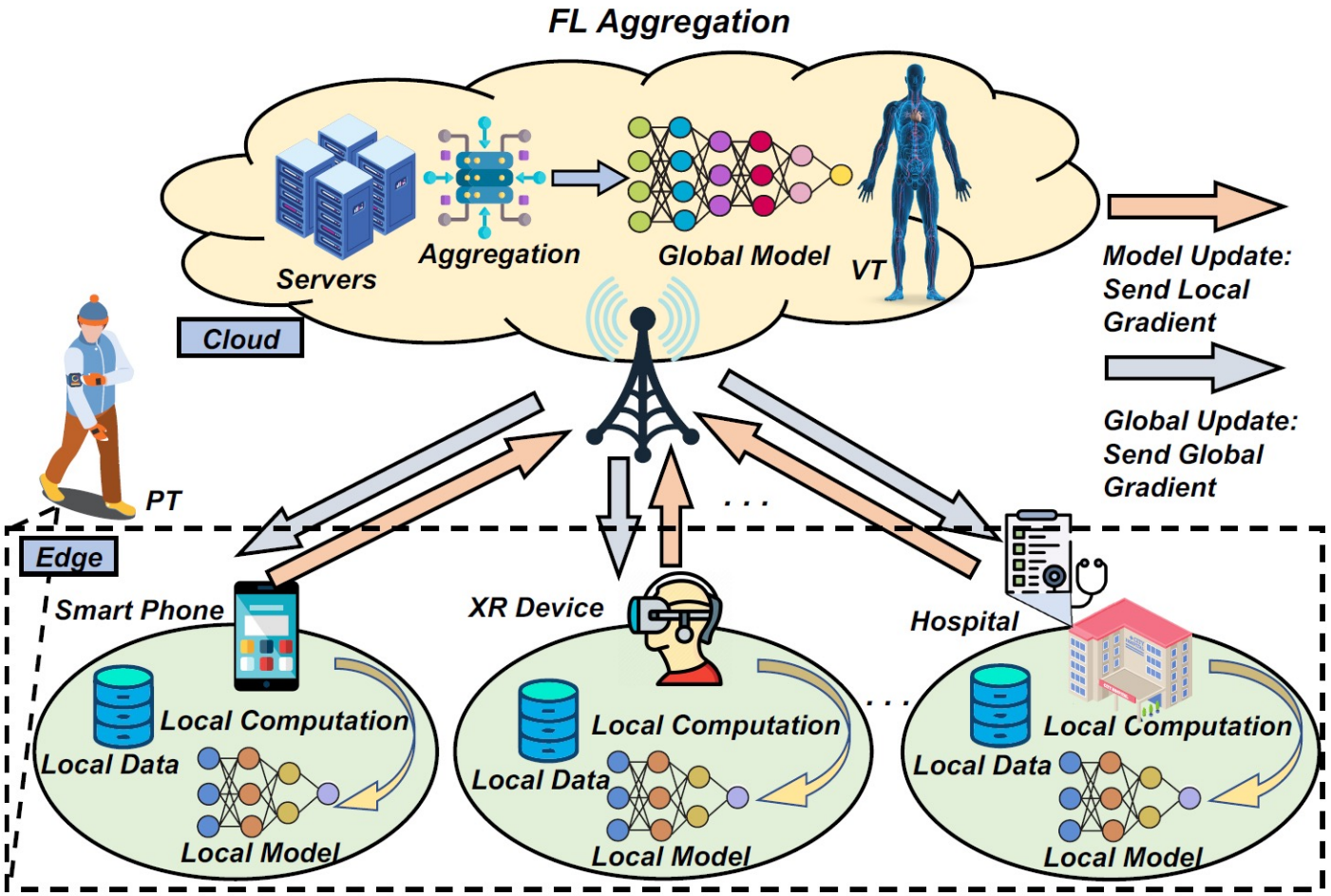
Communication in HDT



Communication in HDT involves both on-body and beyond-body communications

- Interference
- Security
- Resource Utilization Efficiency

Computation in HDT



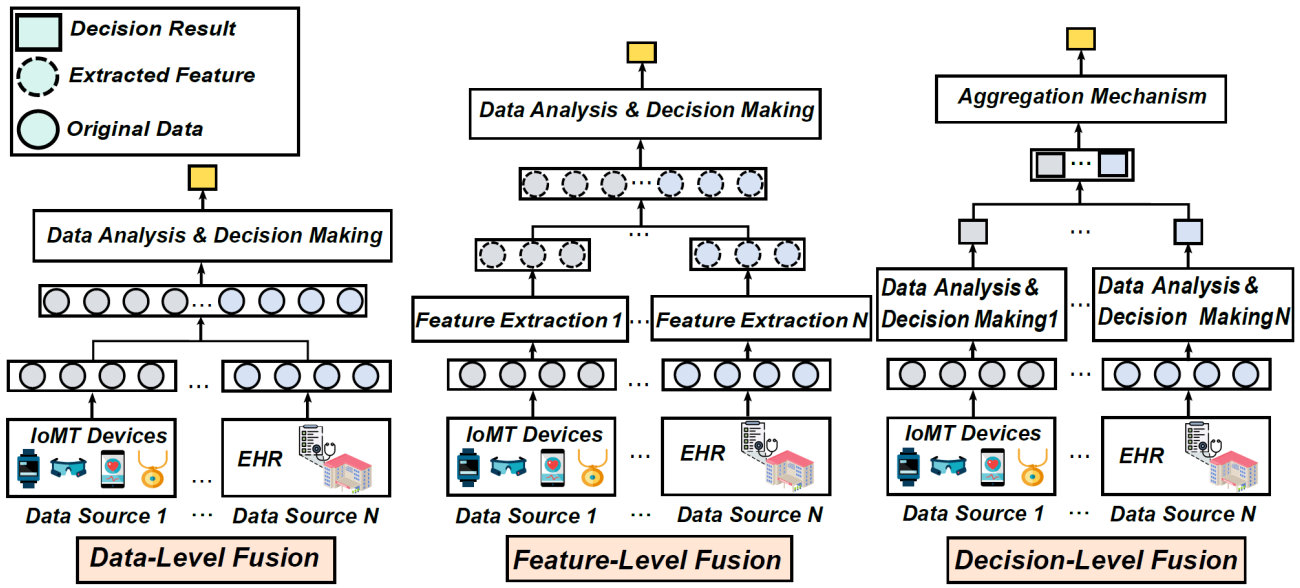
The implementation of HDT results in a series of computationally intensive tasks that require a powerful and fast-responsive computing service, necessitating edge-cloud collaboration

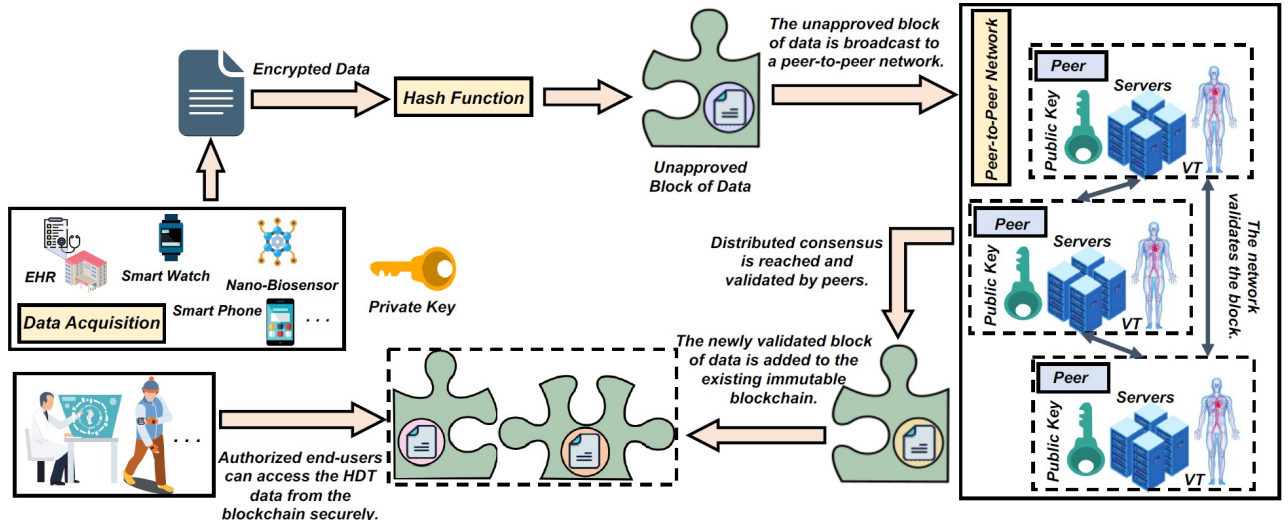
Load balance

Incentives

Privacy in Distributed Manner

Data Management in HDT





Sheer volume of data are constantly being generated and exchanged in HDT between the PTs and their corresponding VTs

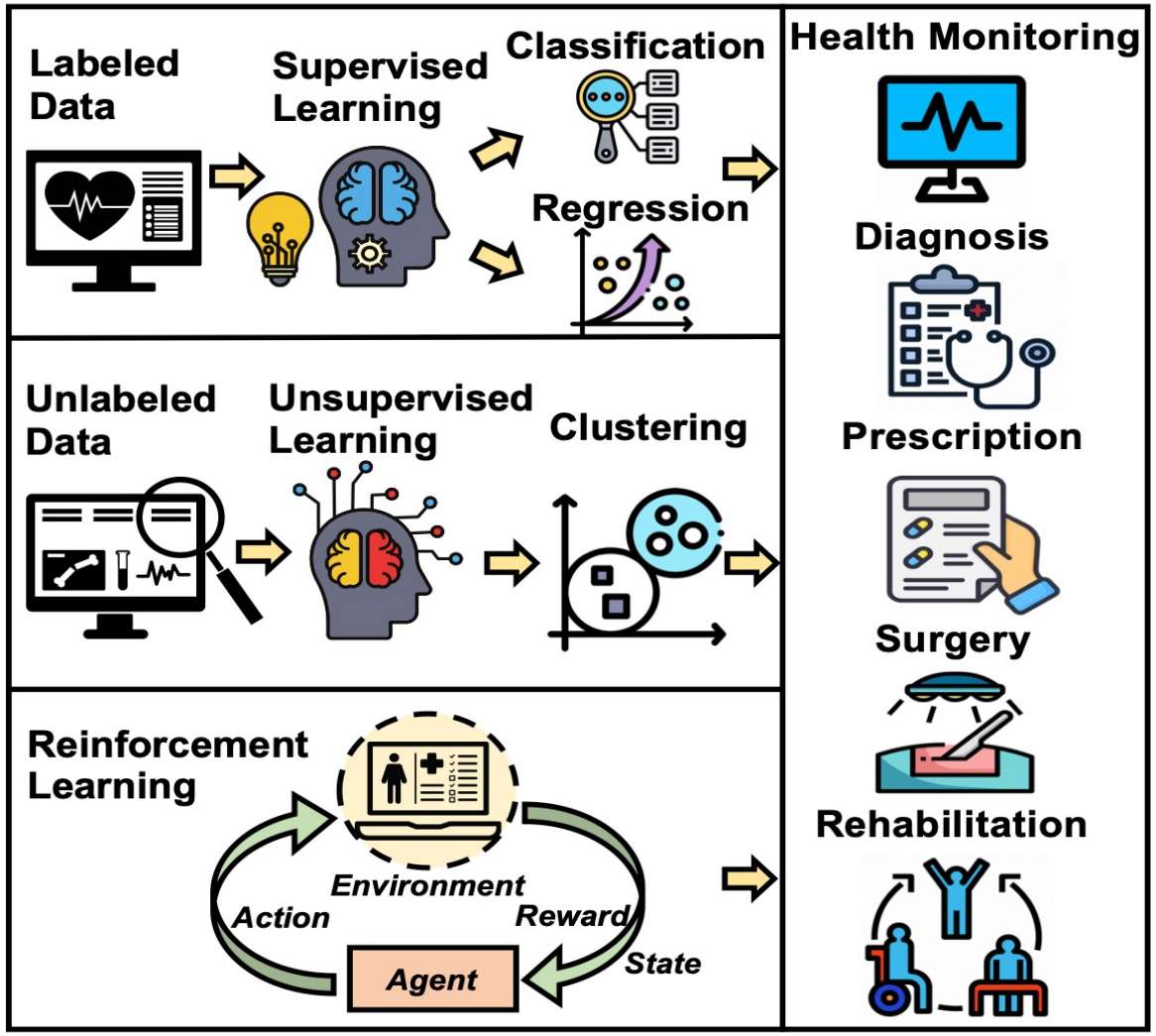
Heterogeneity, Scalability and Noise

Standardization

Interoperability

Blockchain in Data Sharing

Data Analysis and Decision Making in HDT



AI algorithms can assist HDT to analyze and mine valuable information from HDT data, enabling intelligent decisions

Full-Fledged Explainability

Light-Weight Implementation

Challenges of HDT on the Network Edge

- **Issues introduced by frequently update of HDT on the network edge:**
  1. Different types of signals with different frequencies
  2. Collaborative update among distributed HDT subsystems (strong correlations among subsystems)
  3. Efficient PT-VT pair synchronization

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- **Issues introduced by big HDT model deploying on the network edge:**
  1. Edge-cloud collaboration enabled asynchronous HDT model deployment
  2. Dynamic HDT service migration w.r.t. PTs' positions and tasks
  3. Green operation of large-scale systems

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- **Issues introduced by immersive interactions of HDT on the network edge:**
  1. Joint uplink-downlink design for end-to-end performance
  2. Seamless interactions under uncertain mobility
  3. High-fidelity interactions with limited power budget (which may also restrict the service coverage)

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Future Research Directions