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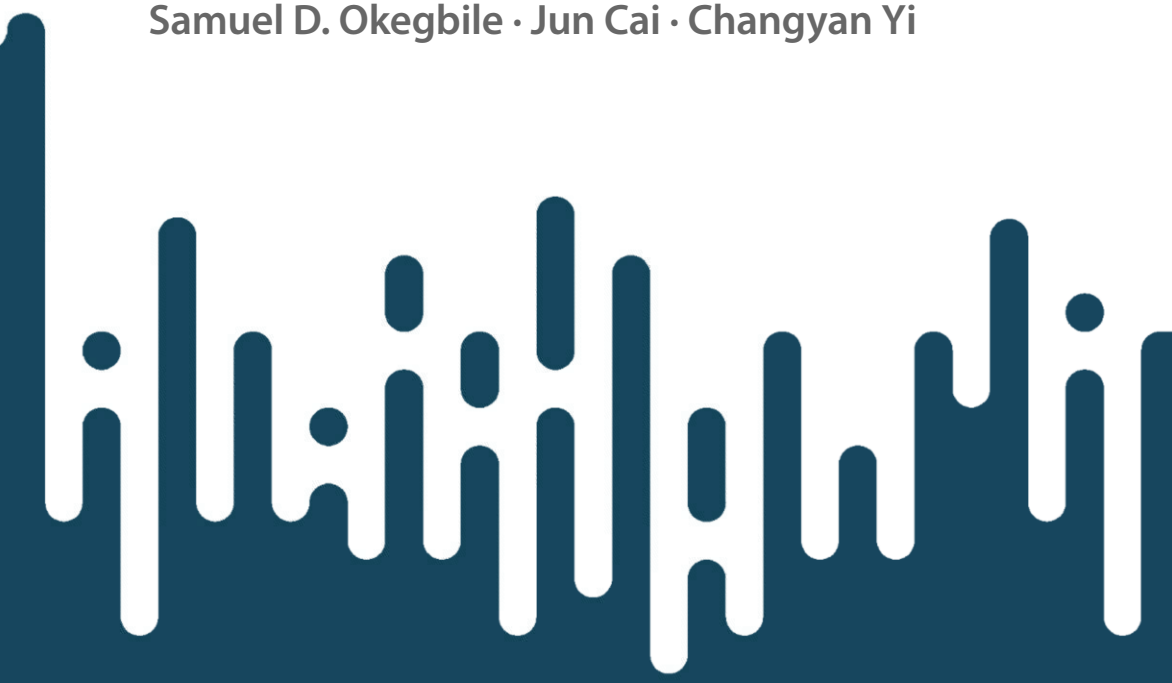

Human Digital Twin
Exploring Connectivity and Security Issues

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This book is dedicated to God—the giver of lives, knowledge and understanding. Also to family.

Preface

Human digital twin (HDT) is a pivotal emerging technology poised to revolutionize the existing human-centric landscape. When adopted toward personalized healthcare systems, it has the potential to deliver fast, efficient, and accurate healthcare services following the concept of digital twin by combining various technologies including artificial intelligence (AI), data analytics, internet of things (IoT), and virtual and augmented reality. The HDT framework encompasses three fundamental components: humans who are generally located in the physical environment, their counterpart digital replicas—also called their virtual twins—located in the virtual environment, and ultrareliable data links facilitating the co-evolution of both physical and virtual environments.

Despite enormous promising solutions that may come with such a framework, HDT relies on real-time physical-to-virtual connectivity due to the need for continuous exchange of data and information among each human-virtual twin pair. Thus, physical-virtual connectivity modelling becomes one of the most important issues for HDT. One specific concern in modelling the physical-virtual connectivity of HDT pertains to establishing a secure and privacy-preserving data-sharing framework between every human and its paired virtual twin. Considering the benefits of HDT, considerable research has been carried out toward the design and modelling of physical-virtual connectivity. To the best of our knowledge, there is currently no book addressing secure, privacy-preserving, and efficient human-to-virtual twin connectivity problems in HDT. This book endeavors to bridge this gap, providing academia and industry a comprehensive coverage of connectivity modelling in HDT.

The book covers a range of essential topics, encompassing the overarching concept of HDT, its design requirements and challenges, an edge-assisted human-to-virtual solution, blockchain-enabled data sharing, and differentially private federated multi-task learning (DPFML) schemes for HDT, accompanied by in-depth discussions and insightful analyses. In the first part of this book, the general overview of HDT, its application scenarios, and its specific characteristics compared to conventional digital twin models are discussed. In addition, specific requirements and challenges related to sophisticated and high-quality data; extreme ultra-reliable

and low-latency communication; ultra-low round-trip time; data privacy, security, and integrity; as well as storage, computation, and information technology-driven analytics are explored. In the second part of the book, an edge-assisted human-to-virtual twin connectivity framework is first introduced before delving into the human-to-virtual twin connectivity modelling. An extensive discussion on the general practical Byzantine fault tolerance (PBFT) framework is then discussed, followed by presenting a shard-based Byzantine fault-tolerant scheme for HDT with exploration of latency and throughput analysis modelling. This part concludes with the introduction of the DPFML-assisted human-to-virtual twin connectivity scheme and the modelling of the connectivity cost based on a new consensus algorithm called the proof of model quality. Finally, this book closes up with conclusions and promising research directions.

This book is expected to stimulate future research in the field of HDT from several perspectives including networking, data management, and security and privacy. While the primary audience is researchers and professionals in wireless communications and physical-cyber systems, advanced-level students in computer science and/or electrical engineering will also find the content valuable.

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Contents

Acronyms

5G	Fifth generation
6G	Sixth generation
AI	Artificial intelligence
AIGC	AI-generated content
AoDP	Age of data package
AoI	Age of information
AR	Augmented reality
BeDS	Blockchain-enabled data sharing
BFT	Byzantine fault tolerance
BS	Base stations
BSN	Body sensor network
DDPG	Deep deterministic-policy gradient
DOs	Data owners
DP	Differential privacy
DPFML	Differentially private federated multi-task learning
DQN	Deep Q-network
DRL	Deep reinforcement learning
DRs	Data requesters
DT	Digital twin
ECC	Edge-cloud collaboration
eQoS	Extremely high quality-of-service
FCFS	First come first serve
FL	Federated learning
FML	Federated multi-task learning
HDT	Human digital twin
HPPP	Homogeneous Poisson point process
GA	Global aggregator
IHD	Ischemic heart disease
IoT	Internet of Things
LA	Local aggregator
LCFS	Last come first serve