Digital Twin Network: Concepts and Reference Architecture

draft-zhou-nmrg-digitaltwin-network-concepts-05

Cheng Zhou (zhouchengyjy@chinamobile.com, **Presenter**)
Hongwei Yang(yanghongwei@chinamobile.com)
Xiaodong Duan (duanxiaodong@chinamobile.com)
Diego Lopez (diego.r.lopez@telefonica.com)
Antonio Pastor (antonio.pastorperales@telefonica.com)
Qin Wu (bill.wu@huawei.com)
Mohamed Boucadair (mohamed.boucadair@orange.com)
Christian Jacquenet (christian.jacquenet@orange.com)

Objectives

- Define digital twin in networking field
- Sketch a ***Reference Architecture*** for digital twin networks
- Identify ***key values*** of digital twin networks as well as ***research challenges***
- Document ***application scenarios***

Updates since IETF#111

- Updated version based on inputs and comments from both NMRG mailing list and internal reviews
  - Many thanks to Ramin Sadre, Pedro Martinez-Julia, and other experts
- **Main Changes**
  - Clarified the difference between digital twin network platforms and legacy network management systems
  - Refined the description of the reference architecture
  - Added references to digital twin networks research
  - Clarified the benefits of 'Privacy and Regulatory Compliance‘
  - Other editorial changes

Addressed comments on -04 (1/2)

- Summary of major comments and updates

No.	Comments	Actions Taken
1	**Section 1:** "Not sure why you have a reference here, because you are not providing references for the other fields (e.g. smart city)"	**Explained via Email:** "The reference mentioned all mentioned fields, including intelligent manufacturing, smart city, and complex system operation and maintenance."
2	**Section 1:** "Google Scholar shows several recent papers (2020/2021) that apply the concept of DT to networks. Have you compared your definition to theirs? Is it worth citing them? (it would make sense since you are also citing other papers)"	**Revised via adding more references.**
3	**Section 5.4:** Privacy and Regulatory Compliance "This paragraph is difficult to understand. Is privacy important for DTNs or is it a benefit? If it is a benefit, why? "	**Revised via refining the section.**
4	**Section 6:** "New applications might need new functional models that don't exist yet. **How can new functional models be deployed in the DTN?** I guess that's one of the tasks of the Entity Management?"	**Explained via Email:** "If new model is needed, 'Service mapping models' subsystem can create new models based on data retrieved from 'Data Repository'. Regarding models, Entity Management aims to manage the life-cycle of model instances, model combination, and relations between 'model instances and application'."
5	***Section 6:*** *Suggest to* map the DTN reference architecture and the typical network management architecture.	**Revised via describing differences between DTN and other network management architecture.**

Addressed comments on -04 (2/2)

No.	Comments	Action Taken
6	***Section 6:*** *Functional models refer to various* ***data models*** *such as network analysis , simulation, diagnosis, prediction, assurance , etc.* **"Not clear. Are you saying that network analysis is a data model? Or do you mean data models FOR network analysis?"** **"Just for clarity: These are all examples for OAM applications and will be implemented in the application layer? "**	**Explained via Email:** "data models that have the capability for network analysis, simulation, diagnosis, etc. We will revise it later. Applications have detailed network operation requirements, and functional models in network digital twin layer can be build in common or partially common to maximize DTN's ability on analysis, simulation, diagnosis, prediction, etc."
7	***Section 6:*** "The service mapping models can be **quite complex and consume a lot of CPU and memory resources**. This can become a concern for the DTN because certain applications will expect near real-time capabilities of the DTN. The Entity Management will **need to monitor the performance and resource consumption** of the entity or even of individual models. Will this require a unified interface between the models and the entity management?"	Good suggestion on monitor the performance and resource consumption of data models. And, **explained via Email:** "Yes, unified interface are needed between models and entity management. And, entity management can also be designed as on-demand 'monitor' with configurable monitor frequency to save resources."
8	***Section 6:*** *"Digital Twin Entity Management completes the management function of digital twin network,* ***records*** *the life-cycle of the entity, ..."* **"Not sure what "records" mean here"**	**Revised via refining the description.**
…	14 more other comments of grammatical errors, typos, and suggestions on better wording	**Revised via making editorial changes.**

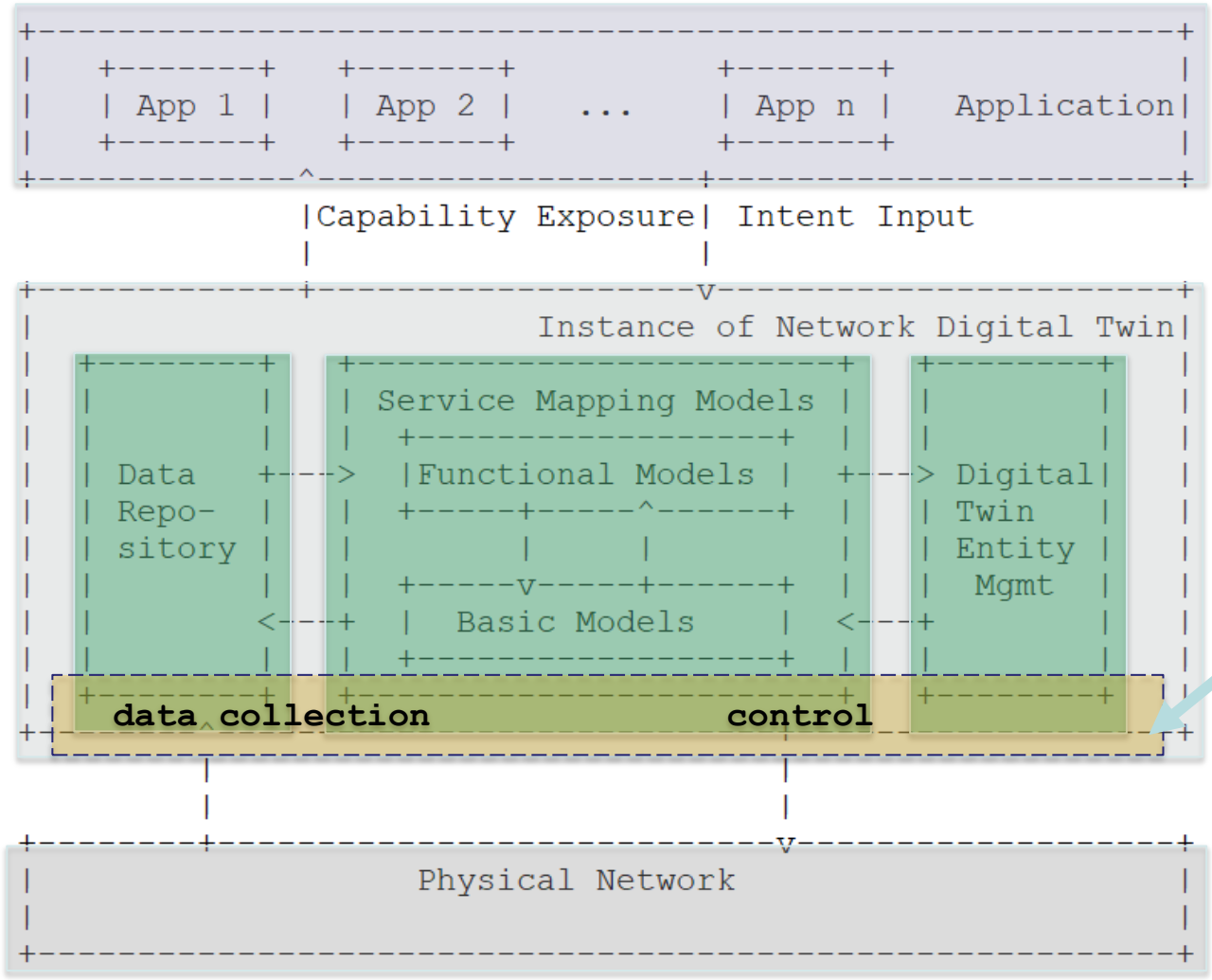
Difference between DTN and other Network Frameworks

Clarified in the Introduction Section

"The main difference compared to other network management systems is the use of interactive virtual-real mapping to build closed-loop network automation. Through the real-time data interaction between the physical network and its twin network(s), the digital twin network platform might help the network designers to achieve more simplification, automatic, resilient, and full life-cycle operation and maintenance."

- This allows for
  - Integrating AI-based mechanisms emulating the behavior of network sections not under consideration but relevant for the considered section
  - Considering several parallel options or courses of action
  - Incorporating real-time monitoring data from the physical with other real or virtual data sources
  - Repeating and reproducing specific situations under controlled variations
- Combines the features of network emulation and software-based control environments

Refine the Description of the Reference Architecture



Three-layer DTN reference architecture

- **The Lowest Layer:** Physical Network
- **Top Layer:** Network Application
- **The Intermediate Layer:** Network Digital Twin
  - Core layer of DTN system
  - 3 key subsystems: Data repository, Service mapping models, and Digital Twin entity mgmt
- **Optional sub-layer**

'Data collection' and 'change control' are regarded as southbound interfaces between virtual and physical networks. From an implementation perspective, they can **optionally** form a sub-layer or sub-system to provide common functionalities of data collection and change control, enabled by a specific infrastructure supporting bi-directional flows and facilitating data aggregation, action translation, pre-processing and ontologies.

Next Steps

- **Request document adoption by NMRG**

- Welcome to join our work, and any comments are welcome!

Appendix

Key Enabling Technologies for Building DTNs

- **Data Collection**
  - Diverse existing tools (e.g., SNMP, NETCONF, Telemetry, INT, etc.) can be used to collect different type of network data
  - Innovative new tools (e.g., sketch-based measurement) can be explored
  - Semantic aggregation mechanisms for data integration and action translation
- **Data storage and services**
  - Unified data repository to effectively store large-scale and heterogeneous network data
  - To provide data services including fast search, batch-data handling, conflict avoidance, data access interfaces, etc.
- **Data Modeling**
  - For small scale network, network simulating tools (e.g., NS-2, GNS3) can be an option
  - For large scale network, low-cost solution is required to create network element and topology models
  - AI/ML can be used to build complex functional models in twin entity.
- **Visualization**
  - Display the network topology, operational status in multiple dimensions and fine granularity
  - The interactive visualizing the execution of models to help users better understand, deduce and explore the network Interfaces and protocols
- **Interfaces**
  - **Twin interfaces** between the physical network and its twin entity: existing interfaces (SNMP, NETCONF, etc.) or new interfaces
  - **Application-facing interfaces** between the network digital twin and applications, e.g., Intent, “what-if” planning app, ...
  - **Internal interfaces** within network digital twin: Interfaces of high-speed, high-efficiency, high-concurrency, etc.

More Researches on Applying Digital twin to Networking: Samples

- **In Academia , more research efforts to apply the digital twin concept to the networking field, e.g.:**
  - Dong R., She C., HardjawanaLiu W, et. al, "Deep Learning for Hybrid 5G Services in Mobile Edge Computing Systems: Learn from a Digital Twin. IEEE Transactions on Wireless Communications,vol. 18, no. 10", July 2019
  - Dai Y., Zhang K., Maharjan S., and Yan Zhang, "Deep Reinforcement Learning for Stochastic Computation Offloading in Digital Twin Networks. IEEE Transactions on Industrial Informatics, vol. 17, no. 17", August 2020
  - Nguyen H., Trestian R., To D., and M. Tatipamula, "Digital Twin for 5G and Beyond. IEEE Communications Magazine, vol. 59, no. 2", February 2021
- **In industry, more companies are investigating solutions of digital twin in networking, e.g.:**
  - **Aria Networks:** 'Step-T' establishes a digital twin on the backbone network of operators' customers, and uses AI technology to complete routing optimization and fault simulation.
    - *https://www.aria-networks.com/blog/tier-1-operator-goeslive-with-automated-traffic-engineering-using-ai-and-a-digitaltwin*
  - **NetBrain:** 'Dynamic Maps' simplifies the whole network into a searchable database; then create the digital twin of the network and provide specific information according to different task
    - *https://www.netbraintech.com/cisco-aci-google/*
  - **Huawei:** 'NetGraph' establish an intelligent digital twin platform toward automatic and intelligent management of data center network.
    - *Hanshu Hong, Qin Wu, Feng Dong, et. al. NetGraph: An Intelligent Operated Digital Twin Platform for Data Center Networks. In ACM SIGCOMM 2021 Workshop on Network-Application Integration (NAI '21), August 27, 2021*
  - **SPIDER:** Use digital twin network platform for 5G Cyber-range security training. *https://spider-h2020.eu/*
    - *S. Vakaruk, A. Mozo, A. Pastor and D. R. López, "A Digital Twin Network for Security Training in 5G Industrial Environments," 2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence (DTPI), 2021*