Digital Twin Network: Concepts and Reference Architecture

draft-irtf-nmrg-network-digital-twin-arch-00

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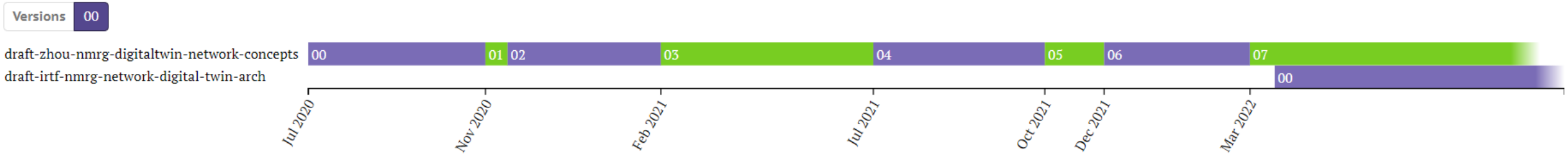
Scope & Objectives

- **Scope**
  - Present an overview of the concepts of Digital Twin Network
  - Provide the basic definitions and sketch a reference architecture
  - Identify use cases and discuss the benefits and key challenges of the technology

- **Objectives**
  - Promote the widely adopted digital twin concept to networking field
  - Establish a reference architecture to rationalize Digital Twin Network effort
  - Identify future technical research directions on enabling technologies

Changes Log



- **RG Adoption:**
  - Dec 10, 2021: Call for adoption was issued
  - Mar 8, 2022: the draft was adopted by the RG
  - draft-irtf-nmrg-network-digital-twin-arch-00 uploaded to IRTF
- **Addressed comments from NMRG reviewers**
  - 50+ comments received since the RG adoption call on draft -06
  - Many thanks to the NMRG participants: Daniel King, Quifang Ma, Laurent Ciavaglia, Jerome Francois, Jordi Paillisse, Luis Miguel Contreras Murillo, Alexander Clemm, Qiao Xiang, Ramin Sadre, Pedro Martinez-Julia, Wei Wang, Zongpeng Du, and Peng Liu.
  - Addressed most comments in the submitted -00 version (03/2022)

A summary of Comments

No.	Reviewer	Amount	Major comments	Actions Taken
1	**Daniel King**	19	1) To make core requirements and research challenge; 2) To cite more other researches; 3) To go deeper in one or two use case; 4) To desribe more on 'digital twin' and other terms of 'model' and 'shadow'; 5) to add new section of 'enabling technologies'	Explained in mail list and revised for most comments. Remaining open issues: **1) To go deeper in one or two use case;** **2) to add new section of 'enabling technologies'**
2	**Alexander Clemm**	4	1) to add the origin of the twin; 2) to expand research challenges; 3) to refer to previous work related to digital twin network	Explained in mail list and revised for most comments. Remaining open issues: **To study the mentioned earlier techniques related to digital twin network**
3	**LUIS MIGUEL CONTRERAS MURILLO**	6	1) quesion on DT control; 2) physical network should focus on IETF related networks; 3) to refer to IETF model technologies; 4) whether physical network layer contains controller;	Explained in mail list and revised for most comments.
4	**Jordi Paillissé**	4	1) recommended a modeling soluiont 'MimicNet' for reference; 2) what are the output of the 'digital twin'? 3) to add more references.	Explained in mail list and revised for most comments.
5	**Jérôme François**	16	1) to emphasize the benefits of the digital twin, comparision with other simulation platform; 2) to refine the challenges and describe more on 'enabling technologies'; 3) why distinguish data and model; 4) Is 'real time interactoin mapping' always bidirectional and mandatory?	Explained in mail list and revised for most comments. Remaining open issues: **to add new section of 'enabling technologies'**
6	**Qiufang Ma**	2	1) do we allow the application layer to interact with physical network directly? 2) should physical network only be controlled by digital twin network?	Explained in mail list
7	**Qiao Xiang**	1	Expreesed strong support, especially on the "3-layer architecture"	N/A
8	**Wei Wang**	0	Support with no quesitons	N/A
9	**Zongpeng Du**	0	Support with no quesitons	N/A
10	**Peng Liu**	0	Support with no quesitons	N/A

Major Changes

- Better structure the content
  - Adding more subsections on concepts of digital twin network, removing the 'Requirements Language' section, and moving ahead the 'Challenges' section
- Strengthen research background
  - Cited more papers or industrial information on digital twin concepts and digital twin for networks.
- More focus on Challenges
  - Added more information to describe the challenges and key characteristics of digital twin network
- Close OLD Issues
  - Mainly those related to investigating related digital twin network efforts and identify the differences/commonalities
- Focus on Future Research Directions
  - Added several new open issues for future studies

Remaining Open Issues

No.	Issue Description	Action plan
1	Should a new section of ‘enabling technologies’ be added?	The draft focuses on concept and architecture of digital twin network, not including enabling technologies. Actually, each 'enabling technology' is worth of a separate draft to study in details in future. **A decision is needed that whether to add a section to describe the enabling technologies in brief.**
2	It is recommended to describe recent IRTF/IETF technologies in the draft.	Related to above issue, if section of enabling technologies is added, recent technologies (e.g. Network connectivity, Real-time data communication, Collaboration management, conflict detection and resolution, etc.) recently discussed in the IRTF/IETF should be described.
3	It is recommended to go deeper in one or two use case.	Once the reference architecture is stable, will consider adding a case study section to go deeper in one specific case, following the architecture.
4	To study the mentioned earlier techniques related to digital twin network.	The idea behind digital twin networks is reminiscent of earlier work from the 1990s that should be referenced/acknowledged. Examples include the Shadow MIB concept, Inductive Modeling Technique, etc.
5	Which level of details should the document to include without losing its purpose, especially for ‘challenges', and 'enabling technologies’?	Opened in mailing list for comments.

Open Discussion Items

- Motivation & requirements
- Challenges & problems
- Reference architecture
- Enabling technologies, and case studies
- Future research directions (*not limited to this draft*)

Motivations and Requirements

- **Challenges in network operation and maintenance**
  - New network services emerge endlessly, and the network scale continues to expand
  - The complexity of network O&M is becoming higher
  - Innovative technologies need longer time to deploy with no high-fidelity testbed
  - Network optimization has high cost and high risk due to vulnerable production environment
- **Network automation and autonomous operation are becoming a new vision**
  - Intent-based Networking (IBN), Auto-driving Network (ADN), Zero touch network are studied
  - AI/ML technologies are widely used in network filed to help achieve the vision
- **Digital twin brings a new chance to meet the challenges**
  - Virtual-real mapping and interaction brings a solution beyond physical network
  - The network digital twin can help the physical network realize low-cost trial, intelligent decision-making, efficient innovation and predictive maintenance.

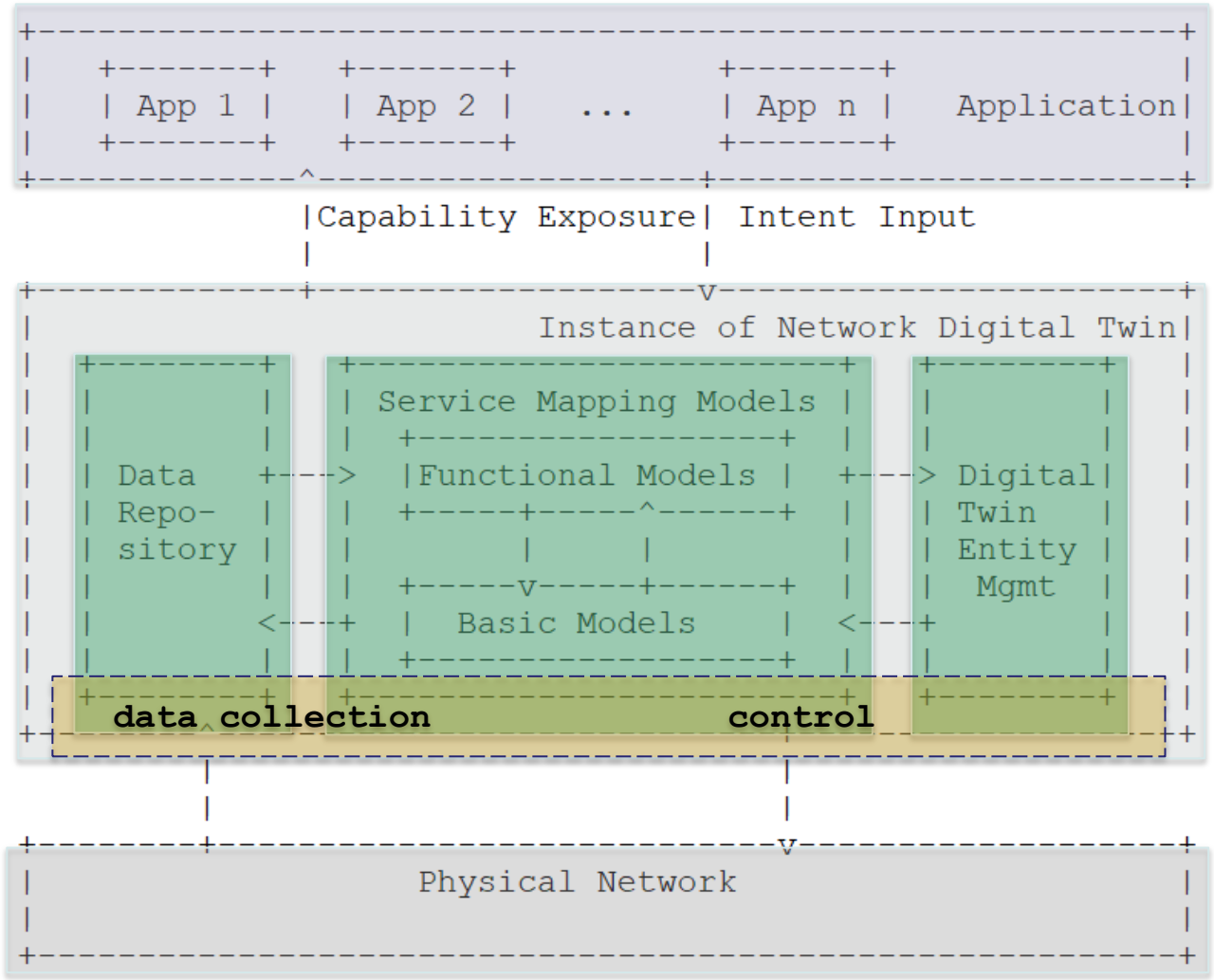
Challenges to Build Digital Twin Network

- **Challenges to build digital twins in industrial fields**
  - Data acquisition and processing
  - High-fidelity modeling
  - Real-time, two-way connection between the virtual and the real twins
  - Unified development platform and tools
  - Environmental coupling technologies

Hu, W., Zhang, T., et al., ***Digital twin: a state-of-the-art review of its enabling technologies, applications and challenges****. Journal of Intelligent Manufacturing and Special Equipment, Vol. 2 No. 1, pp. 1-34", 2021.*

- **Challenges to build DT for network**
  - Large scale challenge: complex giant system brings trouble to all SW designs
  - Interoperability: multiple vendors
  - Data modeling difficulties: tradeoff between cost, efficiency and complexity
  - Real-time requirements: the faster, the better? Tradeoff between latency and accuracy
  - Security risks: Severe impact in face of attacks or info leakage.
  - Any others?

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.
  - They can optionally form a sub-layer or sub-system to provide common functionalities

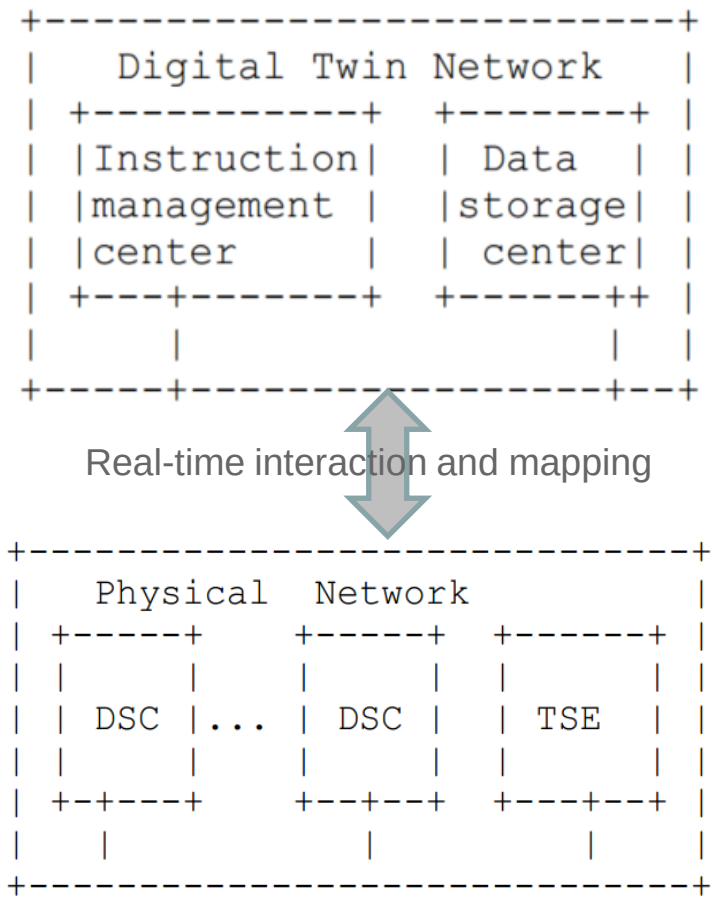
Enabling Technologies for Building DTNs

- **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.
- **Network Modeling**
  - For small scale network, network simulating tools (e.g., NS-2, GNS3) , or virtualization tools (VNF/VM) can be an option
  - For large scale network, low-cost solution (normally based on **formal methods**) 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.

Data Collection – a case study

An Efficient Data collection method for Digital Twin Network, NMRG draft 2021

- Current collection methods collect raw and full data from Physical Network, and have the problems:
  - Time-cost
  - Insufficient storage resources
  - Low computational efficiency
  - Waste of bandwidth resources caused by data transmission.
- This draft proposes an efficient and lightweight data collection, aggregation and correlation method.
  - Twin Network sends instructions to Physical Network to collect data on demand
  - Physical Network completes instructions such as knowledge representation
  - Telemetry Streaming Element (TSE) of Physical Network completes data aggregation and correlation.
  - Finally TSE sends the represented data to the Twin Network.

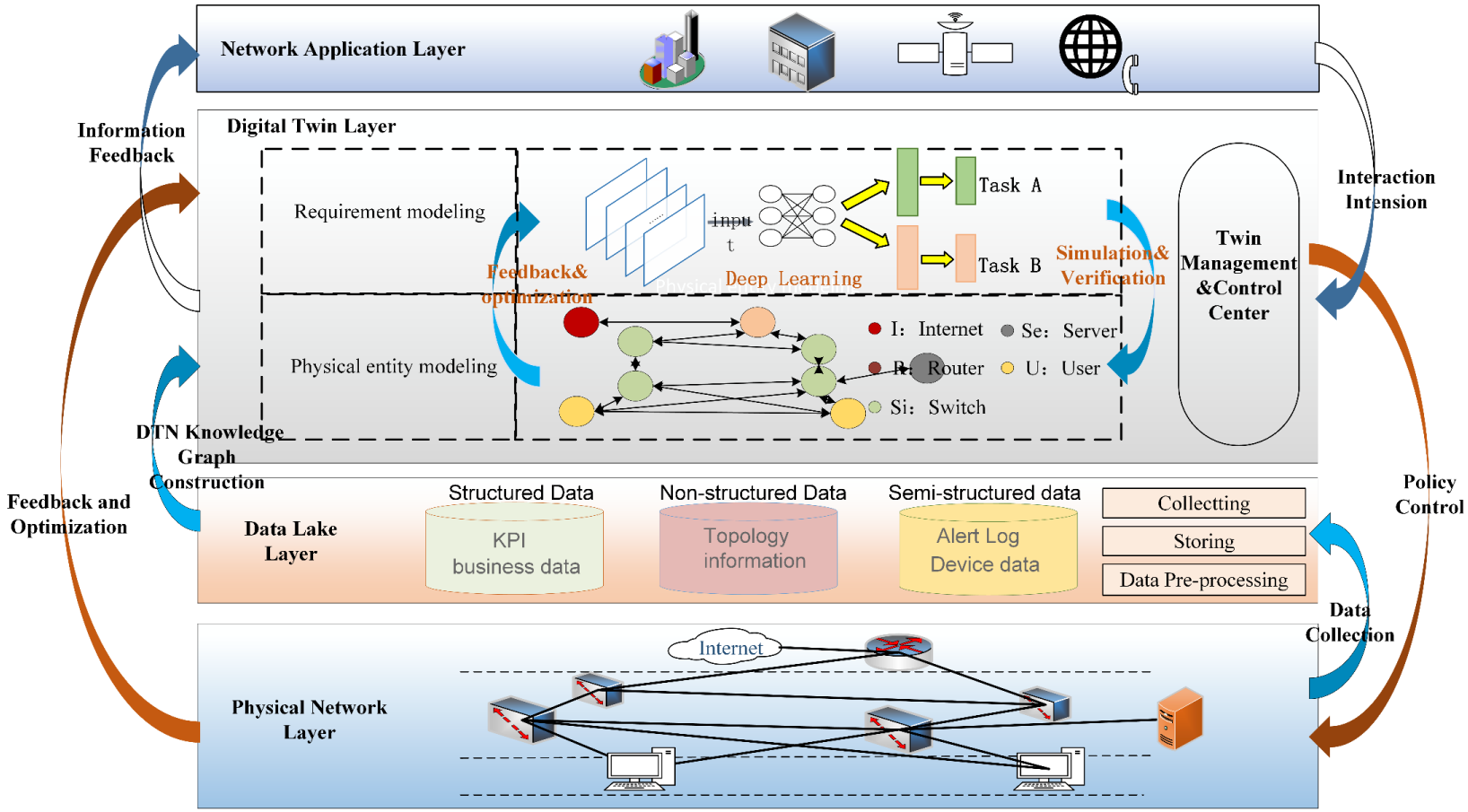


https://datatracker.ietf.org/doc/draft-zhu-nmrg-digitaltwin-data-collection

Network modeling – a case study

A knowledge graph-based construction method for Digital Twin Network, 2021 IEEE DTPI.

- DTN system design **referred the architecture in the draft**.
- **Basic models are built via formal methods.**
  - Network device models are built based on a ‘six-turple’ **ontology**.
  - Topology models are built using **knowledge graph**: A NRE algorithm composed of LSTM and CNN is proposed to mine the complex relationships between topologies or network elements.
- Functional models can be built using AI/ML algorithms.



Future Candidate Research Directions

- not limited to this draft

- Deeper researches on the 5 key enabling technologies
- More assessment to quantify the gain brought by DTN to Network management?
- AI/ML/RDL algorithms used for network modeling
- How can ‘knowledge’ be injected to network digital twin to help achieve vision of ‘autonomous network’ ?
- How can DTN integrate and evolve with legacy network management system?
- Define capability levels and the evaluation methods. For instance：
  - the resource requirements and effectiveness evaluation of a DTN system for a given business requirements on a specific physical network.
  - metrics and measurement to evaluate the accuracy/fidelity of a digital twin.

Next Steps

- Issue threads for each of the candidate research directions
- Record the outcome of these threads in the draft as appropriate
- We also welcome proposals to enhance the document

- **Your comments are always welcome!**