Digital Twin Network: Concepts and Reference Architecture

draft-zhou-nmrg-digitaltwin-network-concepts-04

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Document Status

- This is the fourth time to present the I-D in this RG
  - Basic Idea: Define digital twin network in the network field
  - Goals:
    - Define a new tool for efficient and intelligent management
    - Stimulate innovation with optimized cycles
  - Technical Contributions:
    - Sketch a Reference Architecture for digital twin network
    - Identify key values of digital twin network , and challenges to build digital twin network
    - Provide typical application scenarios

- Actions taken since IETF#110
  - Resolved open issues raised in section 9 and reported back to the mailing list; then presented the updates on NMRG interim meeting of May 17th.
  - Collected input and comments from NMRG mailing list; and thanks Ramin Sadre, Pedro Martinez-Julia and other experts.

- Changes in -04 since IETF#110
  - Update data definition and models definitions to clarify their difference.
  - Remove the orchestration element and consolidated into control functionality building block in the digital twin network.
  - Clarify the mapping relation (one to one, and one to many) in the mapping definition.
  - Add explanation text for continuous verification.
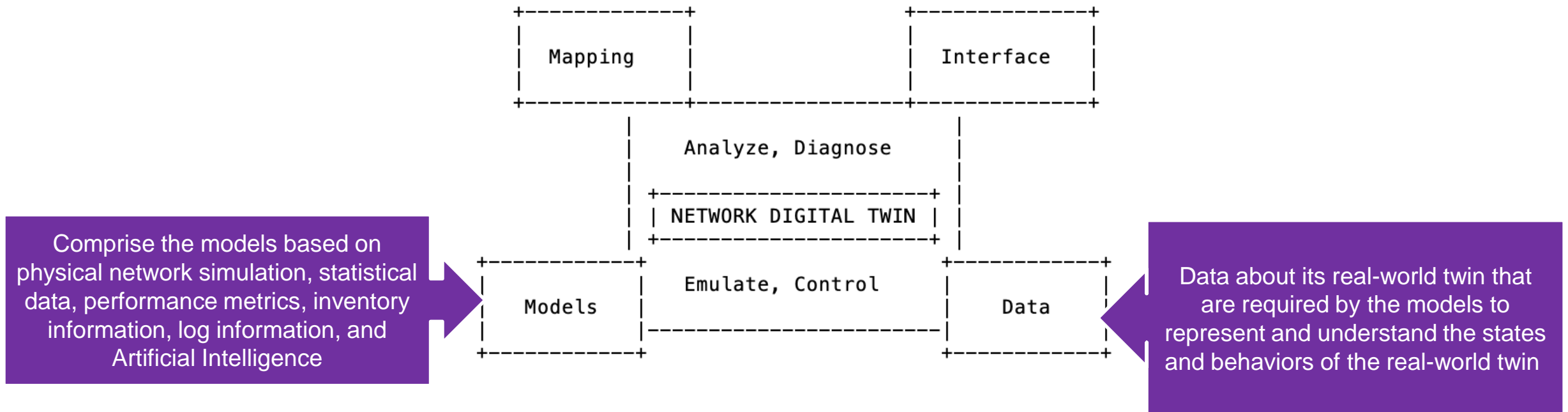 - Change the I-D title from jinia

Update on Digital Twin Network core elements

- Orchestration is removed from the core elements
- Orchestration functionality can be consolidated into control functionality building block in the digital twin network, and also can be part of the functionality in the reference architecture of 'digital twin entity management'.
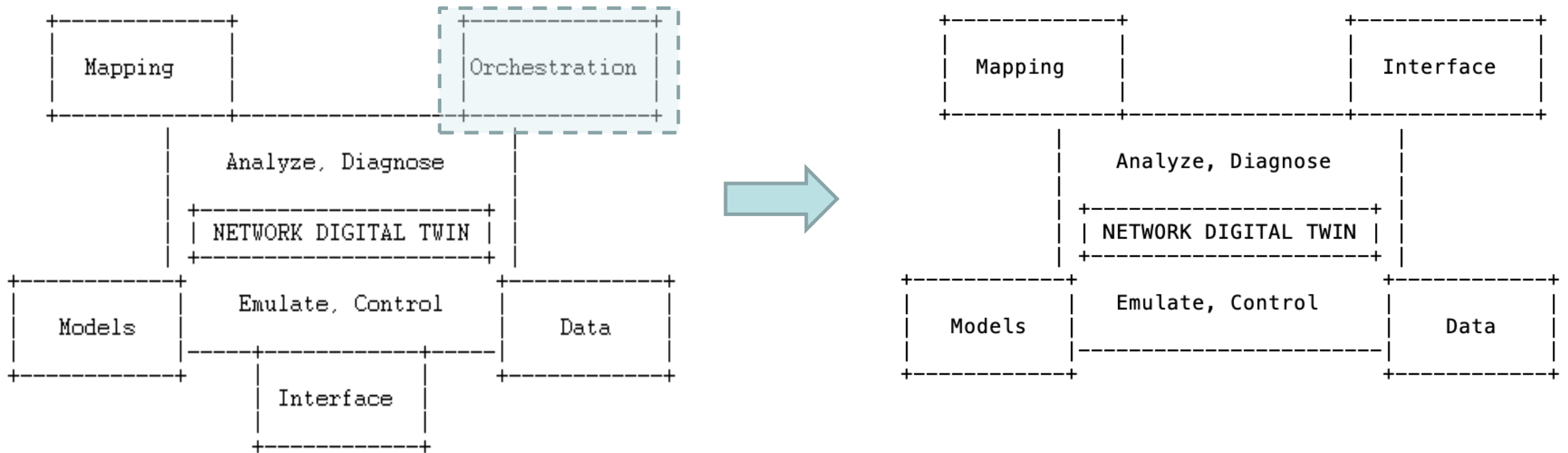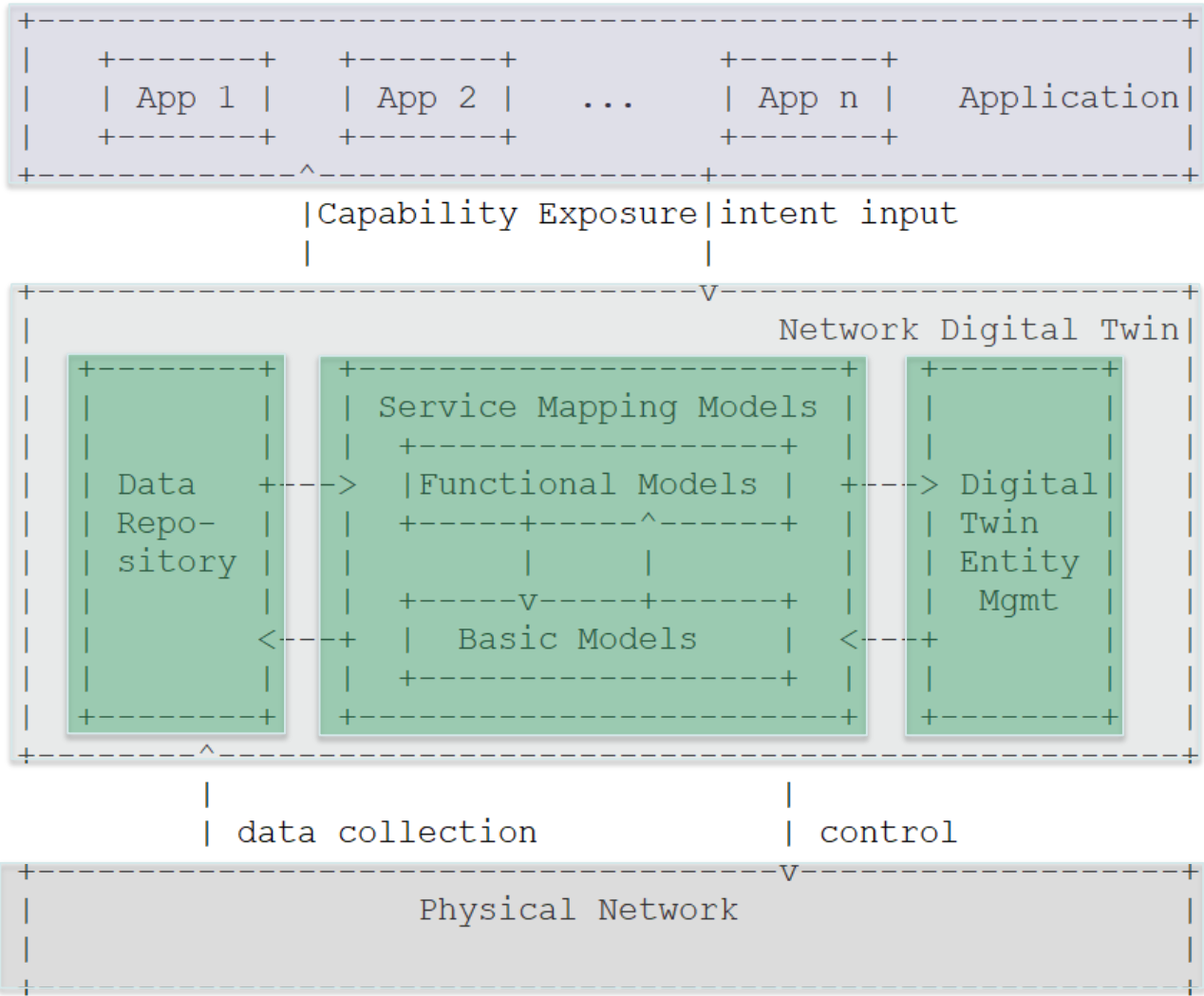
Update definitions on data and models

- **Data and models** are usually the two common and separated elements/components for digital twin.
- **Data:** A digital twin network should maintain historical data and/or real time data about its real-world twin. The data is characterized as the single source of the "truth" and populated in the data repository, which provides timely and accurate data service support for building various models.
- **Models:** Techniques that involve collecting data from one or more sources in the real-world twin and developing a comprehensive representation of the physical network. They are used as emulation and diagnosis basis to provide dynamics and elements on how live physical network operates and develop reasoning data utilized for decision-making.

```
+-------------+          +-------------+
|             |          |             |
|  Mapping    |          |  Interface  |
|             |          |             |
+-------------+          +-------------+
        |                      |
        |   Analyze, Diagnose  |
        |                      |
        |  +----------------+  |
        |  | NETWORK DIGITAL TWIN | |
        |  +----------------+  |
+-------------+          +-------------+
|             |          |             |
|   Models    | Emulate, Control |  Data |
|             |          |             |
+-------------+          +-------------+
```

Comprise the models based on physical network simulation, statistical data, performance metrics, inventory information, log information, and Artificial Intelligence

Data about its real-world twin that are required by the models to represent and understand the states and behaviors of the real-world twin

Clarify the mapping definition, and continuous verification

- **Mapping:** Is used to identify the digital twin and the underlying entities and establish a real-time interactive relation between the physical network and the twin network or between two twin networks. The mapping can be:
  - One to one (pairing, vertical): Synchronize between a physical network and its virtual twin network with continuous flow.
  - One to many (coupling, horizontal): Synchronize among virtual twin networks with occasional data exchange.

- **Continuous Verification (CV)** is an extension of DevOps practices that are concerned with verifying the system as a whole.
  - The application of CI/CD models in network management operations increases the risk associated to deployment of non-validated updates.
  - Close loop control and simulation enclosed in Digital twin network supports such dynamic mechanisms required by DevOps procedures.

Changed the I-D title to "Digital Twin Network: Concepts and Reference Architecture"

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+----------------------------------------------------------------+
|  +--------+     +--------+            +-------+                 |
|  | App 1  |     | App 2  |    ...     | App n |   Application|  |
|  +--------+     +--------+            +-------+               |  |
+----------^------------------------------------V----------------+
           |Capability Exposure|intent input
           |                   |
+----------------------------------V-----------------------------+
|                                        Network Digital Twin|   |
|  +--------+     +--------------------------+   +--------+   |   |
|  |        |     | Service Mapping Models   |   |        |   |   |
|  |        |     | +----------------------+ |   |        |   |   |
|  | Data   +---->|  |Functional Models |   +----> Digital|   |   |
|  | Repo-  |     |  +-----+-----^------+   |   | | Twin   |   |   |
|  | sitory |     |        |     |          |   | | Entity |   |   |
|  |        |     |  +-----v-----+------+   |   | | Mgmt   |   |   |
|  |        |<----+  |   Basic Models   |   |   <---+      |   |   |
|  |        |     |  +------------------+   |   |        |   |   |
|  +--------+     +--------------------------+   +--------+   |   |
+----------^-----------------------------------------------------+
           |                         |
           | data collection         | control
+----------------------------------V-----------------------------+
|                       Physical Network                         |
|                                                                |
+----------------------------------------------------------------+
```

Three-layer DTN reference architecture

- **The Lowest Layer: Physical Network**
  - Various network domains
  - Exchange data and control with Network Digital Twin
- **The Intermediate Layer: Network Digital Twin**
  - Core layer of DTN system
  - 3 key subsystems: Data repository, Service mapping models, and Digital Twin entity mgmt.
- **Top Layer: Network Application**
  - Both conventional and innovative applications.
  - Provide requirement to Network Digital Twin entity;

Review comments on -04 (1/3)

- We received detailed review comments from Ramin Sadre offline and will incorporate his comments in v-05. Below are the major comments.

No.	Comments	Initial Reply
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)"	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)"	Good suggestion, we will double check and revise it later.
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? "	With DTN's strong modeling capability, few sensitive data will be needed to achieve similar or even higher intelligent analysis. This way, DTN helps benefit the privacy and regulatory compliance. We will refine the paragraph later.
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?"	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'.

Review comments on -04 (2/3)

No.	Comments	Initial Reply
5	*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? "**	"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.
6	*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. 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.
7	*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"**	'record' means to record important (if not all) transactions. Revising it to "records the life-cycle
…	14 more other comments from Ramin are of grammatical errors, typos, and suggestions on better wording	Accepted all comments and will revise it later. **Thanks very much to Ramin Sadre for the careful review and valuable comments.**

Review comments on -04 (3/3)

- One comment raised by Pedro Martinez-Julia on the list is about mapping of the reference architecture and the typical network management architecture.
  - We believe our work is an expansion of network simulation/emulation, and the unique difference from traditional network management architecture is using interactive virtual-real mapping to build closed loop network automation.
  - Our concern is
    - providing survey on other architecture might lose focus of this draft.

- Proposal:
  - Add text in the abstract and introduction to clarify the scope and the relation with traditional network management architecture.

IEEE DTPI 2021 – Digital Twin Network Online Session

- IEEE DTPI 2021 is a conference to collect the latest scientific achievements in digital twins and parallel intelligence, aiming to promote academic exchanges and discussions among experts and scholars.

- **Digital Twin Network** Online Session was hold on July 20th, 2021. The session built a platform for exchanging ideas on research and application of digital twin technology in network and communication fields.

- Seven presentations, dealing with
  - Base technologies
    - Traffic modeling
    - GANs and security applications
    - Blockchain for trusted data
    - Modeling of wireless channels
  - Architectural concepts
    - Close to the draft and providing a method for DTN construction
  - Applications
    - Data-driven routing
  - Relate standardization activities
    - The ETSI ENI framework

Next Steps

- Keep investigating more use cases and requirements of DTN.

- Address any issues raised in this meeting.

- After address all comments and issues on -04, **we will request RG adoption call for this document.**

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