Concepts of Digital Twin Network

draft-zhou-nmrg-digitaltwin-network-concepts

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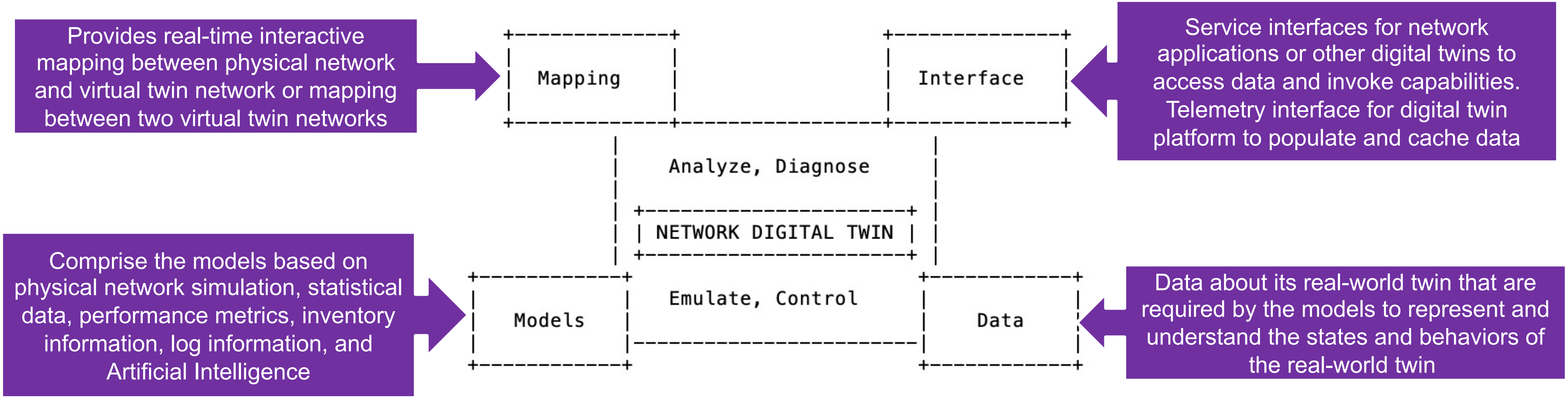
Replication in the Digital Era

- Digital twins are digital replications of physical entities that enable data to be seamlessly transmitted between the physical and virtual worlds
  - Facilitate the means to monitor, understand, and optimize the functions of the replicated entities
  - Originally applied in manufacturing industry processes and machinery
- Main elements
  - Sensors and actuators, so that digital twins can replicate the real twin behavior
  - AI, in order to make fast and intelligent decisions on behalf of their real twin.
  - Communication, to interact in near real time with the environment, real twins, and/or other digital twins
  - Representation, from a 3D avatar to a graphical dashboard, depending on the application domain
  - Trust, for real twins to trust their digital twin
  - Privacy and security, including the resolution of regulatory and political issues
- For networks, help realize efficient and intelligent network management and network innovation
  - Addressing increasing complexity and supporting faster evolution

Defining a Digital Twin Network

- A digital twin network is a virtual representation of the physical network
  - Used to analyze, diagnose, emulate, and control the physical network
  - Based on data, models and open interfaces
- A real-time and adaptive mapping is required between the physical network and its virtual twin network.



A Functional View

- Analyze, diagnose, emulate, and control the physical network
  - Apply optimization algorithms, management methods, and expert knowledge
  - Lower the cost of network optimization
  - Optimized decision making
  - Safer assessment of innovative network capabilities
  - Privacy and regulatory compliance
  - Customize training
- Orchestrate the digital twin to derive the required system behavior
  - Repeatability: the capacity to replicate network conditions on-demand.
  - Reproducibility: the ability to replay successions of events, under controlled variations as needed

Architecure Framework

```
+-----------------------------------------------------------+
|   +--------+   +--------+   ...    +--------+   Application|
|   | App 1  |   | App 2  |          | App n  |              |
|   +--------+   +--------+          +--------+              |
+--------------^--------------------+-----------------------+
               |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                        |
|                                                          |
+-----------------------------------------------------------+
```

Physical Network

- The lowest layer in the architecture
- Data from all network elements is fed to the network digital twin entity
  - Through twin southbound interfaces
  - A data infrastructure should be applied in both directions (and in most cases)
    - Aggregation
    - Normalization
    - Anonymization
    - Action ontology
    - Provenance assessment
    - . . .
- Any kind of network or network segment: mobile, fixed, datacenter, access, core, backbone…
- At any domain
  - Covering a single domain
  - Multi-domain
  - Integration can happen at the twin layer

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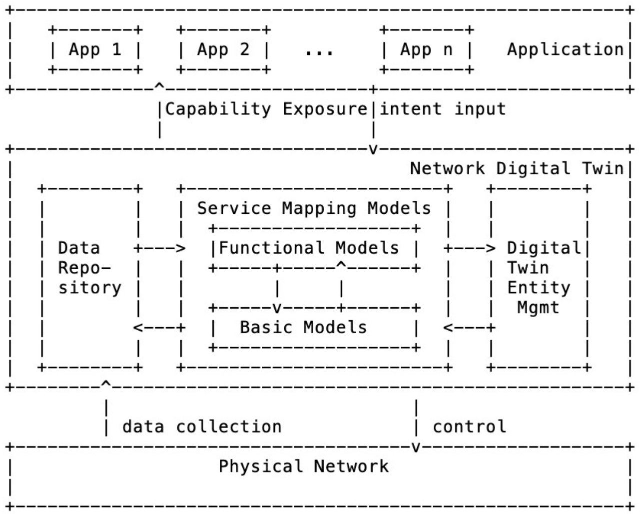
|  | Repo-  |   |  +-----+-----^------+   |   | Twin   |  |
|  | sitory |   |        |     |          |   | Entity |  |
|  |        |   |  +-----v-----+------+   |   |  Mgmt  |  |
|  |        <---+  |  Basic Models    |   <---+        |  |
|  |        |   |  +------------------+   |   |        |  |
|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

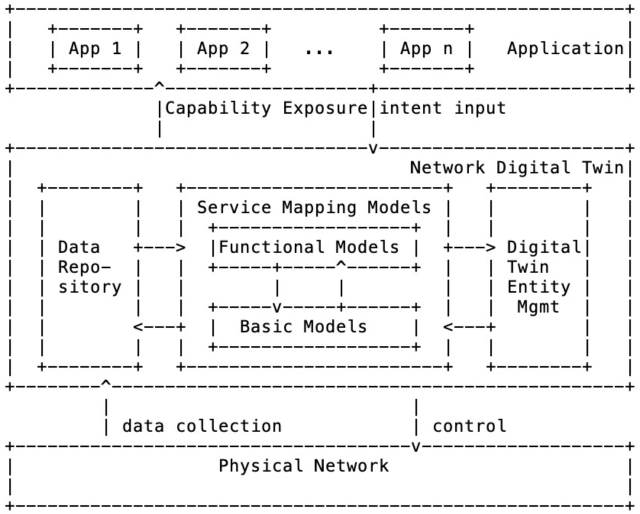
Network Digital Twin

- A Data Repository, collecting and storing network data for supporting the different network models
  - Providing general data services (fast retrieval., concurrent conflict, batch service…) to the modules un the layer
  - The upper interface of the network data flow
- Service Mapping Models, completing data modeling, and providing data model instances for network applications
  - Basic models refer to the network element model and network topology, providing the real-time accurate characterization of the physical network.
  - Functional models refer to various functional views: network analysis, simulation, diagnosis, prediction, assurance
  - Functional models are structured along multiple dimensions
    - By network type, serving for a single or multiple network domains
    - By function type: monitoring, traffic analysis, security exercise, fault diagnosis, quality assurance…
    - By network lifecycle stage: planning, construction, maintenance, optimization, operation…
  - Several dimensions can be combined to create a model for specific application scenarios
- A Digital Twin Entity Management, in charge of the management and orchestration functions of the digital twin network
  - Lifecycle of the twin components
  - Topology of the twin infrastructure network
  - Model management
  - Security management

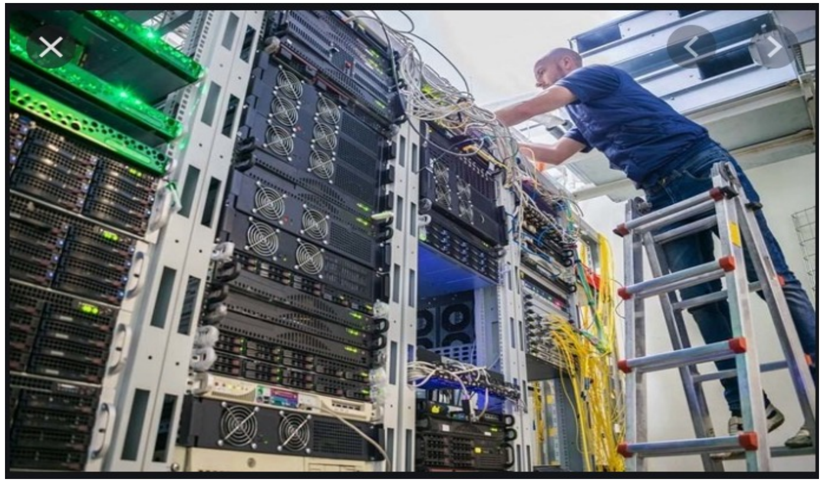


Applications

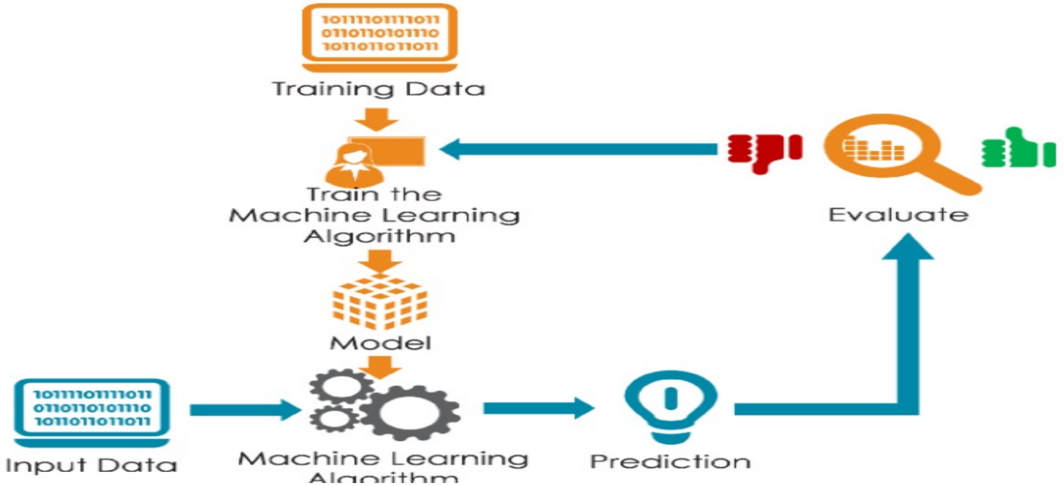
- Several kind of applications can run on a digital twin network platform
  - OAM, IBN…
  - Applying conventional or more innovative technologies
- A *safe playground*
  - Lower cost
  - Limited impact on services
  - Fast prototype evaluation
  - Controlled variability
  - Support for different operational modes, once changes are evaluated
    - Applied to the running physical network(s)
    - Deployed on the physical network(s)
- Application requirements are exchanged through a Northbound interface
  - Required services can be provided by different twin service instances



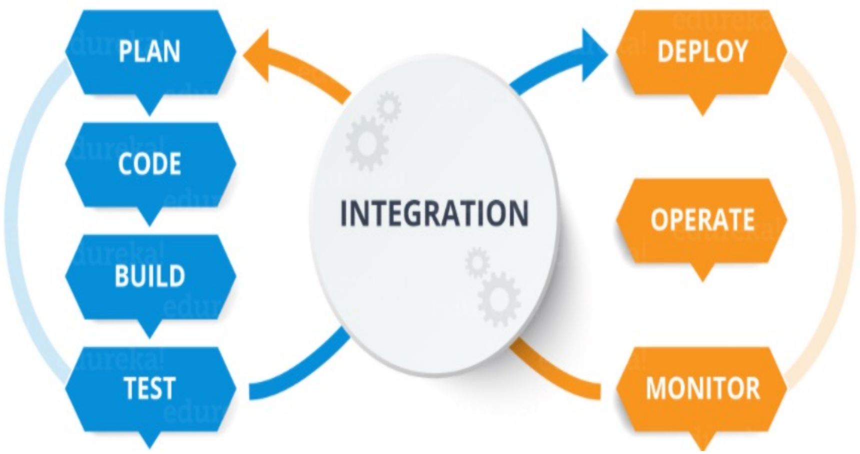
Sample Application Scenarios



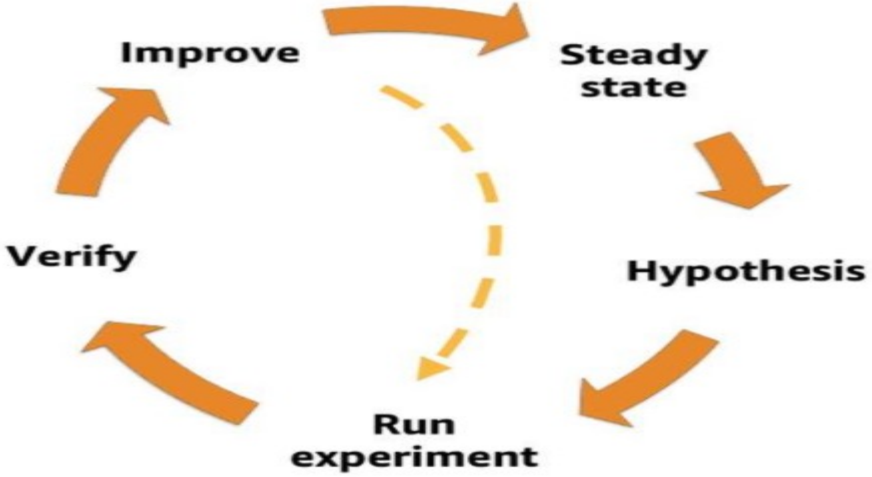
Network Engineer Training



Machine Learning Environments



DevOps-oriented Certification



Network Fuzzing

Challenges in DTN

- Large scale issues – The Borges' Paradox
  - Data acquisition and storage
  - Design and implementation of model
  - Infrastructural requirements of software and hardware of the system will be even more constraining.
- Heterogeneity – Fragmentation vs monoculture
  - Heterogeneity of implementations, requirements, application scenarios, regulations…
  - Do we really need to establish a unified digital twin platform with a unified data model for whole network domains?
  - What is the appropriate balance without sacrificing interoperability?
- Data modeling – Applied ontology
  - Models not only to focus on ensuring accuracy, but also need to consider flexibility and scalability
  - Explore appropriate ontology models to support mapping and transformations
  - Do not forget the action flows
- Real-time requirements – Longer supply lines
  - Processing through a digital twin network will increase the control delay, so the
  - Real-time requirements will impact system infrastructure and modeling capabilities
- Security risks – The Big Twin issue
  - A central, holistic data consumer and control point
  - Extremely appealing as target of several types of attack
  - Privacy preservation