

On two different points of view of the Network Digital Twin

draft-paillisse-nmrg-performance-digital-twin

IETF 118 Prague, November 2023

Albert Cabellos (alberto.cabellos@upc.edu), Christopher Janz

What is a Digital Twin?

- a dynamic model in the virtual world that is fully consistent with its corresponding physical entity
- a comprehensive digital representation of an individual product. It includes the properties, condition, and behavior of the real-life object through models and data.
- the cyber part of a Cyber-Physical System.
- a digital representation that contains all the states and functions of a physical asset and has the possibility to collaborate with other digital twins to achieve a holistic intelligence that allows for decentralized self-control.
- *Network Digital Twin (NDT) is a new technology that builds on the concept of Digital Twins (DT) to create a virtual representation of the physical objects of a telecommunications network. NDT bridges physical and virtual spaces to enable coordination and synchronization of physical parts while eliminating the need to directly interact with them*

Semeraro, C., Lezoche, M., Panetto, H., & Dassisti, M. (2021). Digital twin paradigm: A systematic literature review. *Computers in Industry*, 130, 103469.

Mozo, Alberto, et al. "B5GEMINI: AI-driven network digital twin." *Sensors* 22.11 (2022): 4106.

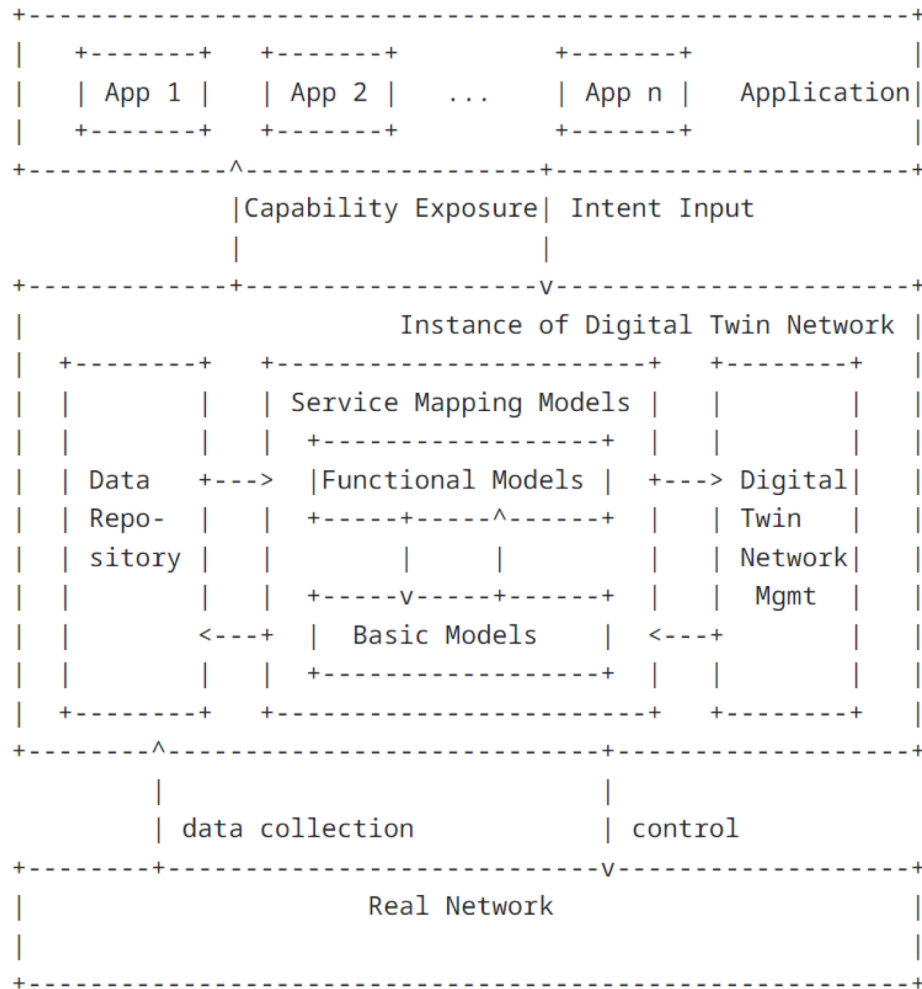
Wu, Yiwen, Ke Zhang, and Yan Zhang. "Digital twin networks: A survey." *IEEE Internet of Things Journal* 8.18 (2021): 13789-13804.

What is a Network Digital Twin?

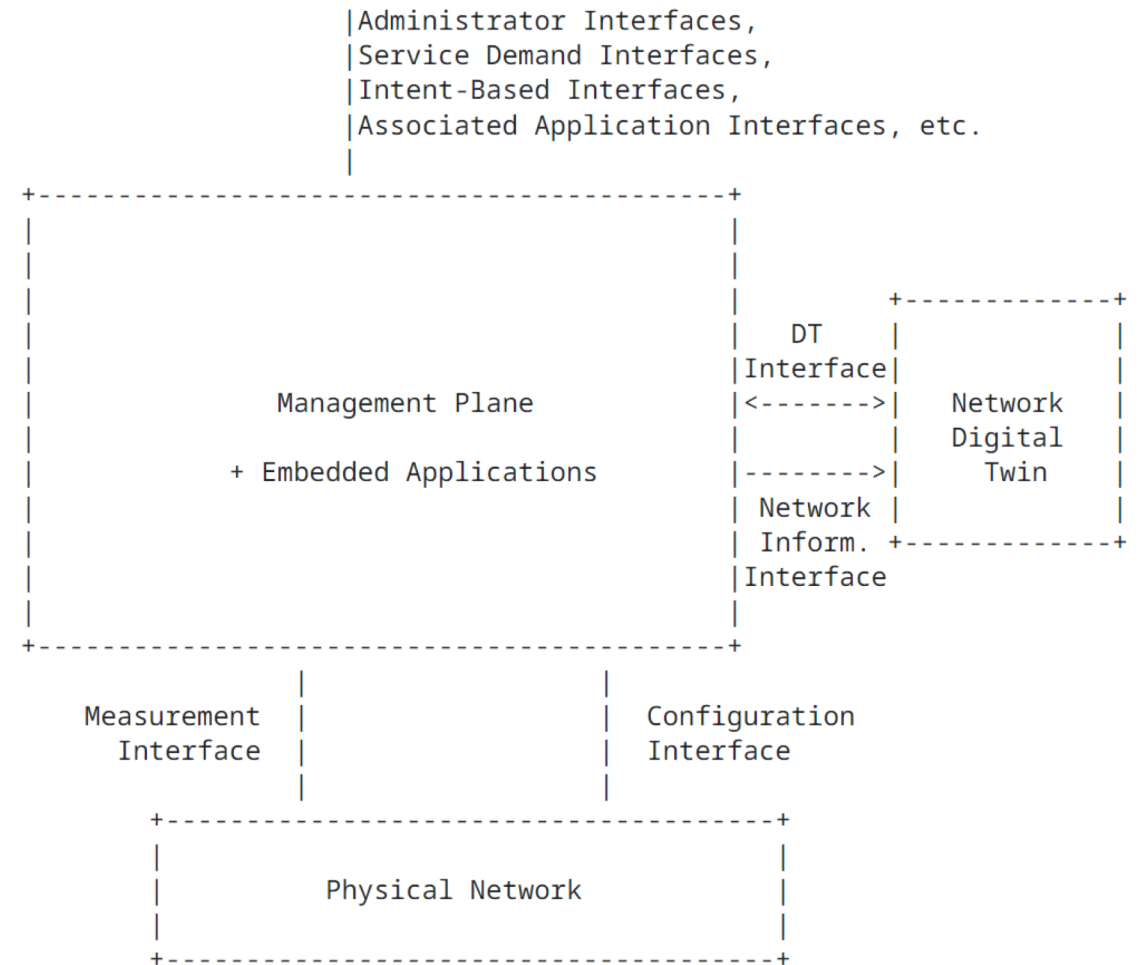
- No **consensus** has been reached by the academic community¹
- No **well-established** Digital Twin definition, architecture or prototype
- You can find a paper supporting –almost- whatever definition you want
- Can we have this debate at the NMRG?
 - **What is a Network Digital Twin?**
- In this presentation I'll describe the view from the authors of:
 - **draft-paillisse-nmrg-performance-digital-twin-02**

[1] Semeraro, C., Lezoche, M., Panetto, H., & Dassisti, M. (2021). Digital twin paradigm: A systematic literature review. *Computers in Industry*, 130, 103469.

Two different views:

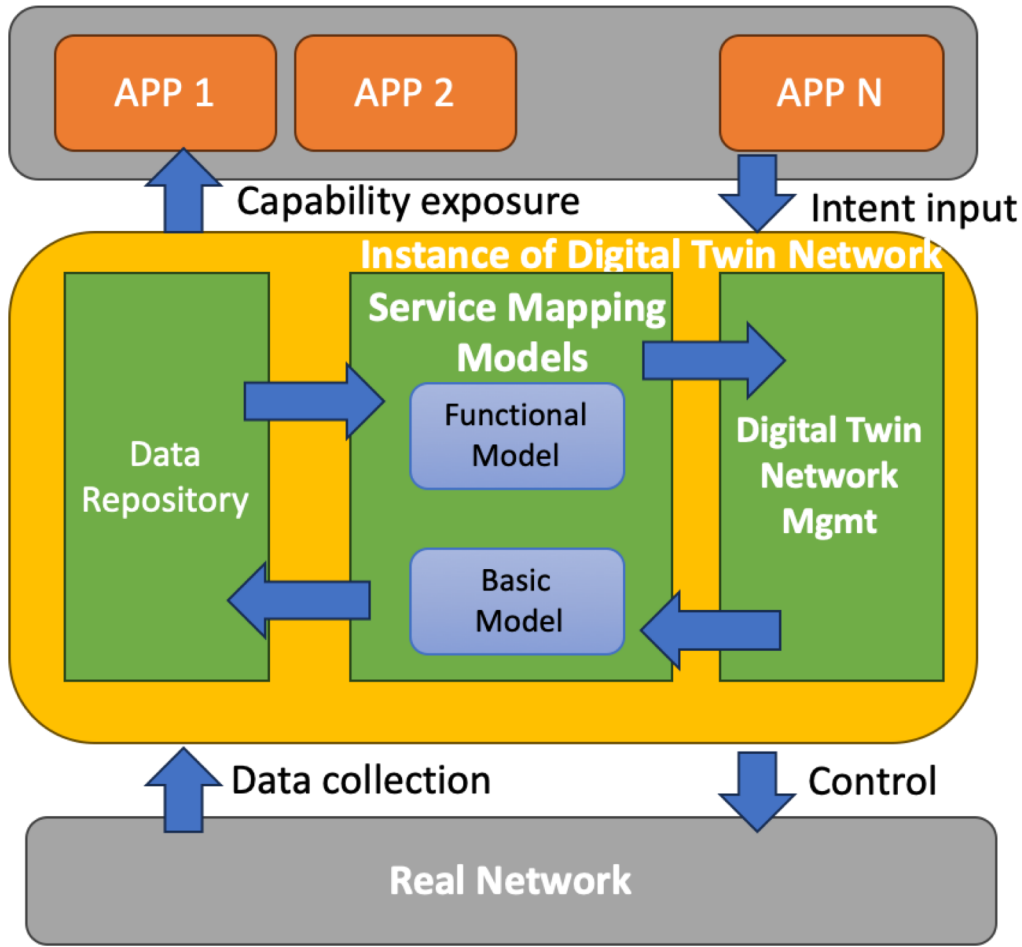


draft-irtf-nmrg-network-digital-twin-arch
Controller



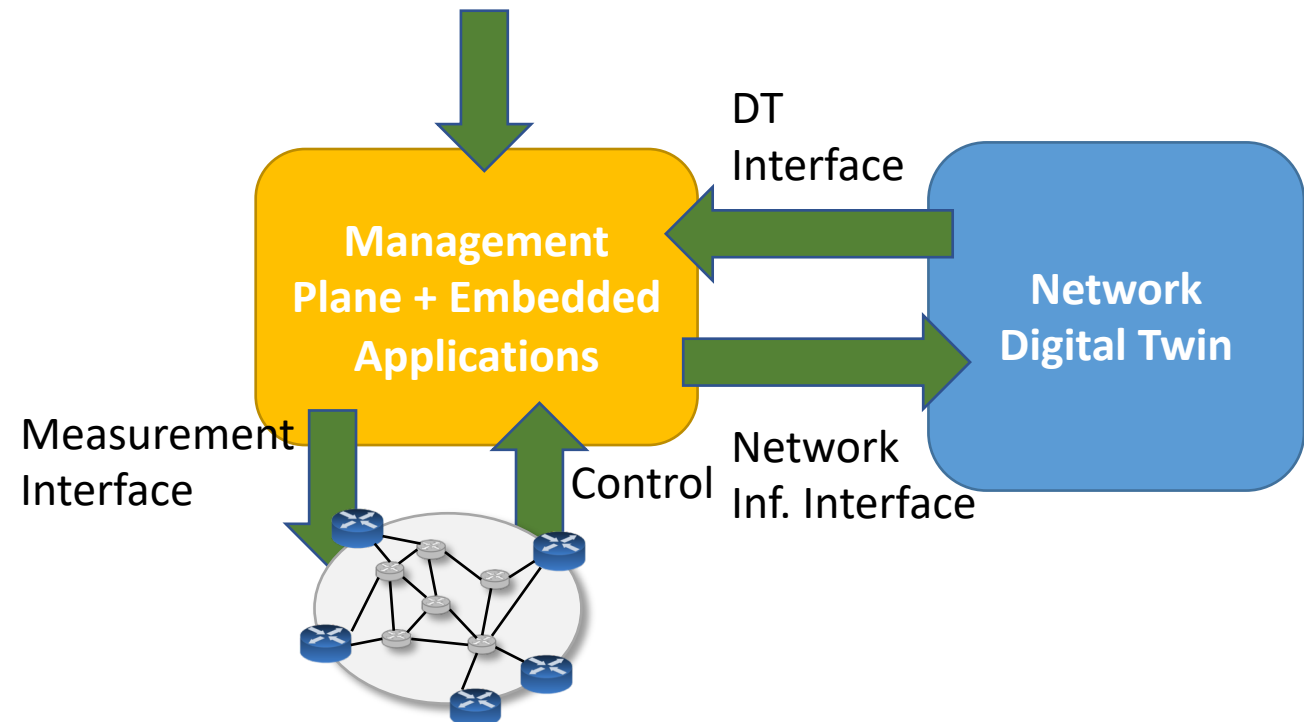
draft-paillisse-nmrg-performance-digital-twin
Model

Two different points of views



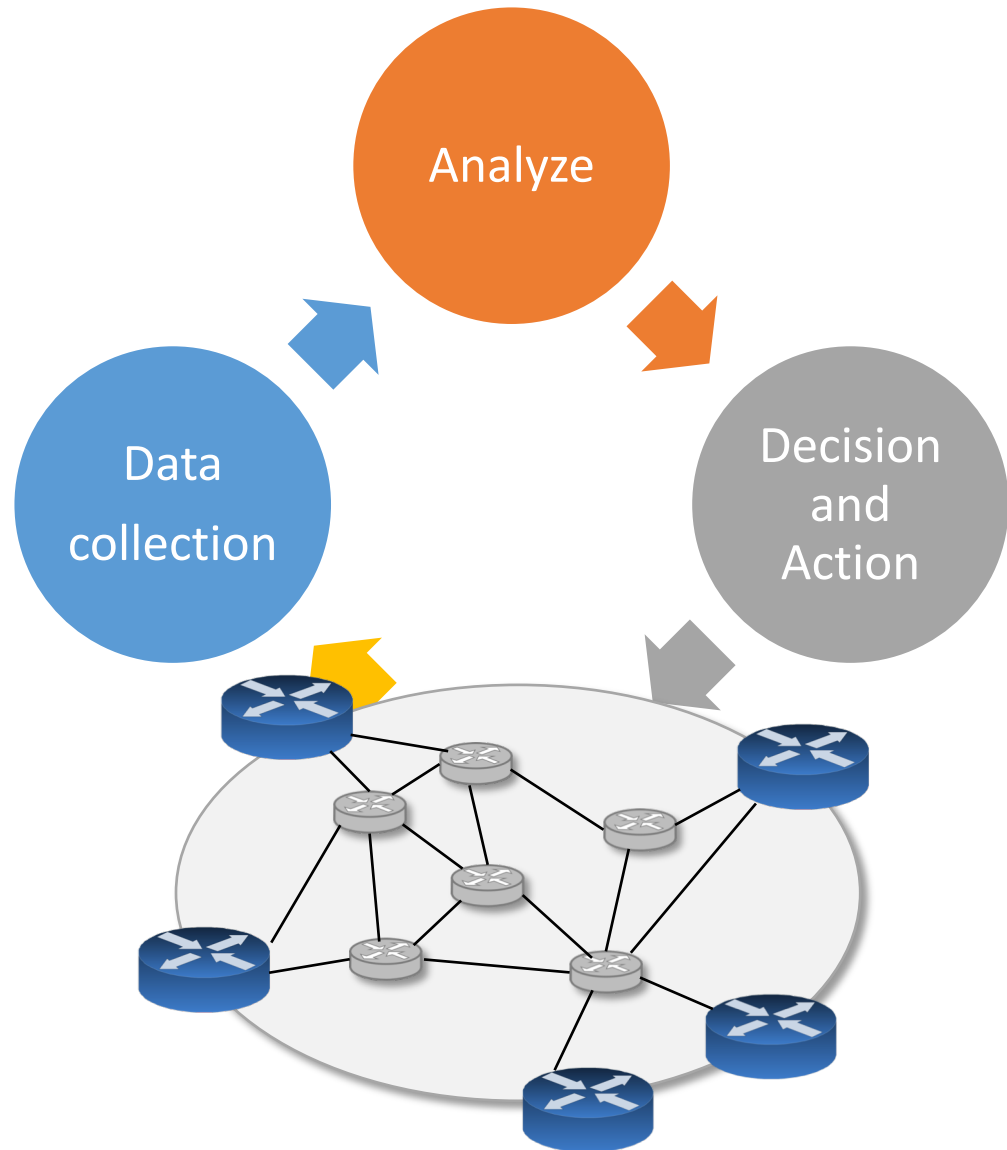
draft-irtf-nmrg-network-digital-twin-arch
Controller

Administrator Interfaces, Service Demand Interfaces, Intent-Based Interfaces, Associated Application Interfaces, etc



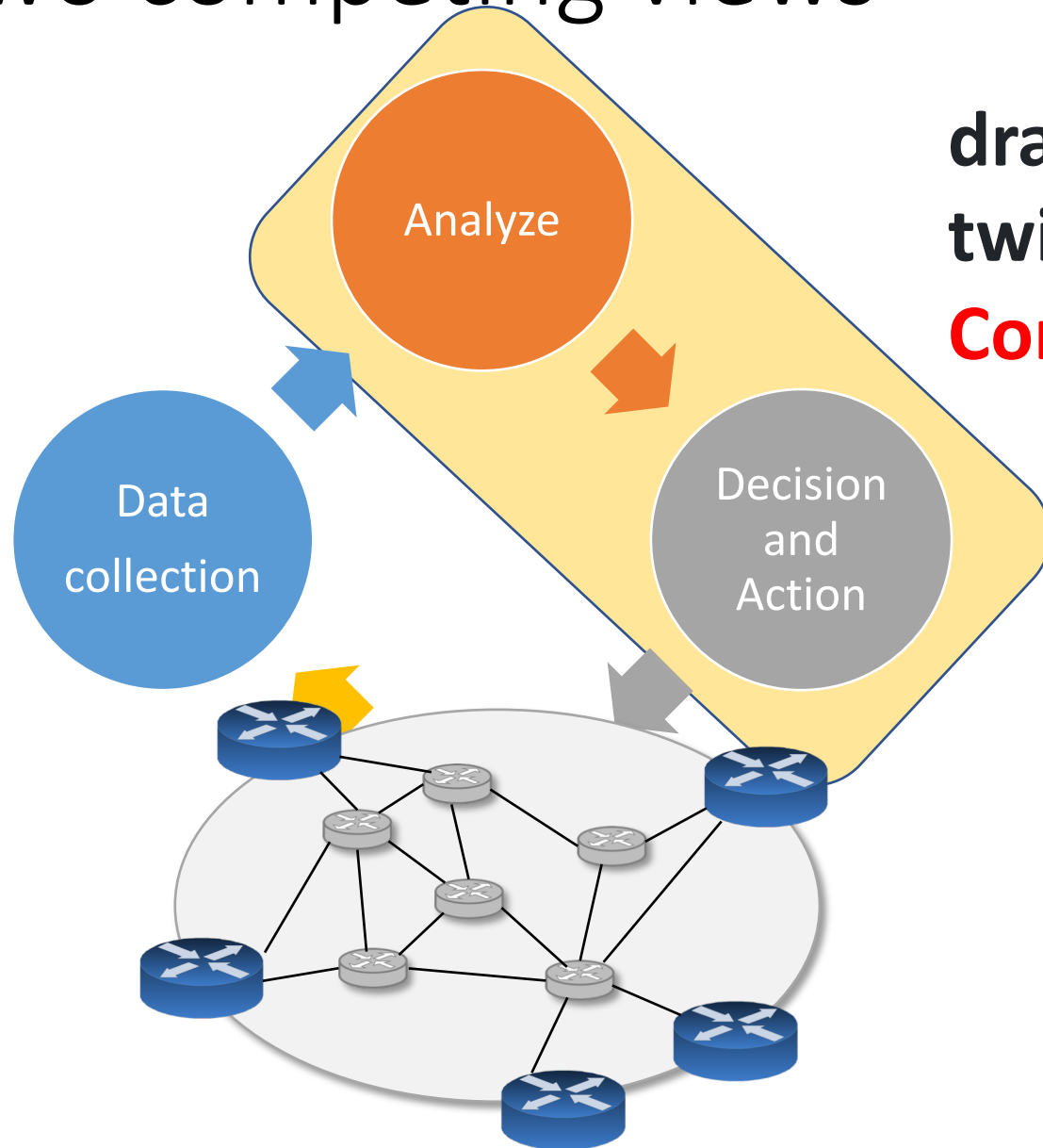
draft-paillisse-nmrg-performance-digital-twin
Model

Closed Loops in Network Management



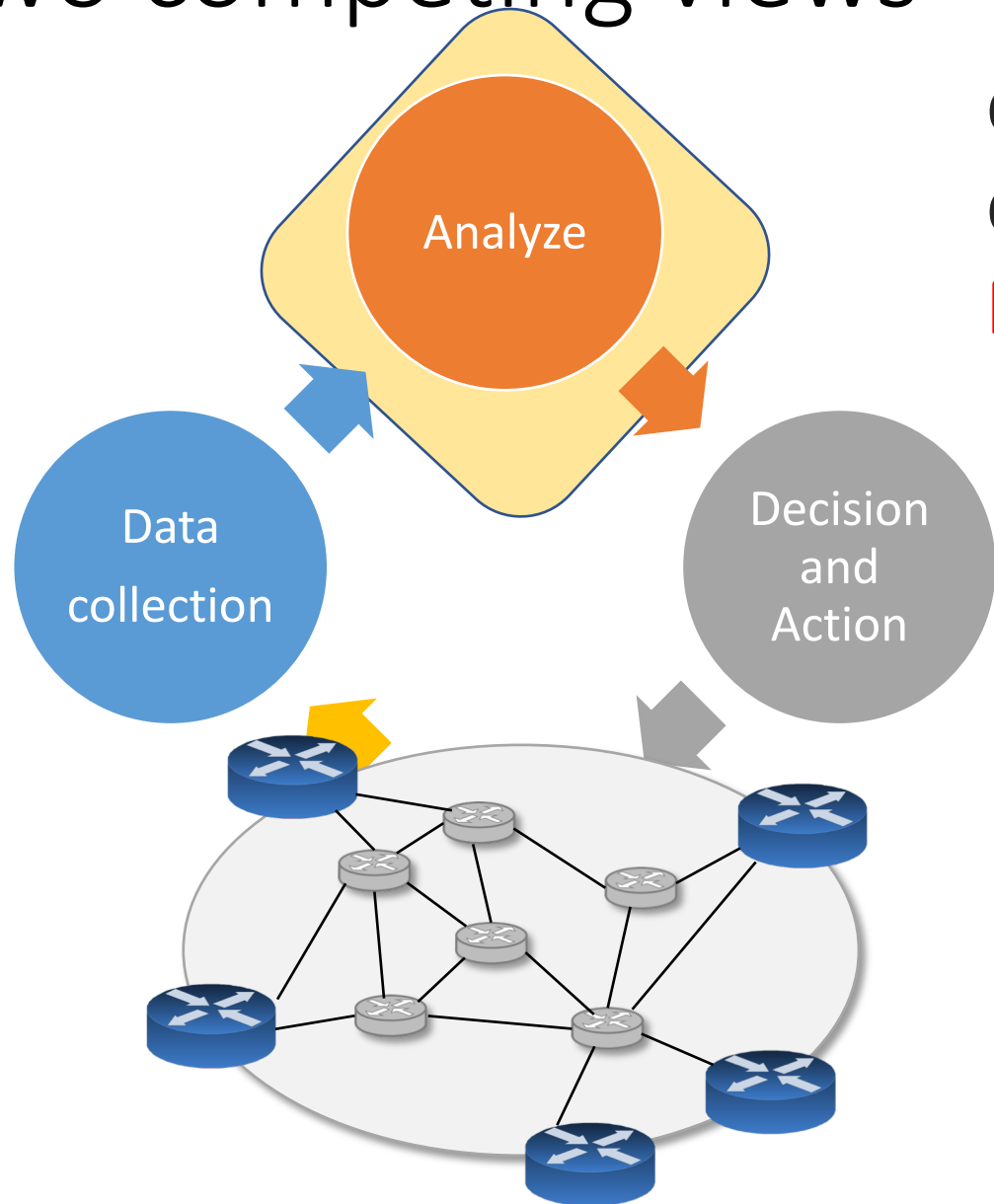
- Management closed loops (roughly) works as follows:
 1. Collect data from the real network infrastructure
 2. Analyze such data
 3. Take a decision and act upon the real network infrastructure

Two competing views



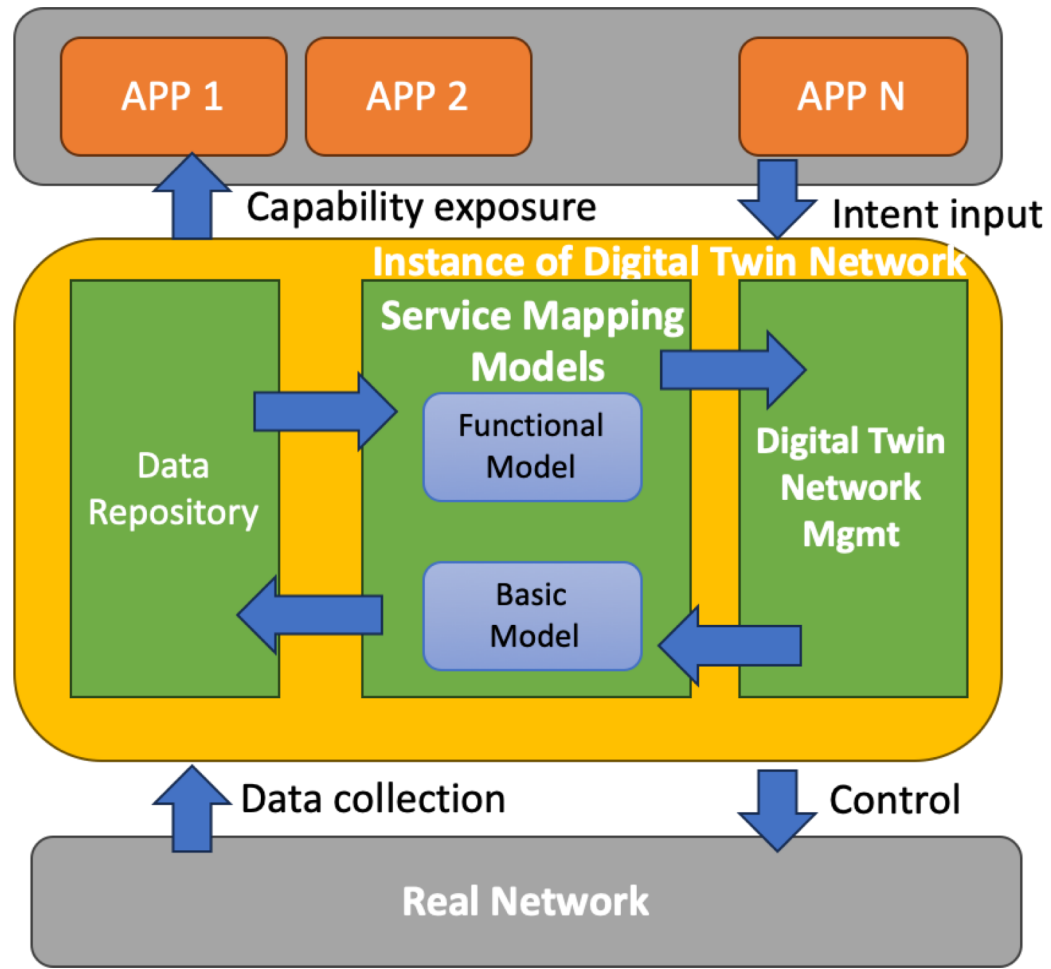
draft-irtf-nmrg-network-digital-
twin-arch
Controller

Two competing views



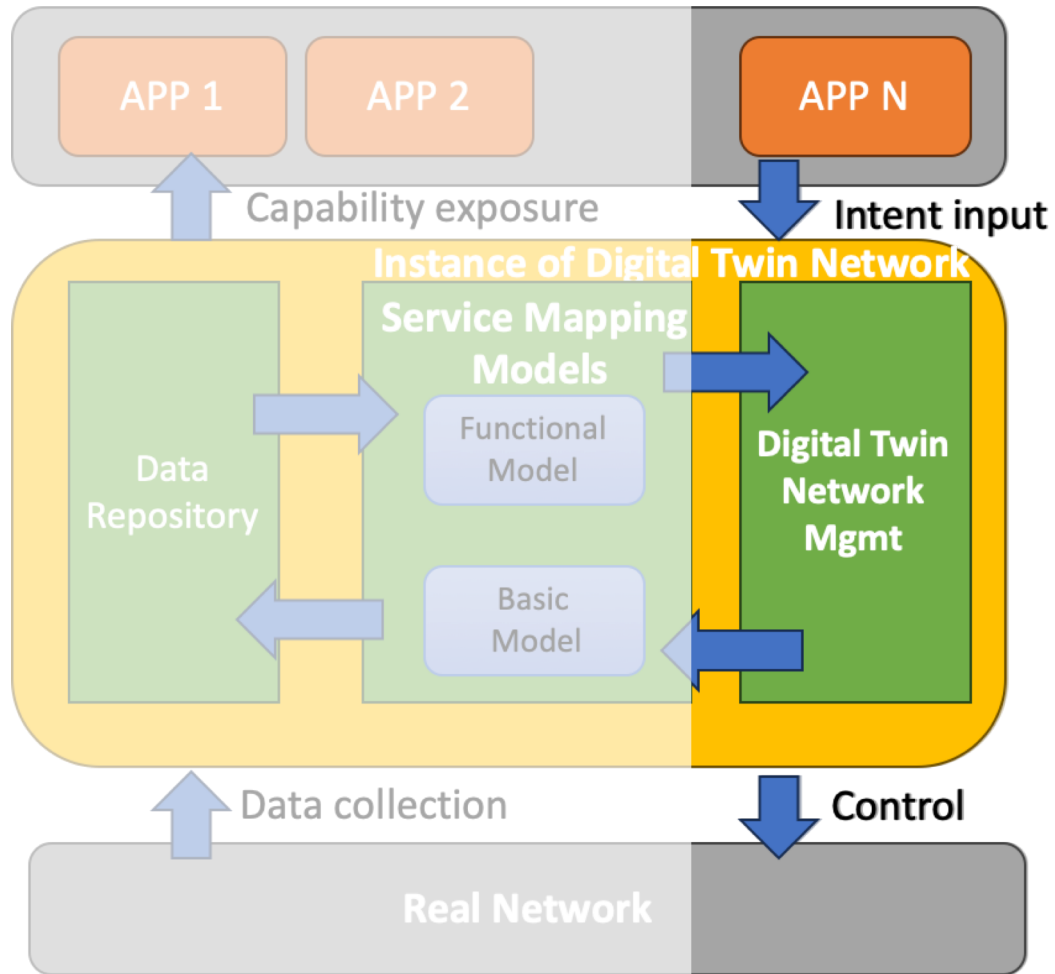
draft-paillisse-nmrg-performance-
digital-twin
Model

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



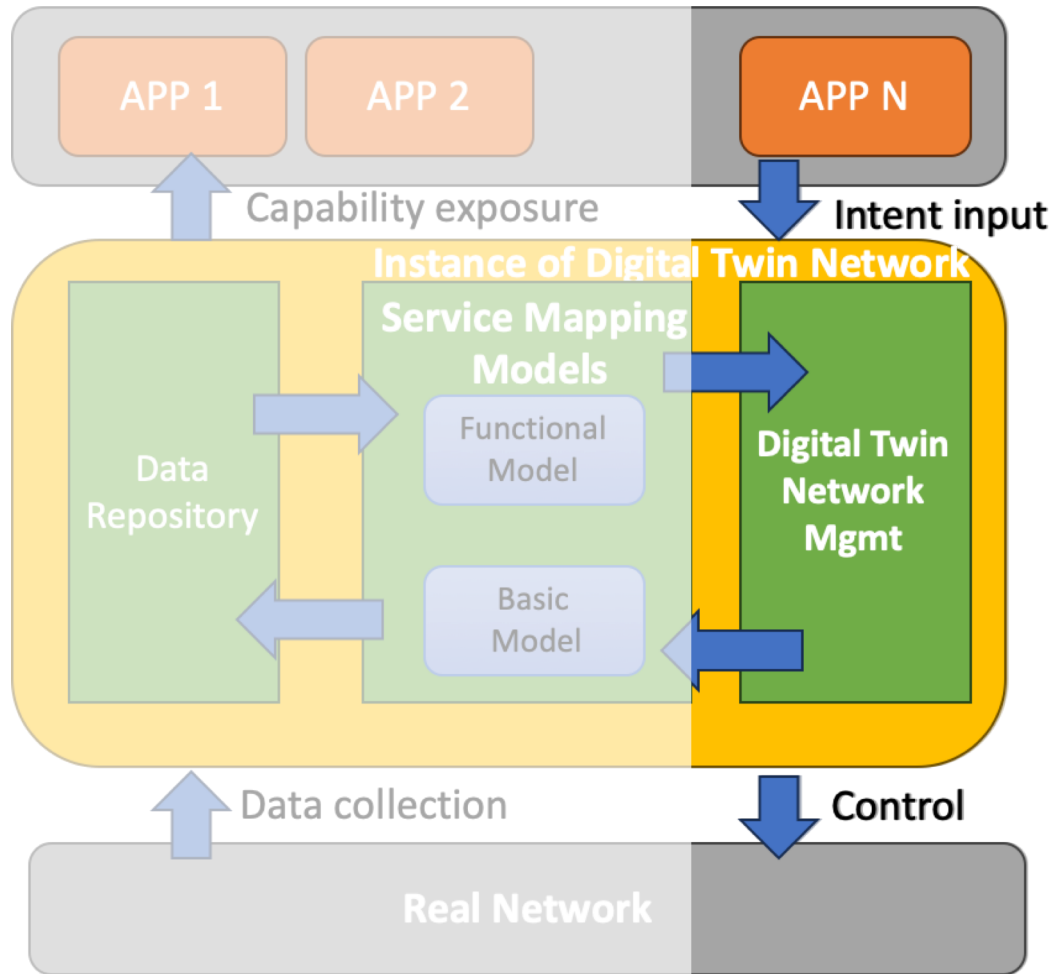
- In this approach the DT includes both the analyze and decision/action
- Intent is the input and the output is control
- From a functional perspective, this is very **similar to an SDN controller**

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



- In this approach the DT includes both the analyze and decision/action
- Intent is the input and the output is control
- From a functional perspective, this is very **similar to an SDN controller**

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

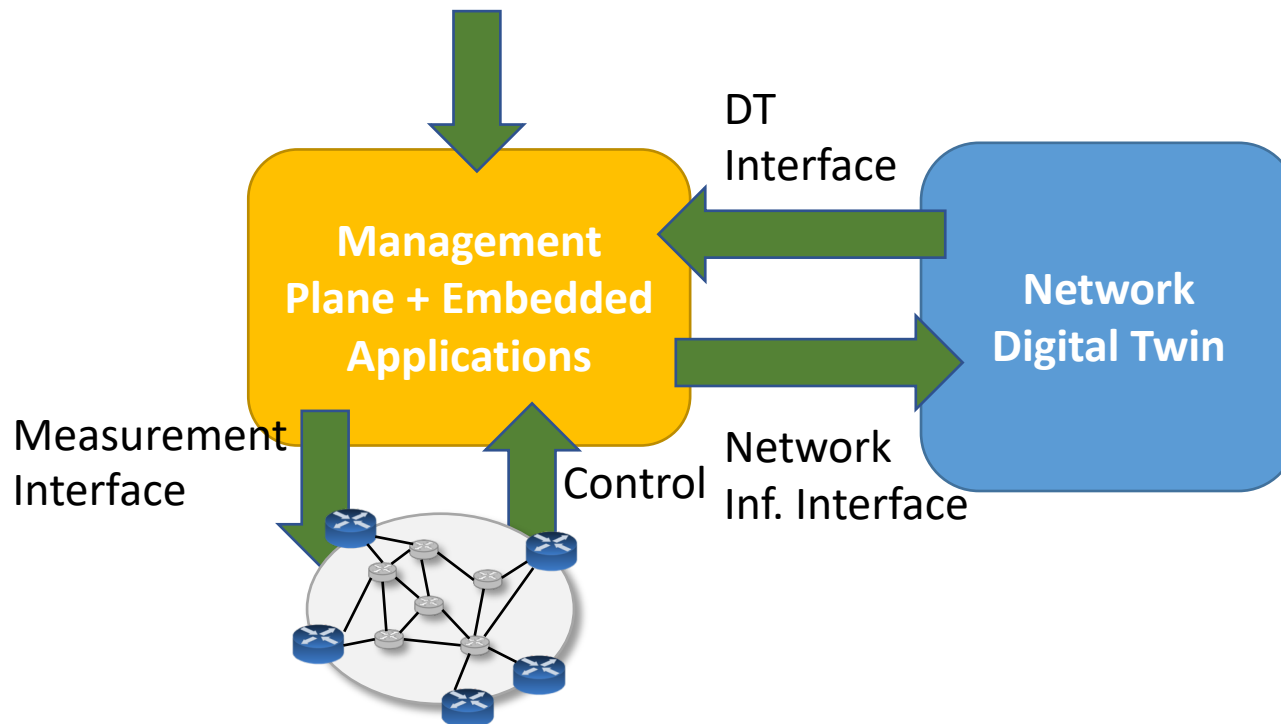


draft-irtf-nmrg-network-digital-twin-arch
Controller

- Why the Digital Twin is tied to Intent?
 - How intent is ingested? Related to the Digital Twin? Rendered into imperative control?
 - This is an open research topic by itself
- How is the control signal generated?
- How are the models (functional/basic) used for control?

draft-paillisse-nmrg-performance-digital-twin

Administrator Interfaces, Service Demand Interfaces, Intent-Based Interfaces, Associated Application Interfaces, etc



draft-paillisse-nmrg-performance-digital-twin
Model

- The Network Digital Twin is only a high-fidelity model of the network
- No control operations
- It fundamentally answers the following type of question:
 - What will be the behavior of the network if X happens
 - Examples on this later
- It is easily understood as a simulator of the network, but can be implemented using emulation, simulation or neural networks

Example 1: IP Networks

Configuration

Topology, Link Capacity
Routing

- Overlay: SRv6, MPLS...
- Underlay: OSPF, BGP...

Scheduling Policy (arbitrary)

- Queue Length
- Policy
- Hierarchy of policies

ECMP, LAG, etc

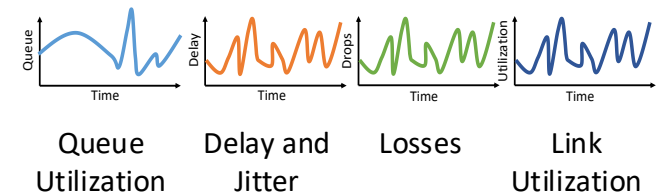
Traffic Load

Traffic Matrix
Start/End Flow
Flow Model (VoIP, VoD, Web, etc)

- Inter-arrival time
- Size distribution

Network
Digital Twin

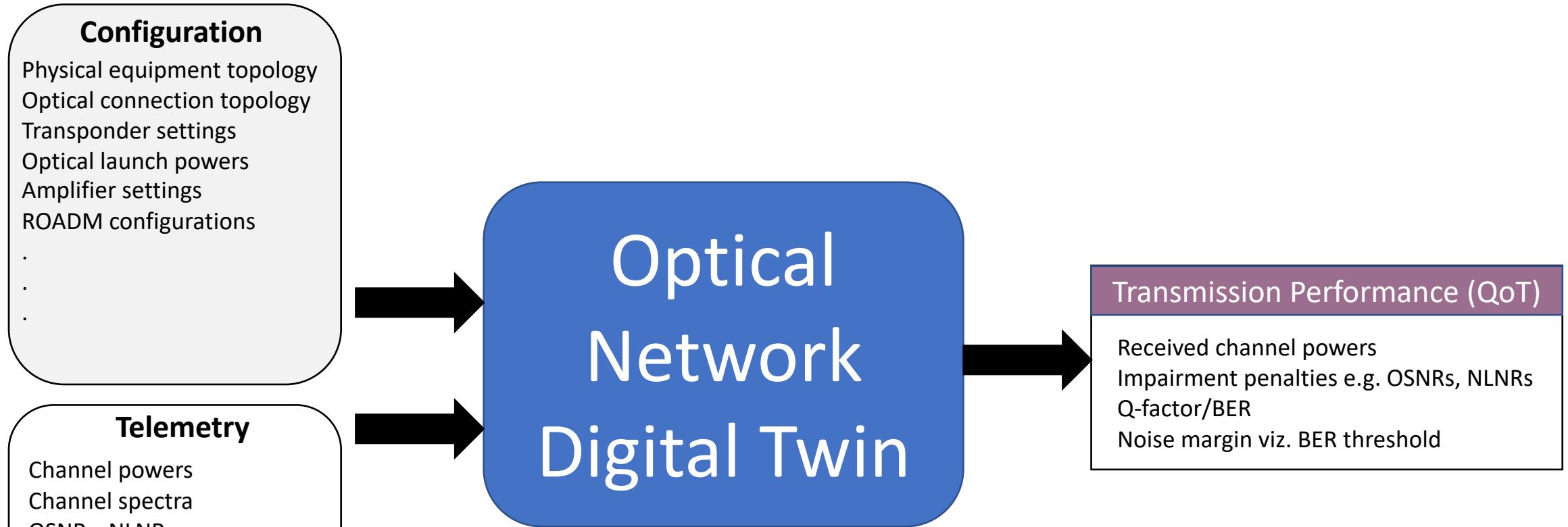
Per-flow Performance Metrics



What will be the impact on the network load if my company acquires company X?

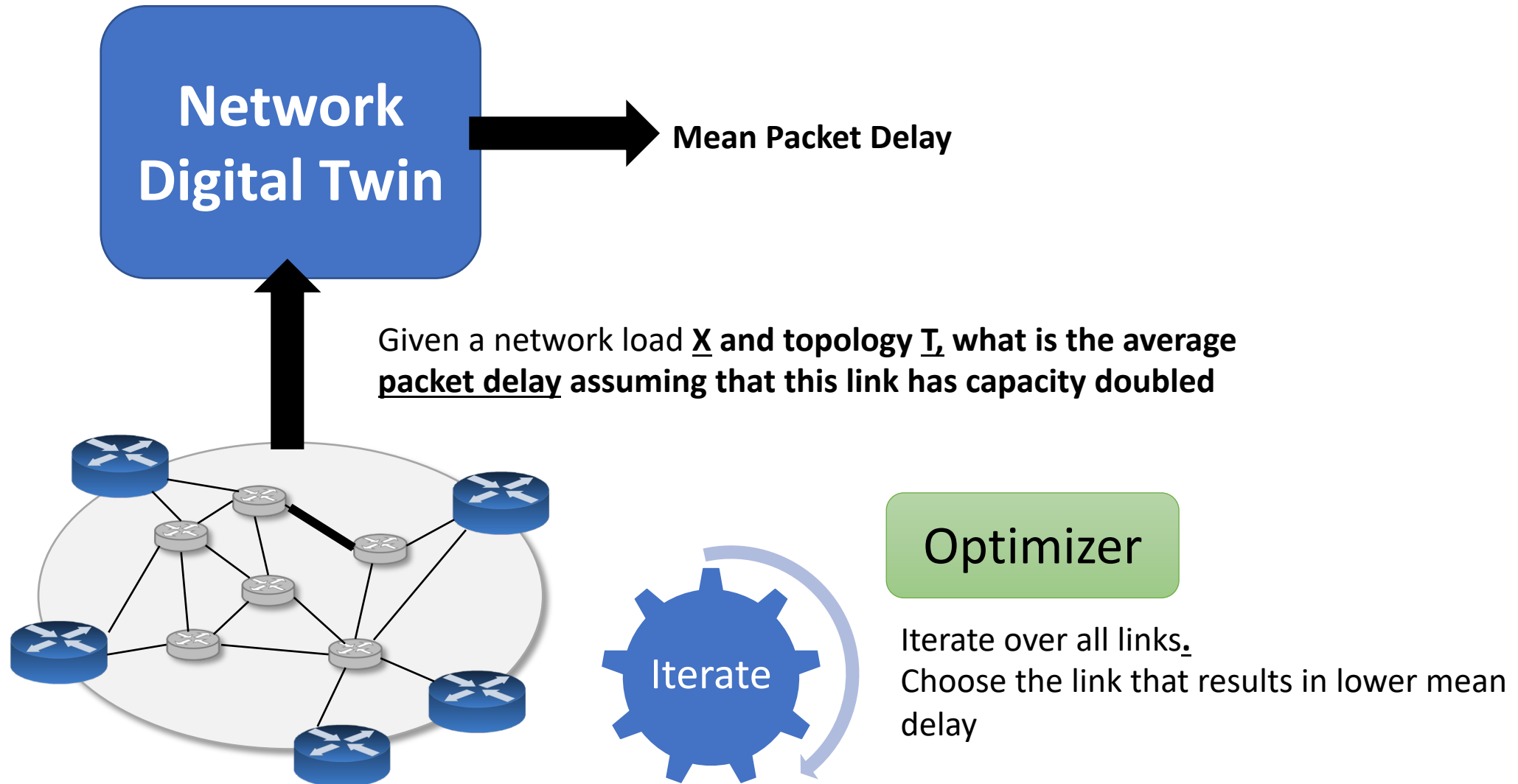
What is the optimal link capacity upgrade? Optimal defined as minimize average delay with minimum cost

Example 2: Optical Networks

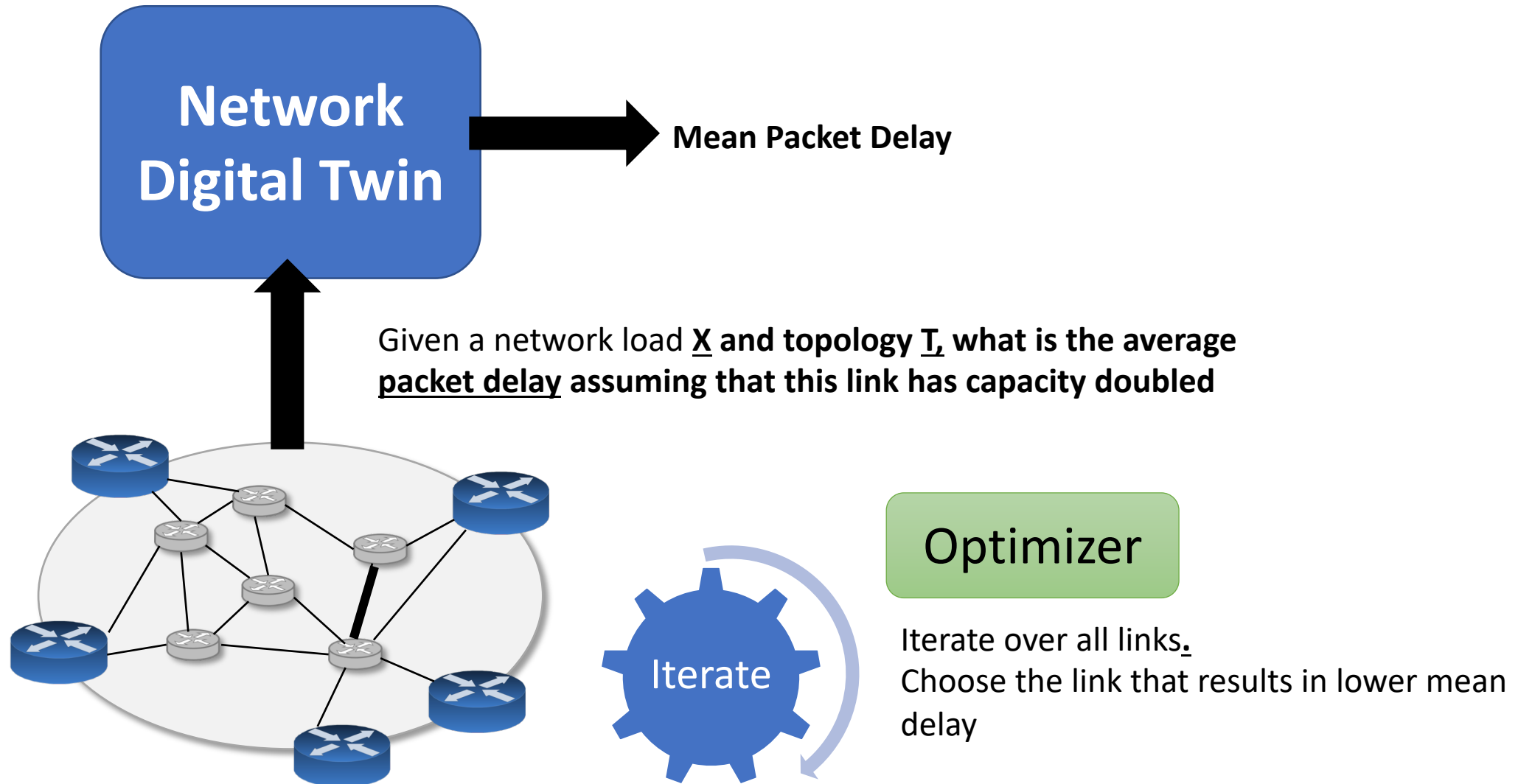


- What will be the transmission performance of postulated optical connections under the postulated network and other conditions?
- Will any margins be inadequate: connections not functional? Will any margins be excessive: resources not efficiently used?

Example: Use of DT in optimization scenarios



Example: Use of DT in optimization scenarios



Recent advances in network modelling

- Available network modelling techniques are:
 - Discrete Event Simulators (NS3, Omnet++) → Accurate but slow (≈hours to simulate a single 1Gbps link)
 - No available accurate analytical technique
- Recent progress in network modelling because of neural networks

Paper	Features	Technology	Remarks
DeepQueueNet	IP networks including packet-level visibility	Transformers	10-100x faster than network simulation (DES)
RouteNet	IP networks with aggregated traffic models	GNN	Very fast (ms) but no packet-level visibility
MimicNet	TCP Performance in Data-Center Networks	Simulation + RNN	10x faster than network simulation (DES)
SCRCON	Mobile Performance of 5G network (traffic & signal propagation)	A combination of	Used to optimize 5G networks of 5 cities (2000 cells)

Summary

- We request the MRG to help define what a Network Digital Twin is
- So far there are two different point of view
 1. draft-paillisse-nmrg-performance-digital-twin
 - Digital Twin is a model of the network
 2. draft-irtf-nmrg-network-digital-twin-arch
 - Digital Twin is a controller of the network (inputs intent, outputs control)
- **Other point of view are more than welcome**