A Performance-Oriented Digital Twin for Carrier Networks

draft-paillisse-nmrg-performance-digital-twin

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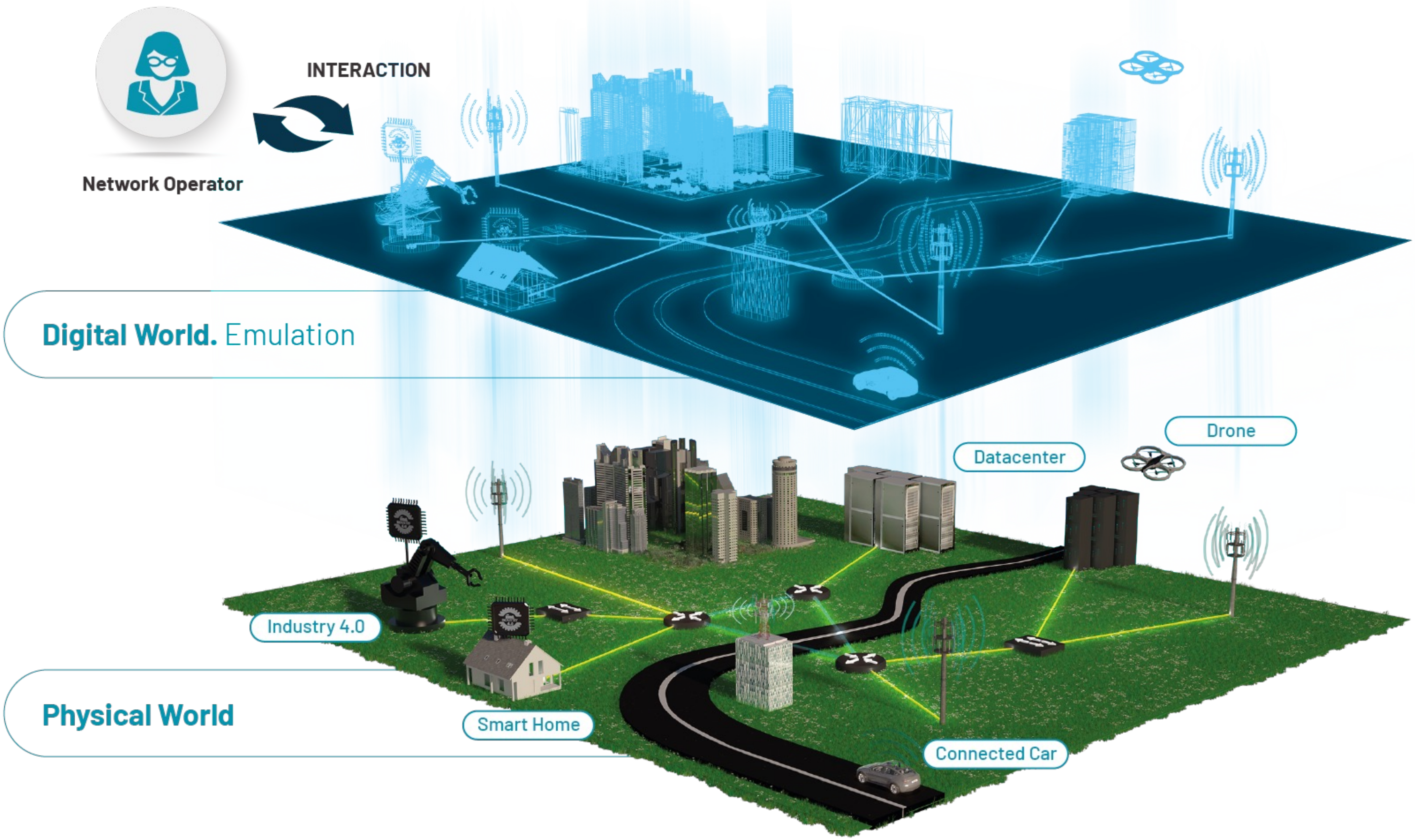
Digital Twin for Computer Networks



https://datatracker.ietf.org/doc/draft-irtf-nmrg-network-digital-twin-arch/
Almasan P, Ferriol-Galmés M, Paillisse J, Suárez-Varela J, Perino D, López D, Perales AA, Harvey P, Ciavaglia L, Wong L, Ram V. Digital Twin Network: Opportunities and Challenges. arXiv preprint arXiv:2201.01144. 2022 Jan 4.

Network Performance Digital Twin

Configuration

Topology, Link Capacity
Routing
- Overlay: SRv6, MPLS…
- Underlay: OSPF, BGP…

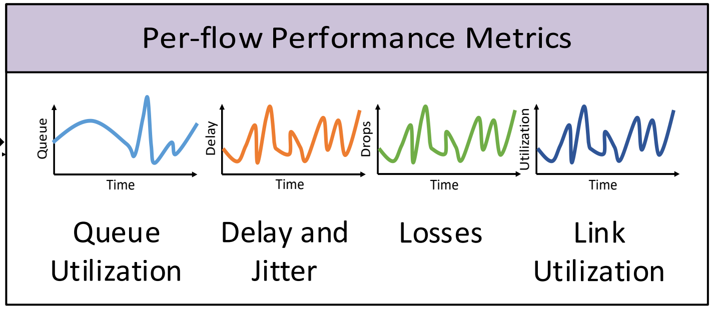
Scheduling Policy (arbitrary)
- Queue Length
- Policy
- Hierarchy of policies

ECMP, LAG, etc

Traffic Load

Traffic Matrix
Start/End Flow
Flow Model (VoIP, VoD, Web, etc)
- Inter-arrival time
- Size distribution

Network Performance Digital Twin (NPDT)



Requirements

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- Fast
- Accurate
- Scalable
- Wide range supported networks:
  - Routing
  - Scheduling
  - Topologies
  - Traffic intensity
- Accessible

Requirements

- Fast → Network optimization
- Accurate
- Scalable
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- Fast → Network optimization
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- Scalable → Testbed << Production
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Requirements

- Fast → Network optimization
- Accurate
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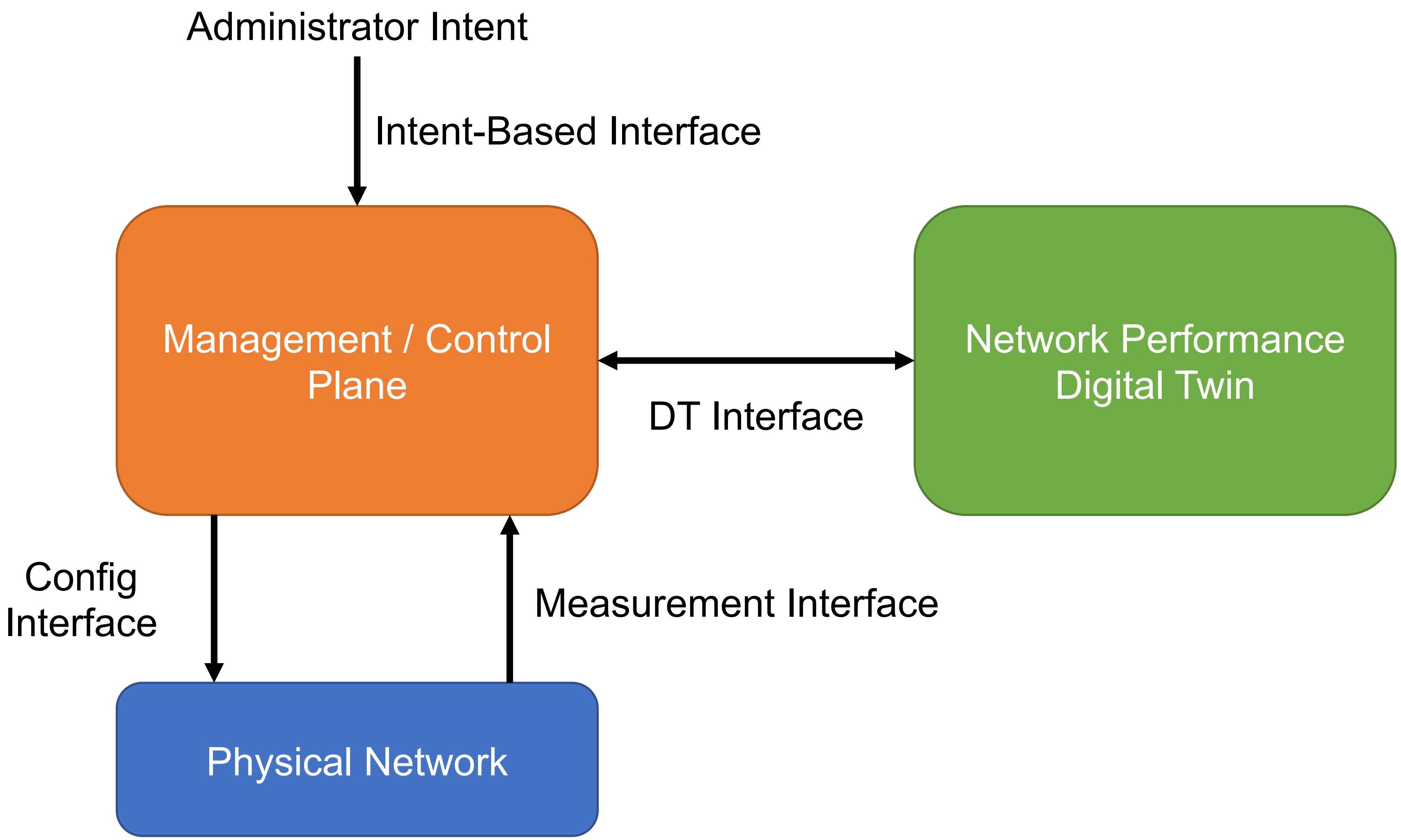
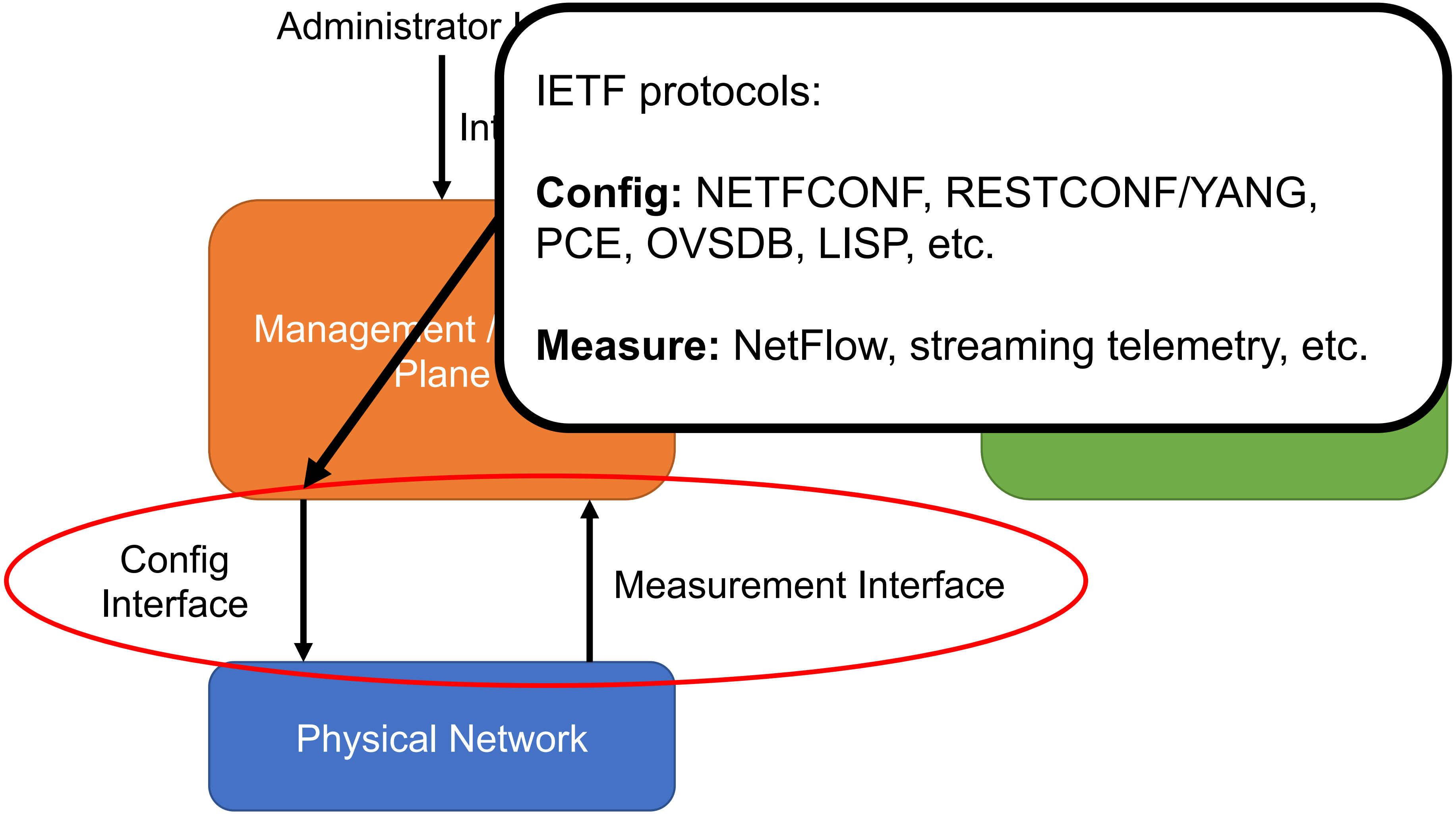
- Wide range supported networks:
  - Routing
  - Scheduling
  - Topologies
  - Traffic intensity
- Accessible
  - → Communicate with existing systems
  - → Metrics commonly used in network engineering

Architecture and Interfaces

Architecture



Architecture

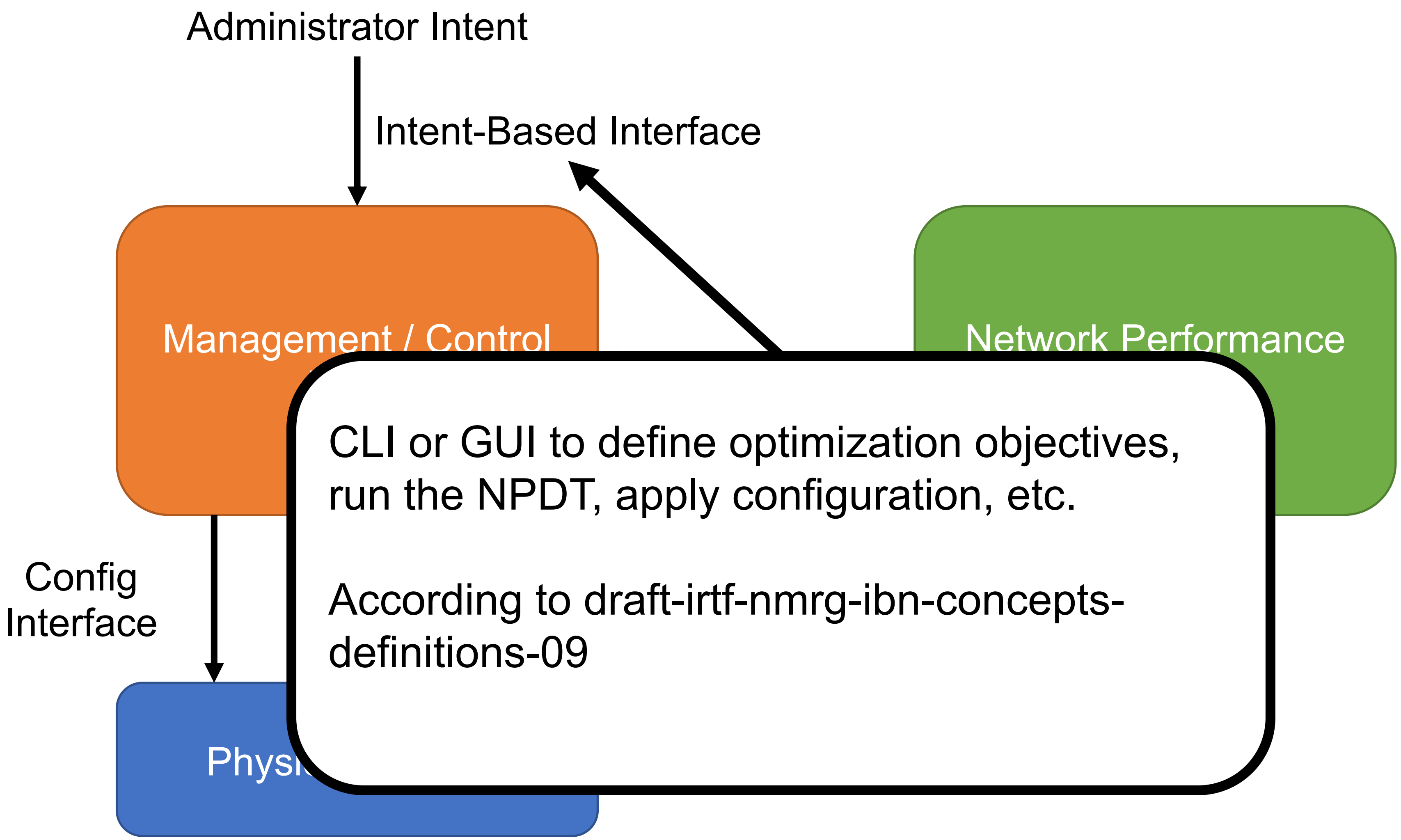


IETF protocols:

Config: NETFCONF, RESTCONF/YANG, PCE, OVSDB, LISP, etc.

Measure: NetFlow, streaming telemetry, etc.

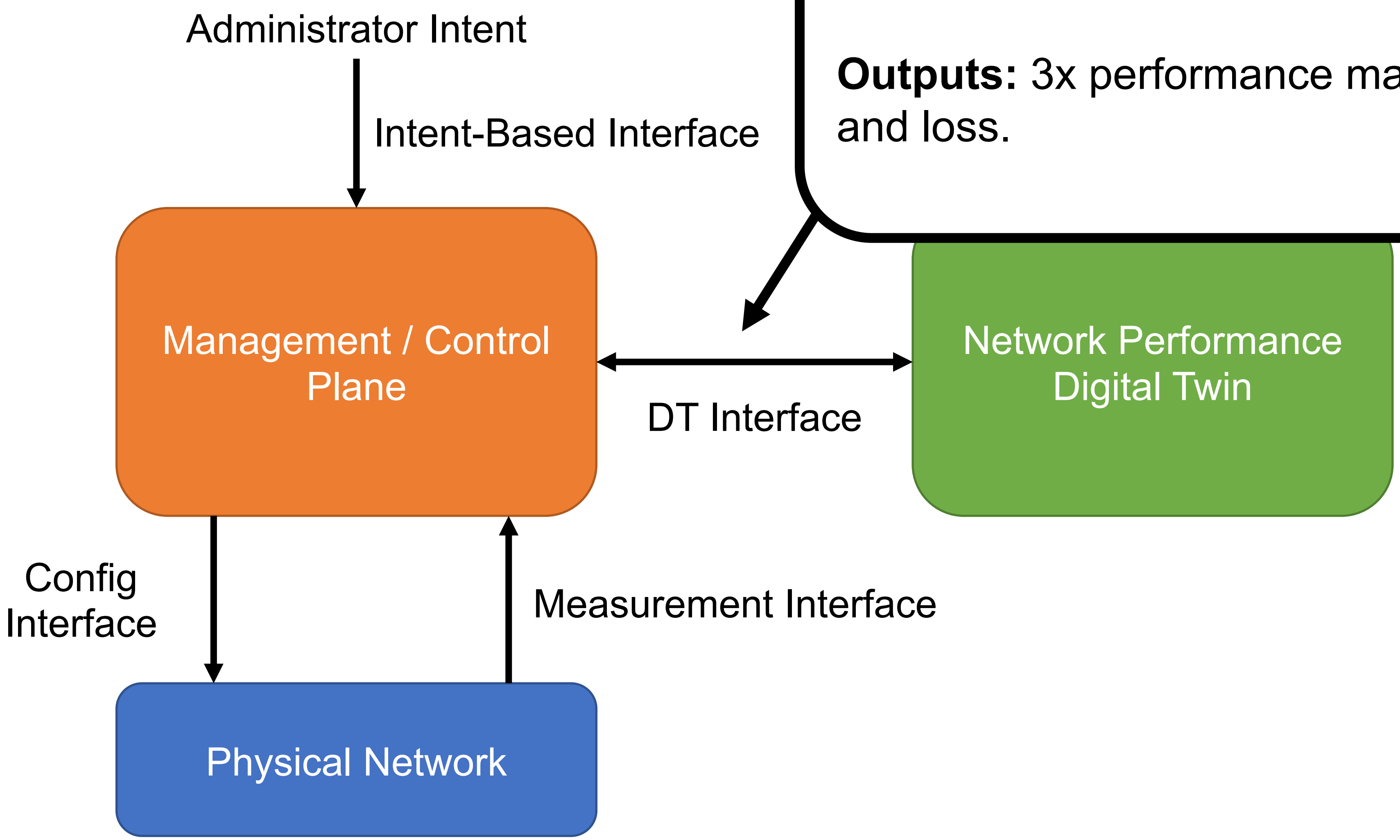
Architecture



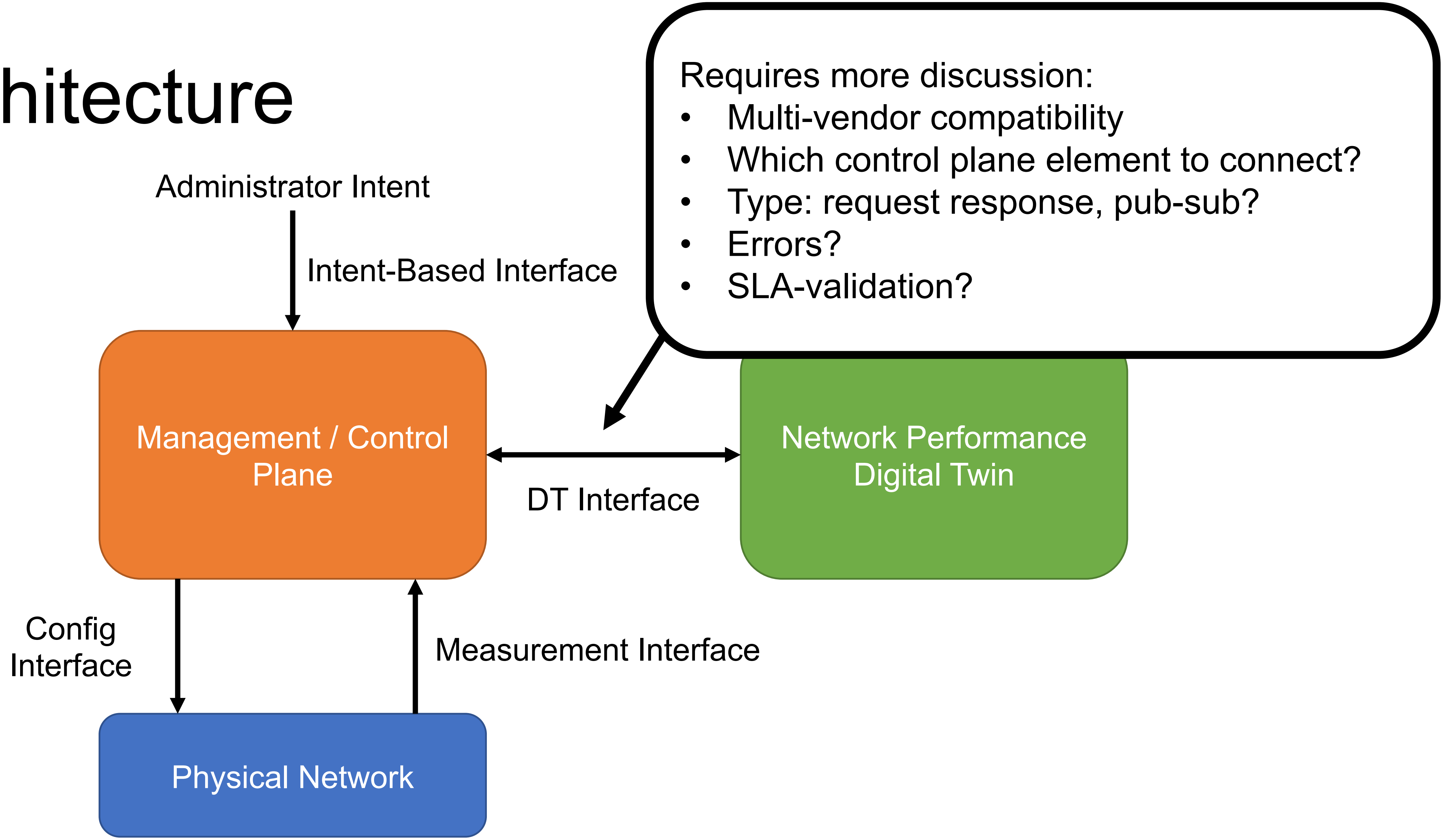
Architecture

CSV, JSON or other.
Inputs: topology, routing config, traffic demands, traffic mode, scheduling policies.

Outputs: 3x performance matrix: delay jitter and loss.



Architecture



Implementation

Implementation Options

Technology	Accuracy	Speed	Why?
Emulation	Poor	Slow	Emulation is useful to check for configuration errors or test the interaction between different protocols. **It is not accurate in performance estimation.**
Simulation	Good	Slow	Simulation time scales with the amount of packets, 1min of a 10Gbps link takes 11h to simulate. **It is too slow for performance estimation.**
Analytical Models (Queuing Theory)	Poor	Fast	Fast and accurate, **but does not work well under realistic traffic models (e.g., TCP)**
Neural Nets (MLP and Recurrent NN, see Backup slides)	Poor	Fast	Fast and accurate, **but it does not work in scenarios not seen in training (e.g, Link failure)**
Graph Neural Networks	Good	Fast	GNNs are tailored to learn network-structured data. **They offer oustanding accuracy in scenarios not seen in training.**

Machine Learning

- Continuously developing technology
- Complexity [1]
- Limitations to take into account:
  - Requires large amount of data
  - Cannot predict what is has not seen
- RouteNet-Erlang: NPDT prototype
  - Based on GNNs [2]
  - Open-Sourced [3]

[1] Suárez-Varela J, Almasan P, et al., Graph Neural Networks for Communication Networks: Context, Use Cases and Opportunities, 2021 Dec 29, arXiv preprint https://arxiv.org/abs/2112.14792
[2] M. Ferriol-Galmés, M, Rusek K, et al., "RouteNet-Erlang: A Graph Neural Network for Network Performance Evaluation," *IEEE INFOCOM 2022* - 2022, pp. 2018-2027, doi: 10.1109/INFOCOM48880.2022.9796944.
[3] https://github.com/BNN-UPC/RouteNet-Erlang

Backup Slides

Building a Network Digital Twin using: Neural Networks (MLP and RNN)

Building a Network Digital Twin using Neural Nets

Configuration

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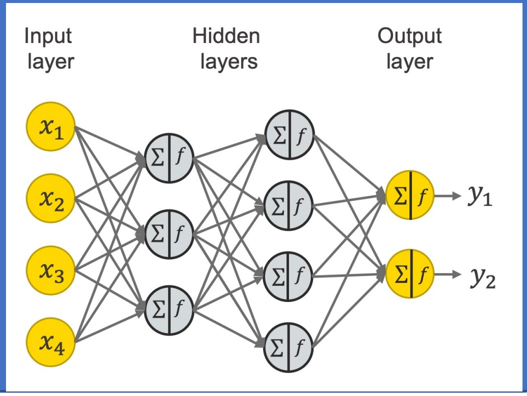
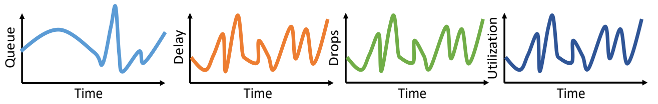
Performance Network Digital Twin



Network Digital Twin is built using a neural network

Per-flow Performance Metrics



Queue Utilization | Delay and Jitter | Losses | Link Utilization

Building a Network Digital Twin using Neural Nets

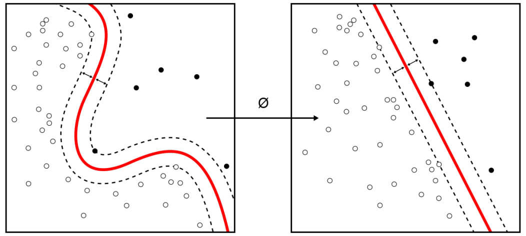
- Both RNN and MLP are fast (milliseconds)
- They scale –roughly- constantly (O(1)) with all network parameters
- They offer poor accuracy when operating in configurations (routing, link failures) not seen in training

	Accuracy Error (MAPE) when estimating the delay. Percentage error of the real vs. predicted value	
	MLP (Fully-connected)	Recurrent NN
Same routing as in training	12.3%	10.0%
Different routing as in training	1150%	30.5%
Link Failure	125%	63.8%

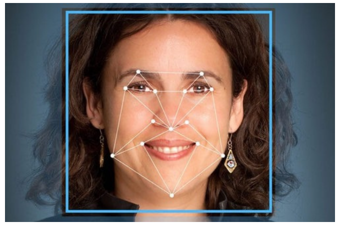
It is impractical to build a Network Digital Twin using MLPs and RNNs **because they do not support different network topologies, routing or link-failures**

Overview of the most common NN architectures

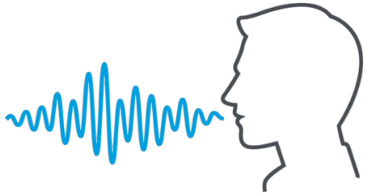
Type of NN	Information Structure
Fully Connected NN (e.g., MLP)	Arbitrary
Convolutional NN	Spatial
Recurrent NN	Sequential
Graph NN	Relational



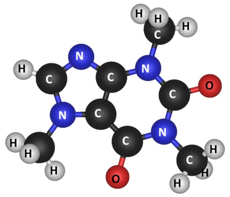
Classification, Unsupervised Learning



Images and video



Text and voice



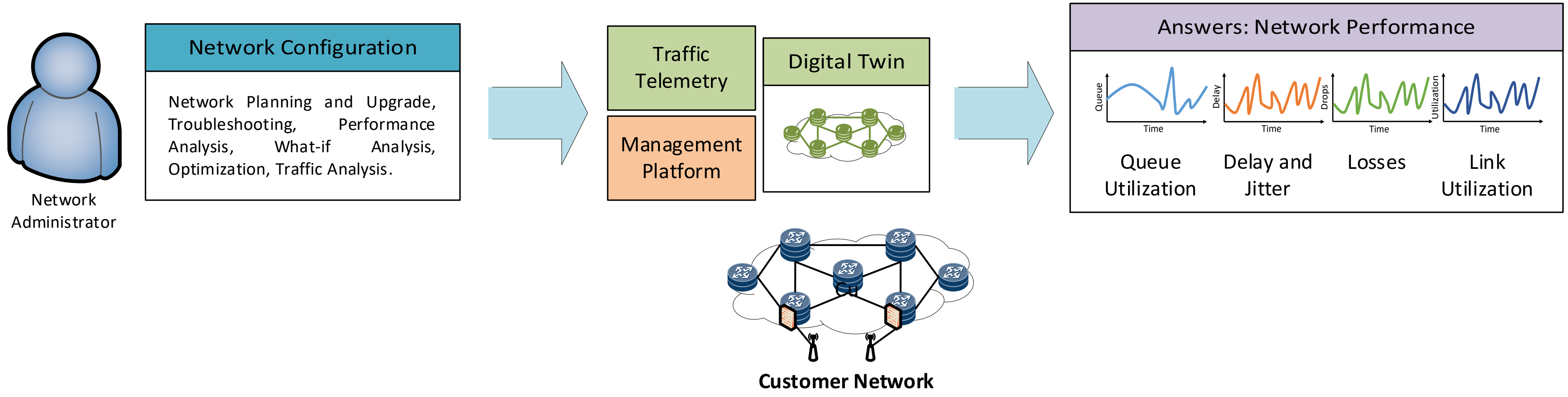
Graphs (molecules, maps, networks)

Overview of the most common NN architectures

Type of NN	Information Structure		Use
Fully Connected NN (e.g., MLP)	Arbitrary		Classification, Unsupervised Learning
Con			
Recurrent NN	Sequential		Text and voice
Graph NN	Relational		Graphs (molecules, maps, networks)

RNNs, MLPs and CNNs are unable to understand information structured as a network

Use-Cases of Performance Network Digital Twin



- Network planning
  - What is the optimal network equipment upgrade to support this new set of users?
- Troubleshooting
  - Why VoD packet losses was high yesterday?