Challenges & Key Solutions for Autonomous IP Network

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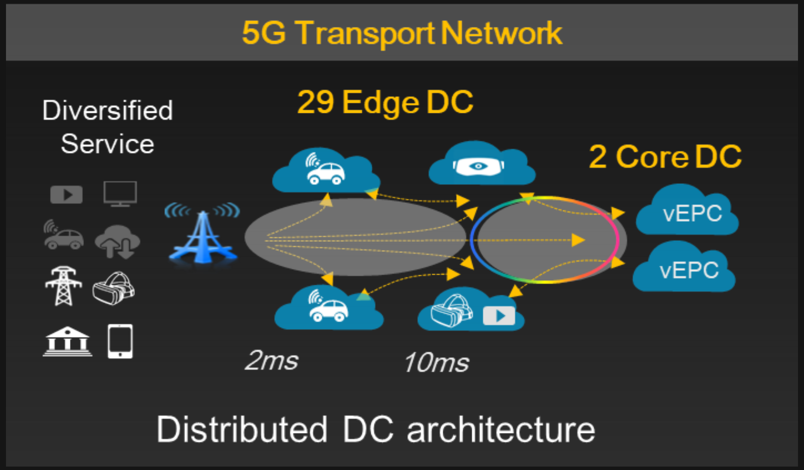
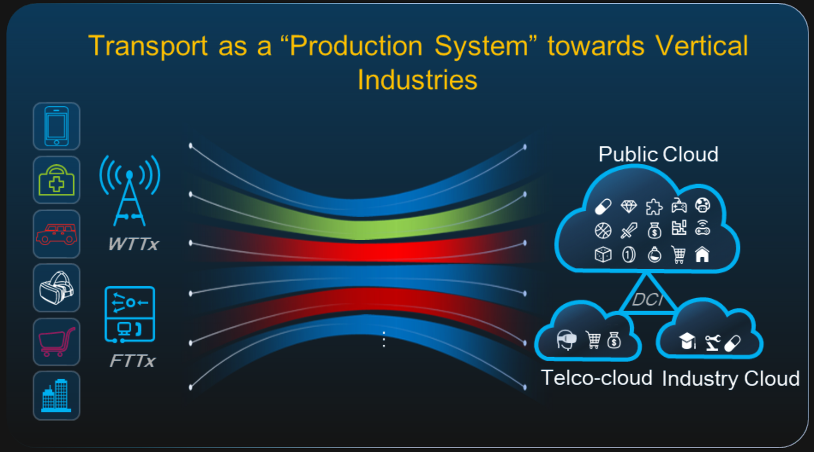
Content

- Towards Autonomous Networks
- Intent-Driven Networking
- Proactive Traffic Optimization Use Case
- Optimization Challenges for Network Automation

Challenges in the 5G & Cloud Era

- High complexity Introduced by 5G & Cloud architectures
  - South-North traffic → Full-direction traffic
  - Static connectivity → Dynamic connectivity
  - Manual configuration → Automatic provisioning
- Need to manage a lot of SLAs
  - Limited tenant types → All vertical industries
  - A connectivity service → Diversified SLAs
- Need to move from reactive O&M to proactive O&M
  - OPEX = 3X CAPEX, and 70% Major Issues due to Manual Mistakes
  - Low Network Utilization but Congestion always occurs





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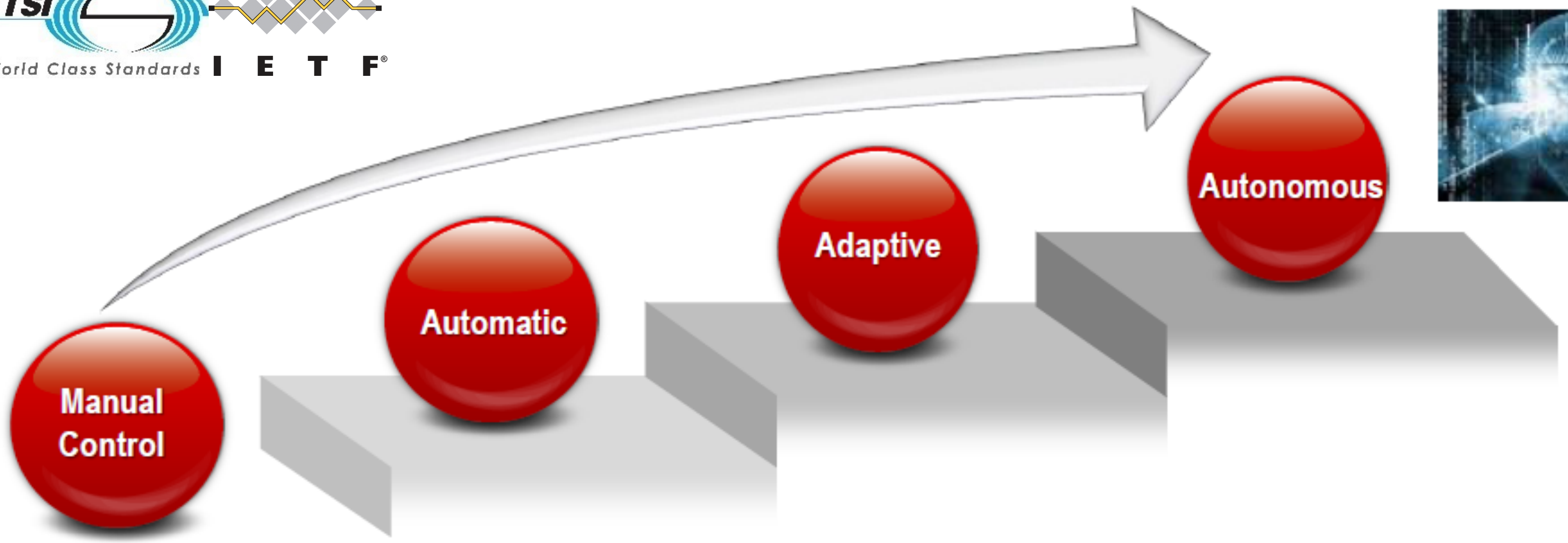
Evolution Towards Full Autonomic Networks



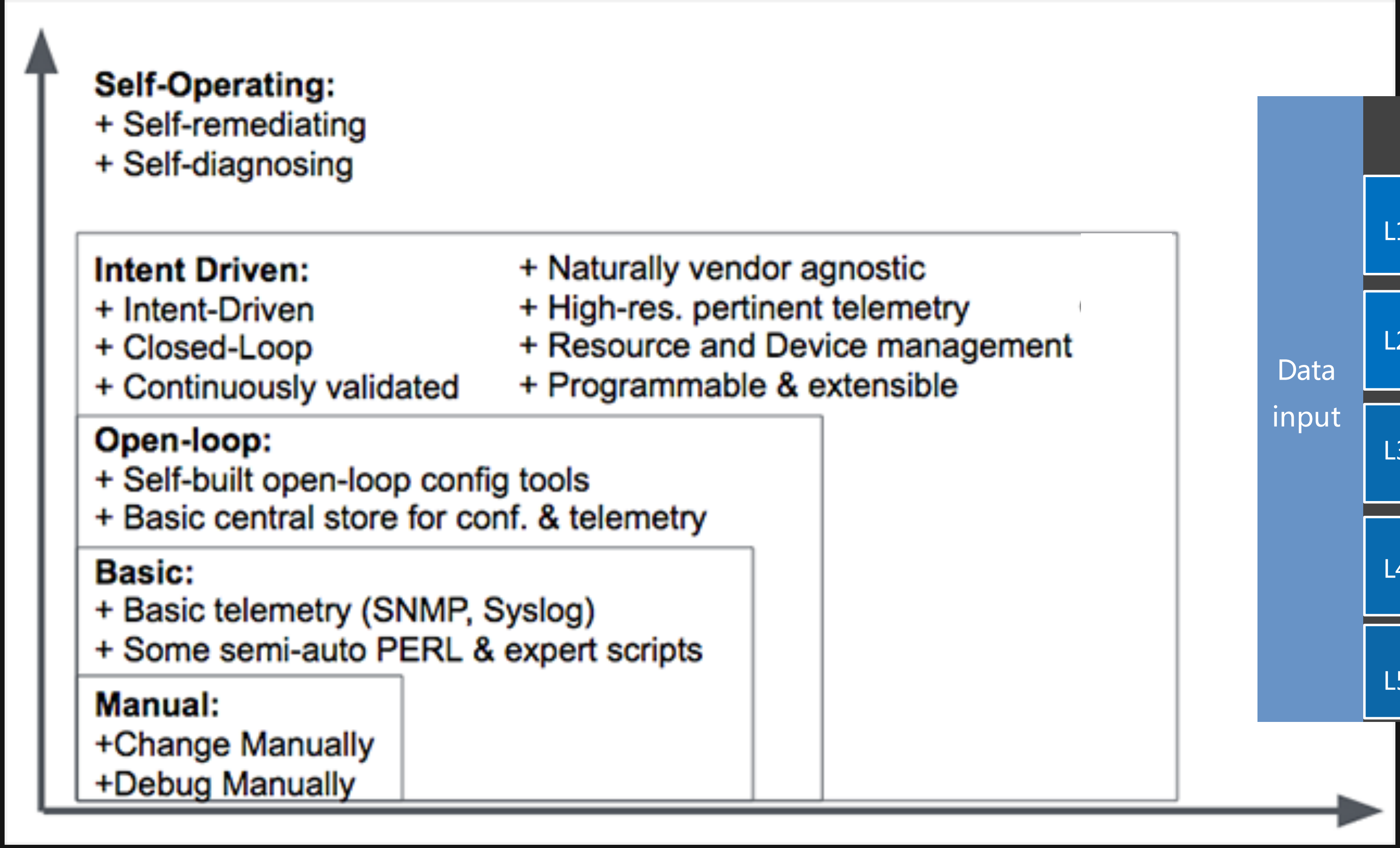
Data ➡ Information ➡ Knowledge ➡ Wisdom

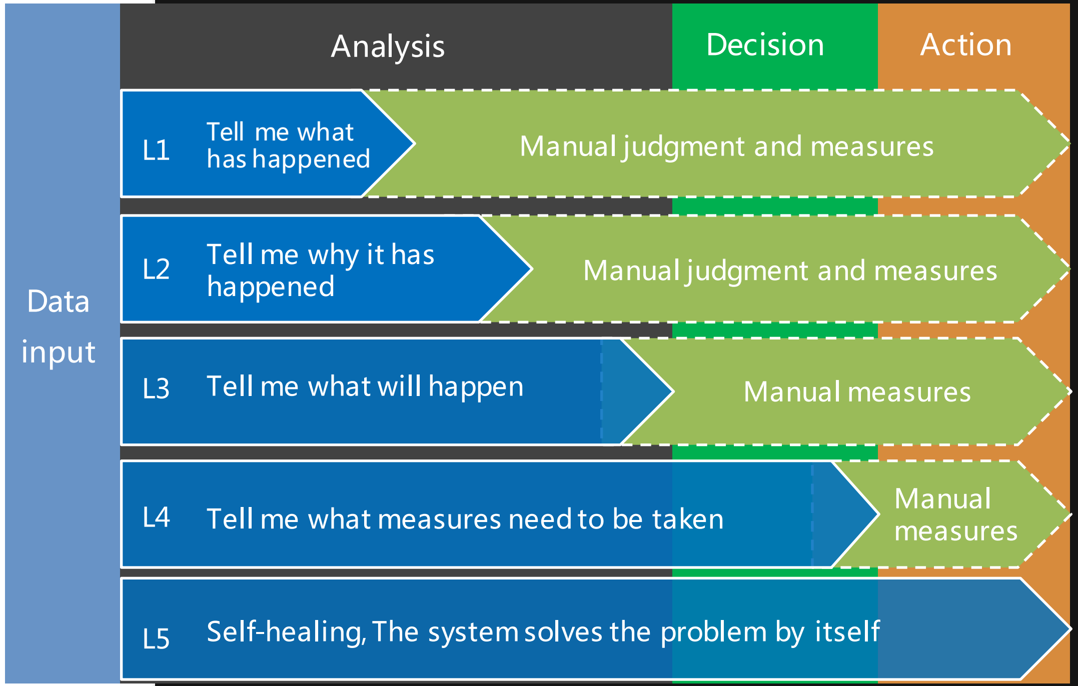
Automatic: automation of service distribution, network deployment and maintenance, through the integration of network management and control. Human controlled.

Adaptive: intelligent analysis, real-time acquisition of network data, perception of network status, generate optimization strategies to enable closed-loop operation.

Autonomous: Introduction of artificial intelligence to realize self-* features, based on a robust knowledge representation. Includes context-aware situation awareness as part of a comprehensive cognition framework, and uses policy-based management to enable adaptive and extensible service offerings that respond to changing business goals, user needs, and environmental constraints.

Evolution Towards Full Autonomic Networks





5 stages towards autonomy

Similar to the automotive industry, the evolution towards a self-operating network will happen in phases, through a process of continuous improvement.

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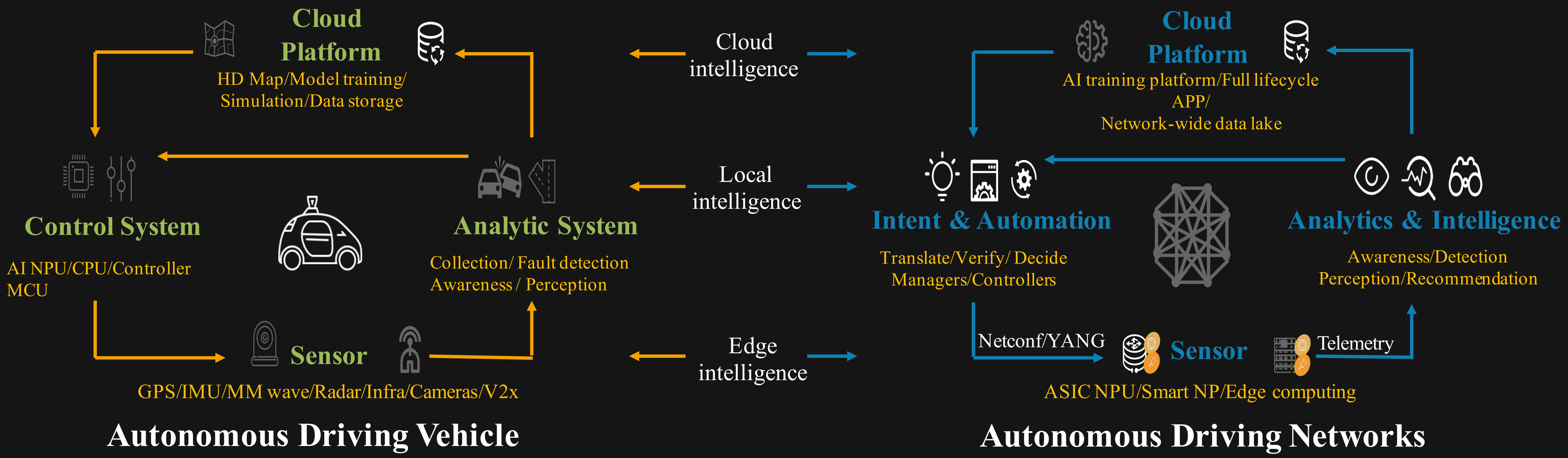
Autonomous Driving Networks

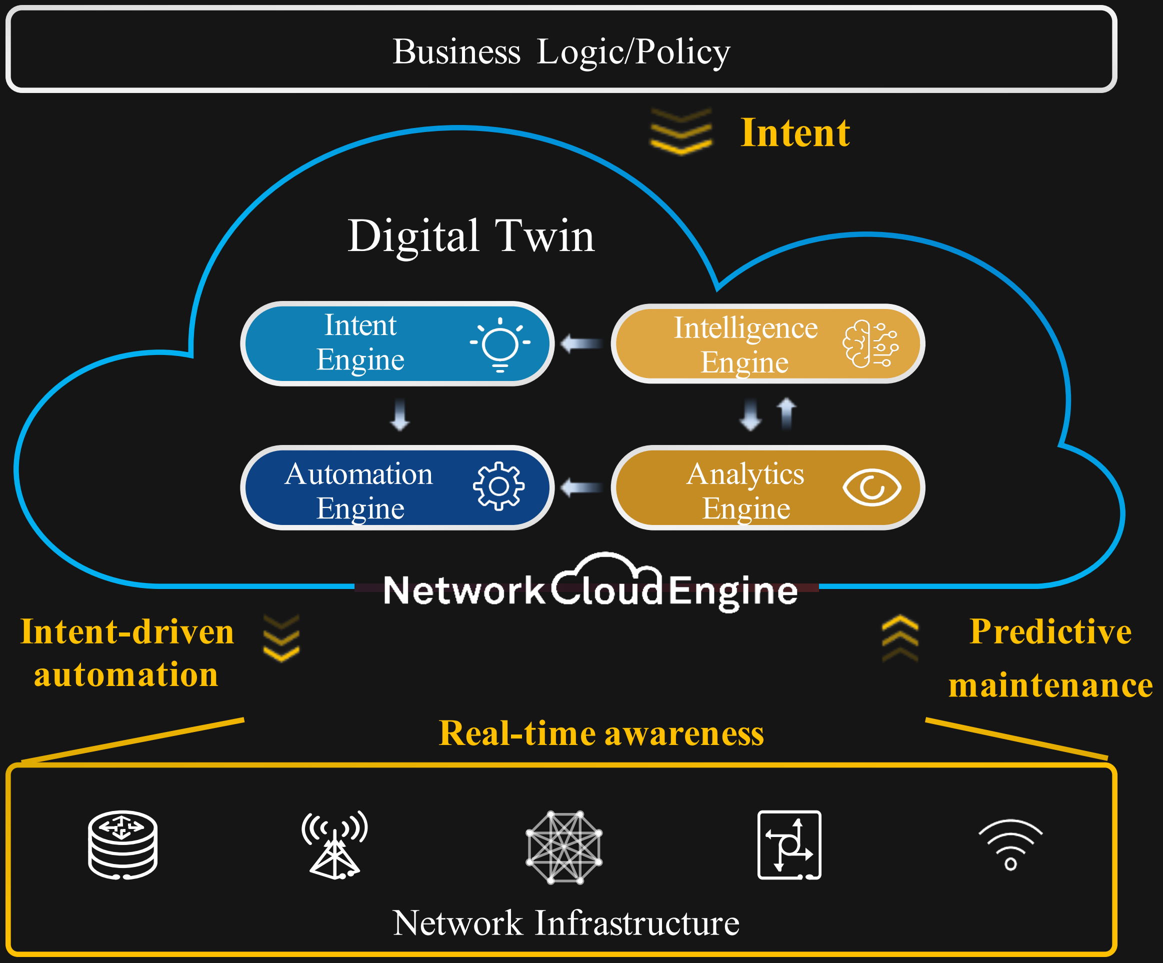


IDN: Intent-Driven Networks

IDN
Intent-Driven Network

Traditional O&M

- **Network-centric**
- **Fragmented**
- **Reactive**
- **Skill-dependent**



New O&M

- **User-centric**
- **Closed-loop**
- **Predictive**
- **AI/Automation**

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A use case: Proactive Traffic Optimization

As Is

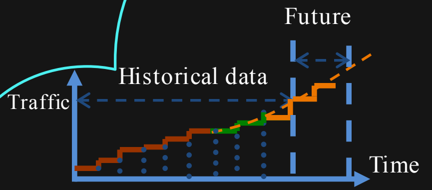
Local congestion coexists with whole network low utilization

Low BW Utilization	30% On Average
Packet Loss Frequently	Burst ↓ Congestion
Manual Optimization	Days-level, Error Prone

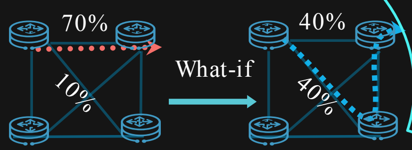
To Be

AI-based Optimization & Steer Traffic by SR

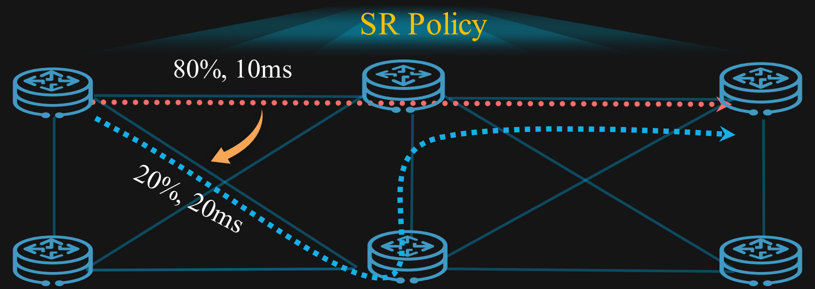
NetworkCloudEngine



1 Traffic Prediction based-on big-data



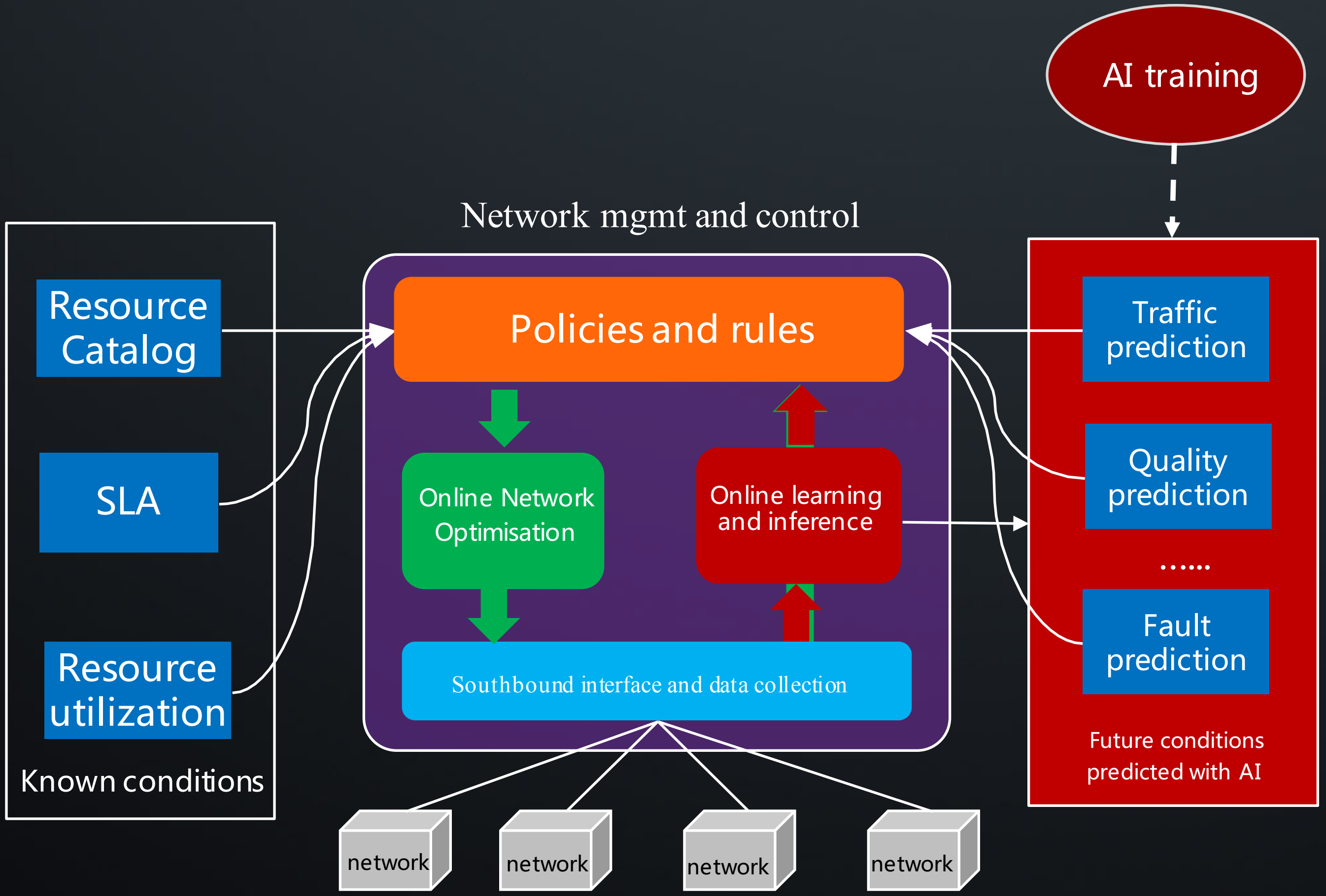
2 Anticipation models to avoid mistakes



3 Automatic Traffic Adjustment in real time

80%	BW Utilization
0	Packet Loss
Minutes Level	Automation

AI and Optimization under the hood…



- AI to predict future conditions and missing information (e.g. quality, traffic, and faults)
- Online optimization of the network based on future / estimated conditions.
- Goals:

  "Prevent a fault before it happens"

  "Improve quality before it deteriorates"

  "Steer traffic before congestion occurs"

6 Optimization Challenges for Network Automation

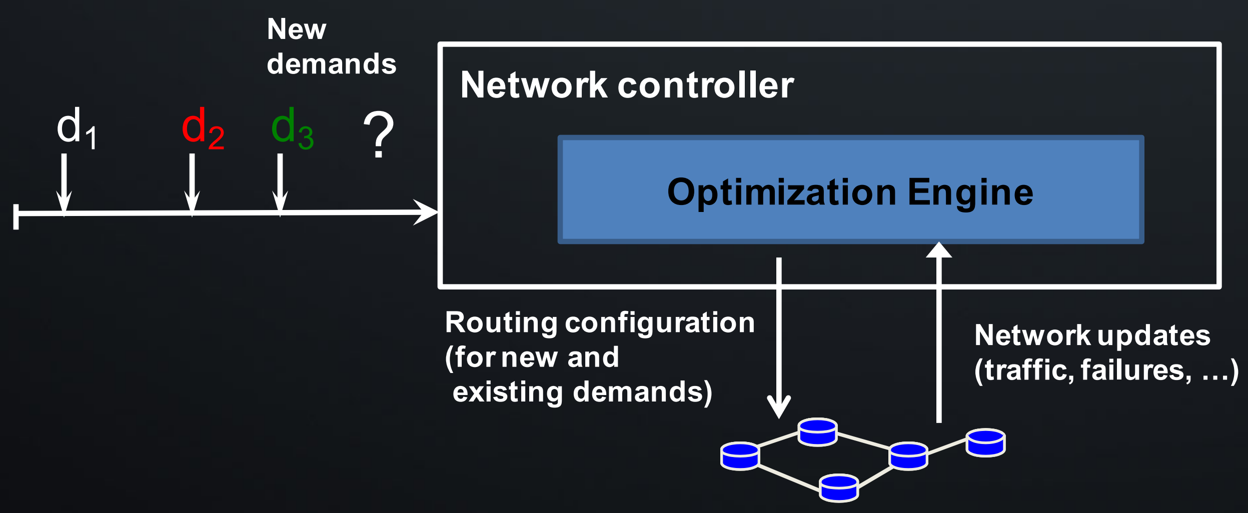
1. Solve evolving instances of optimization problems
2. Take non-myopic decisions to stabilize the system
3. Consider uncertainty as a problem input
4. Learn from past decisions to update optimization policies
5. Re-use domain expertise from model-based algorithms
6. Operate at large-scale by distributing the intelligence

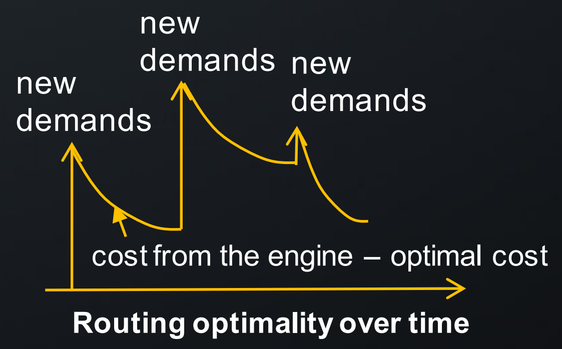
1. Solve evolving instances of optimization problems

- Sequential discovery of problem inputs as user requests arrive and depart, congestions and failures happen
- Limited time to solve the problem ➔ possibly not enough time to converge to the optimal point.

Should I accept and how ?

Is there a better configuration ?





Should I reconfigure?
How should I move to the new target configuration?

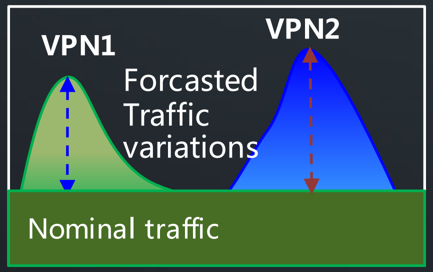
Need for fast convergence & iterative algorithms

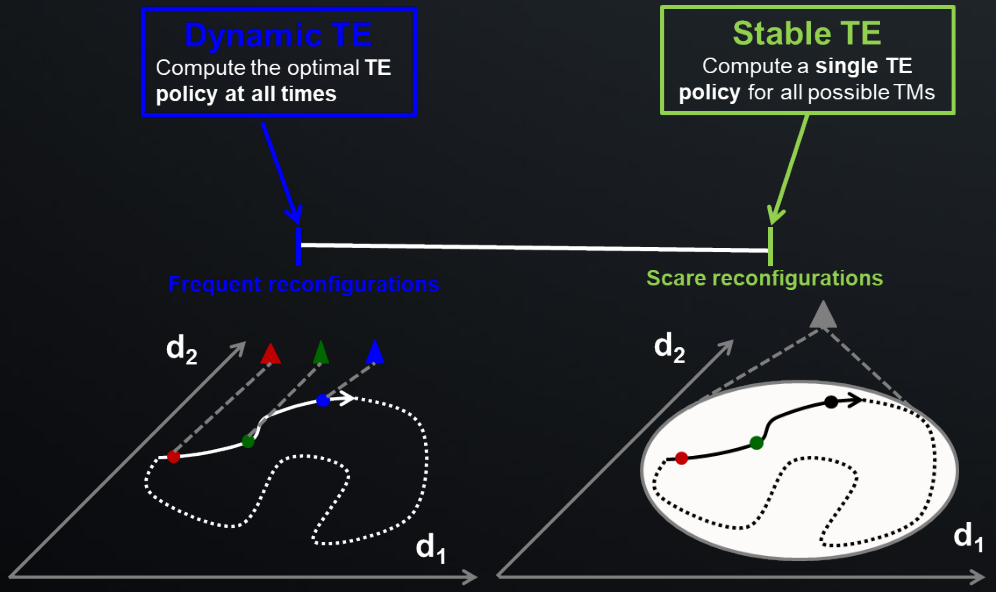
2. Take non-myopic decisions to stabilize the system

TE Optimization
based on

Traffic profiles

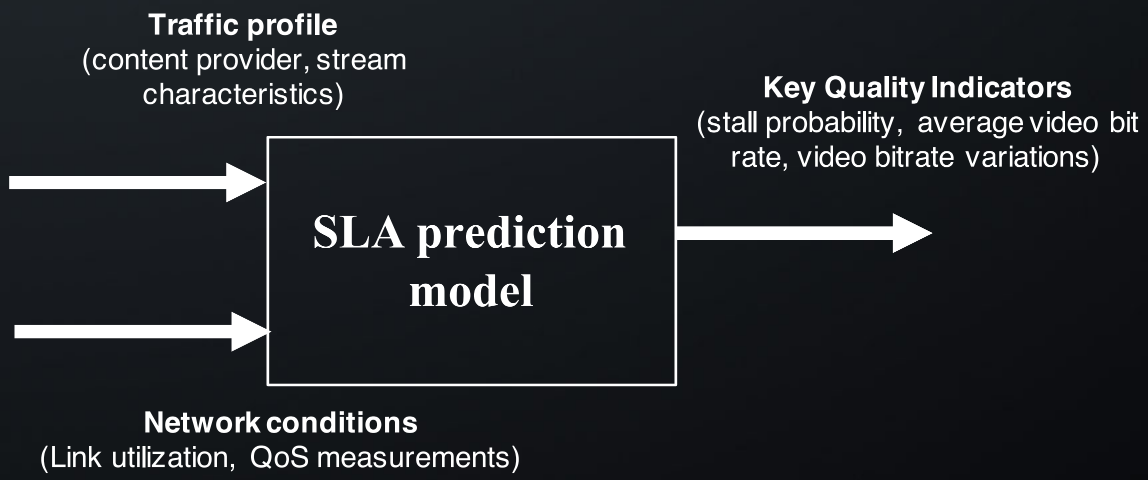
- Use traffic forecasts and traffic profiles to anticipate traffic variations





Performance models

- Anticipate delay and packet loss variations
- And Key Quality Indicators such as Quality of Experience (QoE)

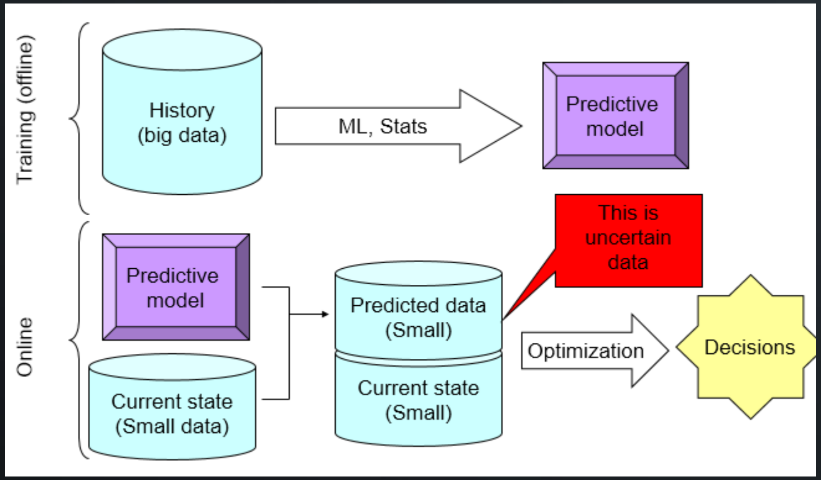


Need to find the right trade-off between stability and performance

3. Consider uncertainty as a problem input

Sources of uncertainty

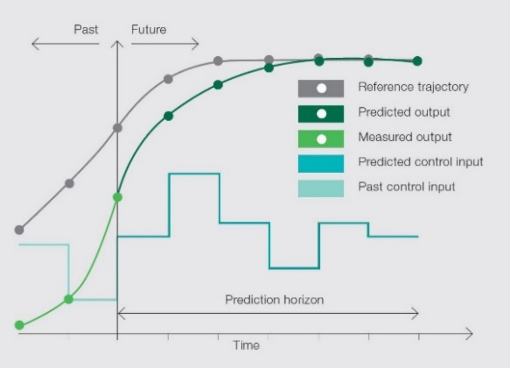
- Predictions errors



- But also failures, traffic anomalies…

2) ONLINE DECISION MAKING

- Step-by-step optimization with imperfect predictions (robust model predictive control)



Optimization & Control Methods

1) OPTIMIZE UNDER UNCERTAINTY

- Robust optimization (model uncertainty with min / max intervals)
- Stochastic optimization (model uncertainty with scenarios)

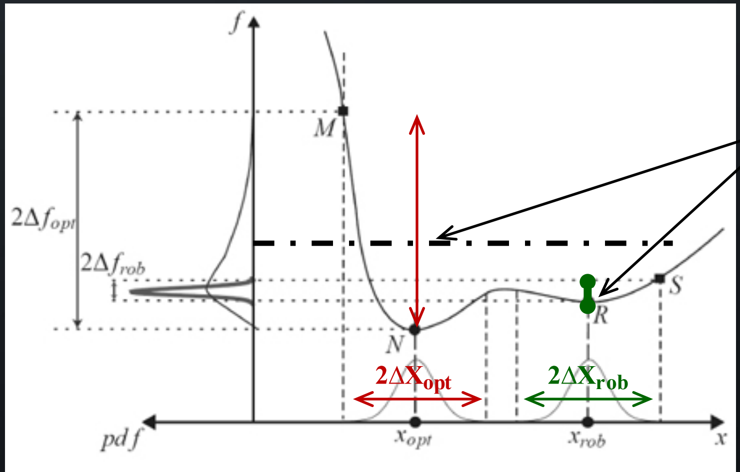


Figure 1 – A robust solution *vs.* an optimal solution.

- **N → deterministic minimum**
- **R → robust minimum**

Same interval for decision variables (Δx)
Different variation of objective function (2Δf)

Search for feasible configurations
- with the lowest variation
- with the variation bounded in an area
- …

Need to properly deal with uncertainty to avoid optimizing over the worst case

4. Learn from past decisions to update optimization policies

Closing the loop…

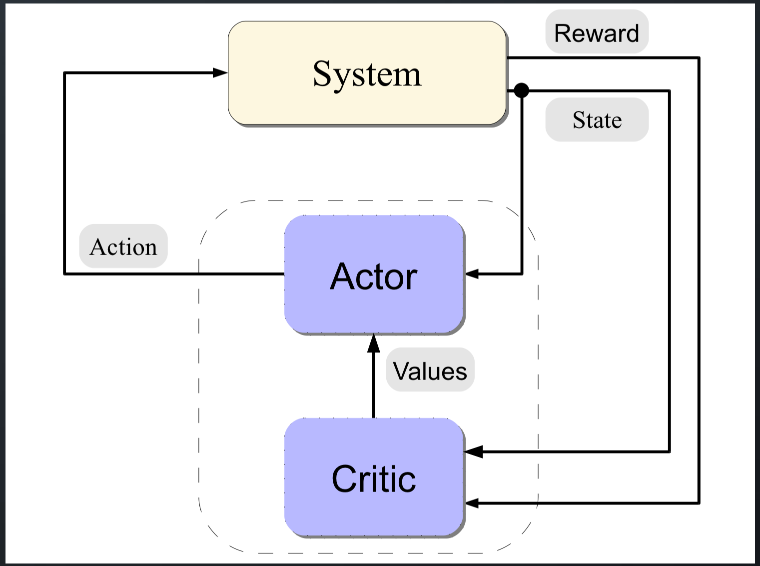
- Measurements on the goodness of past policies can help converging to the optimal policy

(Deep) Reinforcement Learning

- Proven performance in many application domains
- Suffers from instabilities if not well tuned (exploitation vs exploration trade-off)
- Needs a large number of iterations to converge (state explosion…)

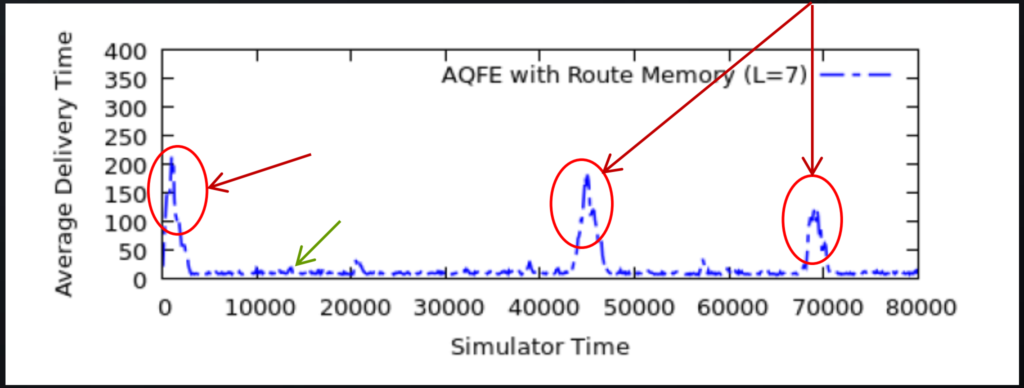
Good use case for the Digital Twin

Combine with other optimization tools



Reinforcement Learning (Actor-critic model)

Spikes in flow delivery time during stable routing conditions



Load balancing with Q-learning

Close the loop but master instabilities and convergence

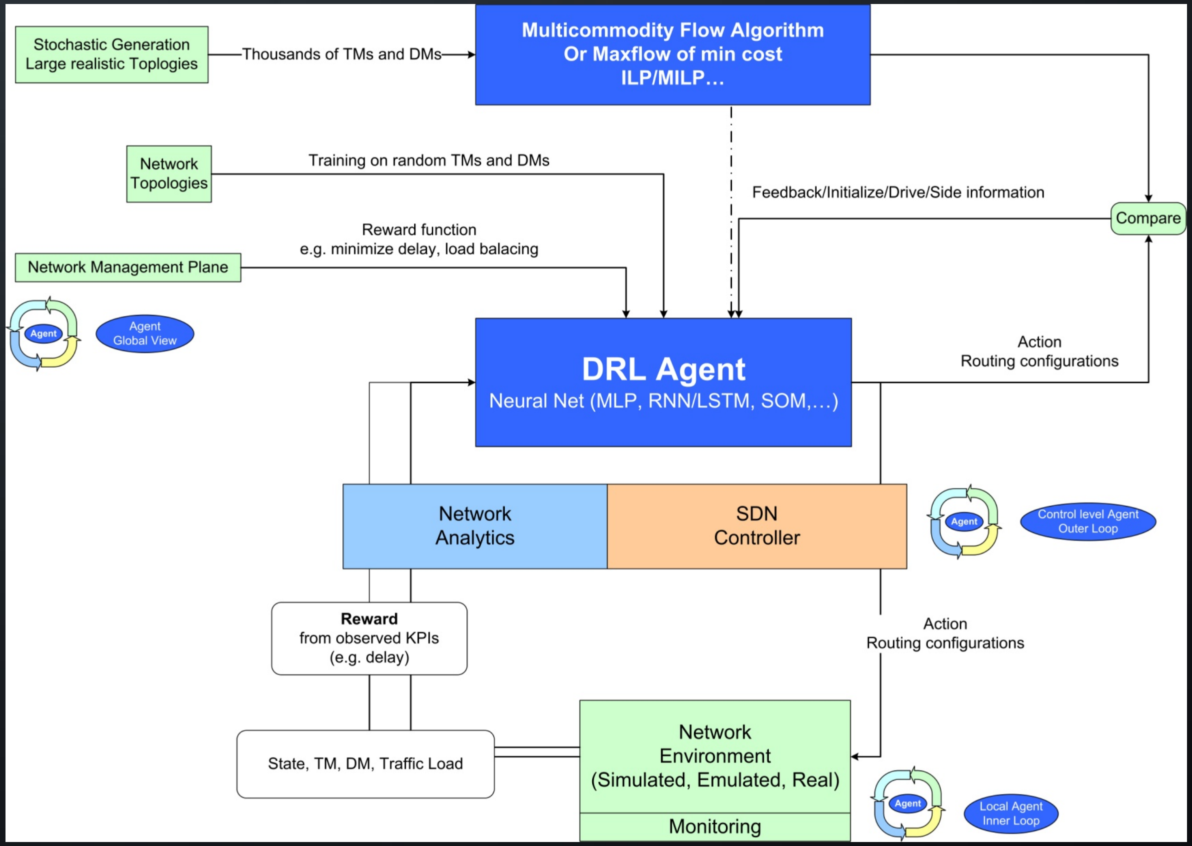
5. Re-use domain expertise from model-based algorithms

Self-adaptive and intelligent routing using distributed agents

- Smarter than IGP
- More scalable than SDN

Need to go beyond legacy but a non need to start from scratch

- PCE / SDN optimization algorithms can be used
  - In control policies
  - To exhaustively explore system states in a simulator (Digital Twin)
- SDN controllers can work in background
  - As a Critic to provide feedback
  - To organize communications between agents to speedup convergence



PCE legacy algorithms can help Deep Reinforcement Learning

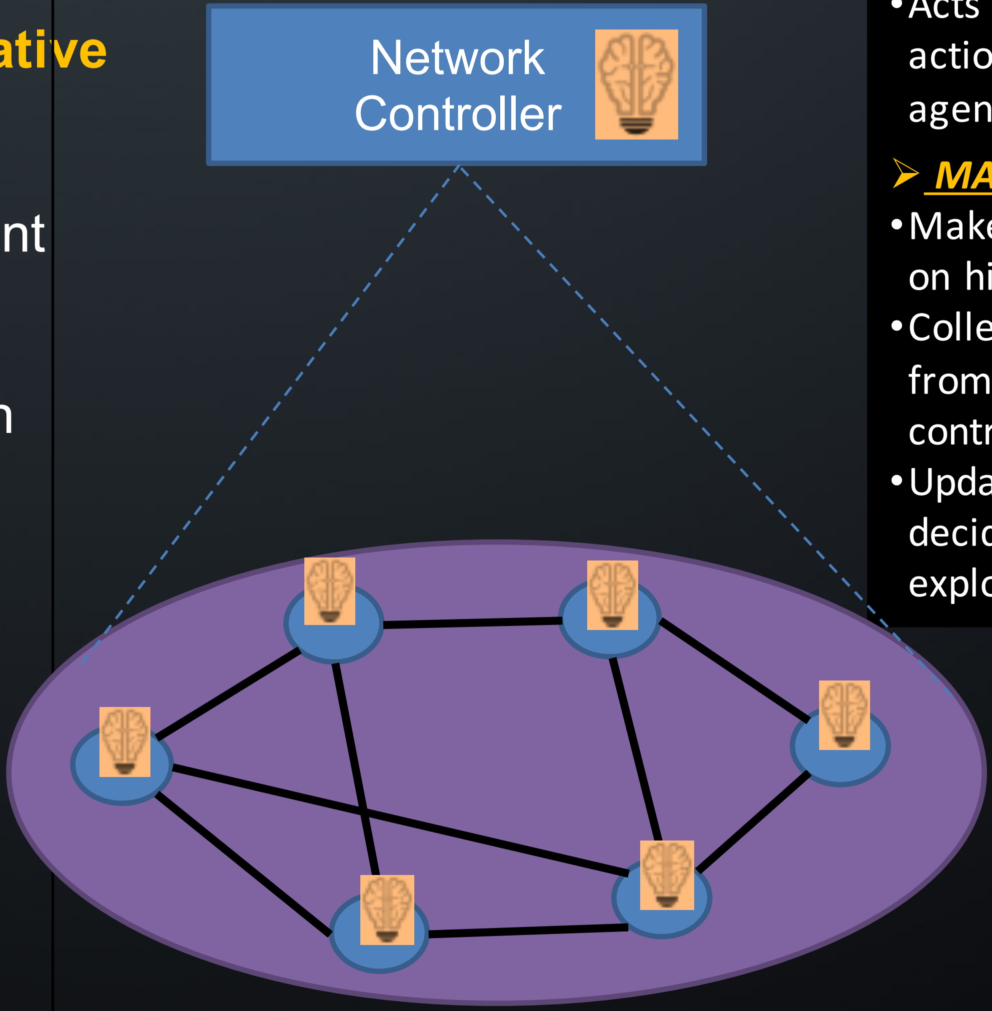
PCE algorithms can boost the convergence of online learning algorithms

6. Operate at large-scale by distributing the intelligence

Multi-Agent Systems (MAS) for Collaborative and Distributed Learning

- Composed of multiple interacting intelligent agents.
- Solve problems that are too difficult for an individual agent or a monolithic system

Successful Application Domains
Robotic, traffic control, sensor networks, industrial automation, etc.



Semi-distributed multi-agent architecture

➢ **Controller / Twin**
- Acts as critic for collective action with distributed agents to ensure stability

➢ ***MAS-enabled switches:***
- Make a local decision based on his current policy
- Collect feedback locally, from neighbors or from the controller
- Update their policy and decide about exploration-exploitation

Distribute the intelligence to scale but control convergence

Thank you

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