HUAWEI | IRELAND RESEARCH CENTER, SNI Lab

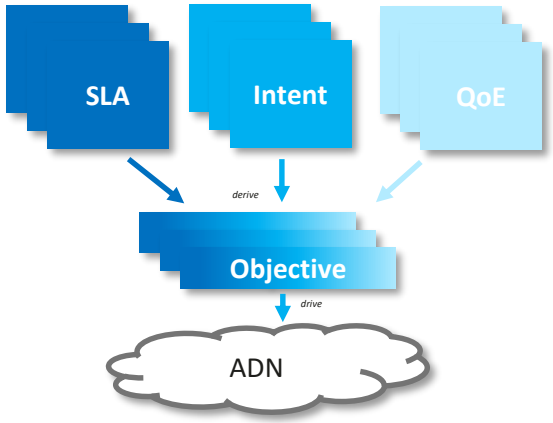
ADN Autonomous Assurance

Research Directions and Key Technologies

Aleksandar Milenovic, IRC SNI Lab

Terminology

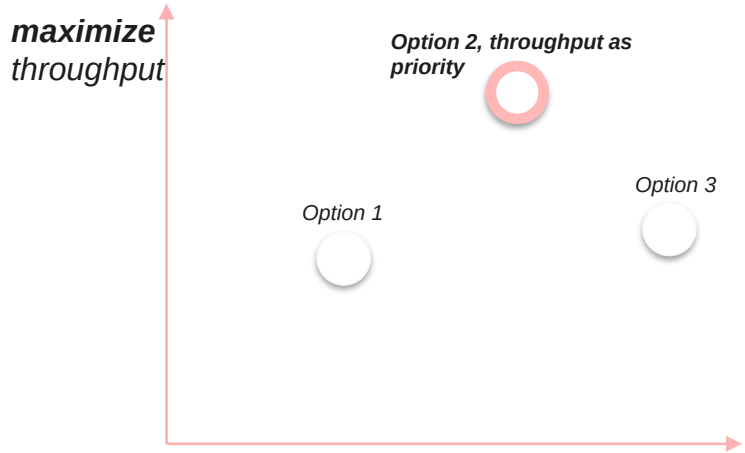
Objectives

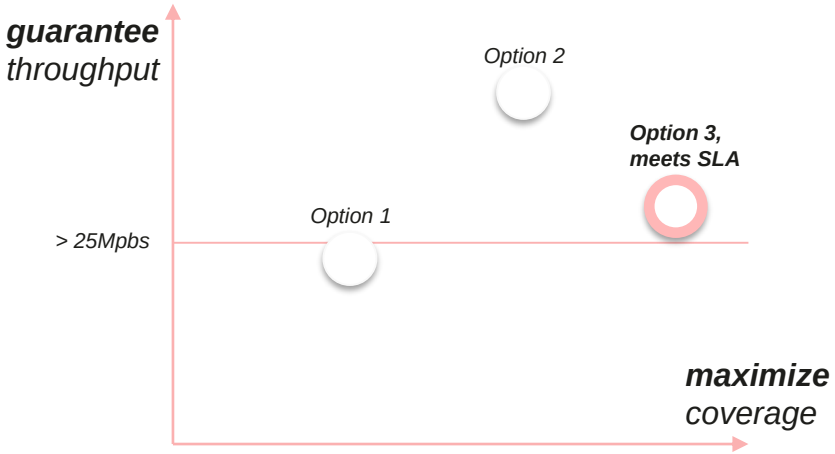


guarantee *accessibility > 99.999%*
keep *coverage > 90%*
minimize *power consumption*
maximize *throughput*

KPI

Multi-objective decision making





上下文包括 时间、属性（如站型、链路类型）、环境（话务模型）、地理位置、角色、状态（小区退服）等。

上下文信息的变更会影响决策。

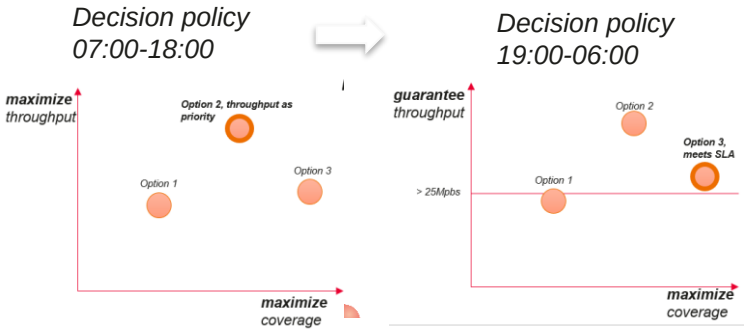
Context

Any information that characterizes the situation of the Network
(based on Schilit 1994 definition)

Examples:

Time	Busy hour, time of the day, …
Profile	Cell type, Link type, …
Environment	User behaviours, service demands, …
Location	South Dublin, …
Role	NOC Operator, LTE Network Planning, …
State & status	Cell Outage fault, Path protection enabled, …
…	…

3LConOnt: a three-level ontology for context modelling in context-aware computing, Oscar Cabrera, Xavier Franch, Jordi Marco, 2017



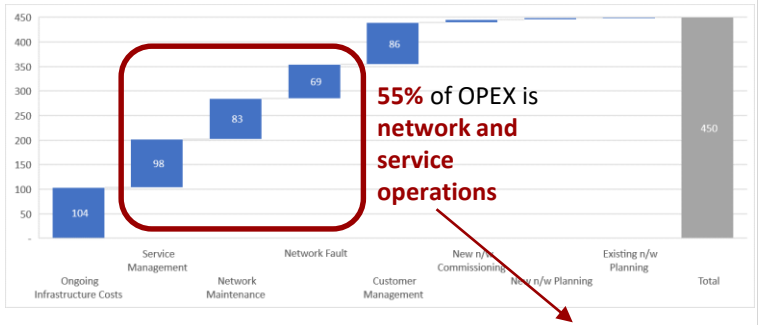
Context change can influence decision making

ADN L4/L5 Business Drivers: Complexity and Mission Critical Applications

Telco Network is costly to operate

Source: Ireland Research Center, SPO Lab

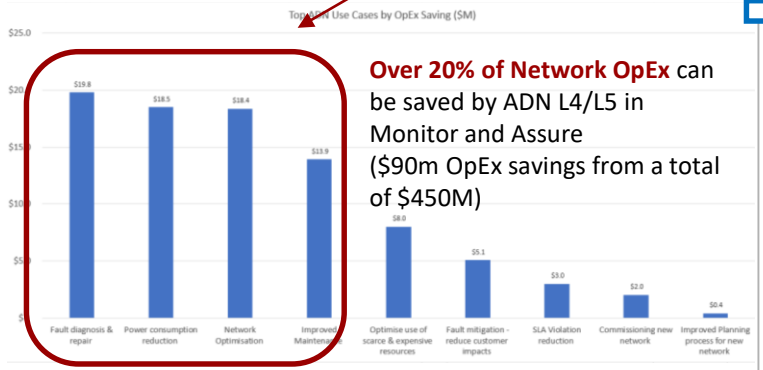
EU mid size operator with 10M subscribers with $450M OPEX



55% of OPEX is **network and service operations**

Figure 2: The enterprise service lifecycle

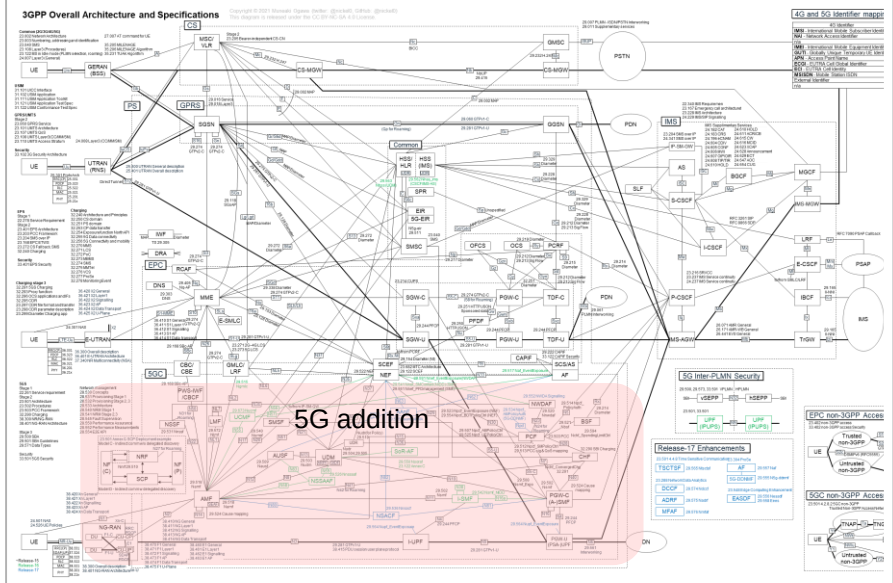
Most frequent activity



Over 20% of Network OpEx can be saved by ADN L4/L5 in Monitor and Assure ($90m OpEx savings from a total of $450M)

Telco Network complexity increases

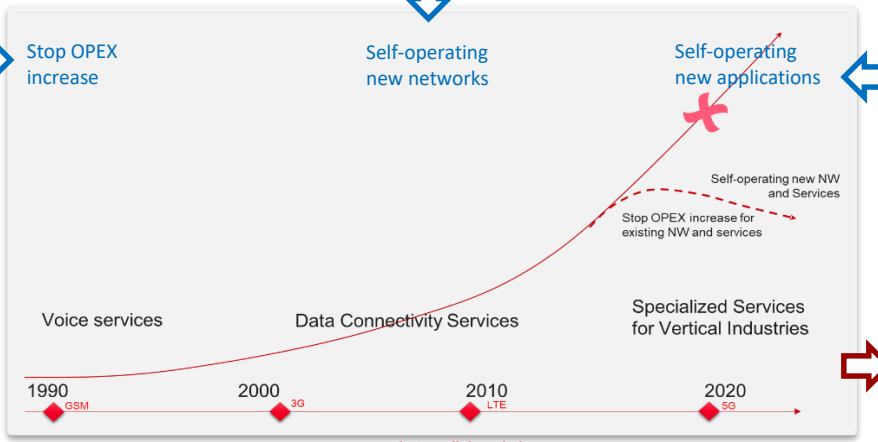
Source: 3GPP Overall Architecture and Specifications including 2G, 3G, 4G, and 5G Systems up to Release-17



Stop OPEX increase

Self-operating new networks

Self-operating new applications



Mission Critical Applications Assurance

Sources: ITU Network 2030 Blueprint, 6G 5GPPP Vision whitepaper

New use cases, from 'Vertical' industries

5G eHealth, AR/VR for urgent diagnostics

NW 2030 Use Cases

Figure 1:Pervasic Holographic Media

Mission critical applications require **guaranteed assurance** on network characteristics:

- increased **bandwidth**,
- low **latency**,
- full **security**,
- guaranteed **reliability**

Impossible for human operator to react quickly **in assuring**

Operate in **changing conditions**, on **shared resources**

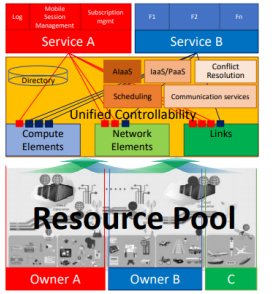


Figure 5.1: 6G as a smart service execution platform.

Many mission critical applications and their **objectives**, on potentially same shared network resources, might result in **conflicts**.

Changing conditions

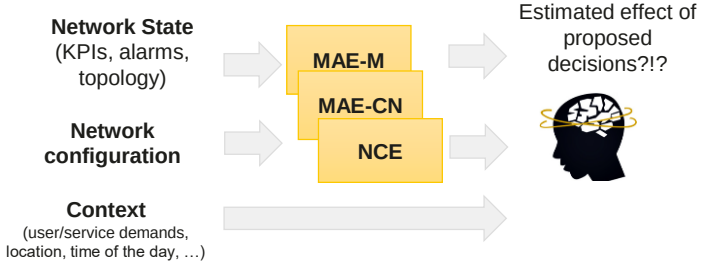
- User demand drifts
- Service demand drifts
- Radio conditions
- Unplanned outages
- New service/application introduction
- …

Vision: **ADN Autonomous assurance L4/L5**

- **Self-healing**
- **Self-optimization**
- **Changing network conditions** with **unpredictable** or even **unknown scenarios**.

ADN L4/L5 Autonomous Assurance: New Capabilities

AS IS: Humans Analyse and Decide



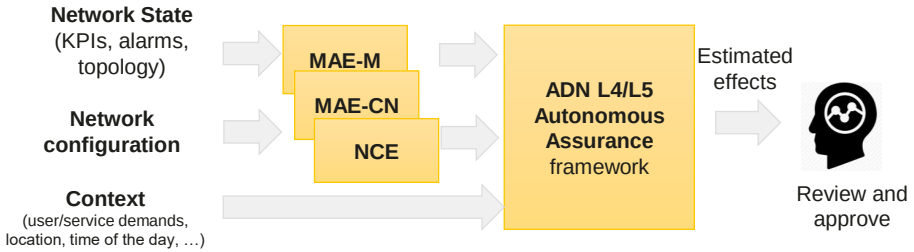
专家评估

Table 7. Levels of Autonomous Networks

Autonomous Levels	L0: Manual Operation & Maintenance	L1: Assisted Operation & Maintenance	L2: Partial Autonomous Networks	L3: Conditional Autonomous Networks	L4: High Autonomous Networks	L5: Full Autonomous Networks
Execution	P	P/S	S	S	S	S
Awareness	P	P/S	P/S	S	S	S
Analysis	P	P	P/S	P/S	S	S
Decision	P	P	P	P/S	S	S
Intent/ Experience	P	P	P	P	P/S	S
Applicability	N/A	Select scenarios				All scenarios

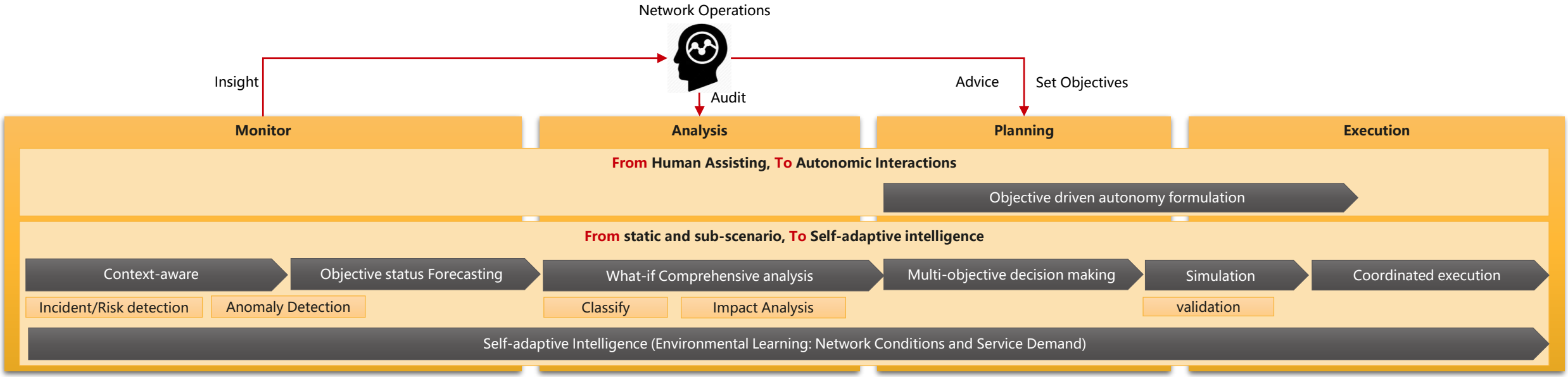
P People (manual) S System (autonomous)

TO BE: System Analyse, Decide and Explain



因果推理评估

Vision: ADN L4/L5 Framework for Autonomous Assurance



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Feedback from customers on ADN L4/L5 Autonomous Assurance new capabilities

vodafone

Valerio Ceci, Vodafone Global Automation Strategy Team

"Positive the presentation of all the relevant data while interacting with expert, this save lot of time in investigating the network before to make an informed decision."
希望呈现所有信息给专家

TIM

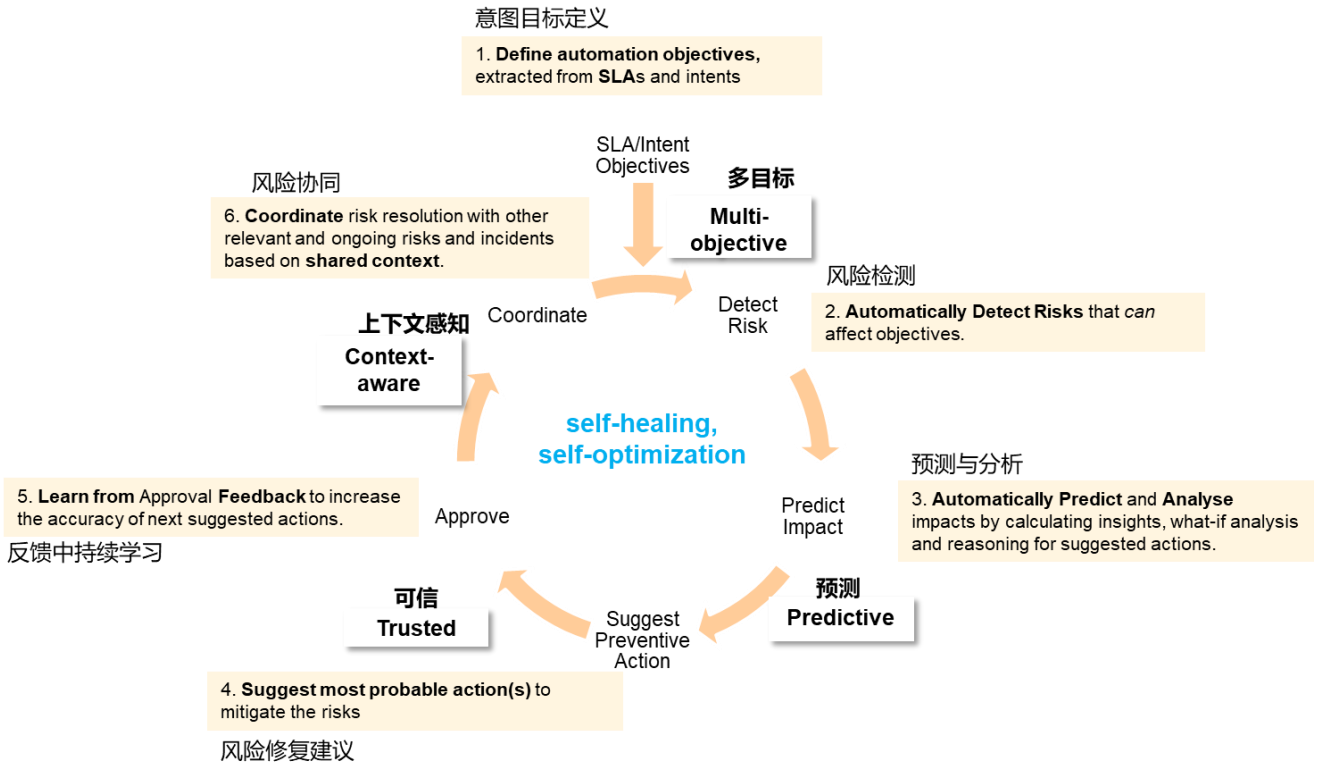
Massimo Bansi, Senior Standardization & Innovation Manager

"I think that if someone in the Operation is confident that this is what can be done, there **will be a race to acquire the solution**.
It's very elegant in its simplicity and effectiveness"
前端的简洁，后端的可信

BT

Dr. Azahar Machwe, OSS Automation at BT (AI)

"It sparked off a lot of thoughts… so all in all a successful conceptual demo!"
认可ADN的概念和Demo



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Agent trend approaching our Industry, **Automation → Autonomy**

Important for ADN L4/L5, brings autonomous decision making which we don't have in our products

Source: Zero-touch network and Service Management (ZSM); Closed-Loop Automation; Part 1: Enablers, ETSI GS ZSM 009-1 V1.1.1 (2021-06)

Standards

ETSI ZSM: Most complete thinking is in ETSI ZSM, over 3GPP and TMF 想法最完善

Closed-loops automation (CLA) is unit of autonomy and is divided in many cooperating management domains (MD)

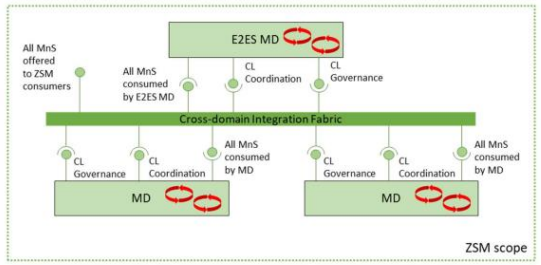


Figure 7.1-1: CL related management capabilities introduced in the present document

A convolution of the two classifications can be created resulting in Figure 8.2.2-1 and Figure 8.2.2-2.

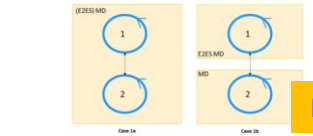


Figure 8.2.2-1: Hierarchical Closed Loops

Hierarchy: top CL governs child CL's properties in decision making

Multi-Agent System

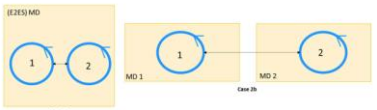
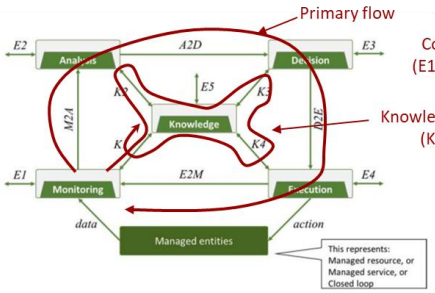


Figure 8.2.2-2: Peer Closed Loops

Peer CLs cooperate in joined decision making

Agent ↔ Flow



Control flow (E1, E2, E3, E4)

Knowledge-enablling flow (K1, K2, K3, K4)

Flows are automation parts, composing a Closed Loop

Closed-loop design (MAPE-K) Monitor→Analyse→Decide→Execute

Agent

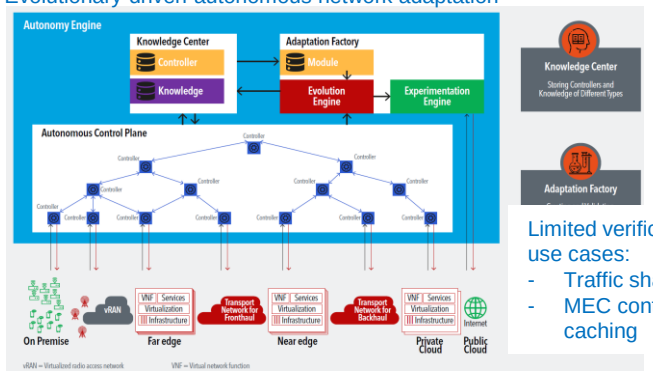
自治系统可以分解为分层的闭环流，闭环流构成Agent，闭环流的协同协作依赖多智能体系统。

Source: Towards A Truly Autonomous Network, P. Imai, P. Harvey, T. Amin, April 24, 2020

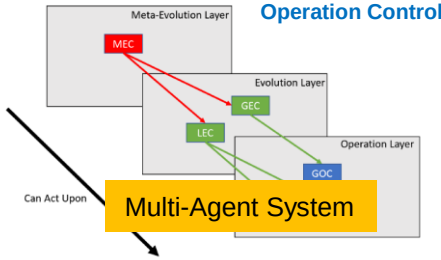
Operator

Rakuten: Most complete architecture for Autonomous Networks 架构最完善

Evolutionary-driven autonomous network adaptation



Limited verification on 2 use cases:
- Traffic shaping and
- MEC content caching



Multi-Agent System

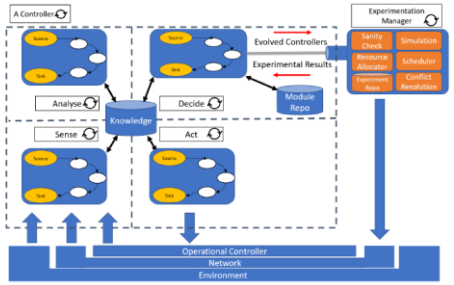
Operation Controller is a unit of autonomy

Agent

Controller types:
- Operation Controller (OC), controls Network elements or other Ocs
- Evolution Controller (EC), to evolve OCs
- Meta-Evolution Controller (MEC), to evolve ECs

All controllers are organized in the single graph **hierarchy**

Figure 6: Conceptual controller hierarchy as separate layers.



Controller design (SADA) Sense→Analyse→Decide→Act

Operation Controller **evolution**:
- OC can be improved using new SW modules.
- Experimentation Manager

Agent evolution

基于控制器的分层架构，上层控制器负责下层控制器的演进，控制器的概念等同于Agent。基于控制器的演进实现自适应。

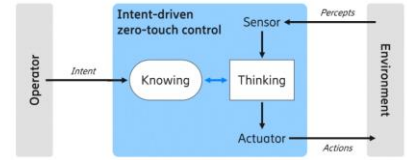
Sources:
Ericsson Cognitive networks – towards an end-to-end 6G architecture, Jan 12, 2022
Ericsson presentation to TMF, June 2022

Competitor

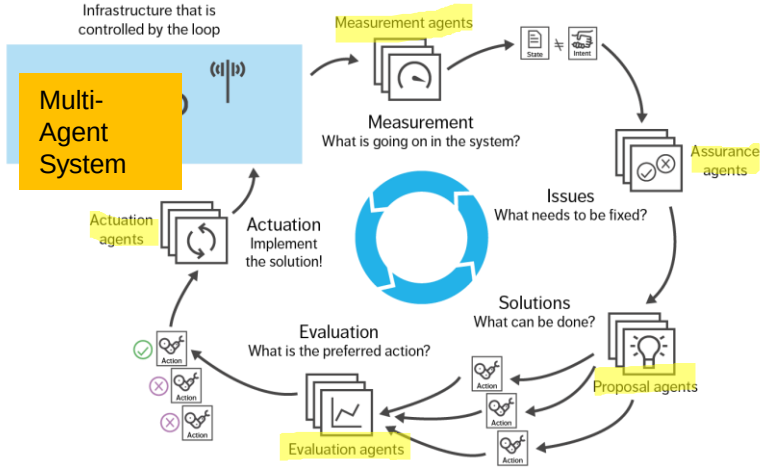
Ericsson: Cognitive Networks 认知网络

"Autonomous system which understands operational objectives given as intents, and then determine complex sequences of actions to fulfil these intents in the best way."

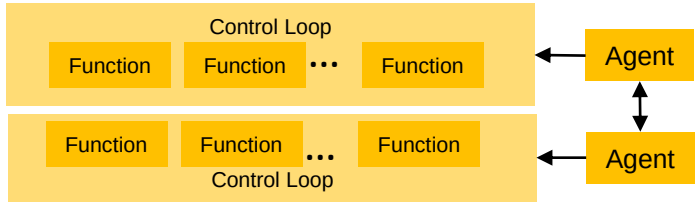
Agent



Multi-Agent System



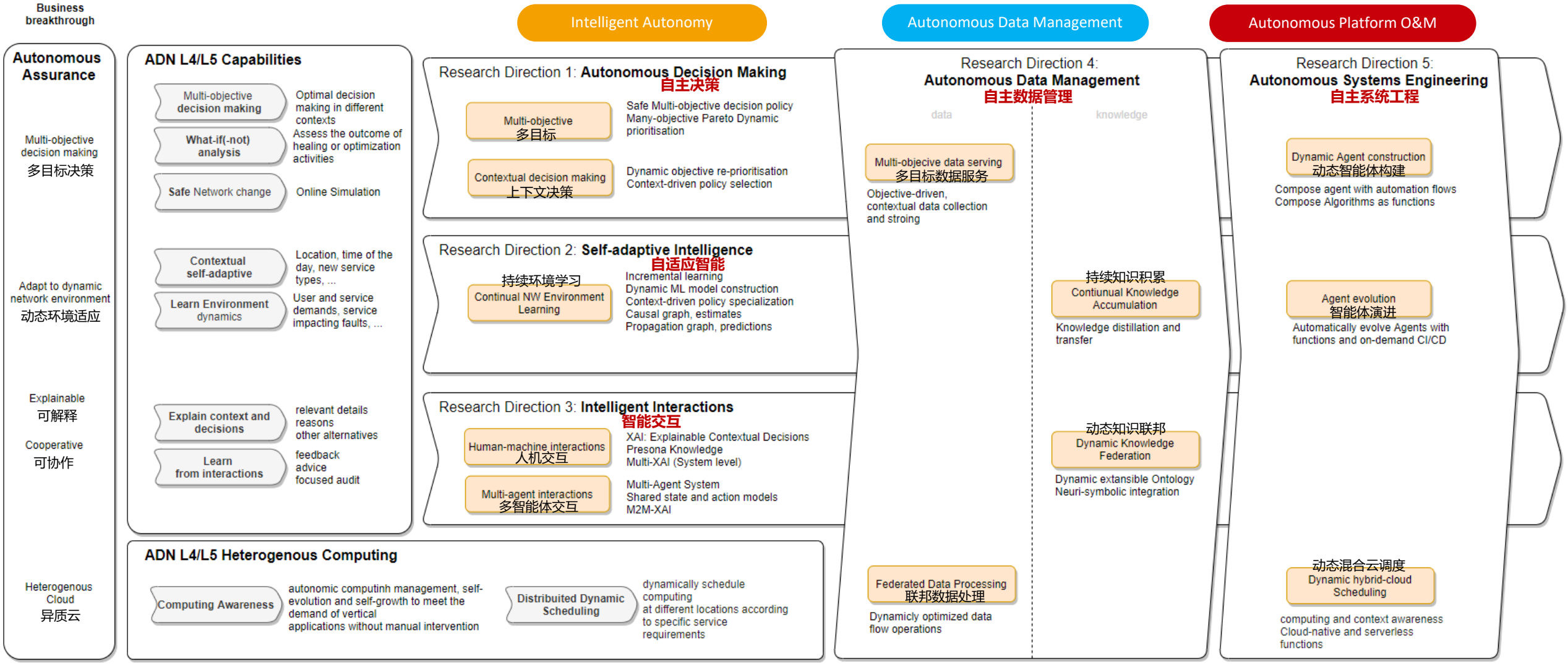
"Different control functions and algorithms will be assembled to form many control loops, each with a different purpose. The procedures to dynamically set this up need to be in place, as well as methods to govern the resulting system of interconnected control loops."



Dynamically assembled

多智能体系统，Agent就是闭环流，闭环流由Function串接组成。

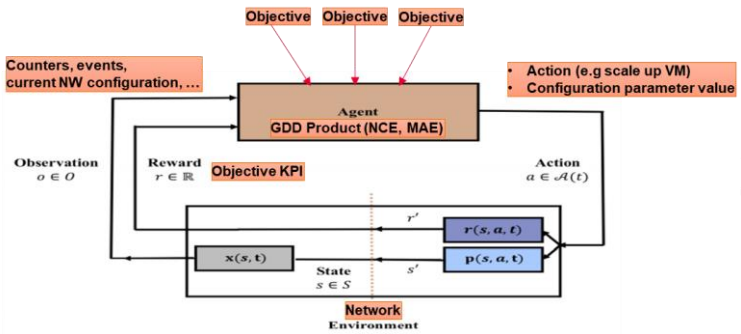
Software Technology Map for ADN Autonomous Assurance

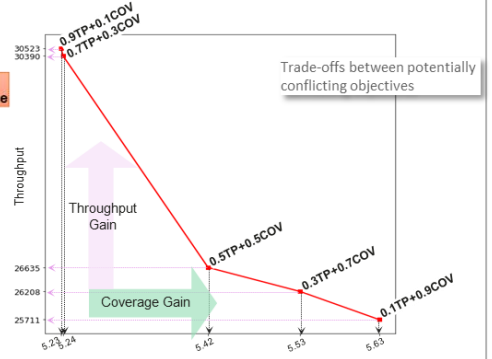


ADN L4/L5 Autonomous Decision Making

Intelligent Autonomy

Multi-objective





Lifelong Many-objective Learning
- Dynamic multi-objective formulation in runtime
- Dynamic trade-offs between objectives, based on context-driven priorities
- Dynamically identifying and adding objectives in sample efficient way (limited data)
- Hybrid of policy-based RL and many-objective Evolutionary Optimization for dynamic utility functions

Safe RL
- Guarantee safe network state, after executing a decision
- Guided explorations based on predefined safety

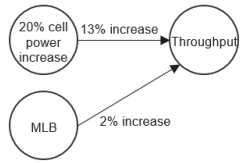
Hierarchical Decision Making
- Abstracted State and Action representation
- Hierarchical problem decomposition
- Coordinated actions in different levels of abstraction

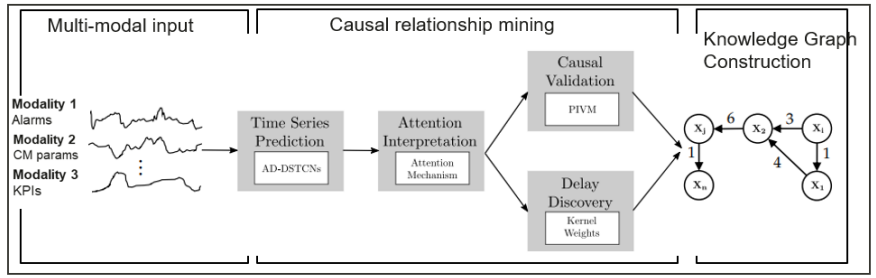
Interventional and Counterfactual Reasoning

Contextual Causal Inference

Was it the increased power that caused an increase in throughput of a macro Cell by 10%?

Had I not increased the power, would I still have observed an increase in throughput?





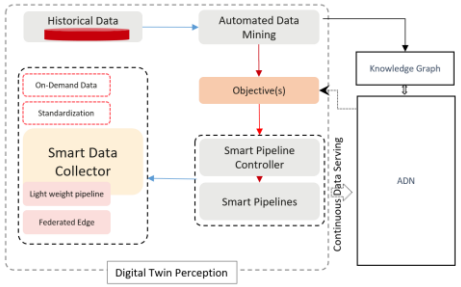
Contextual Causal Graph
- Enrich causal graph with context-expressing confounders.
- Support accuracy for different context-driven NW conditions

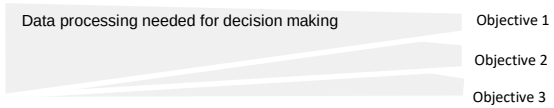
Online Causal Estimation
- High-dimensionality accurate predictions of objective KPIs per suggested action
- Less data needed

Online Causal Discovery
- Identify new relationships
- Adapt Causal Knowledge for high accurate estimations

Neuro-Symbolic Knowledge Reasoning
- Dynamic look-ahead search for real time action planning
- Dynamic construction of behaviour trajectories based on propagation knowledge graph and predictive modelling
- Incident and Risk propagation estimations

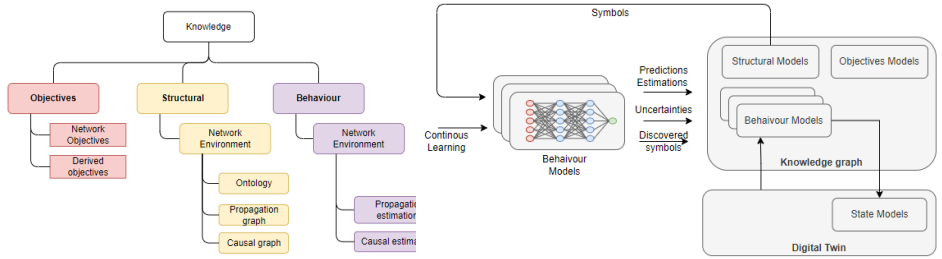
Autonomous Data Management





Smart pipelines for continuous Data Serving
- Multi-objective, automatically adjust data collection
- Reduce data collection
- Assure data quality

Dynamic Knowledge Federation
- Knowledge Design
- Knowledge, Packaging and Transfer
- Neuro-Symbolic Integration



Scenarios
- Add new objectives from new services or network features **新特性**
- Network conditions changing, existing network features/services require optimization **新条件**
- Changing priorities of objectives for optimization, require network re-configuration **新场景**

Scenarios
- Assess remediation of Self-Healing and Self-optimization actions before changing the NW
- What-if (hypothetical) analysis

Add objectives, zero product change — No upfront design effort to add new objective

Priority change of many objectives — Prio 1 maximize throughput; Prio 2: maximize coverage

Technology breakthrough
- Multi-objective control policies that **guarantee safe operation** of mission-critical network systems **at all times**.
- Fast decisions within **minutes/hours**, **not days/weeks**
- Reduce data processing **10x**

High accuracy — Accurate estmating the effect of a decision on Objectives KPI

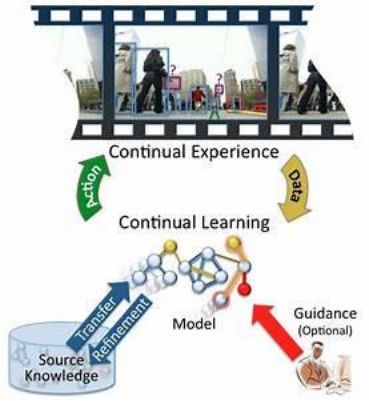
Limitted data for training decision making — No data for all decision combinations to learn from

Technology breakthrough
- Scalable causal inference
- Autonomous effect estimate prediction with **>90% accuracy**
- Adapting to NW environment changes
- Use **50% less data** for online on-premise training.

ADN L4/L5 Self-Adaptive Intelligence

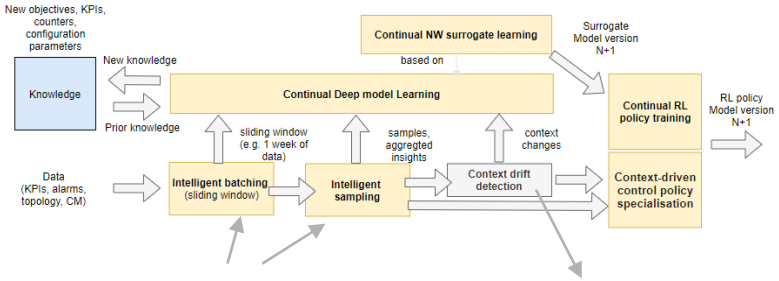
Continual Network Environment Learning

Intelligent Autonomy



Learning methods	Data mode	Operating premise	Self-extension (Sequential learning of tasks)	Adapt to concept drifts (non-stationary tasks)	Adapt to domain shifts (difference in training and deployment distributions)	Universal model (easier maintenance / less resources)	Continual accuracy Improvement (of previous tasks; backward transfer)
Incremental	Batch	Off-premise On-premise	No (catastrophic forgetting)	Yes (slow)	No (needs retraining)	No	No
Online	**Stream**	On-premise	No (catastrophic forgetting)	**Yes (fast)**	No (needs retraining)	No	No
Transfer	Batch	On-premise	**Yes**	No	**Yes**	No	No
Multi-task	Batch	On-premise Off-premise	No (tasks are simultaneously learned)	No	No	**Yes**	No
Continual Online	**Stream or Batch**	**On-premise**	**Yes**	**Yes (fast)**	**Yes**	**Yes**	**Yes**

Autonomous Data Management



Intelligent data batching and sampling

- **Reduce data retention** for online training (**weeks to days**), using dynamic batching and sampling

Continuous Knowledge Accumulation

- Context extractions
- Unknown situation detection

Continual Learning Framework

Stream-based online learning.

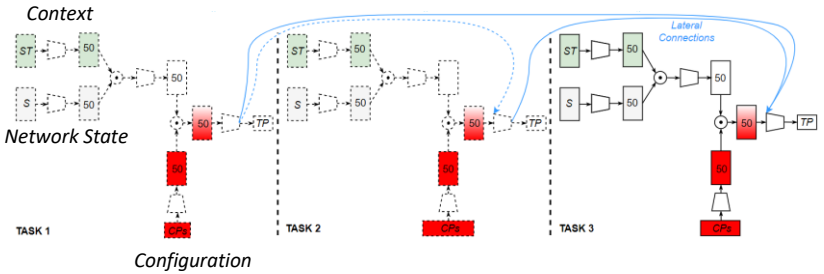
Dynamically adapting modular DNN architecture

- Modular components that are reused/shared across tasks and scenarios, with a learning update that only affects a subset of parameters (major focus on forward transfer of knowledge).

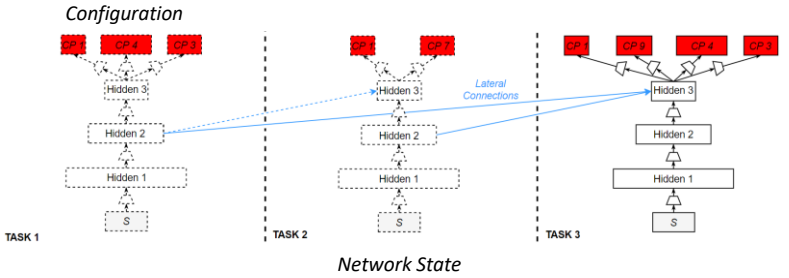
Progressive Neural Networks

- Lateral connections enable transfer of experience from prior tasks to a new task, thus reducing training data size required to achieve high accuracy.
- Separate columns are trained for each task and previously trained columns are frozen, thus ensuring the model is immune to catastrophic forgetting.

Continual Surrogate Model



Continual Policy



Data on-premise, no transfer off-premise	Not feasible to collect data from customer(s)
High-dimensionailty, Context changes	Large number configuration parameters, counters, KPIs
Keep high accuracy continually	Existing objectives in changing conditions New objectives No code change
Improve AI models continually	On context change No code change

Technical Challenges

1. **Online storage** for training data **is limited – we cannot keep all data we collect**
   - *Minimal access to previous tasks*.
2. **Continually maintain high accuracy** in prediction and in decision making **of existing objectives.**
   - No impact on existing tasks
   - *Minimising catastrophic forgetting*
   - Keep learning effective as new tasks arrive in a sequence (*Maintaining plasticity)*
   - The model should be capable of fast adaptation to novel tasks or domain shifts.
3. Establish **high accuracy** in prediction and in decision making **faster and with less data** when dynamically **adding new objectives.**
   - Maximising forward transfer: Learning a task should improve learning efficiency (faster convergence with less data) and performance of future tasks.

Scenarios

- Network environment prediction and control models self-extension for network optimization
- Accurate NW optimization/healing decisions in changing NW conditions

Technology breakthrough

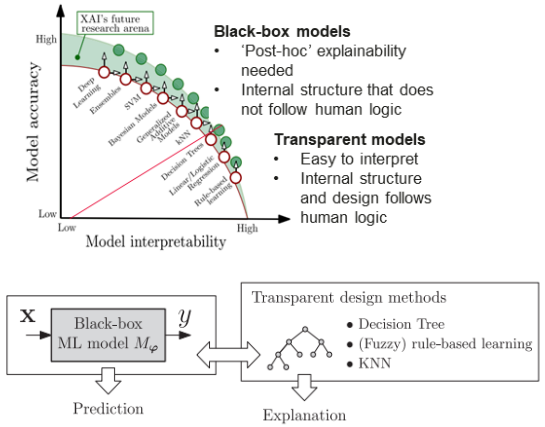
- **Self-extended Deep Learning/RL** structure and training done online, with no code change
- NW environment prediction kept with >**90% accuracy**,
- Adapting to NW environment changes **from weeks to hours (>50% data reduction)**
- **Efficient data processing** for online on-premise training, require no new CPU/mem req.

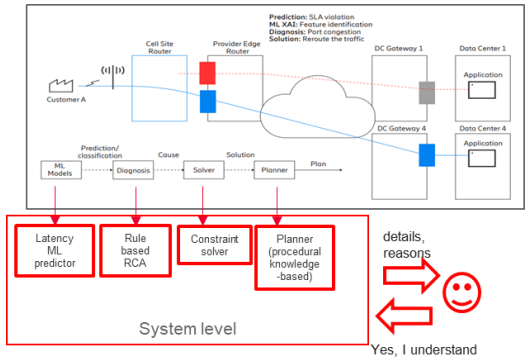
ADN L4/L5 Intelligent Interactions

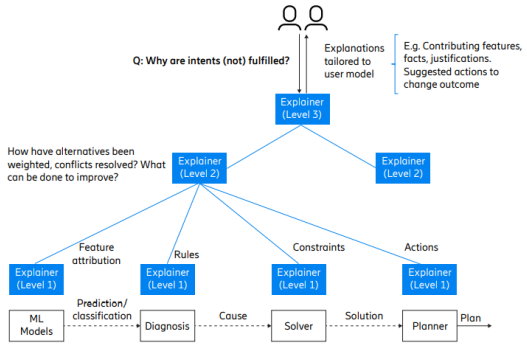
Explainable Contextual Decisions

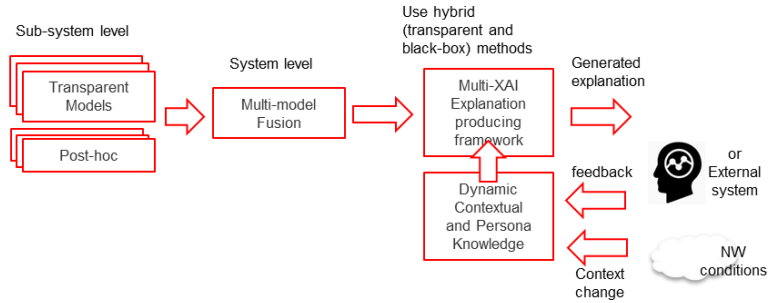
Autonomous NW O&M

Sources:
Explainable Artificial Intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI, Information Fusion, June 2020
Machine Reasoning Explainability, Ericsson Research, Dec 2020
Ericsson Technology Review Explainable AI – how humans can trust AI, April 2021









XAI Post-hoc and Model Fusion

- Post-hoc explainability of deep learning models for risk classification and network configuration parameter control based on a mixture of time-series and tabular data.
- Hybridisation of Neural Networks with Symbolic Knowledge, i.e. causal graph and contextual information.

System level (Multi-XAI) Explanation producing framework

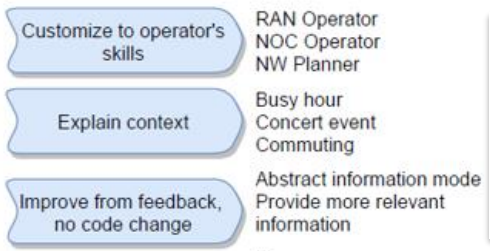
- **Automatically produce explanations** with scores >90%
- Online continual improvement of explanation producing system, through feedback from human user or through context drifts

Multi-Agent (M2M) XAI

- multi-vendor agents/ AI components interfacing with each other to meet high-level intents
- Hybridisation with Multi-Agent Systems protocols.

Dynamic Contextual and Persona Knowledge

- Persona-driven explanations, driving abstractions and/or levels of details required for quick understanding
- Contextualized and customized explanations



Technical Challenges

- DNN black box models are hard to explain （黑盒模型难以解释）
- Combining transparent model (rule based) and black-box into more informative explanation （黑白盒混合难度更大）
- Context change results in reduced accuracy of black box models, which is hard to explain （解释还需要考虑具体上下文信息）

Scenarios

- Single domain explanations of self-healing and self-optimization
- Cross domain explanations of self-healing and self-optimization

Technology breakthrough

- **Generate contextual** and **persona** specific **system level explanations** for decision making, **automatically**
- **Relevance score >90%**, measured by human feedback
- **Informativeness score > 90%**, measured by human feedback

IRELAND RESEARCH CENTER, SNI Lab