WHITE PAPER

ENGINEERING AUTONOMOUS NETWORKS

Abstract

Being autonomous is the ultimate goal for any entity in the world. Technology has often intervened and accelerated different products and domains to achieve this goal, machines, vehicles, robots etc. are good examples. With the recent uprise of AI and Gen AI, there are more to join this league and Network is the latest one with the Autonomous Networks being looked upon as one of the most promising revolutions in communication industry. A recent study from Markets and Markets projects a **market size of 17.5 BUSD by 2029 with a healthy CAGR of 20.1%** for autonomous networks. Keeping aside the market growth, the visible efficiencies autonomous networks bring to planning, design, build, deployment, and operations itself is a good business case. The customer experience improvement which will be the end result of all the above will be a plus too. While there are lot of positives, there is often a question on the feasibility of implementing this revolutionary change in the critical communication network infrastructure. This paper explores the foundational elements required for the implementation of Autonomous Networks, the current technology landscape, and the future roadmap evolution.

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Automated to Autonomous Networks

Often, we see a direct equation of automation to autonomous and hence a misconception that making the network related activities automated will make the network autonomous. However, this is not fully right. Extreme automation is one of the important steps towards autonomous networks, but it is not all. Hence, it will be worthwhile to understand the Autonomous Networks (AN) expectation first before anything. According to our analysis and the research with standard forums like TmForum, ETSI, the fundamental capabilities for achieving Autonomous Networks (AN) are:

A. **Awareness:** The is the capability of the network to be aware of the context of an event, be able to detect any gap from the desired behavior, record and expose it to the other systems to consume.

B. **Analysis:** This allows the network to analyze an event, any gap and correlate all the information stake holding to it to arrive at an insightful next state or a root cause.

C. **Decision Making:** This capability enables the network to make intelligent decisions by looking at the insightful information coming out of the analysis and suggest the best action.

D. **Auto Execution:** This enables the network and the systems managing it to take actions which are recommended through analysis and decision making.

Why the gold rush for autonomous networks?

Autonomous networks are slated to impact the entire stack of network from service creation all the way to resource layer and sustainability considerations.

Impact Areas	Unlocked value levers	
	CURRENT	AN
Resource Usage	Pre-configured	Autonomic
New Product and Services	Static	Dynamic and On demand
Slicing	Policy based	Elastic
Service Realization	Best effort automated	Zero Wait
Operations	Reactive To Proactive	Predictive To Preventive
Sustainability Factors	Planned and Policy based	Dynamic and Intelligent

The above value levers can impact a variety of futuristic needs as follows,

5G Advanced and 6G: Intelligent and closed loop network is one of the important features of 5G Advanced and 6G. Autonomous networks evolution will accelerate the technology adoption to 5G advanced and to 6G.

Liquid Infrastructure: Highly flexible and on-demand infrastructure is an important ask by network service providers. Especially, with edge and un-predictable workload conditions in the edge, this is an important ask. The autonomic resource control capability unleashed by AN will cater this ask to the fullest extent.

On-demand services: The puzzle which network service providers are yet to solve completely is to transform the services to fully dynamic and on-demand. The biggest hurdle was the static nature of network resources and the manual intervention required for the network layer fulfillment. Autonomous Networks enables this better.

Dark NOC: Making operations and operations centers fully autonomous is the holy grail of operations. Autonomous networks and Gen AI can make this journey accelerated and make it technically feasible to achieve.

Fully Autonomous networks – The evolution path

TmForum has defined a good framework depicting the evolution path for Autonomous Networks by considering the basic capability attributes of Autonomous Networks:

Level Definition	L0: Manual Operations & Maintenance	L1: Assisted Operations & 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	P/S	S	S	S
Analysis	P	P	P	P/S	S	S
Decision	P	P	P	P/S	S	S
Internet/Experience	P	P	P	P	P/S	S
Applicability	N/A	Select scenarios				All scenarios

P: Personnel **S**: Systems

Source: TM Forum

By applying this framework, we see that at on an average across the industry, 80% of service providers are at L2 or below. One of the main reason is the non-availability or non-maturity of technology components for implementing the basic capability attributes. There are other factors also contributing to this. Below is our assessment of the top factors which is slowing down the progress on the maturity roadmap.

GAP areas	GAP Width			
	Awareness	Analysis	Decision	Execution
Common Data Management	Low	Low	High	High
Data models and Uniform language	Low	Low	High	High
Off-the-shelf products for critical components	Low	Medium	High	High
Testing frameworks and methods	Medium	High	High	High
Critical Skills	Low	Medium	High	High
Organization Slack	Low	High	High	High

The definitions for these gap areas are as below:

Common Data Management: This includes all the interfaces and systems which are required to collect data in a uniform way across the network elements, process and enrich and then deliver to the required northbound systems in real-time.

Data Models and Uniform Language: Globally accepted methods, data models and ontology which is implemented by the network OEMs and network system providers.

Off-the-shelf products for critical components: This include MDSOs, Intent Orchestrators, Network Digital Brain and other AI Systems which are implemented at scale and maturity for adoption.

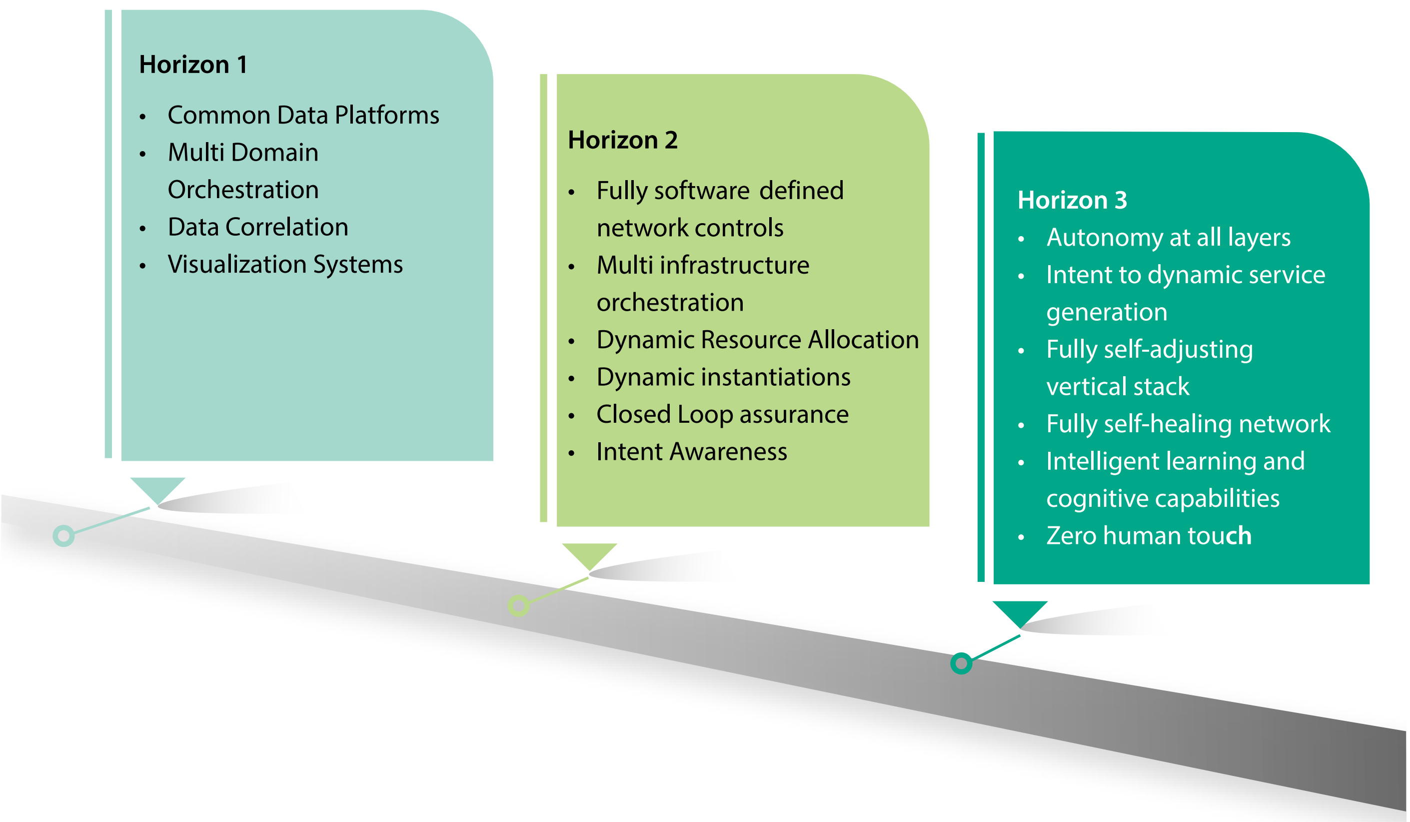
Testing Frameworks and methods: Testing frameworks includes capabilities require for the production and carrier grade testing of the AN elements so that they can be validated for all the possible scenarios in pre-production.

Critical Skills: All the people skills required across the vertical stack of AN from resource layer to the application layer and including niche skills of Gen AI, Intent Orchestration etc.

Organization Slack: The cultural shift of the organization, change management required and the legacy baggage.

The Horizons

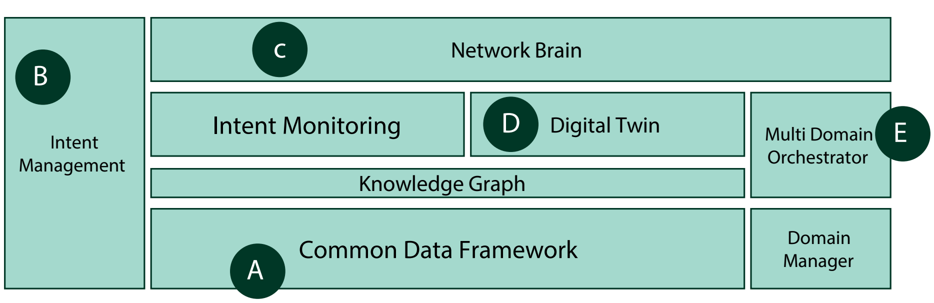
Overlaying the above assessment and by looking at the various technology components, horizon roadmap for autonomous networks could be as below:



The actual timeframe of horizons depends on the specific geo regulatory constraints, technology adoption speed of specific organization and the investments.

Building Blocks for Autonomous Networks

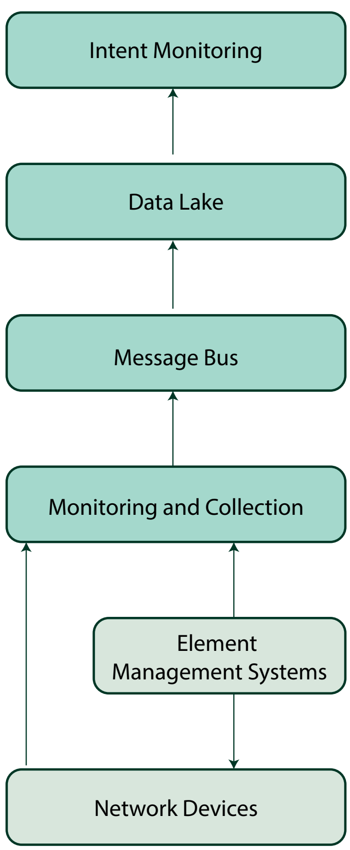
To understand how the autonomous networks can be realized, its better to start with the basic building blocks. The ANs leverage a sophisticated interplay between several key components:



- **Common Data Management and Intent Monitoring:** This acts as the network's information hub, collecting and organizing various data streams from network elements and systems. It visualizes and correlates this data, providing a comprehensive understanding of the network's health. Intent monitor will continuously analyze the data collected by Common Data Management, the Intent Monitor goes beyond simply reacting to issues. It proactively identifies potential deviations from the intended network state, predicting future problems before they occur.
- **Intent Management:** ANs operate based on "intents," which are high-level customer requirements. Intent Management translates human-readable intents into machine-understandable instructions. It then stores and distributes these intents throughout the network, ensuring everyone is working towards the desired outcome.
- **Network Brain:** The AI-powered core of the AN, the Network Brain analyzes data and intents to determine the optimal course of action. It coordinates with other components like Common Data Management and Intent Management to make informed decisions.
- **Multi-Domain Service Orchestrator (MDSO):** The action executor, MDSO plays a vital role in today's complex networks. Network services often span multiple domains (e.g., radio access network, core network etc). MDSO interacts with individual Network Domain Managers (NDMs) to execute actions across these domains, ensuring a coordinated response.
- **Digital Twin:** A virtual replica of the real network, the Digital Twin provides a safe testing ground for the Network Brain. It simulates how the actual network would respond to proposed actions, allowing the AN to validate decisions before implementation.
- **Knowledge Graph:** AN extremely dependent on Cognitive platforms, which are in turn rely on current network state. knowledge graphs provide a structured representation of network information, including entities and their relationships. When used with RAG, KGs ensure retrieved information is not just relevant to the query but also contextualized within a broader knowledge base.

A. Common Data Management

The Common Data Framework acts as a central hub for network data collection, analysis, storage, and distribution in autonomous networks. It offers several key functionalities:



Data Collection: It gathers data from the network using various protocols like SNMP, enabling it to handle continuous streaming and large data volumes.

Data Aggregation: The framework aggregates raw counters collected from the network, providing a condensed view of network performance.

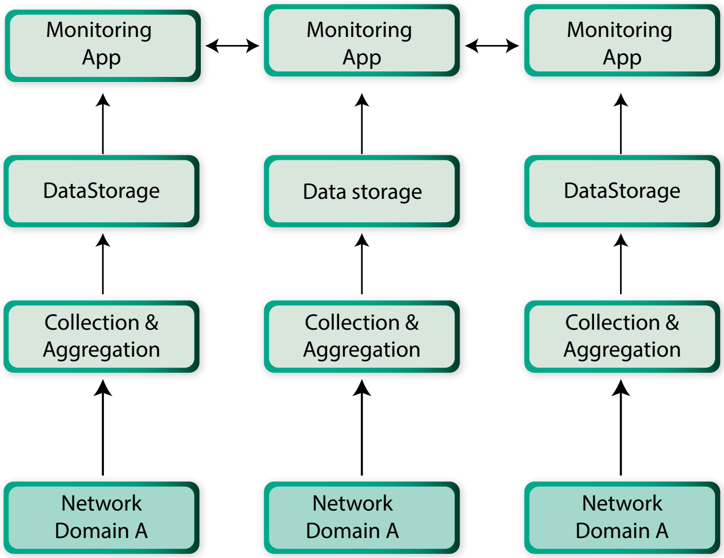
Standardization: Whenever possible, the framework converts raw data into standardized formats like 3GPP for easier integration and analysis.

Data Storage: Data storage stores the collected and processed data, making it accessible for querying by various Operations Support Systems (OSS).

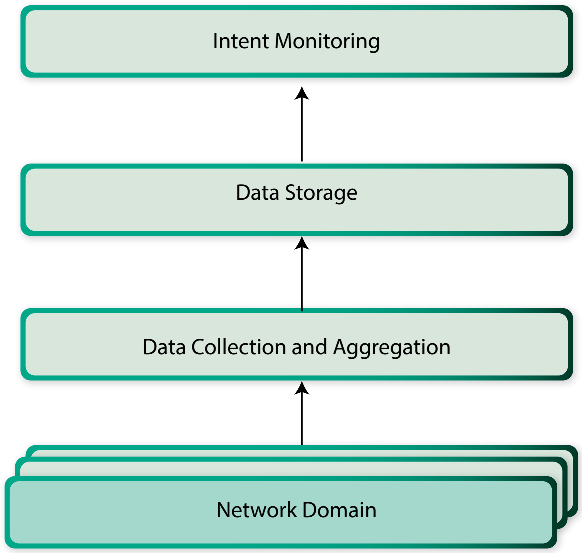
Intent Monitoring: In the context of autonomous networks, the framework plays a crucial role in future-oriented analysis through Intent Monitoring. This involves comparing the collected and aggregated Key Performance Indicators (KPIs) against predefined network service intents to identify discrepancies.

Workflow

Traditional Model Data Collection and Monitoring



Common Data Model for collection and monitoring

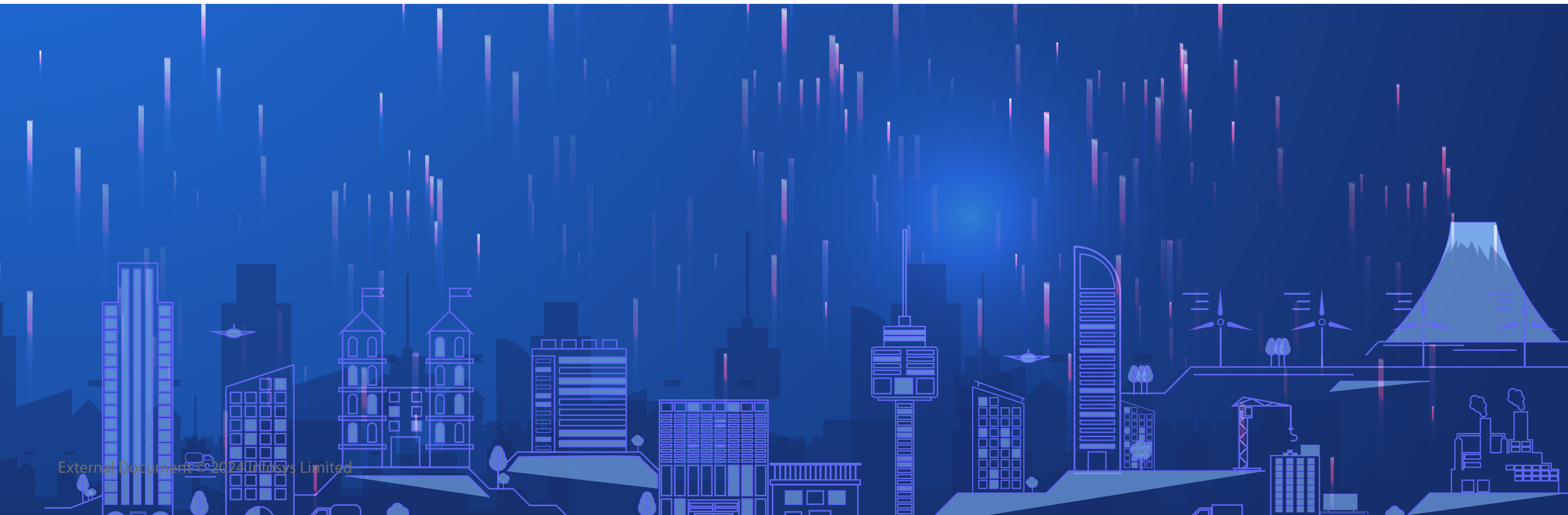


In traditional model, data collection, storage and monitoring for each network domain happens on isolated basis and there is no relationship. Moreover, for each network domain, customized implementation is considered, and this becomes difficult in decision making or for policy enforcement in the end-to-end network. Common Data Model simplifies the approach by having a central hub for network data collection, storage, standardization, relationships and playing crucial role for future-oriented analysis through Intent Monitoring.

Standard Maturity

Below table depicts the standard maturity for the different components of the Common Data Management:

Area	Maturity Level	References
Data Collection and Aggregation	High	SNMP, RESTAPI
Standardization	Medium	TMF GB922
Data Storage	Medium	GQL(ISO/IEC 39075:2024)
Intent Monitoring	Low	None



Technology availability

Below table depicts technology availability for the Common Data Management

Area	Technology Availability	References
Data Collection and Aggregation	High	SNMP, RESTAPI
Standardization	Medium	TMF GB922
Data Storage	High	Apache Cassandra, Titan Graph DB
Intent Monitoring	Low	None

AI intervention

- Process and interpret a variety of data in real time, including network performance data, user behavior, and external market conditions. Understand impact to the network intents based on the data.
- Utilizing advanced machine learning models, GenAI predicts future network states.

B. Intent Management

Intents are crucial to the evolution of networks being Autonomous. Intents are higher level goals that focus on the "What" and not "How". This enables abstracting the network complexity to end user and increasing the degree of automation within the systems.

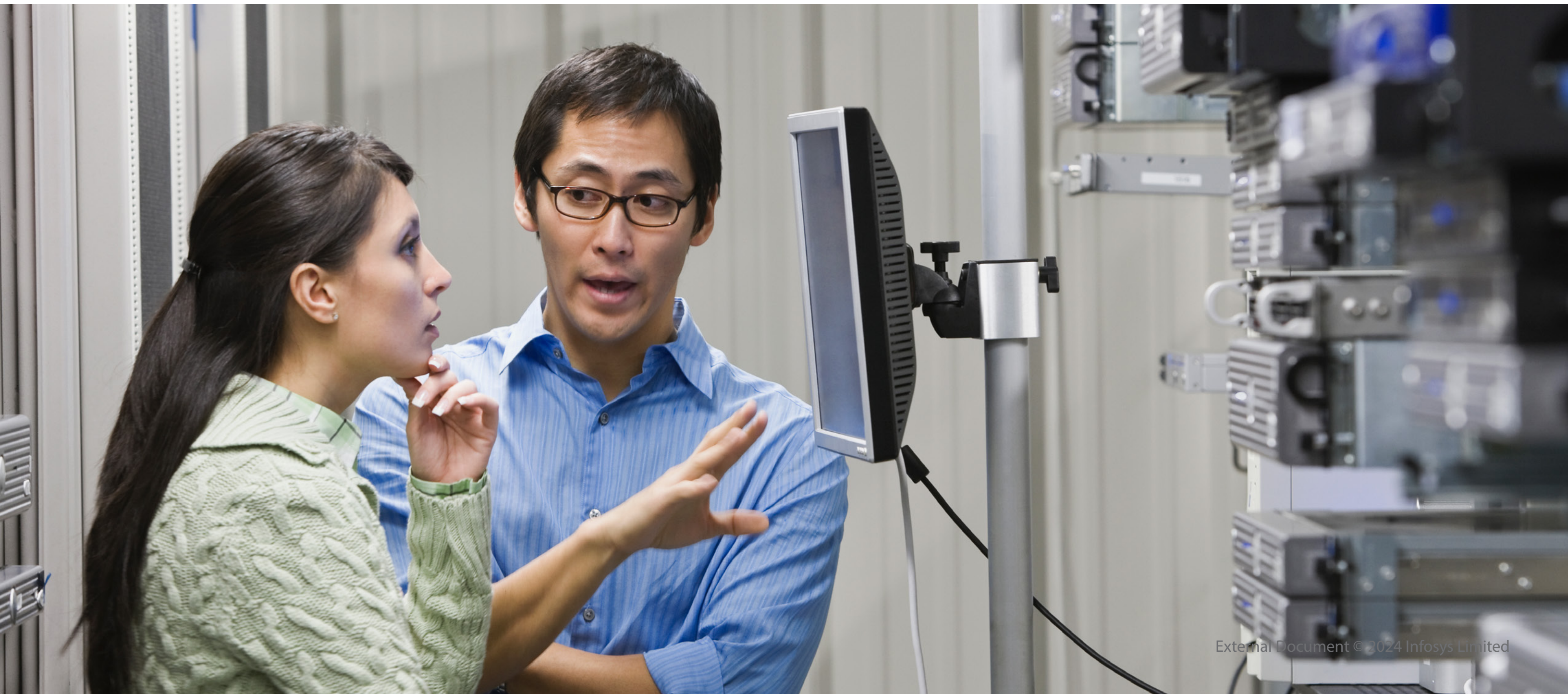
Intent Translator, Storage Manager and Distributor. This also acts as a bridge between human intent and network design.

Following are the key functionalities:

- Intent Interpreter: It processes business goals (expressed in plain English by the Customer Order Provisioning System - CPQ) using AI models. The Intent Manager translates

these high-level business goals into specific service requirements, creating a "service order." Similarly it also converts resource intent into the resource order outlining the necessary network resources.

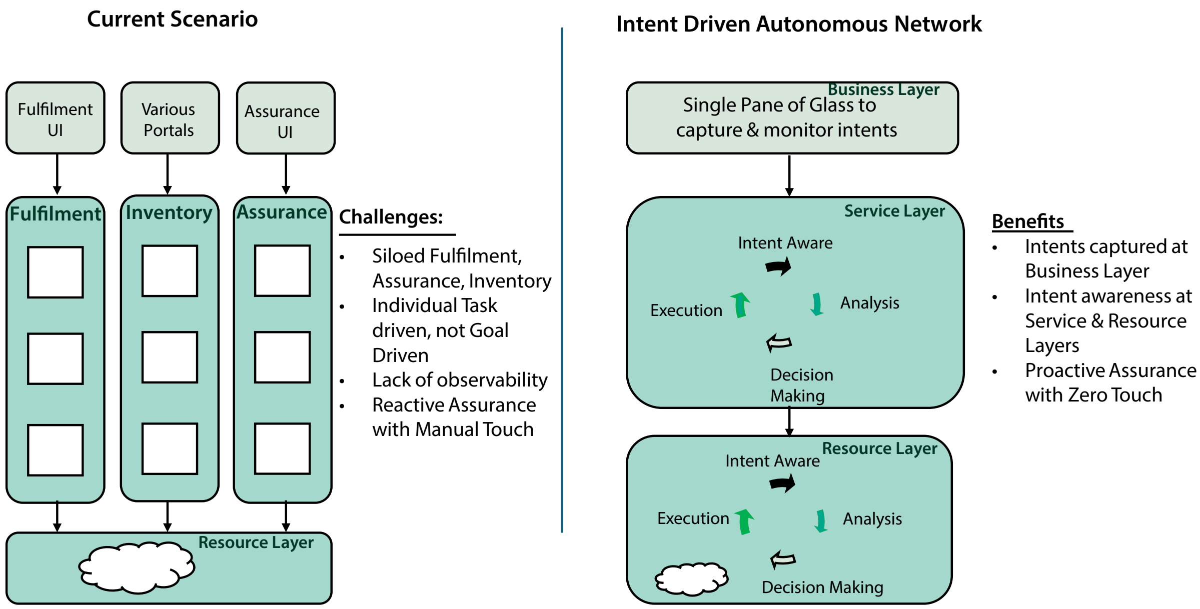
- Intent Distribution : It distributes relevant intents to various network components, such as the Network Digital Brain, Digital Twin, and Intent Monitoring, for further processing and action.
- Intent Storage and Distribution: It stores all defined intents (business, service, and resource) in a central repository.
- Intent Manager acts as Intent Translator, Storage Manager and Distributor. This also acts as a bridge between human intent and network design.



Workflow

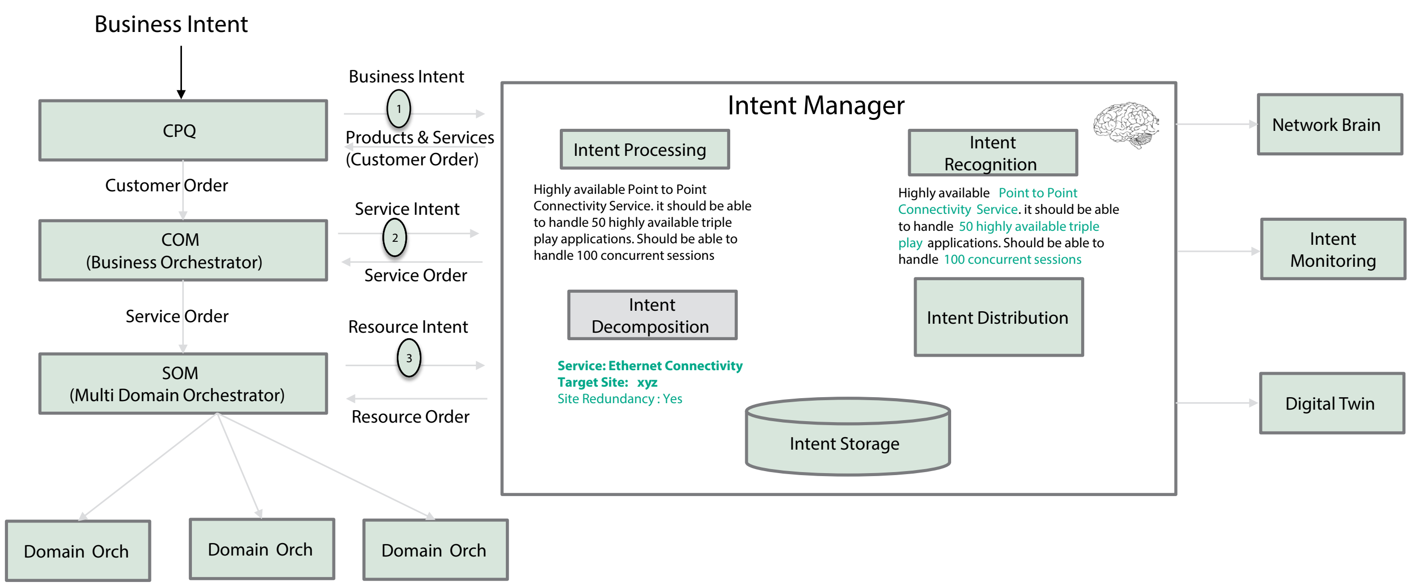
Current systems in a telco environment are siloed with a task-based approach. The systems focus on individual tasks and not the end goal. There is lack of visibility and correlation across various stacks. Assurance is mostly reactive i.e Telcos wait for a problem to be reported and then manual corrective action is taken.

The image below depicts a comparison of current scenario and To-Be State with Intent Driven



In a Intent Driven Autonomous Networks, Intents are captured at business layer. The service layer receives the intent and decomposes it into respective resource layers.

The key point is that the respective layers are aware of desired intent state and current state of intent. The system analyses the difference and decides to take the required action. To-Be State with Intent Driven Networks



Standard Maturity

Area	Maturity Level	References
Intent Metamodel	Low	TMF IG1259
Intent Grammar / Ontology	Medium	TMF TR292
Intent API Specification	Medium	TMF921
Decision Making Framework	Low	None

The are three main aspects with respect to standard definition in intents:

- **Intent Metamodel:** Metamodel refers to construction and development of rules, constraints and models applicable for modeling. Although TMForum IG1259 guidebook exists for intent metamodel definition, telcos are generally having their custom versions of meta model and rules.
- **Intent Grammar or Ontology:** Intent Grammar or Ontology refers to the syntax of intents based on metamodel concepts. This is important as there needs to be a common language which can be understood by systems. TMForum has defined intent ontology in the TR292 specification.
- **Intent API Specification:** Intent API's need to have a standardized format which can be invoked by respective upper/lower layers for intent lifecycle operations. TMForum has defined the intent API specification in TMF-921 which can be leveraged by telcos to implement intent API's
- **Decision Making Framework:** Currently there is lack of any industry standard or framework for decision making. Telcos are having bespoke implementations of ML algorithms which make the decisions on state of intents.

Technology availability

Following are the various technology aspects to be considered to realize intents in an autonomous networks:

- Automated Intent Translation: Leverage GenAI to translate business intents to service intents. Also leverage GenAI to translate intents at scale between service and resource layers
- Intent Grammar: TMForum has defined Turtle expressions to realize intent grammar. This is similar to JSON based data structures
- Intent API implementation: Modern software languages like python, Java, Node can be used to implement intent API's as defined in TMF 921 specification

Area	Technology
Automated Intent Translation	GenAI
Intent Grammar / Ontology	Turtle Expressions
Intent API	Python/Java/Node

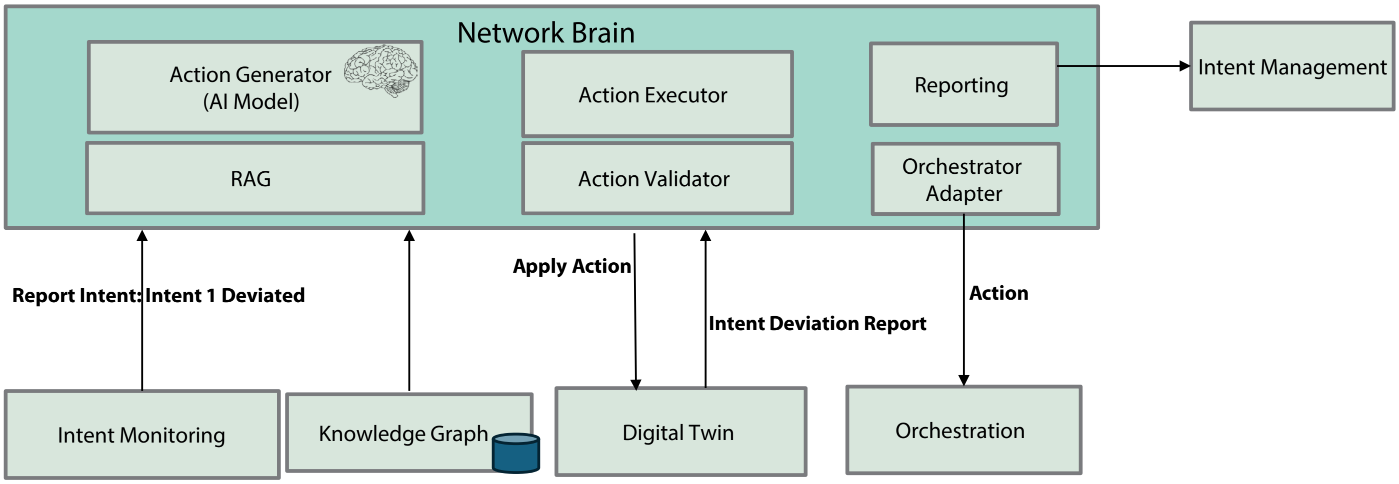
AI Intervention

- Autonomous networks use NLP and GenAI to interp the intents expressed by users in human language and translate to system understandable API calls.
- Another crucial aspect of autonomous networks is the ability of awareness of intents and actionizing in case the intent is not being met. The actionizing is based on a combination of supervised and unsupervised machine learning algorithms. This is such that the system can take action in an autonomous manner based on historical data as well as any new situation that is encountered.

C. Network Digital Brain and Knowledge Graph

The Network Digital Brain is the intelligent engine driving autonomous networks. It uses Pre-Trained AI Model to analyze the network, identify optimal solutions, and orchestrate actions to ensure the network operates efficiently and adheres to predefined intents

AI Model pre-trained on diverse knowledge sources , including product manuals, historical fault resolution methods, and best practices. Not just about historically trained data, The AI model utilizes RAG technique to analyze the current knowledge which is stored in the form of a knowledge graph. Knowledge Graph is the structured representation of real-time network data allowing the AI model to efficiently process information



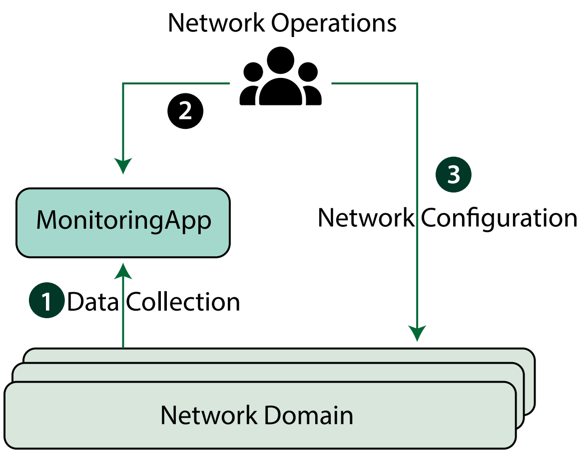
Following are the main functions of Network Brain:

- **Action Identification:** The brain analyzes network details like inventory, configuration, and current faults using an AI model to identify list of possible actions to fix the intent deviation.
- **Action Prioritization:** The brain doesn't just generate possibilities; it also ranks them. It prioritizes actions based on their potential effectiveness in achieving network intents.
- **Action Validation:** The top-ranked action is then validated against a digital twin of the network. This ensures the action aligns with overall network goals and doesn't introduce unintended consequences.
- **Action Execution:** If the action is validated, the brain sends it to the Multi-Domain Orchestrator for execution on the actual network.
- **Intent Violation Detection:** If the chosen action is not feasible, the Network Digital Brain raises an alarm to the Intent Management Layer. This indicates a potential intent violation requiring human intervention.

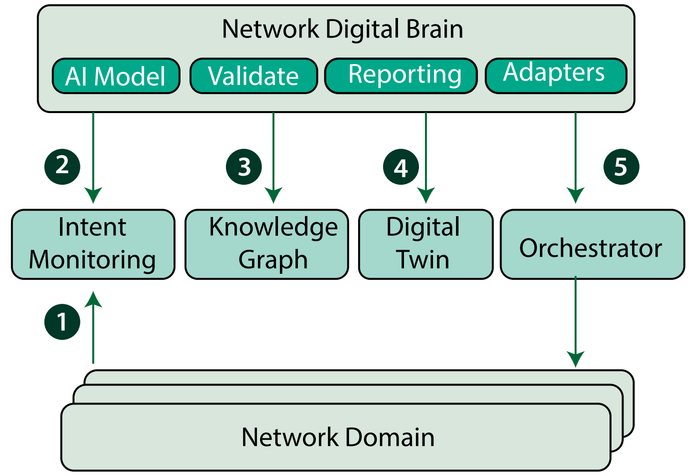
In essence, the Network Digital Brain acts as a cognitive center for autonomous networks. This automation not only streamlines network management but also enables proactive optimization and faster response times to network issues.

Workflow

Traditional Network Decision for Operational Efficency



Network Digital Brain for Operational Efficiency



In traditional model, network operations analyze the KPIs and alerts from monitoring application and decides optimal solutions and configures the network. The model is person dependent, and Network Operations teams must be skilled in different network topologies. The Network Digital Brain uses Pre-Trained AI model to analyze, identify optimal solutions, and orchestrate actions to ensure the network operates efficiently.

Standard Maturity

Below table depicts maturity level for the Network Digital Brain:

Components	Maturity Level	Standards
Action Generation (AI Model)	Low	None
Action Validator	Low	DT4DI
Orchestration Adapter	High	RESTAPI

Technology availability

Below table depicts technology availability for the Network Digital Brain:

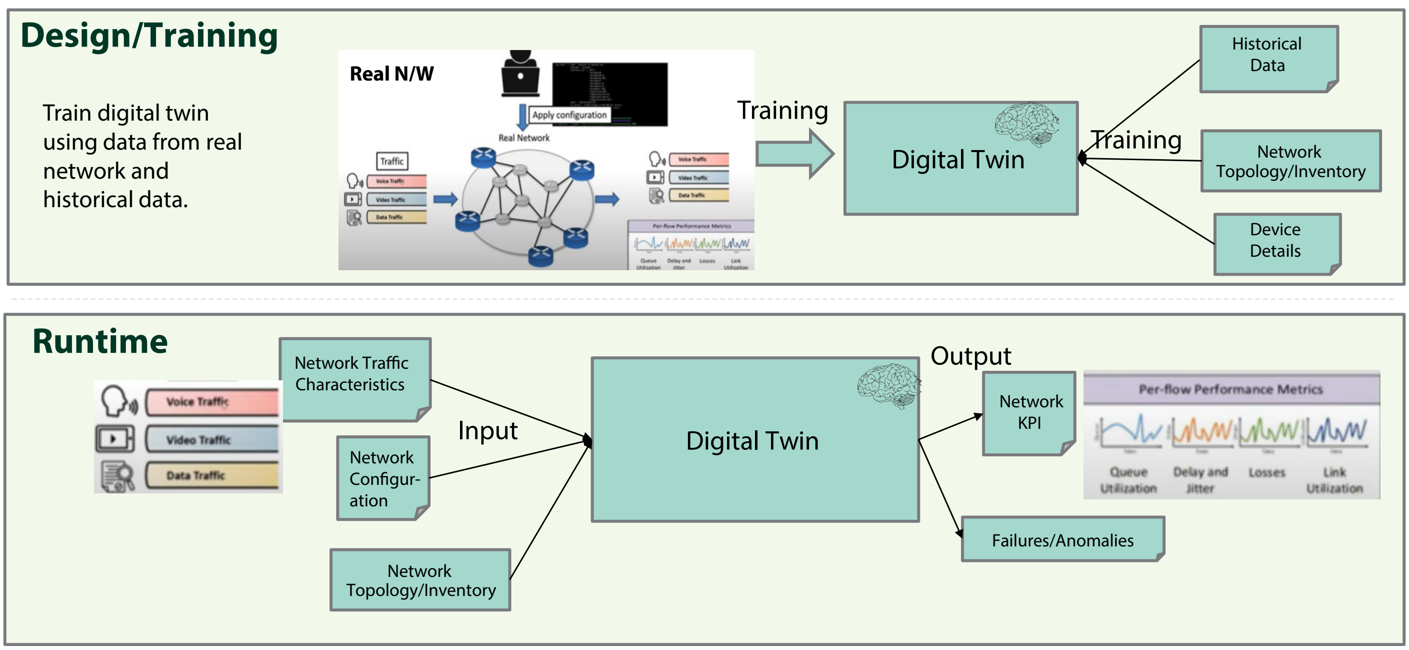
Component	Technology Availability
Action Generation (AI Model)	Low
Action Validator	Low
Reporting	High
Orchestration Adapter	High

AI Intervention

- AI Model should be able to the recognize and list of possible actions based on the Intent Deviation Report and current network state. The actionizing is based on a combination of supervised and unsupervised machine learning algorithms. This is such that the system can take action in an autonomous manner based on historical data as well as any new situation that is encountered.
- AI Model needs to be trained on the network manuals, MOPs, historical network events and possible resolutions. For current network state, RAG technique would be used in conjunction with trained AI Model.
- Current Network data would be stored in the graph data structure for an effective RAG.

D. Digital Twin

Digital twin acts as a virtual replica of the real network. This replica serves a critical role in validating actions before they are implemented on the actual infrastructure.



Following are the functions of digital twin:

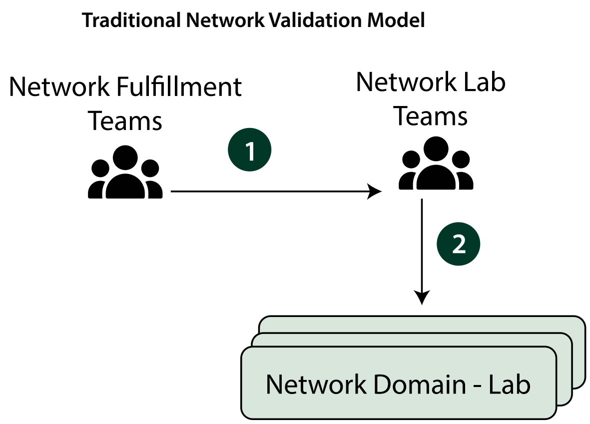
- **Network Simulator:** The digital twin takes proposed actions, configurations, and the current network topology as input and simulate actual network in terms of its performance.
- **Performance Prediction:** Based on the input given i.e. topology,configuration and action, the twin predicts the network's Key Performance Indicators (KPIs) after the action is applied.
- **Failure Detection:** It also identifies potential failures or unintended consequences that might arise from the proposed action.

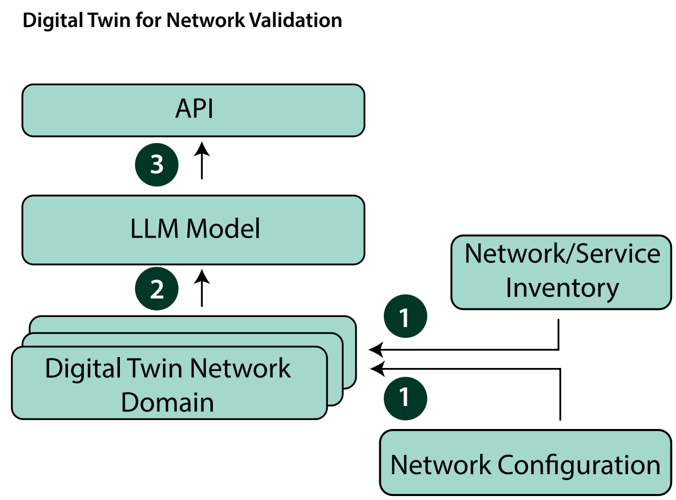
The digital twin's accuracy hinges on a rich training dataset. This data typically includes:

- **Historical Network Performance:** Past network behavior under various conditions.
- **Network Faults:** Records of past network issues and how they impacted performance.
- **Network Topology:** A detailed map of the network's physical layout and connections.
- **Device-Level Details**: Information extracted from device manuals and specifications.

In essence, the digital twin acts as a crucial safety net in the autonomous networks decision-making process. It ensures proposed actions are well-considered and minimizes the potential for negative consequences on the live network.

Workflow





The above diagram depicts of workflow of the traditional and Digital twin model for Network doing Validation and to understand the impacts. In Traditional model, Network Fulfillment Team will send request to the Network Lab Teams to validate the network configuration in the Lab and based on that impacts, Network Fulfillment teams to provision the network accordingly.

Unlike traditional model, Digital Network Twin creates a digital replica of the physical network using the Network inventory and configuration. This includes network devices, topologies and real-time traffic data. LLM models will interact with digital twin to generate the network impacts based on the configurations received and sent back to the Intent Manager via API layer.

Standard Maturity

Below table depicts maturity level for the Network Digital Brain:

Components	Maturity Level	Standard
Digital Twin	High	draft-irtf-nmrg-network-digital-twin-arch-04(dt4di)
LLM Model	Low	None

Technology availability

Below table depicts technology availability for the Network Digital Brain:

Components	Technology Availability	Technology Solutions
Digital Twin	High	Microsoft Azure Digital Twins, Oracle Digital Twin, HPE Network Fabric Simulator/Composer (NFSim), Nokia WaveSuite
LLM Model	Low	None

AI intervention

- Before deploying changes, AI can simulate and validate configurations to ensure they will perform as expected without disrupting existing services.
- AI can continuously learn from ongoing operations and adapts its models without explicit reprogramming.

E. Multi Domain Service Orchestration

Telcos have complex networks spanning wireless and wireline networks. The complexity is exacerbated with a gamut of network devices and element managers across the various domains of access, edge, core and transport. To achieve autonomous capabilities in a complex network environment requires the need of a centralized brain/controller which has the visibility across domains. This is the capability fulfilled by a multi domain service orchestrator

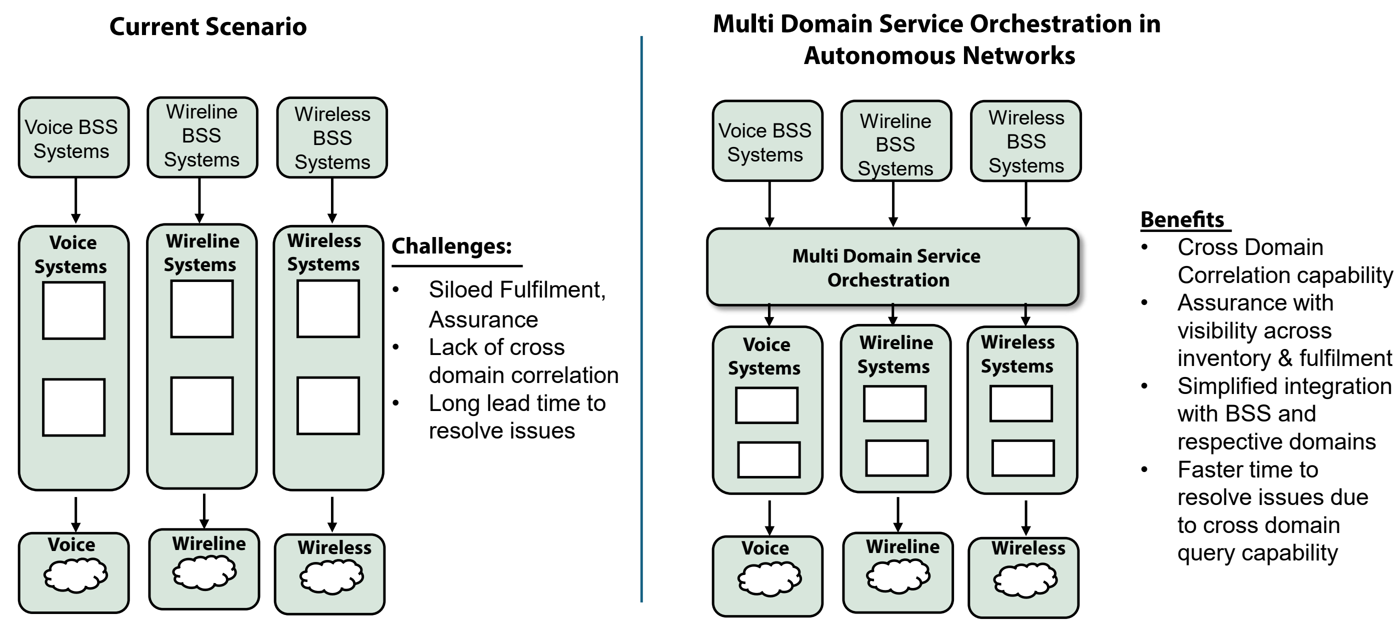
Here's a breakdown of its key functions:

- **Service Order Management:** MDSO receives service order from the Network Digital Brain or Customer Order Orchestrator depending on the provisioning or an assurance stage.
- **Workflow Decomposition:** It breaks down complex actions into smaller, more manageable workflows.
- **Multi-Domain Coordination:** MDSO acts as a bridge between different network domain, communicating and coordinating their actions. MDSO collaborates with individual domain orchestrators, sending them the resource orders for execution within their respective domains.
- **Resource Order Management:** It can decompose service orders into multiple, specific resource orders for each domain.
- **Order Tracking and Visibility:** MDSO keeps track of individual resource orders, providing a holistic view of the entire service orchestration process.

Workflow

There are two primary scenarios where MDSO comes into play:

- Initial Provisioning: During the initial service setup, the Customer Order Manager sends a service order to MDSO. MDSO then decomposes it into resource orders for each network domain (e.g., transport, radio, etc.) and sends them to the respective domain orchestrators for execution. Traditionally all individual domains were siloed and does have their own end to end stack.
- Operationsal Assurance: The Network Digital Brain might identify an issue requiring corrective action. It utilizes MDSO to orchestrate the solution across various domains, ensuring a coordinated network response.



Standard Maturity

Below table lists the standards available and their maturity for MDSO components:

MDSO Capability	Maturity Level	References
COM	High	TMF-620 TMF-622 TMF-637
SOM	High	TMF-633 TMF-638 TMF-641 TMF-645
ROM	High	TMF-639 TMF-640 MEF LSO Presto
MDSO to BSS API	Medium	MEF LSO Legato

Technology availability

Multi domain orchestration is a complex solution with various functionalities of service design, service orchestration, resource orchestration etc. Building a multi domain orchestrator would be complex and it would be prudent to consider leveraging open source solutions or commercial off the shelf options.

Area	Vendor
Multi Domain Orchestrator Commercial Off The Shelf	Multiple Standard OEMs
Multi Domain Orchestrator Open Source Implementation	ONAP

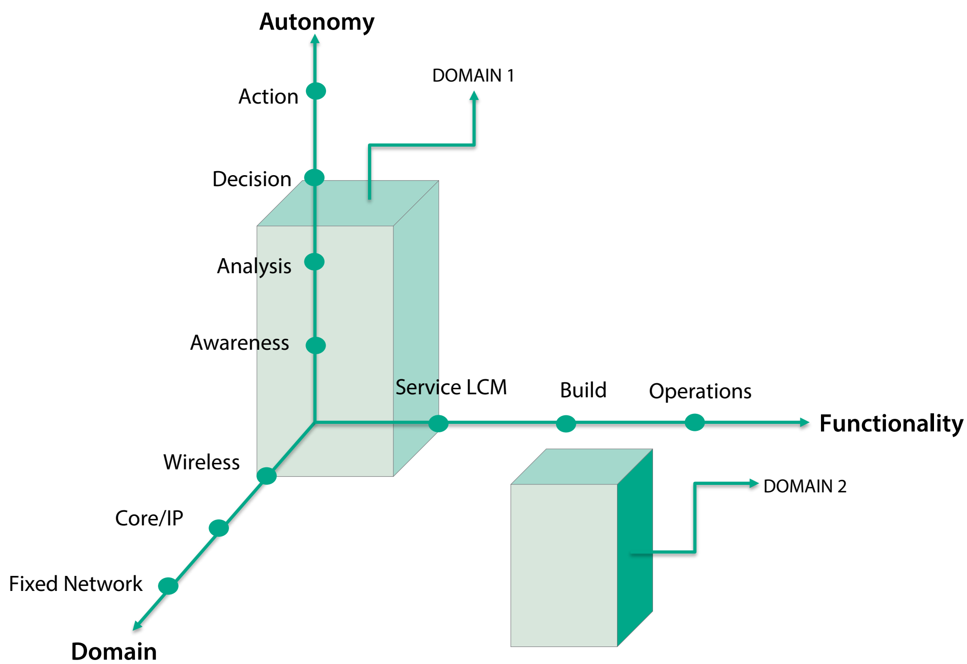
AI Intervention

Generative AI can be leveraged to automate complex decision-making processes within multi domain orchestrator. Coupled with ML algorithms enabling systems to learn from data and improve over time, generative AI can provide network operators with powerful tools to optimize resource allocation, improve network efficiency, and deliver enhanced services. AI enabled multi domain orchestrators can help service providers realize the use cases of:

- AI Driven Network Efficiency and Optimization
- Real time adaptability
- Predictive maintenance

The way forward

The implementation roadmap for autonomous networks within an organization could be multi path. Our assessment is that there are 3 angles of influencing factors – a) the technology maturity of a particular domain b) functionalities for which autonomy is targeted and c) the AS-IS level of autonomy. Accordingly, there could be different paths and velocity for a particular domain or for a particular functional area. For eg:, we see most of the service providers are within the L2 level of autonomy in the current state for operations but has most of the fundamental checks done to move to higher levels. Hence, operations might move faster to Level 3 and 4 in most organizations.



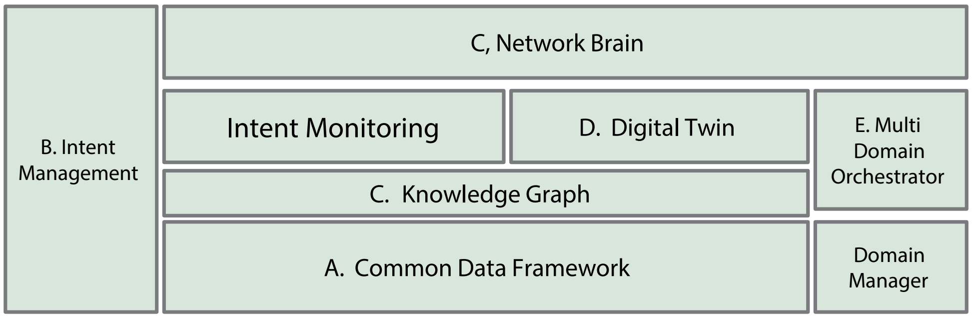
Applying the same framework and from our secondary research and assessment, below is the summary of how the roadmap for autonomous networks could progress in general in the industry.

	WIRELESS			TRANSPORT/IP CORE			Fixed Network		
	SLCM	BUILD	Operations	SCM	BUILD	OPERATORS	SLCM	BUILD	Operations
Awarness	Mid Term	Mid Term	Short Term	Mid Term	Mid Term	Short Term	Mid Term	Mid Term	Short Term
Analysis	Mid Term	Mid Term	Short Term	Mid Term	Mid Term	Short Term	Long Term	Long Term	Short Term
Decision	Long Term	Long Term	Mid Term	Long Term	Long Term	Mid Term	Long Term	Long Term	Mid Term
Action	Long Term	Long Term	Mid-Long Term	Long Term	Long Term	Mid-Long Term	Long Term	Long Term	Mid-Long Term

The operations across the network domain are better poised to reach the higher levels while build and service life cycle management may require longer cycles to achieve them.

Infosys proposition

Infosys has worked along with standard forums like TMF, LFN and had invested in building talent and solutions to glue the autonomous networks framework.



A

- Common data management platform approach blue print
- Infosys Smart Network Assurance modules for data correlation and enrichment

https://www.infosys.com/services/engineering-services/service offerings/smart-network-assurance.html)

B

- Expertise in TMF IG1259 and TR292
- Contribution to TMF921 standard evolution.

Intent-driven autonomous networks - PhaseIII (tmforum.org)

- Expertise in implementation of supervised and unsupervised ML Algorithms for decision making algorithms.
- Expertise in usage of Gen AI for translating intents expressed in natural language and translating to system API's.

C

- Best practices in the deployment and integration of Digital Twin solution with Network OSS (configuration management and inventory)

Connected Digital Twin for IoT-EDXWireless

D

- Expertise in SLMs/LLMs Training and implementation
- Reusable components from Infosys Smart Network Assurance for predictive fault management and CLA

E

- Consulting framework to choose the best fit product
- Expertise in implementing Open source multi domain orchestration solutions.

Nephio – Linux Foundation Project

Conclusion

As you would have learned through this paper, autonomous networks has the potential to impact multiple tenets of networking industry going forward. The building blocks of this disruptive transformation is at different stages of maturity. The standards are evolving and the ecosystem is yet to come together fully. From an adoption perspective, the service providers are mostly at the lower band of autonomy levels and are in the process of defining their respective roadmap. In that context, the approach and guidance elaborated in this paper will be valuable for service providers to firm up their thoughts. It is also clear the autonomous networks is going to be powered heavily by the software defined networks and AI/Gen AI principles. So, the ecosystem vendors who had foreseen this to make inroads and investments in these technologies will play a major role in **engineering the Autonomous Networks of the future.**

About the Authors

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Ganesh Narayan is a Principal Technology Architect with Infosys Engineering Services. He has over 19+ years of experience working with telecom service providers across the globe and has experience in developing cutting edge production grade innovative solutions for telcos. He has been part of TMF catalyst for Autonomous Networks and has guided multiple telcos in their journey for the adoption of autonomous networks.

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