Closed Control loops in Autonomous Network and Service Management: Current Trends, Challenges and Future Directions

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Go far, together.

Agenda

Introduction

Autonomous Networks: Self-managing networks that can adapt and optimize without human intervention.

Control Loops: A process where feedback from the system is used to adjust and optimize its performance (monitor → analyze → plan → execute → feedback).

Closed Control Loops: These loops operate autonomously by continuously monitoring, analyzing, and executing adjustments to improve network and service performance in real-time.

Why It Matters

Scalability: As networks grow, manual management becomes impractical. Closed control loops enable scalability through automation.

Self-healing: Networks can detect and resolve issues without human intervention, ensuring higher reliability and reduced downtime.

Optimization: Continuous optimization improves network performance, resource utilization, and cost-efficiency.

Goal of the Study

Define closed control loops in the context of autonomous network and service management.

Compare closed control loops to traditional network management approaches.

Identify key components and architecture of closed control loops in autonomous networks.

Explore how closed control loops are integrated into existing network management systems.

Examine the ethical, governance, and security issues associated with AI-based closed control loops.

Propose future research directions to overcome current challenges and gaps in the field.

Research Methodology

Search Strings Used

- “Closed control loops”
- “service management”
- “Autonomous network automation”
- “network automation”
- “network management”
- “Intent-driven closed loops”
- “Autonomous service management”

Research Questions

- What are closed control loops in autonomous network and service management?
- What makes closed control loops different from traditional network management approaches?
- What are the main components and architectures of closed control loops in autonomous networks?
- How are closed control loops integrated with existing network management systems and legacy infrastructures?
- What ethical, governance, and security challenges arise when using AI-based closed control loops in network management?

Paper Selection

1

1. Search and Collection: Used search strings on Google Scholar to find papers from year 2020 to 2025.

2

2. Initial Screening: Reviewed titles and abstracts to filter relevant papers, finding 19,279 papers, and filtering around 100 using keywords.

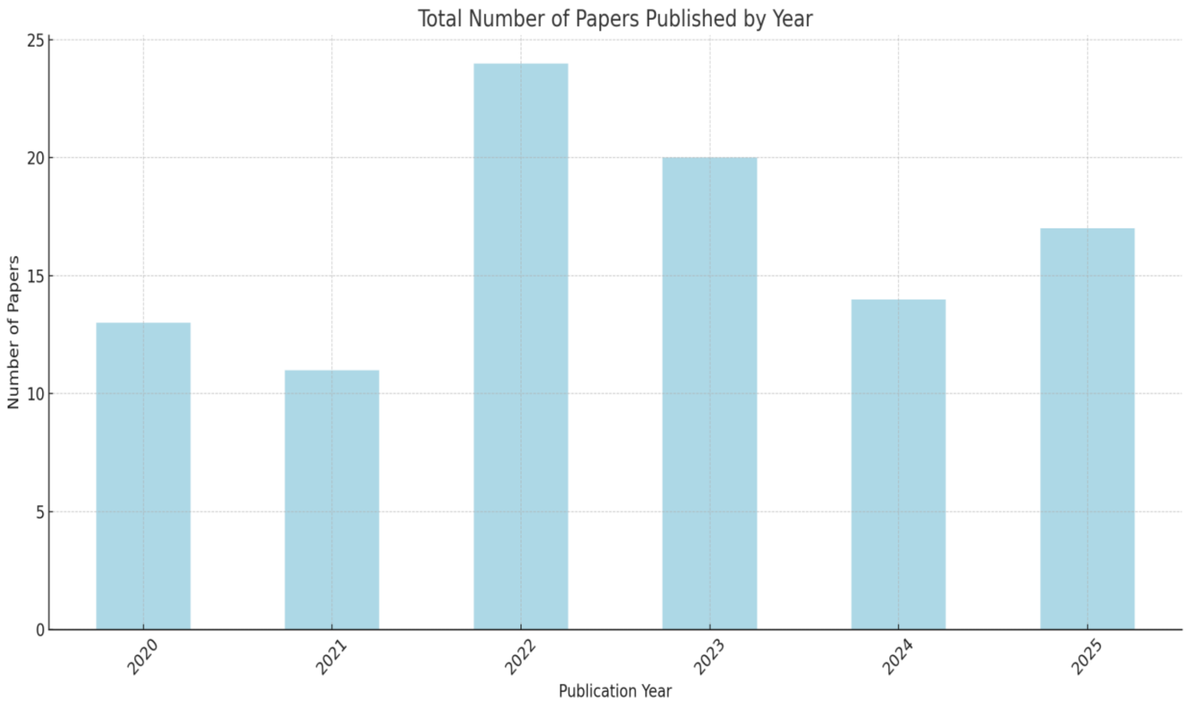
3

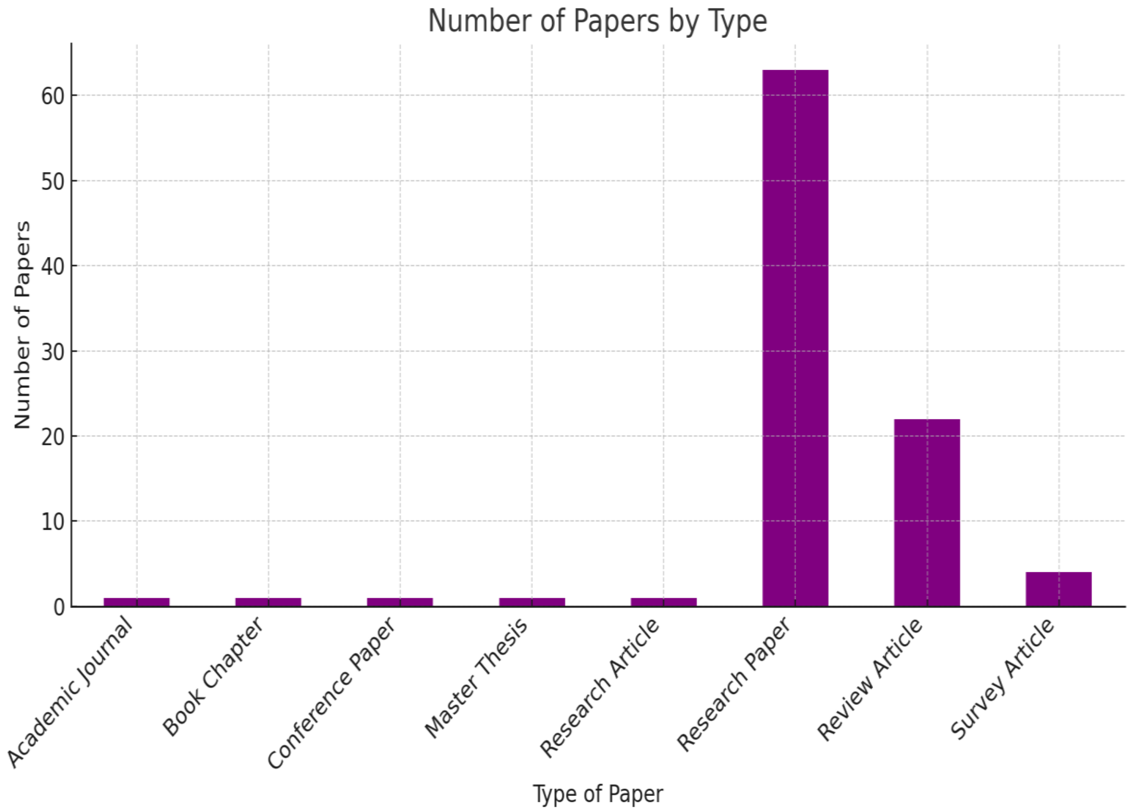
3. Organizing Papers: Found pre-final 20 papers and categorized them based on priority.

4

4. Final Selection: Reviewed papers in the "Selected" folder and chose 5 most relevant one

Outcomes of Research Methodology





Taxonomy

https://drive.google.com/file/d/1x_r32Ac8VEj5E6lJ-kfbexW42JcHj3qk/view?usp=sharing

Paper Summaries

Paper 1:Tanabe et al. – An Autonomous Closed-Loop Network Management System

What has been done?

- Combined two systems — KANVAS (monitoring) and Weaver (network design) to create a fully autonomous closed-loop network management system.
- Developed new modules such as failure localization, congestion detection, and a format converter to link both systems automatically.
- Built an automated workflow that detects a failure or congestion, generates recovery intents, redesigns the network, and applies changes without human action.
- Tested the system in realistic testbeds, including a campus network failure scenario and a VPN congestion scenario.
- Showed successful automated recovery, restoring a failed service in ~8.5 minutes and rerouting a congested VPN path in ~35 seconds.
- Demonstrated end-to-end automation, including VM creation, IP assignment, configuration updates, and route optimization.

Limitations

- Tested only on small-scale service networks.
- The system’s behavior in larger or multi-domain networks is not evaluated.

Future directions

- Improve the system to work across larger and more complex networks.
- Reduce the response time and make the system more scalable.

Paper 2: Hirayama et al. – Autonomic Closed-Loop Service Management Based on Interworking Multiple AI Models

What has been done?

- The paper presents a closed-loop management system that interconnects three different AI models to monitor, configure, and optimize cloud-native services automatically.
- The authors built a proactive failure-prediction system using logs and AI models like Autoencoder to detect issues before they cause service disruption.
- They redesigned and migrated services automatically using a configuration AI and an optimization AI, allowing services to move to healthy clusters without manual work.
- They developed a full prototype running on Kubernetes clusters, managing real microservices (like MySQL and RabbitMQ) and validating both service creation and service migration end-to-end.

Limitations

- The system is designed only for cloud-native environments.
- It does not cover broader network scenarios, such as hybrid or legacy networks.

Future directions

- Extend the system to support more network types.
- Improve the accuracy and speed of the AI models used in the loop.

Paper 3: Gomes et al. – Intent-driven Closed Loops for Autonomous Networks

What has been done?

- The paper presents an intent-driven system based on RDF models to coordinate many closed loops.
- It defines an “Intent Meta-Model” and uses SHACL rules so loops can automatically understand and validate intents.
- It introduces delegation, reporting, and escalation models to keep loops synchronized.
- The method is tested on a network slicing example using RAN and Core closed loops.
- A hierarchical closed-loop model is shown to reduce manual effort and improve alignment across domains.

Limitations

- Mainly demonstrates the concept through network slicing only.
- Does not deeply explore real-time fault handling across different domains.

Future directions

- Apply intent-driven coordination to more network functions.
- Improve how multiple closed loops share information and avoid conflicts.

Paper 4: Antonakoglou et al. – CAMINO: Cloud-native Autonomous Management and Intent-based Orchestrator

What has been done?

- The paper presents CAMINO, an intent-based orchestrator for automating cloud-native network functions.
- It uses the Configuration-as-Data model with GitOps to handle deployments, scaling, and configuration automatically.
- The authors built components like Domain Manager, Orchestration Manager, Network Manager, and monitoring tools.
- CAMINO manages multi-edge deployments and sets up service connectivity automatically using Istio Service Mesh.
- It provides zero-touch provisioning with real-time monitoring and admission control.

Limitations

- Limited to cloud-native setups.
- Does not address how it would work with mixed (legacy + cloud) infrastructures.

Future directions

- Extend support to hybrid networks.
- Improve automation capability for multi-domain deployments

Paper 5: Fallon et al. – Autonomic Closed Control Loops for Management, an idea whose time has come?

What has been done?

- The paper reviews how closed-loop control has evolved and how it fits into telecom management today.
- It explains why traditional TMN management systems make automation difficult.
- The authors describe the MAPE-K model and how autonomic loops work.
- They show examples like C-SON and ONAP where closed loops already exist.
- The paper outlines challenges preventing full autonomic adoption and what is needed to standardize closed loops in real systems.

Limitations

- Mostly conceptual; real-world implementations or testing are limited.
- Does not give detailed examples of large-scale deployments.

Future directions

- Develop clearer frameworks for applying closed loops in operational networks.
- Integrate these ideas into existing platforms like ONAP and NFV systems.

Conclusion and Future Research Directions

Conclusion:

The project highlights the progress made in autonomous network management using closed-loop control and intent-driven systems. Tools like Weaver, KANVAS, and CAMINO show strong potential for automating failure recovery, service migration, and network orchestration. However, challenges remain in scaling solutions across hybrid and legacy networks, as well as improving real-time decision-making and cross-domain coordination.

Future Research Challenges:

- **Scaling to Multi-Domain Networks:**
    - Expand solutions to cover hybrid and legacy networks.
- **Proactive Failure Management:**
    - Improve AI-driven predictions for quicker responses to issues.
- **Multi-Domain Coordination:**
    - Enhance coordination between closed loops in different management areas.
- **Standardization:**
    - Develop common APIs for smooth integration of different AI models and network components.
- **Handling Network Complexity:**
    - Tackle complexities in managing multi-layered networks for seamless operation.

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Thank you