American Journal of Applied Science and Technology

VOLUME Vol.06 Issue 04 2026
PAGE NO. 180-184
DOI 10.37547/ajast/Volume06Issue04-24

Research of Network Management Automation Algorithms Based on Software Defined Networking Technology

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Received: 18 March 2026; **Accepted:** 06 April 2026; **Published:** 30 April 2026

Abstract: This analytical article explores the potential of Software Defined Networking (SDN) technology in automating network management, in particular from the perspective of integrating artificial intelligence and machine learning algorithms. The principle of separating the control and data planes of the SDN architecture allows for centralization of network management and software flexibility. The article analyzes advanced algorithmic approaches to optimal controller placement, dynamic traffic management, predictive allocation of network resources, and closed-loop automation mechanisms. It also discusses the problems, limitations, and future research directions in the practical implementation of intelligent algorithms.

Keywords: Software Defined Networking, network management automation, machine learning, deep reinforcement learning, controller deployment, traffic optimization.

INTRODUCTION:

One of the main challenges facing modern telecommunications networks is the rapid growth of traffic volume, diversification of services, and increasing demands for real-time decision-making. Traditional network architectures, with their distributed control mechanisms, face limitations in ensuring flexibility and efficiency in such dynamic conditions.

Software Defined Networking (SDN) has emerged as a new paradigm to address these challenges. The main idea of SDN is to separate the control and data planes of the network. This approach allows for the integration of network intelligence into a logical, centralized controller and allows network devices (switches, routers) to be managed programmatically.

However, the SDN architecture itself has a number of challenges: the issues of controller performance, scalability, security, and optimal decision-making in dynamic network conditions remain relevant. It is at this point that the integration of artificial intelligence and machine learning algorithms with SDN has ushered in a new phase of network management automation. The purpose of this article. is to systematically analyze advanced algorithms used in network management automation based on SDN and evaluate their effectiveness.

The SDN architecture consists of three main planes: the data plane, the control plane, and the application plane. The data plane consists of physical or virtual devices that perform the function of routing network packets. The control plane is the logical center of the entire network, defines routing policies and has a global view of the network topology. The interaction between these planes is carried out through southbound interfaces such as OpenFlow.

The introduction of 5G networks and the exponential growth in the number of devices has made automation a critical requirement in network management. Traditional manual configuration and monitoring methods are ineffective at managing billions of connections, adapting to real-time traffic changes, and troubleshooting complex faults.

METHOD

Cisco experts say that three key components are necessary for successful automation:

- Visibility – the ability to monitor in real time the processes taking place in the network every second
- Concept – anomaly detection based on network analytics and data correlation
- Action – automatic decision-making to resolve identified issues and improve network health

This three-component model forms the basis of the concept of "closed-loop automation." In closed-loop automation, the network continuously monitors its state, analyzes the collected data, and independently makes necessary changes.

Algorithms used in SDN-based network management automation can be divided into several main categories according to their functional tasks. In multi-controller SDN architectures, the optimal controller placement problem (Controller Placement Problem – CPP) is of great importance. This problem is NP-hard and cannot be effectively solved in large networks using traditional methods.

Recent research has proposed a new approach called AP-DQN, which integrates the Affinity Propagation clustering algorithm with Deep Q-Network (DQN). In this approach:

- In the first phase, network switches are clustered based on criteria such as end-to-end latency, traffic load, connection costs, and security level.
- In the second stage, the controller deployment problem, modeled as a Markov Decision Process (MDP), is solved by a DQN agent.

Simulation results show that this approach provides a 24% improvement in load balancing, a 25% reduction in latency, and a 28% savings in operational costs compared to traditional methods.

Traditional SDN controllers use deterministic routing algorithms such as Dijkstra or ECMP (Equal-Cost Multi-Path). However, these algorithms cannot dynamically adapt to traffic changes.

A study conducted at the University of Tampere applied reinforcement learning algorithms to manage traffic in an SDN environment. The researchers integrated Q-Learning and Deep Q-Learning (DQN) algorithms with a RYU controller and OpenFlow switches. The results showed that the DQN-based agent achieved faster convergence and more stable routing performance than a tabular Q-Learning agent.

Predictive network control algorithms

Predictive models play a significant role in the efficient allocation of network resources. The Dynamic Predictive Feedback (DPF) mechanism implements short-term traffic forecasting based on clustered-LSTM, and predicts network congestion in advance and reallocates resources accordingly.

The DPF mechanism consists of the following components:

- Forecasting module – predicts queue depth and packet arrival intensity based on In-band Network Telemetry (INT) data
- Meta-controller feedback controller – continuously adjusts queuing parameters based on congestion risk and fairness criteria

Experimental results show that the DPF mechanism increases throughput by 32%, reduces latency by 40%, and uses 10-12% less CPU and memory resources compared to A-WFQ and DRL-based queuers.

Algorithms for allocating intellectual resources

Dynamic scaling of virtual network functions (VNFs) is a critical challenge in SDN/NFV environments. Machine learning-based proactive approaches enable automatic scaling or scaling of VNF resources, adapting to traffic changes in real-time.

Artificial intelligence techniques enable network management optimization through lightweight models that can work effectively, especially in resource-constrained environments (e.g., edge computing devices). Clustering and classification algorithms are being successfully used to support decision-making processes in resource-constrained SDN nodes.

Practical implementation of algorithms: Closed-loop automation

One of the most promising areas of application of theoretical algorithms in practice is the creation of closed-loop automation systems. Cisco's Crosswork Network Controller (CNC) platform is a practical embodiment of this concept.

The CNC platform is an SDN controller designed for networks based on segment routing, which includes a number of intelligent components:

Crosswork Optimization Engine (COE) – allows for real-time network optimization, ensuring efficient resource utilization and minimizing manual intervention.

Crosswork Health Insights (HI) – provides live KPI monitoring, alert generation, and automated troubleshooting. The user can define their own logic rules, and HI continuously monitors the health of the network based on these rules.

Crosswork Change Automation – automates routine operations such as configuration changes, installation and upgrades of new software versions. This process uses Ansible playbooks.

Crosswork Zero Touch Provisioning (ZTP) – fully automates the process of adding new devices to the network, loads day-0 configurations, and quickly integrates devices into the monitoring system.

All of these components work in an integrated manner, allowing the SDN controller to not only monitor the network, but also make independent decisions and implement them automatically.

Comparative efficiency of algorithms

The results of empirical studies conducted to evaluate the effectiveness of various algorithms can be summarized in the following table:

Algorithm	Scope of application	Main results	Delay	Conductivity	Operating expenses
AP-DQN	Controller placement	24% improvement in load balancing, 12% improvement in security	25% reduction	No information available.	28% decrease
DQN (Tampere)	Traffic management	Faster convergence compared to tabular Q-Learning	No information available.	Sustainable growth	No information available.
DPF (clustered-LSTM)	Predictive resource management	Fairness index ≥0.96, CPU/memory consumption 10-12% less	40% reduction	32% increase	No information available.

The table shows that predictive models based on deep reinforcement learning (DQN) and LSTM show significantly higher performance than traditional algorithms. In particular, the DPF mechanism reduces latency by 40% and increases throughput by 32%, which is important for real-time services (VoIP, video conferencing, online games).

The 28% reduction in operational costs of the AP-DQN approach is a significant indicator of cost-effectiveness for large network operators. Also, the 12% increase in security level of this approach expands the possibilities of application in environments with high risk of cyber attacks.

Despite the positive results obtained, there are a number of problems in implementing network management automation algorithms based on SDN:

Model training and adaptability. Most proposed models are trained offline and have delays in adapting to real-time network changes. In the future, the development of online learning mechanisms, the implementation of multi-agent systems and distributed control architectures are urgent tasks.

Computing resource constraints. Complex neural network models require high computing power. This is especially problematic for edge computing devices. The development of lightweight AI models and in-network computing technologies is crucial to solving this problem.

Standardization and interoperability. The issue of interoperability between SDN controllers and algorithms from different manufacturers has not yet been fully resolved. The development of OpenAPI and standard interfaces, the introduction of declarative modeling languages, will help to mitigate this problem.

Data quality and security. Machine learning algorithms rely on high-quality and representative data sets. Anomalies in network traffic, cyberattacks, or errors in data collection can cause algorithms to make incorrect decisions. At the same time, centralized SDN controllers and their intelligent algorithms also create new attack vectors.

The following can be identified as future research directions:

- Integrating federated learning methods with SDN
- Applying intelligent algorithms in multi-domain SDN environments
- Applying explainable AI models to network management
- Developing ultra-low latency algorithms that meet the requirements of 6G networks

CONCLUSION

Software Defined Networking technology creates a solid foundation for automation by centralizing network management and providing software flexibility. The integration of artificial intelligence and machine learning algorithms with SDN allows networks to not only be automatically managed, but also to transform them into "self-healing", "self-optimizing" intelligent systems.

Research shows that deep reinforcement learning (DQN) is more effective in optimal controller placement and dynamic traffic management, while LSTM-based predictive models are more effective in pre-allocation of resources. Hybrid approaches such as AP-DQN allow for simultaneous optimization of multiple objectives (latency, throughput, security, cost).

From a practical implementation perspective, closed-loop automation platforms (such as Cisco Crosswork) are enabling network operators to implement intelligent network management by combining monitoring, analytics, and automated action steps.

In the future, the integration of advanced approaches such as online learning, multi-agent systems, and federated learning into SDN architecture is expected to usher in a new era in network management automation.

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