Autonomous Network Healing Using AI-driven Diagnostics and Corrective Actions

AI for System Edges and Networking

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Motivation for Selecting This Idea:

In network infrastructures, maintaining high availability and performance becomes more complex, particularly in distributed environments like edge computing and cloud networks. Manual detection and resolution of network issues are increasingly inadequate in these dynamic settings. Autonomous Network Healing addresses this challenge by leveraging AI for diagnosing and resolving network anomalies in real time. The potential for such systems to automatically detect, diagnose, and mitigate network issues without human intervention is not only aligned with industry trends toward self-managing networks but also has the potential to significantly reduce operational costs and downtime.

This project stems from the increasing demand for networks that can self-heal, detecting and correcting their own issues before they impact users or services. The idea of using AI-driven anomaly detection is particularly compelling. It can drastically improve efficiency in network management. Unlike traditional monitoring methods that rely on predefined thresholds, AI-based systems can dynamically adapt to network conditions, making them capable of detecting anomalies such as traffic congestion, link failures, and misconfigurations in ways that static rules-based systems cannot.

Project Focus: Network Anomaly Detection

The Problem: Network Anomalies

The core problem we are addressing is network anomaly detection by identifying irregularities in the network's behavior that could lead to performance degradation or failures.

Some anomalies can include:

- Traffic Congestion: Sudden spikes in traffic that overwhelm a network node or link, causing delays and potential packet loss. Is a real-time issue that requires immediate rerouting or load balancing.
- Link Failures: The disruption of communication pathways due to hardware issues, misconfigurations, or environmental factors. Is a real-time issue that may need node isolation or reconfiguration of routing protocols.
- Routing Issues or Misconfigurations: Incorrect routing or misconfigured network elements that disrupt optimal data flow, leading to bottlenecks or network partitioning.

The traditional approaches to network monitoring typically rely on static thresholds or predefined rules to flag issues. These approaches fall short in dynamic environments like cloud or edge computing, where network conditions are constantly changing, and problems may not follow predictable patterns. For AI-driven methods, particularly those using machine learning and reinforcement learning, they offer the ability to detect anomalies by identifying deviations from normal patterns of network behavior. These Machine learning models can be trained on historical network data to identify normal operation states. Reinforcement learning can be used to take corrective actions based on real-time feedback loops.

Approach: Detailed Plan for Anomaly Detection and Autonomous Healing
Network Model: We are focusing on distributed networks like those used in cloud infrastructures or edge computing environments. These networks are often heterogeneous, consisting of nodes with varying processing and network capacities. Each node or link in the network is subject to potential issues such as failures, traffic congestion, or misconfigurations that could lead to anomalies.

Anomaly Detection Mechanism: The anomaly detection system will be based on a combination of unsupervised learning methods, such as clustering or autoencoders, and reinforcement learning.

- Unsupervised Learning: Autoencoders or clustering algorithms will be used to detect deviations in the network's normal traffic patterns. These methods don't require labeled datasets, which makes them suitable for detecting new, unforeseen anomalies in real time. By training models on normal network behavior, we can use them to spot anomalies in live traffic data.
- Reinforcement Learning (RL): RL will be used to automate corrective actions when an anomaly is detected. For instance, if a link failure is detected, the RL model will identify the optimal path to reroute traffic. The model will "learn" over time by taking corrective actions and receiving feedback based on network performance (e.g., reduced latency or packet loss).

Modeling Network Conditions: We will simulate different types of anomalies using NS3, a network simulator that allows us to model and study the behavior of various networking scenarios in detail. Examples of how we will model conditions:

- Traffic Congestion: Simulate high traffic loads at specific nodes to observe how the system reroutes traffic.
- Link Failures: Deliberately disable communication links to mimic hardware failures and measure the system's response time in re-establishing new paths.
- Misconfigurations: Introduce incorrect routing tables or IP address configurations to observe how the AI detects and resolves these.

The choice of NS3 is justified because it provides fine-grained control over network scenarios, allowing us to model complex topologies and simulate failures realistically. This will enable the system to be tested under a wide range of conditions, providing a robust environment for evaluating AI-based anomaly detection and autonomous healing mechanisms.

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<u>System Metrics:</u> To measure the effectiveness of the autonomous healing system, we will focus on the following key performance indicators:

- <u>Detection Latency:</u> How quickly the system detects an anomaly after it occurs.
- <u>Restoration Time:</u> The time taken to resolve the anomaly and restore normal network operations.
- <u>Downtime Reduction:</u> Total reduction in network downtime compared to manual intervention methods.
- <u>Efficiency:</u> The overall impact on network performance, measured by throughput, packet loss, and latency, before and after the anomaly occurs.

The goal of this project is to narrow the focus to network anomaly detection. We can develop a more concrete and testable system that addresses a specific challenge within network management. The use of AI-driven models, coupled with NS3 simulations to replicate real-world conditions, will allow us to evaluate the potential of autonomous network healing systems to revolutionize how networks are managed. This approach will directly tackle the scalability issues of manual intervention, reduce downtime, and optimize network performance through intelligent, automated corrections.

<u>The next steps will involve:</u>

- Defining the specific machine learning models to be used
- Collecting historical network data for training
- Setting up the simulation environment in NS3.

References and Related Work

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