TRON: Traffic Management and Resource Allocation for SDN-Enabled 5G/6G Networks

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***Abstract*—The evolution of Software-Defined Networking (SDN) and network slicing has revolutionized network management in Fifth-Generation (5G) and Sixth-Generation (6G) systems to enable flexible and programmable resource control. However, efficient traffic management and dynamic resource allocation under heterogeneous traffic demands remain challenging. This paper proposes TRON, an adaptive traffic management and resource allocation framework that leverages OpenFlow Group Tables to optimize link utilization across network slices for data and VoIP traffic. Integrated with the Ryu SDN controller, TRON employs real-time flow redirection and intelligent traffic splitting. Experimental evaluations using Mininet and Open vSwitch show that TRON improves link utilization by 22.5%–43.25% and network throughput by 31.64%–56.55% compared to baseline approaches. The simulation results highlight that TRON provides a lightweight and real-time traffic management framework for SDN-enabled 5G/6G networks.**

***Index Terms*—5G/6G Network, SDN, Group Table, Traffic Management, Mininet Emulator.**

I. Introduction

The emergence of Software-Defined Networking (SDN) and network slicing has revolutionized modern network architectures by enabling dynamic, flexible, and programmable network management [1]. Network slicing is a fundamental concept in 5G and emerging 6G networks to facilitate the creation of multiple virtual network instances over a shared physical infrastructure [2], [3]. One of the key challenges in SDN-based network slicing is ensuring efficient resource allocation, adaptive traffic handling, and network resilience [4]. In this work, we address these challenges by leveraging the link utilization capabilities of OpenFlow's Group Table. We introduce an adaptive traffic management scheme named TRON, which utilizes Group Tables to optimize link utilization across network slices dedicated to different traffic types, such as data traffic and Voice over Internet Protocol (VoIP) traffic. By integrating this mechanism with the Ryu SDN controller, our framework enables real-time traffic adaptation through dynamic flow redirection, Quality of Service (QoS) enforcement, and intelligent traffic splitting capabilities that surpass traditional methods. Figure 1 depicts the proposed Group Table-based traffic management architecture. It demonstrates how multiple hosts are interconnected through SDN-enabled switches, controlled centrally by an SDN controller. The Group Tables at various switches dynamically manage the outgoing and incoming traffic of buckets for link utilization. The proposed approach is validated using Mininet network emulator and Open vSwitch.

II. System Model

We consider set of IoT devices $\mathcal{N}$ as hosts that generate the data traffic passing through the set of SDN switches $\mathcal{S}$. Each switch maintains OpenFlow's Group Table and each Group Table has multiple buckets with different weights and traffic splitting policies. Let $\mathcal{L}$ be the set of physical links between switches and λ_i denotes the traffic arrival rate from an IoT device $i \in \mathcal{N}$. Each link $l \in \mathcal{L}$ has a capacity denoted by C_l, and its utilization at time t is represented by $U_l(t)$. Associated with each link $l \in \mathcal{L}$, there is a Group Table consisting of a set of buckets $\mathcal{B}_l$. Each bucket $b \in \mathcal{B}_l$ has an assigned weight w_b such that the bucket weights satisfy the normalization condition $\sum_{b \in \mathcal{B}_l} w_b = 1$, and lie within the range $0 \leqslant w_b \leqslant 1$.

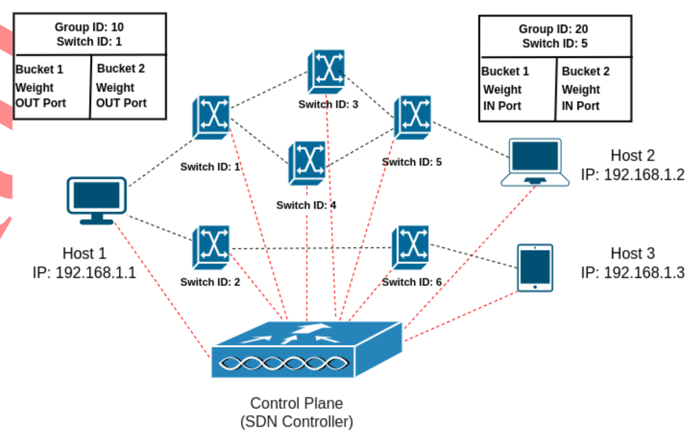


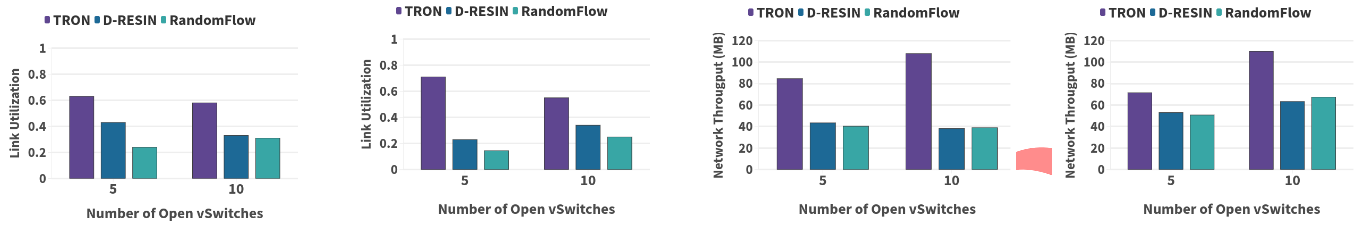
Fig. 1: Schematic Architecture of Traffic Management using Group Tables in SDN-Enabled 5G/6G Networks.

Definition 1. *The incoming traffic to each switch $s \in \mathcal{S}$ is split across buckets based on their weights. Thus, we define the traffic allocated $\lambda_b(t)$ to a bucket $b \in \mathcal{B}_l$ at time t as follows:*

$$\lambda_b(t) = w_b \times \sum_{i \in \mathcal{N}} \lambda_i(t) \tag{1}$$

Definition 2. *We define link utilization $U_l(t)$ of each link $l \in \mathcal{L}$ at time t as the ratio of the total incoming traffic on the link to its capacity C_l. Mathematically,*

$$U_l(t) = \frac{\sum_{i \in \mathcal{N}} \lambda_i(t)}{C_l} \tag{2}$$



(a) Link Utilization for Data Traffic

(b) Link Utilization for VoIP Traffic

(c) Network Throughput for Data Traffic

(d) Network Throughput for VoIP Traffic

Fig. 2: Performance Analysis of the TRON Framework in terms of Link Utilization and Network Throughput.

III. TRON: The Proposed Traffic Management and Resource Allocation Framework

We propose a lightweight heuristic framework, named TRON, for adaptive traffic load balancing in SDN-enabled 5G/6G networks. Initially, the controller assigns predefined bucket weights $w_b(t)$ across the available paths to distribute the traffic load. The controller collects traffic statistics from each switch including flow counts and byte counts for each group table by sending OpenFlow `GroupStatsRequest` and `GroupDescStatsRequest` messages. The controller objective is presented in Equation (3) to dynamically update the bucket weights $w_b(t)$ of group table of each switch $s \in \mathcal{S}$ over time t based on Definition 1.

$$\min_{w_b(t)} \max_{l \in \mathcal{L}} U_l(t) \tag{3}$$

Using the collected statistics, the controller estimates the link utilization $U_l(t)$ for each link $l \in \mathcal{L}$ based on Definition 2. If the link utilization exceeds a predefined threshold θ, the controller updates the bucket weights. Specifically, it decreases $w_b(t)$ for heavily loaded paths and increases $w_b(t)$ for lightly loaded paths according to the rule as follows:

$$w_b(t+1) = w_b(t) \times (1 - \alpha(U_l(t) - \theta)) \tag{4}$$

where α is a positive constant to control the magnitude. Following the weight adjustment, the controller normalizes the updated bucket weights to satisfy the constraint $\sum_{b \in \mathcal{B}_l} w_b(t+1) = 1$. Finally, the controller reprograms the switches by sending updated `OFPGroupMod` messages containing the new bucket weights $w_b(t+1)$. The network throughput $T(t)$ at time t is represented as the sum of the received traffic rates $\lambda_i^{recv}(t)$ at the receiver hosts from all IoT devices. Mathematically,

$$T(t) = \sum_{i \in \mathcal{N}} \lambda_i^{recv}(t) \quad \forall i \in \mathcal{N} \tag{5}$$

IV. Performance Analysis

We used Mininet network emulator with Ryu SDN controller, and Open vSwitch. We used two topological configurations, consisting of 50 IoT devices distributed among either 5 or 10 Switches through TCLink links, each configured with a 10 Mbps link capacity. Traffic is generated using iPerf, including both TCP flows (for data) and UDP flows with QoS tags (for VoIP) over a 120 seconds interval. The performance of the proposed TRON framework is evaluated in terms of link utilization and network throughput for heterogeneous traffic against two benchmark schemes: D-RESIN [5] and RandomFlow. For data traffic, TRON improves link utilization by approximately 22.5% compared to D-RESIN and by 33% compared to RandomFlow as shown in Figure 2(a). Similarly, for VoIP traffic, TRON achieves an improvement of 34.5% over D-RESIN and 43.25% over RandomFlow as shown in Figure 2(b). As depicted in Figure 2(c), TRON improves network throughput by 55.44% and 56.55% compared to D-RESIN and RandomFlow, respectively for data traffic. Similarly, for VoIP traffic, TRON improves network throughput by 32.6% and 31.64% in comparison to D-RESIN and RandomFlow, respectively as shown in Figure 2(d). In summary, the evaluation results confirm that TRON effectively enhances link utilization and network throughput under heterogeneous traffic conditions in SDN-enabled 5G/6G networks.

V. Conclusion

In this paper, we presented TRON, an adaptive traffic management and resource allocation framework for SDN-enabled 5G/6G networks. The TRON framework leverages OpenFlow's Group Tables to enable dynamic traffic splitting and enhance overall network throughput. In future work, we plan to enhance TRON by integrating deep learning, game-theoretic models, and advanced optimization techniques with potential applications in edge-cloud architectures for latency-sensitive industrial and smart city environments.

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