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A Simulated Smart Patient Room: Dynamically Allocating Bandwidth To Wearable Sensor's Critical Data For Real-Time Health Monitoring By Integrating Iot, Telemetry And Edge Computing

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Abstract

In the current healthcare era, a lot of network traffic data is generated via the Internet of Things (IoT) devices and wearable IoT sensor-based devices. An efficient and fast management of the high priority vitals data generated from these devices is crucial for the health monitoring of a critical patient. In remote places, health monitoring could be a challenge due to limited bandwidth and unreliable internet connectivity.

This paper proposes a dynamic traffic prioritization scheme for healthcare IoT networks using software-defined networking (SDN) principles. The proposed model leverages the Ryu controller's capabilities to intelligently manage traffic flow, prioritize critical health data while minimizing the transfer of non-urgent data and allocate bandwidth dynamically based on the criticality of the transmitted information. The model incorporates a queue size estimation algorithm utilizing Exponential Weighted Moving Average (EWMA) for high-priority queues and simple averaging for medium and low-priority queues. Queue sizes drive weight adjustments, where weights represent the relative importance of each traffic category. Bandwidth allocation is dynamically computed based on these weights, ensuring that critical health data receives higher priority over non-urgent traffic. Proactive adjustments, such as traffic prioritization and dynamic bandwidth allocation enhances the system's responsiveness and adaptability to changing network conditions.

Keywords: *Internet of Things, Wearable devices, healthcare, traffic prioritization, load balancing, SDN, Telemetry, Data Analysis, Edge computing, Dynamic Bandwidth Allocation, Mininet-WIFI, Sensors.*

Introduction

The rapid evolution of the Internet of Things (IoT) has revolutionized communication scenarios, creating a seamless environment where all addressable objects can communicate and cooperate [1][2][3]. This paradigm shift opens new avenues for the development of innovative services tailored to[1] both personal and professional needs [4]. Among these opportunities, the prospect of enabling humans to access and control remote machines for desired tasks emerges as a transformative application of IoT.

IoT's implementation spans diverse sectors, including Smart Cities [5], manufacturing [6], healthcare [7][8], Smart Homes [9][10], smart grids [11], and transportation and logistics [12][13]. This widespread integration has not only transformed existing infrastructures but has also given rise to novel business opportunities.

This technical research study focuses on the benefits of continuous health monitoring facilitated by the rapid proliferation of IoT-enabled healthcare devices, ranging from wearables and remote sensors to smart implants [14]. Beyond medical devices, the integration of everyday items like TVs, lights, and fans in patient rooms establishes a comprehensive and interconnected healthcare ecosystem.

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Wearables, such as fitness bands, and wirelessly connected medical devices like blood pressure and heart rate monitoring cuffs and glucometers, provide patients with unprecedented access to personalized attention. These devices can be finely tuned to send reminders for critical health parameters, including calorie counts, exercise regimens, upcoming appointments, and real-time monitoring of vital signs.

For the vulnerable demographic of elderly patients, IoT has become a transformative force by enabling continuous tracking of health conditions [15]. This has profound implications for individuals living alone and their families, offering a vital lifeline through an alert mechanism that signals family members and healthcare providers in the event of any disturbances or deviations from routine activities.

However, managing the myriad IoT devices efficiently and cohesively demands a centralized approach. In this context, Software-Defined Networking (SDN) emerges as a pivotal tool, providing a robust framework for the centralized management and orchestration of the diverse IoT devices employed in healthcare settings.

This paper aims to delve into the technical intricacies of utilizing SDN for the efficient management of a multitude of IoT devices, with a specific focus on healthcare applications. By presenting real-world applications and case studies, we seek to elucidate the transformative potential of IoT in healthcare and underscore the critical role of SDN in achieving seamless integration and management of these interconnected devices. The contribution of this paper is threefold.

A remote, real-time, and secure patients healthcare monitoring architecture using Telemetry and SDN is discussed in here where SDN will manage the devices and through telemetry all devices were continuously monitored and managed.

this paper aims to evaluate related research on designing and implementing an IoT-based Remote healthcare monitoring system that can be utilized in urgent conditions. This system depends totally on IoT devices and sensors (connected on wearable devices mostly) to connect patients with the doctors, nurses and their family members.

The main contribution of this research paper is to highlight IoT -based centralized SDN and telemetry monitored healthcare systems in detail. and making the robust system and intelligent system which can work in emergency needs on the limited network resources also because in villages and many areas bandwidth of network and data dropping is major problem. In this research paper, we provide a general idea of critical stations traffic processing on network at priority. We have used Markov model for poisson traffic. Moreover, we discuss the usage of wearable things (bands, ECG, Bp monitoring ..) in healthcare systems from an IoT perspective.

This paper is organized as follows: In Section 2, we discuss and understand the most relevant existing works. Our proposed architecture and design goals are presented in Section 3. In Section 4, we describe in detail implementation using SDN Mininet tool followed by experimental results and performance evaluation in Section 5. Finally, Section 6, comparison of traffic coming from different stations on concludes this paper. This research underscores the advantages of ongoing health monitoring, customized care, prompt disease detection, and minimized hospitalization (if the patient condition is not alarming). It also accentuates the obstacles in healthcare IoT networks: diverse traffic types with varying latency and bandwidth demands, security and reliability requirements (possible to be done at controller, out of scope for this paper), and the growing number of connected devices. To address these challenges, the main objective of this paper is to propose a novel intelligent network management framework for healthcare IoT.

I. LITERATURE REVIEW

Existing frameworks and systems that utilize IoT, Software-Defined Networking (SDN), telemetry, and load balancing in healthcare settings have been used in this paper. However, these approaches have limitations, and the proposed framework seeks to usage of these in

Remote Health monitoring of patients. The critical analysis of the limitations of existing approaches and the finding of the gaps in previous work, We proposed framework aims to fill those crucial gaps to achieve the desired results.

A. INTERNET OF THINGS

Several billion devices are connected to the Internet. These are growing continuously as reported by Gartner , which states that approximately 8.4 billion devices were connected to the Internet. This number increased by 30 billion in the coming years by 2030, due to the Internet of Things (IoT) concept that seems to be the backbone of the future connected world.

The IoT is a new and most discussed paradigm in communication, which is the interconnection of existing small and high end devices with additional intelligence using sensors. These devices process the sensed data and communicate with other devices through the internet [16], [17]. Initially, the IoT devices were operated in the unlicensed band using ZigBee and Bluetooth technologies. Currently, the 4G and 5G mobile infrastructures are used for IoT deployment. However, they do not fulfill the IoT requirements, and new technologies and protocols are needed to improve the existing capabilities. IoT devices have the limitation of short-range transmission of traffic for these devices and the unlicensed spectrum is also overcrowded because of over usage.

IoT devices can use the licensed spectrum and concepts of cognitive radio (CR). A CR is capable of using the licensed spectrum when it is free, and this will make IoT devices capable for long-range applications. Similarly, the notion of Licensed Spectrum Access (LSA) in 5G, which is an implementation of the CR concept. In this way, the applications of IoT are expanding into various fields, which causes different challenges, like security and privacy of IoT devices and networks.

o IoT-based healthcare systems and their applications facilitates people's lives in different ways, such as remote healthcare using IoT based solutions bring healthcare facility to patients rather than the patient to approach to healthcare. Data are collected through IoT-based sensors, and the data are stored and analysed by a program(IoT based programs and techniques running on centralized station or edge devices) before being shared with healthcare professionals for consultation or checkup. Telemetry will be used for real-time monitoring of IoT-driven devices. They are non-invasive sensors which monitors and collect comprehensive psychological information. Edge devices like gateways manage the storage of data on cloud or locally. Preventive care possible in IoT healthcare systems using sensor data, which help with the early detection of emergencies and alerts family members. Machine Learning for Health Trends is the IoT approach allows for health-trend tracking. Machine learning algorithms detect anomalies early, aiding in proactive healthcare management[18].

B. SOFTWARE DEFINED NETWORKS

The main concept of the software-defined network (SDN) is to decouple the network control from forwarding functions, i.e., to decouple the control and data plane [18]. The control plane decides the rules on network devices and controls the network behavior. In this unlike traditional networks each networking device forwards data packets according to the rules configured on that device. The SDN helps to simplify the management of current networks like IoT networks and controls the huge traffic generated by them. Mostly the IoT, AI based networks, Machine learning models using networks, Cloud Computing, and Big data based Systems. These technologies have caused exponential growth in the connectivity of variety of IoT devices to the internet [19]. The logical centralized controlled intelligence of the SDN architecture represents a plethora of challenges due to its single point of failure [20]. It remains the prime obstacle that may throw the entire network into chaos and thus expose it to various known and unknown security threats and attacks[21]. Software-Defined Networking (SDN) is beneficial to healthcare in several ways, Improved Network Management SDN simplifies the management of network infrastructure, making it easier for healthcare professionals staff to manage and scale the network. SDN can enhance security measures because various security algorithms can be on this to support and secure the network. It can track sensitive information and ensure the safety of medical records. Support for IoT Devices: With the increasing number of Internet of Things (IoT) devices and wearable devices introduced into the healthcare industry, SDN can help in manage them from a centralized location and vendor independence. SDN can make efficient usage of money and time by managing all devices from centralized location and automating the system and reducing manpower cost and because it allows access to each facility through network resource provisioning. SDN also supports agile environment because network changes are no longer a bottleneck nowadays for developing new applications. It has been used to support telemedicine health consultations by managing network congestion and facilitating real-time transmission of medical data. In summary, SDN can address challenges with compliance, data protection, management complexity, mobility, and the accelerated development of new applications in healthcare.

C. EDGE COMPUTING

Edge computing is an efficient paradigm that extends Cloud computing. It provides low latency data services by bringing computing resources close to the edge of an IoT-enabled network. The purpose is to alleviate the processing and traffic load from low-powered IoT devices to powerful servers at the edge. In Figure 1,Medical Gateway might be mobile device collects data via Lora WAN, Bluetooth or Wi-Fi from wearable sensor and other devices connected to patient body. Mobile device acts as an edge device that collects and preprocesses the data generated by IoT devices and wearable devices around patient before transmitted to the controller running on network endpoint . Medical Gateway is behaving here as an edge device that has used to reduce latency in collecting critical data. [22,23,24,29].

The medical gateway will complete data collection activities from sensors locally, lowering the network overhead of transmitting a lot of sensor data to the network separately. This can also be easily integrated with other wireless networks to solve network and computational issues. This will transfer the data to switch and then controller for Quality of Service (QoS) based processing because it is having critical sensors data, so that for prior execution different techniques can be used by controller

II. METHODOLOGY

The Proposed Framework

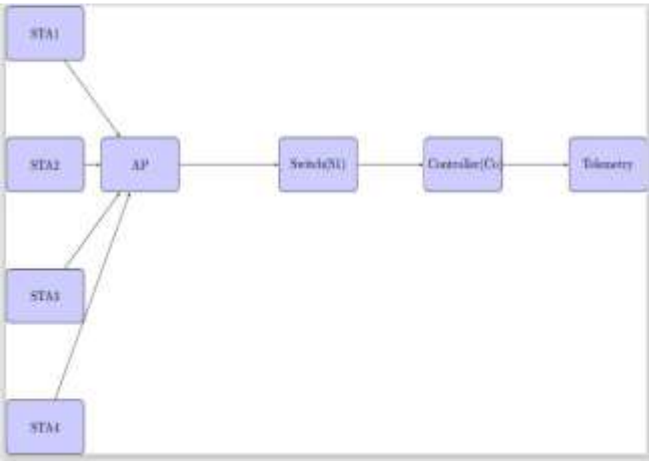


Figure 1: Simulated Smart Patient Room

As depicted in Figure 1, incorporates IoT devices, which collect data from connected devices such as sensors and wearable devices placed on and around the patient's body, as well as the SDN RYU controller and telemetry system. The traffic is prioritized, with emergency alerts such as patient blood sugar, blood pressure, temperature, heartbeat, and sodium levels receiving top priority. Second priority is given to camera real-time monitoring, while third priority is assigned to other data traffic.

1. Medical Gateway Device(STA4): A smartphone or a dedicated hub that collects data of patient health from wearable sensors discussed below (likely via Bluetooth, Zigbee, LoRAWAN or a similar short-range protocol) and preprocesses or aggregates the data as needed. It Securely transmits data to an access point. It also prioritizes vital signs for patient health, which are MOST critical vitals for patients. If the vitals are in range, The data transfer and bandwidth allocation will be of high priority for the traffic generated by all devices. The movement reading of these vitals go above or below the fixed reading alarm wii be buzzed by the Medical Gateway for this station.

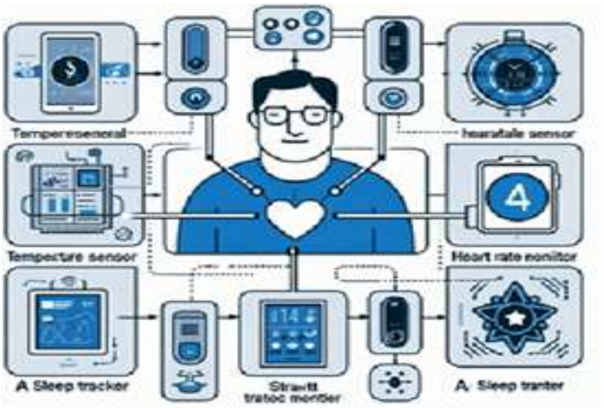


Figure 2: Wearable Sensors placed on patient body.

1.1 Wearable sensors for health monitoring of patients.

As Shown in Figure 2, Wearable sensors connected to patient body and continuously monitoring patient vitals are sent to Medical Gateway.

Blood pressure cuff: Noninvasive and inflatable cuff for regular blood pressure measurements.

Pulse Oximeter: A clip-on sensor measuring blood oxygen saturation (SpO2) levels.

Body Temperature Sensor: A wearable patch or thermometer for continuous temperature monitoring.

Wearable ECG Monitor: Continuous tracking of heart rate and rhythm. It can detect arrhythmias or other anomalies.

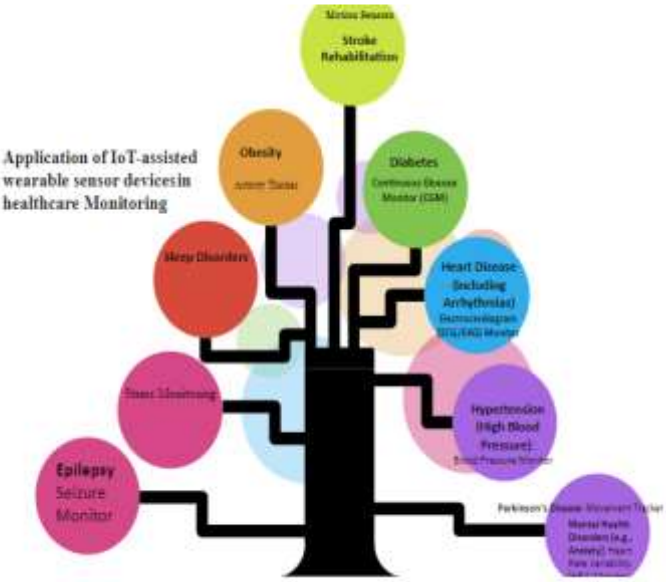
Supplemental Monitoring (Depending on Patient Condition)

Continuous Glucose Monitor (CGM): A small sensor worn for real-time blood glucose tracking is crucial for diabetes patients.

Respiration Rate Monitor: Wearable sensors to monitor breathing patterns.

Weight Scale: Connected scale to track weight, which can be an important indicator of fluid retention or other health issues.

Figure 3. IoT assisted wearable sensor devices in healthcare monitoring



Fall Detection and Safety based :

Smart Bed Sensor: A sensor placed under the mattress that can monitor sleep patterns and movement, it can detect falls out of bed.

Motion Sensors: Placed strategically in the different locations of room to detect falls or patient unusual movement patterns. Smart Speaker, Voice-controlled for patient requests, medication reminders, or communication with healthcare providers. Smart lights like adjustable lighting for patient comfort as per day and night with circadian rhythm support.

2. Camera for Patient (STA3)

Integrated video conferencing using the camera for direct communication between doctor or healthcare service provider and patient. It is required only in case of a critical emergency. Nowadays remote surgeries are possible because of this type of facilities. It is having the second highest priority.

3. Patient Dashboard Section For Presentation of Data in Room (STA2):

This Dashboard is generally used by Nurses or other health staff for keeping local records of patient information. Below are the details generally it keeps.

3.1 Real-time Vitals:

Large, clear display of current heart rate, blood pressure, SpO2, and respiration rate. Color-coded indicators or subtle animations to signify values within normal, cautionary, or critical ranges. This is to just display general health statistics of patient.

ECG Waveform Display: A small scrolling view of the live ECG feed.

3.2 Critical Alerts:

Dedicated section for immediate notifications generated from AI/rule-based analysis of sensor data (e.g., arrhythmia detected).

Implantable cardiac monitor events

Patient-triggered alerts (via a button on the wearable or smart speaker)

It generally shows both visual and potentially audible alerts for high-priority events.

3.3 Historical Trend Graphs

Select the time range (last 24 h, week, and month).

Overlay multiple vitals on a single chart for correlation (e.g., periods of low SpO2 and heart rate variations).

Allow zooming in specific sections of the graph for detailed analysis.

3.4 Medication Log:

Data from the smart pill dispenser on whether the medication was prescribed.

Include reminders for future doses.

3.5 Patient Notes:

A section for healthcare providers to log observations, changes in treatment plans, or communication with patients.

Potential for the patient to log symptoms or mood if they are able.

4. IoTLights (STA1)

It represents background traffic devices (IoT-enabled lights in the room).

5. Ryu Controller's Role

Ryu has a universal view of the patient room network (Wi-Fi access point, patient gateway, and potentially other network devices). It plays a pivotal role in enhancing the intelligence, flexibility, scalability, and proactiveness of healthcare systems' centralized network management. This enables the optimization of traffic routing and prioritization decisions.

5.1 Telemetry driven Control

Ryu collected network-level telemetry by Making informed decisions about strategically routing specific traffic flows based on telemetry insights about the network state. Here it does link utilization by checking if the congestion is there on the wireless link or the patient gateway's uplink to the internet. RSSI Monitors wireless signal strength between IoT devices connected to Ryu controller via switches. It is expected that signal strength will be more for Medical Gateway, because patient wearables devices are connected to the gateway.

5.2 Reactive and proactive action

Prioritizing Heart Data: If congestion is detected or critical health events occur, Ryu increases the priority of health traffic. Dynamic adaptation means during congestion, Ryu can dynamically adjust traffic priorities. For example, it might elevate the priority of heart rate data transmission during critical moments. Depending on device capabilities, Ryu enforces Quality of Service (QoS) policies, allocating bandwidth appropriately and shaping traffic to meet specific requirements. Wearable sensors data if drifts from assigned ranges for any sensor, then generate the automatic alarm in system. because its highest priority. For some health parameters Ryu does Threshold-based detection like it defines simple rules based on medical knowledge.

For example:

```
if heart_rate > 120 or blood_pressure < 90/60: trigger_alert()
```

similarly for other factors

5.3 Proactive Monitoring: If RSSI degrades, suggesting potential connectivity issues with wearables, Ryu can preemptively adjust the network or raise an alert for maintenance.

Prioritization of Traffic generated by IoT Stations (STA1-STA4) :

If congestion or critical health events data arrives, Ryu reacts by prioritizing essential traffic. For example, patient body vitals monitoring data takes precedence over non-health-related data. For the Same below a Dynamic bandwidth allocation model will be used

QoS Adjustments using Dynamic Bandwidth Allocation Model:

Ryu can enforce QoS policies based on device capabilities. For instance, it will allocate more bandwidth to critical health services i.e traffic coming from station 4(STA4) and less bandwidth to low priority data by station 4(STA4) and less bandwidth to low priority data by adjusting the queue sizes and their weight as per the traffic in network .

Proactive Monitoring using Telemetry:

When RSSI degrades (indicating potential connectivity issues with wearables), Ryu takes preemptive measures by adjusting network parameters (like device location) to improve signal quality. Ryu Controller's intelligent management ensures efficient healthcare network operations, responsiveness to critical events, and proactive maintenance.

Hypothetical Scenario to Handle traffic coming from stations (STA1-STA4).

A heart patient experiences a sudden arrhythmia. The ECG sensor detects this, and the analytics engine generates an alert. Whenever Ryu receives critical event notification.

Ryu controller comes into an Action: It Immediately maximizes using the "Dynamic bandwidth allocation model" discussed below. Potentially lowers the priority of non-essential traffic in the room (if other devices are present). If the patient or a caregiver initiates a video call (traffic coming from STA2) with a doctor, Ryu ensures the best possible video quality and minimal latency using a dynamic bandwidth allocation model. Ryu routed traffic based on priority queues.

6. **Experiment**

6.1 Topology Structure Running Ryu Application Logic

1. Mininet WIFI: Create a Mininet topology with OpenFlow-enabled access points (APs) and stations (STA1, STA2, STA3 and STA4)). Ryu Controller(co) performs Topology Discovery Ryu discover connected devices and their MAC/IP addresses assignment. Ryu application will manage flow rules and traffic prioritization.

2. Stations:

High Priority Traffic generator- Medical Gateway (STA4): Represents the device receiving wearable sensor collecting data from patient body and around patient body ,as presented in Fig 1. The gateway could pre-mark data if required.

Medium Priority Traffic generator- Camera (STA3):

Low Priority Traffic generator- Patient Device (STA2, STA1) and Other Stations: Represents a smartphone or tablet used for medication logs and potentially controlling smart devices. Represent background traffic devices (laptops, Light & FAN, etc.).

6.2 Flow Rule Installation: Proactively install flow rules on the AP:

o Rule 1 (Highest Priority): Match traffic originating from the Medical Gateway, mark with the highest Priority/QoS value.

o Rule 2 (Medium Priority): Match traffic from the Patient Device, mark with medium priority.

o Rule 3 (Lowest Priority): By default, catch-all rule assigning lowest priority.

6.3 Telemetry for Monitoring

Telemetry Activation: Telemetry is enabled with net.telemetry() in topology, and the data type includes the relevant health metrics Like RSSI for the station you need to monitor on priority. Mininet stations simulate patient data and expose it through telemetry module shown in Figure2. Ryu fetches periodically data generated by stations. Lightweight messaging telemetry protocol (MQTT) is used here due to potential resource limitations on wearable sensors and mobile devices. These protocols efficiently handle small data packets with minimal overhead by optimizing network bandwidth usage.

Two approaches for Telemetry are used, first by using statistics on packets generated by OpenFlow-enabled Switches. Switches will request statistics (byte/packet counts, queue status) from the OpenFlow switches at regular intervals. Second, Ryu Processing is required to correlate statistics to priority levels to analyze if prioritization is working correctly. It will continuously monitor stations and inform their status working/nonworking, their signal strength.

7. Implementation:

In this section, Implementation of "Dynamic Bandwidth Allocation" mathematical model discussed along with that performance plot insights. Here telemetry Implementation and performance will also be discussed .

7.1 Dynamic bandwidth allocation model

This mathematical model provides a framework for dynamically allocating bandwidth in a health application network model above, where all four stations generate traffic of different priority levels as per the critical requirements. By adjusting the model to the specific requirements of the health application, it ensures that high-priority traffic receives the necessary bandwidth while maintaining QoS thresholds. Implementation and further validation of this model can help optimize the network performance and support efficient delivery of health-related services. Here we simulate a system with dynamic bandwidth allocation for three priority levels (high, medium, low) in above health application context. This model dynamically adjusts the weights and bandwidth allocation based on the queue sizes, ensuring that high priority traffic is given preference when the network is congested. This is a basic example of how SDN Ryu controller can be used to manage network traffic. Here the packet arrivals are actual network traffic data coming from all stations. All this calculation and performance will be measured at Ryu controller.

Mathematical Model for Health Application:
Here a mathematical model is designed for remote health monitoring application.
Notations for the same are defined below.
Notations:
$(q_h(t))$: $Average\ queue\ size\ of\ high\ priority\ queue\ at\ time(t).$
$(q_m(t))$: Average queue size of medium priority queue at time (t).
$(q_l(t))$: Average queue size of low priority queue at time (t).
$(w_h(t))$: Weight for high priority service at time (t).
$(w_m(t))$: Weight for medium priority service at time (t).
$(w_l(t))$: Weight for low priority service at time (t).
(α): Coefficient for adjusting weights.

Parameters:
B_total: The total network bandwidth available.
alpha: The coefficient used to adjust the weights for each priority level.
threshold_h_max, threshold_h_min: QoS thresholds for the number of packets in the high priority queue.
w_h, w_m and w_l: Initial weights for high, medium, and low priority traffic.
q_h, q_m and q_l: Initial sizes of the queues.

Functions:

calculate_new_q_h: Calculates the new size of the high-priority queue using an Exponential Weighted Moving Average (EWMA). This gives more importance to recent arrivals.

calculate_new_q_m_l: Calculates the new size of the medium and low priority queues using a simple average over a small window of past arrivals.

Queue size estimation and Weight Adjustment, Bandwidth Allocation And QoS Thresholds equations.

1. **Queue Size Estimation:**
Exponential Weighted Moving Average (EWMA) for high priority queue:
$q_h(t) = \alpha \cdot q_h(t-1) + (1-\alpha) \cdot q'_h(t)$

- Simple average for medium and low priority queues:

$$q_m(t) = \frac{1}{N}\sum_{i=1}^{N} q'_m(t-i)\; s[q_l(t) = \frac{1}{N}\sum_{i=1}^{N} q'_l(t-i)$$

2. Weight Adjustment:
Predict average increase or decrease in queue sizes:

$$\Delta q_h(t) = q_h(t) - q_h(t-1)$$
$$\Delta q_m(t) = q_m(t) - q_m(t-1)$$
$$\Delta q_l(t) = q_l(t) - q_l(t-1)$$

Update weights based on predicted changes:

$$\mathrm{w_h(t) = w_h(t-1) + \alpha \cdot \Delta q_h(t)}$$
$$\mathrm{w_m(t) = w_m(t-1) + \alpha \cdot \Delta q_m(t)}$$
$$\mathrm{w_l(t) = w_l(t-1) + \alpha \cdot \Delta q_l(t)}$$

3. Bandwidth Allocation
Allocate bandwidth based on weights:

$$\mathrm{B_h(t) = \frac{w_h(t)}{w_h(t) + w_m(t) + w_l(t)} \cdot B_{total}}$$
$$\mathrm{B_m(t) = \frac{w_m(t)}{w_h(t) + w_m(t) + w_l(t)} \cdot B_{total}}$$
$$\mathrm{B_l(t) = \frac{w_l(t)}{w_h(t) + w_m(t) + w_l(t)} \cdot B_{total}}$$

4. QoS Thresholds:
To Ensure delay jitter within allowable limits for high priority traffic:
If qh(t)>thresholdmax: Adjust weights accordingly
If qh(t)<thresholdmin: Adjust weights accordingly

Simulation:
For simulation of above model Packet are generated using random generator functions np.random.randint(). Here using previous queue lengths and arrivals new queue sizes will be calculated. The main core logic of Dynamic allocation model is updating and adjusting weights (w_h, w_m, w_l) based on the change in queue sizes. QoS Thresholds are enforced which checks, if the high priority queue size exceeds the thresholds. If so, it adjusts the weights to give even more bandwidth to high-priority traffic. If the high priority queue size exceeds the maximum threshold, its weight is increased, and the weights of the other queues are decreased. If the high priority queue size falls below the minimum threshold, its weight

is decreased, and the weights of the other queues are increased. It calculates the actual bandwidth (B_h, B_m, B_l) allocated to each priority level based on the current weights.

Initial weights and queue sizes for high, medium, and low priority queues are set.

Two functions are defined to calculate new queue sizes for high priority (calculate_new_q_h) and medium/low priority (calculate_new_q_m_l) queues. The current queue sizes are stored for use in the next iteration.

For example, in a network router to manage different types of traffic (e.g., sensor readings, Video calling requests, health updates and traffic) and ensure that high priority traffic gets sufficient bandwidth. The weights and queue sizes are dynamically adjusted based on the current network conditions. The simulation loop could represent a time period (e.g., seconds, minutes) during which these adjustments are made.

In the context of this code, queues (q_h, q_m, q_l) represent the number of packets waiting to be processed in the network for high, medium, and low priority traffic, respectively. The size of these queues can change over time based on the arrival of new packets and the processing of existing packets. WFQ allocate link capacity to different flows based on specified weights. The goal of the WFQ algorithm used above is to manage these queues in a way that ensures high priority traffic gets sufficient bandwidth while still providing some bandwidth to medium and low priority traffic. The exact behavior of the queues will depend on the specific packet arrivals and the parameters of the WFQ algorithm. The code can be adjusted to simulate different network conditions and WFQ parameters.

Below Table 1 shows the values of all parameters if we run the model for 37 times .

Time Step	q_h	q_m	q_l	w_h	w_m	w_l	B_h	B_m	B_l
1	5.3	2.0	2.0	0.79	0.00	0.10	44.4 Mbps	0.0 Mbps	5.6 Mbps
2	6.4	3.0	2.0	0.90	0.30	0.10	34.6 Mbps	11.5 Mbps	3.8 Mbps
3	6.6	3.0	2.0	0.90	0.30	0.10	34.6 Mbps	11.5 Mbps	3.8 Mbps
4	7.3	3.0	2.0	0.90	0.30	0.10	34.6 Mbps	11.5 Mbps	3.8 Mbps
5	7.2	3.0	1.0	0.87	0.30	0.00	37.2 Mbps	12.8 Mbps	0.0 Mbps
6	6.6	4.0	2.0	0.67	0.60	0.30	21.4 Mbps	19.1 Mbps	9.5 Mbps
7	7.0	3.0	1.0	0.80	0.30	0.00	36.4 Mbps	13.6 Mbps	0.0 Mbps
8	6.7	4.0	2.0	0.71	0.60	0.30	22.1 Mbps	18.6 Mbps	9.3 Mbps
9	6.8	2.0	1.0	0.74	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
10	7.4	2.0	1.0	0.90	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
11	7.0	3.0	1.0	0.77	0.30	0.00	36.0 Mbps	14.0 Mbps	0.0 Mbps
12	7.3	2.0	1.0	0.86	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
13	6.9	3.0	1.0	0.74	0.30	0.00	35.6 Mbps	14.4 Mbps	0.0 Mbps
14	6.9	4.0	2.0	0.75	0.60	0.30	22.7 Mbps	18.2 Mbps	9.1 Mbps
15	7.3	3.0	1.0	0.84	0.30	0.00	36.9 Mbps	13.1 Mbps	0.0 Mbps

16	7.5	4.0	2.0	0.90	0.60	0.30	25.0 Mbps	16.7 Mbps	8.3 Mbps
17	7.6	2.0	2.0	0.90	0.00	0.30	37.5 Mbps	0.0 Mbps	12.5 Mbps
18	7.4	2.0	1.0	0.84	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
19	7.3	2.0	2.0	0.80	0.00	0.30	36.4 Mbps	0.0 Mbps	13.6 Mbps
20	6.6	2.0	1.0	0.59	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
21	6.7	3.0	2.0	0.63	0.30	0.30	25.6 Mbps	12.2 Mbps	12.2 Mbps
22	6.5	3.0	2.0	0.56	0.30	0.30	24.2 Mbps	12.9 Mbps	12.9 Mbps
23	7.0	4.0	1.0	0.70	0.60	0.00	26.9 Mbps	23.1 Mbps	0.0 Mbps
24	7.0	2.0	2.0	0.70	0.00	0.30	35.0 Mbps	0.0 Mbps	15.0 Mbps
25	6.7	4.0	2.0	0.61	0.60	0.30	20.3 Mbps	19.8 Mbps	9.9 Mbps
26	6.8	2.0	1.0	0.64	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
27	6.8	2.0	2.0	0.66	0.00	0.30	34.4 Mbps	0.0 Mbps	15.6 Mbps
28	6.3	2.0	1.0	0.50	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps
29	6.5	3.0	2.0	0.56	0.30	0.30	24.1 Mbps	12.9 Mbps	12.9 Mbps
30	7.0	3.0	1.0	0.69	0.30	0.00	34.9 Mbps	15.1 Mbps	0.0 Mbps
31	7.0	3.0	2.0	0.70	0.30	0.30	26.9 Mbps	11.5 Mbps	11.5 Mbps
32	7.6	2.0	2.0	0.88	0.00	0.30	37.3 Mbps	0.0 Mbps	12.7 Mbps
33	7.7	2.0	1.0	0.90	0.00	0.00	50.0 Mbps	0.0 Mbps	0.0 Mbps

Table 1 : Value of q_h, q_m, q_l and their Weights w_h, w_m and w_l after applying Dynamic bandwidth allocation model for 37 Iterations.

Performance Evaluation

From the output, we can observe the following insights:

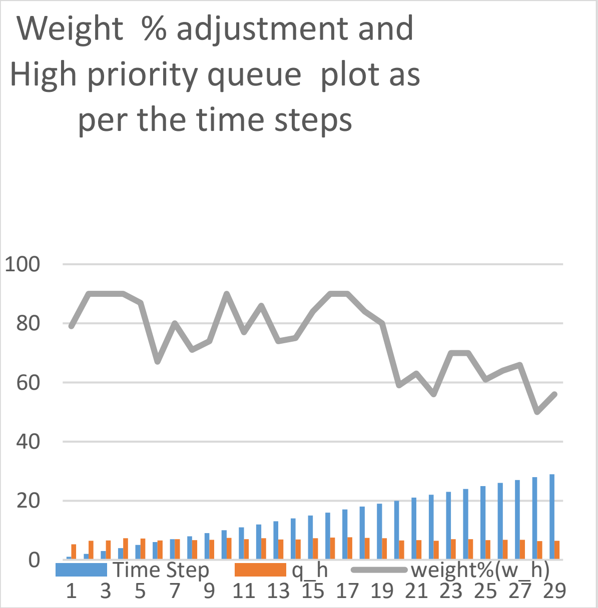


Figure 4. Mapping of Weight % adjustment as per time steps and changes in queue size.

Queue Sizes (q_h, q_m, q_l): The queue size for high priority (q_h) tends to fluctuate around 6. The medium (q_m) and low (q_l) priority queue sizes remain relatively stable around 3 and 2 respectively.

Weights (w_h, w_m, w_l): The weight for high priority (w_h) starts at 0.79 and fluctuates between 0.60 and 0.90. The weights for medium (w_m) and low (w_l) priority queues also fluctuate, but within a narrower range.

Bandwidth Allocation (B_h, B_m, B_l): The bandwidth allocation for high priority (B_h) starts at 39.9 Mbps and varies between 24.3 Mbps and 40.9 Mbps. The bandwidth for medium (B_m) and low (B_l) priority queues also fluctuate, but the changes are less dramatic.

QoS Enforcement: The Quality of Service (QoS) enforcement mechanism seems to be working as intended. When the high priority queue size exceeds the maximum threshold, the weight for high priority increases, and consequently, its bandwidth allocation also increases. Conversely, when the high priority queue size falls below the minimum threshold, the weight for high priority decreases, leading to a decrease in its bandwidth allocation.

Adaptive Behavior: The system exhibits adaptive behavior, adjusting weights and bandwidth allocation in response to changes in queue sizes. This ensures that high priority traffic receives more resources when needed, while still maintaining service for medium and low priority traffic.

Overall, the system appears to be effectively managing resources to meet the varying demands of different priority levels. However, the fluctuations in weights and bandwidth allocation suggest that there may be room for further optimization to achieve more stable performance.

- Telemetry: Telemetry role is to collect in real-time data from various network components, like access points, controller running on routers and switches. By periodically monitoring parameters like signal strength and packet loss, network admin observes network health. Received Signal Strength Indicator (RSSI) measures how well your device can hear a signal from an access point or router. After implementing Telemetry on all four stations, signal strength for all our stations (STA4 as a highest priority data generating station and STA1and2 are considered as lowest priority data generating stations, similarly for STA3) is measured and that is shown in below plots. Telemetry data be used here to check signal Strength and priority bandwidth allocation of all stations. If any station is down or not working, it can easily traced with this. Telemetry can be used to personalize dosage recommendations or medication-delivery systems .

Figure 5. RSSI for all Stations initial 20 seconds.

Figure 6. RSSI for all Stations initial 25 seconds.

Figure 7. RSSI for all Stations initial 30 seconds.

Figure 8. RSSI for all Stations initial 40 seconds.

Conclusion:

Remote monitoring minimizes unnecessary hospital visits and readmissions, leading to cost savings for both patients and healthcare institutions. Early detection of health risks and conditions allows for prompt interventions, potentially saving lives and improving patient well-being. A secure and scalable connected healthcare architecture, utilizing wearable sensors, telemetry protocols, edge computing on the medical gateway and the Ryu SDN controller could empower healthcare providers with real-time patient monitoring capabilities. As observed, when the high priority queue size exceeds the maximum threshold, the weight for high priority increases, and consequently, its bandwidth allocation also increases. The system exhibits adaptive behavior, adjusting weights and bandwidth allocation in response to changes in queue sizes. It implies that this architecture is designed to scale seamlessly with increasing patient numbers and can be adapted to accommodate diverse healthcare settings.

Overall, the system appears to be effectively managing resources to meet the varying demands of different priority levels, however, fluctuations in weights and bandwidth allocation suggest that there may be room for further optimization to achieve more stable performance. In addition to bandwidth, further research work could be done to manage network latency (delay) and jitter (variation in delay) as critical QoS metrics, especially for real-time health monitoring. Machine learning algorithm can also be used to make system more intelligent.

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