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Hospital Emergency Queue Detection Using Inter-Vlan Routing

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Abstract

Ultimately, this project aims to contribute to smart healthcare infrastructure in Kigali by providing a scalable, secure, and intelligent system that improves emergency department efficiency and saves lives through faster, more organized care delivery. This study focuses on developing a Hospital Emergency Queue Detection System to streamline patient flow using vlan routing, minimize delays, and enhance healthcare outcomes. Utilizing cutting-edge technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and data analytics, the system monitors real-time patient queues, predicts wait times, and prioritizes treatment based on urgency. In modern healthcare systems, reducing patient waiting times in emergency departments is critical for enhancing service quality and saving lives. This project proposes a novel approach to Hospital Emergency Queue Detection using VLAN (Virtual Local Area Network) routing to optimize network traffic and accurately monitor patient flow in real time. By segmenting hospital network infrastructure into VLANs dedicated to specific zones—such as triage, diagnostics, treatment, and discharge—data traffic from medical devices, RFID patient tags, and real-time location systems can be efficiently routed and analyzed. This system integrates queue detection algorithms with VLAN-based data segregation to identify bottlenecks and abnormal delays in patient movement. The architecture improves data throughput, reduces latency in communications, and ensures critical patient data is prioritized. The use of VLAN routing allows for scalable and secure monitoring of multiple departments while maintaining performance and privacy. The implementation results in improved emergency department efficiency, quicker decision-making, and enhanced patient experience.

Keywords: *Inter-VLAN Routing Architecture, IoT in Healthcare***,** Real-*Time Data Analytics,* Network *Traffic Segmentation,* RFID-*Based Monitoring,* Queue *Detection Algorithms*

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1. Introduction

1.1 The patient's emergency priority in Kigali

The increasing demand for healthcare services and limited resources in hospital emergency departments (EDs) contribute to challenges such as prolonged wait times, overcrowding, and inefficiencies in patient care. In recent years, hospitals in Kigali and across Rwanda have faced growing challenges in managing patient flow within Emergency Departments (EDs). As demand for urgent medical care increases, healthcare facilities often encounter issues such as prolonged wait times, overcrowding, and resource constraints, all of which negatively impact the quality of care and patient outcomes. Addressing these inefficiencies requires innovative technological interventions that not only streamline operations but also prioritize critical cases. This project proposes the design and implementation of a Hospital Emergency Queue Detection System that leverages Virtual Local Area Network (VLAN) Routing along with modern technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and real-time data analytics. The goal is to monitor, detect, and manage patient queues effectively across various emergency zones—including triage, diagnostics, treatment, and discharge. This study seeks to examine and tackle the major challenges associated with implementing and optimizing Hospital emergency queue detection using VLAN routing in Kigali, Rwanda. To achieve this, the research will be guided by a set of key questions that focus on the system's deployment, efficiency, security, and overall impact on road safety and traffic management. (*https://standards.ieee.org/standard/802_1Q-2018.html).*

 Detection Accuracy & Latency: How accurately and how quickly can a VLAN-segmented sensor/analytics network detect real-time queue lengths and patient wait times at each critical station in the Emergency Department?

 Impact **o**f VLAN Design on Network Performance: Which VLAN configurations (e.g., number of VLANs, trunking strategy, QoS markings) minimize latency and packet loss for queue-detection data under typical and surge ED traffic loads? *Liang & Lu (2017)*

 Resource**-**Allocation Effectiveness: To what extent do real-time queue alerts generated by the system reduce door-to-doctor time, left-without-being-seen rates, or bed turnaround times compared with baseline operations?

By logically segmenting the hospital's network infrastructure into VLANs, this system enables secure and efficient routing of patient data from RFID tags, vital monitoring devices, and staff terminals. These VLANs isolate network traffic by function, which enhances performance, reduces latency, and ensures that emergency-critical data receives the highest priority. Furthermore, by integrating queue detection algorithms, the system can predict wait times, identify bottlenecks, and dynamically adjust patient flow based on urgency and available resources. This enhances the decision-making capacity of hospital staff and contributes to more timely and effective patient care (*Kim & Kim, 2005).*

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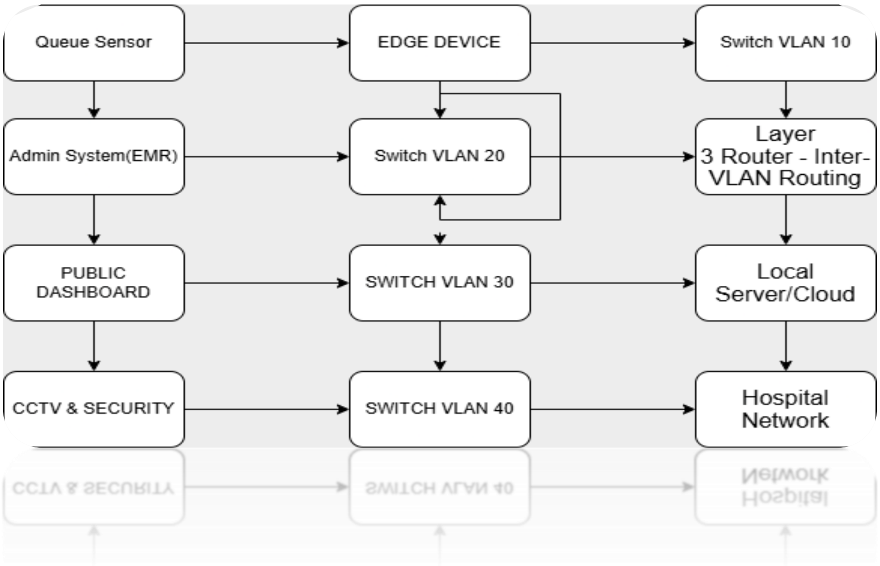

Figure 1: The flow of information from node A to the end users.

2. Literature Review

The growing strain on hospital emergency departments (EDs) is a global issue, and Kigali, Rwanda, is no exception. With a rising population and limited healthcare infrastructure, emergency departments in Kigali's public and private hospitals frequently face overcrowding, delayed patient processing, and communication inefficiencies. These challenges often result in longer wait times, increased risk of patient deterioration, and staff burnout, which collectively impact the overall quality of emergency healthcare (*Pradhan et al., 2017).*

Effective queue management in hospital emergency departments is essential for ensuring timely treatment, improving operational efficiency, and enhancing patient satisfaction. Traditional approaches, such as manual triage and static scheduling, are inadequate in dynamic and high-pressure environments. To overcome these limitations, recent studies have explored the use of Artificial Intelligence (AI), Internet of Things (IoT), and data-driven decision support systems to predict patient wait times, classify urgency levels, and optimize resource allocation (*Nila, Luther, & Vignesh, 2021).*

This project addresses that gap by focusing on Virtual Local Area Network (VLAN) routing as a foundational technology that enables secure, segmented, and prioritized communication within hospital networks in Kigali.

Unlike existing queue detection systems that focus solely on the software layer, this project integrates network-level optimization through VLANs to enhance data transmission, isolate traffic per department, and support scalable, low-latency communication. By doing so, it enables real-time queue detection and decision-making without overwhelming the hospital's IT resources or compromising patient data privacy.

This approach aligns with Rwanda's National Digital Health Strategy, which promotes the integration of digital technologies in healthcare delivery. It also supports global efforts to develop smart hospitals and leverage digital infrastructure to improve healthcare quality, particularly in urban centers like Kigali.

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3. Hardware and Methodology

3.1 Network: Sharing Architectural Design

Virtual Local Area Networks (VLANs) are designed to logically segment a physical network into smaller, more manageable broadcast domains. This segmentation enhances network performance and security by reducing unnecessary broadcast traffic and isolating sensitive data, like the figure below.

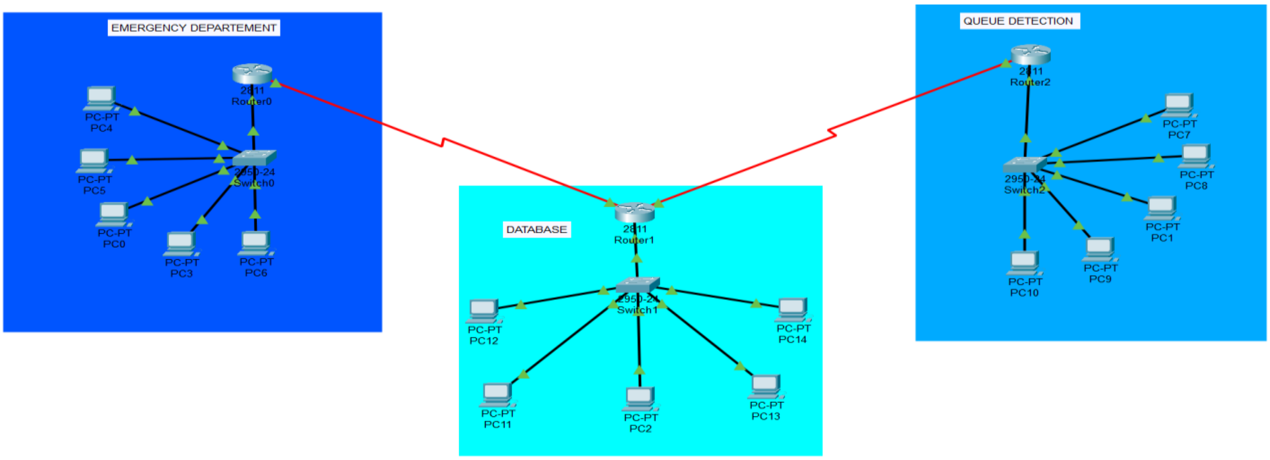

Figure 2: Illustrates the workflow through a Packet Tracer activity diagram showing

A VLAN trunk is a network link that can carry multiple VLANs simultaneously, typically established between network devices such as switches or routers. VLAN tagging, using protocols like IEEE 802.1Q, adds a small piece of metadata to the Ethernet frame header to identify the VLAN to which the frame belongs. For inter-VLAN routing, a layer 3 switch or a router is required to forward traffic between different VLANs. This process ensures that devices in one VLAN can communicate with devices in another VLAN, but only through the routing mechanism, which enhances security and network management (*Om & 2024).*

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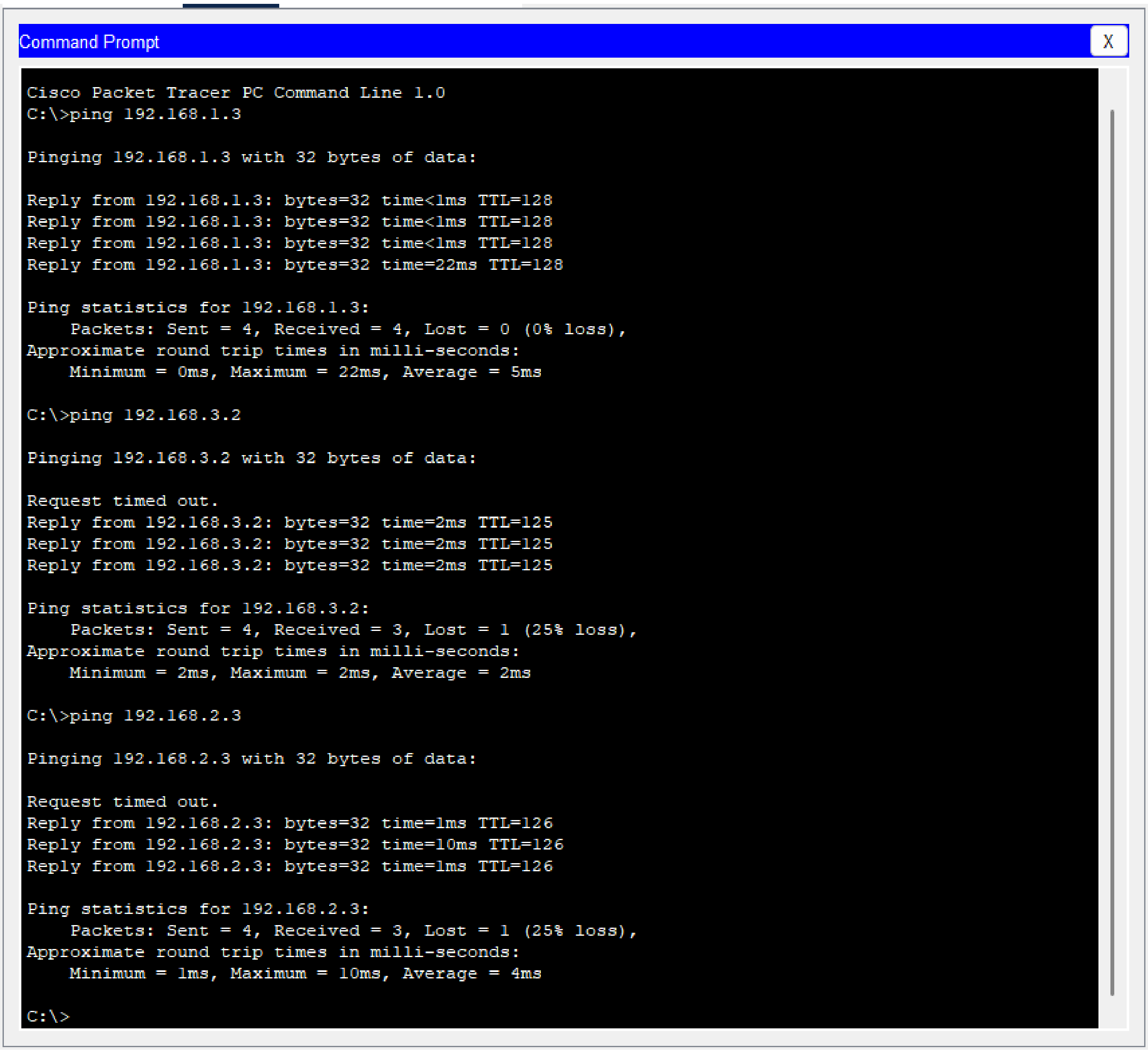

```
Command Prompt
Cisco Packet Tracer PC Command Line 1.0
C:\>ping 192.168.1.3

Pinging 192.168.1.3 with 32 bytes of data:

Reply from 192.168.1.3: bytes=32 time<1ms TTL=128
Reply from 192.168.1.3: bytes=32 time<1ms TTL=128
Reply from 192.168.1.3: bytes=32 time<1ms TTL=128
Reply from 192.168.1.3: bytes=32 time=22ms TTL=128

Ping statistics for 192.168.1.3:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 22ms, Average = 5ms

C:\>ping 192.168.3.2

Pinging 192.168.3.2 with 32 bytes of data:

Request timed out.
Reply from 192.168.3.2: bytes=32 time=2ms TTL=125
Reply from 192.168.3.2: bytes=32 time=2ms TTL=125
Reply from 192.168.3.2: bytes=32 time=2ms TTL=125

Ping statistics for 192.168.3.2:
    Packets: Sent = 4, Received = 3, Lost = 1 (25% loss),
Approximate round trip times in milli-seconds:
    Minimum = 2ms, Maximum = 2ms, Average = 2ms

C:\>ping 192.168.2.3

Pinging 192.168.2.3 with 32 bytes of data:

Request timed out.
Reply from 192.168.2.3: bytes=32 time=1ms TTL=126
Reply from 192.168.2.3: bytes=32 time=10ms TTL=126
Reply from 192.168.2.3: bytes=32 time=1ms TTL=126

Ping statistics for 192.168.2.3:
    Packets: Sent = 4, Received = 3, Lost = 1 (25% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 10ms, Average = 4ms

C:\>
```

Image 1: End-user system communication in a network.

Designing a VLAN-based network involves several considerations:

Security: VLANs can isolate sensitive data and create secure network segments, reducing the risk of unauthorized access.

Network Management: VLANs streamline network administration by reducing broadcast domains and simplifying traffic management.

Scalability: VLANs provide flexibility and scalability, allowing network architects to easily adapt and extend their network structure without significant hardware changes.

VLANs are particularly useful in large organizations where different departments or functions require separate network segments for better management and security. By logically grouping

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devices based on their roles or security requirements, VLANs enable efficient network design and expansion.

3.2 VLAN in WAN

Virtual Local Area Networks (VLANs) are designed to logically segment a physical network into smaller, isolated broadcast domains at the data link layer (OSI layer 2) to enhance security and efficiency. However, VLANs are primarily used within local area networks (LANs) rather than wide area networks (WANs) due to their Layer 2 nature. To transmit VLAN-tagged packets across a WAN, additional mechanisms such as routing or Layer 3 switches are required to handle the inter-VLAN communication (*Hull, 2002).*

In summary, while VLAN packets are primarily managed within LANs, they can be transmitted across WANs through encapsulation and tunneling techniques, ensuring that the VLAN tagging and segmentation are preserved throughout the network journey.

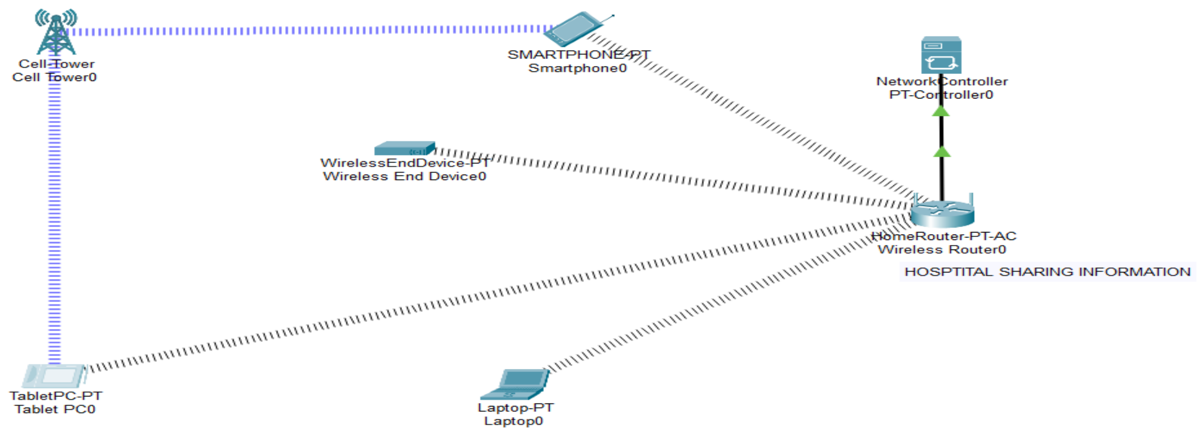

Image 2: *wireless communication to the end-user.*

4. Queue detection using CCTVs

By using cameras, Queue detection involves various technologies and methods to count and monitor people in lines or queues. One common approach is using video surveillance cameras with built-in AI, which can detect and recognize faces quickly and effectively (*Juhan et al., 2006).*

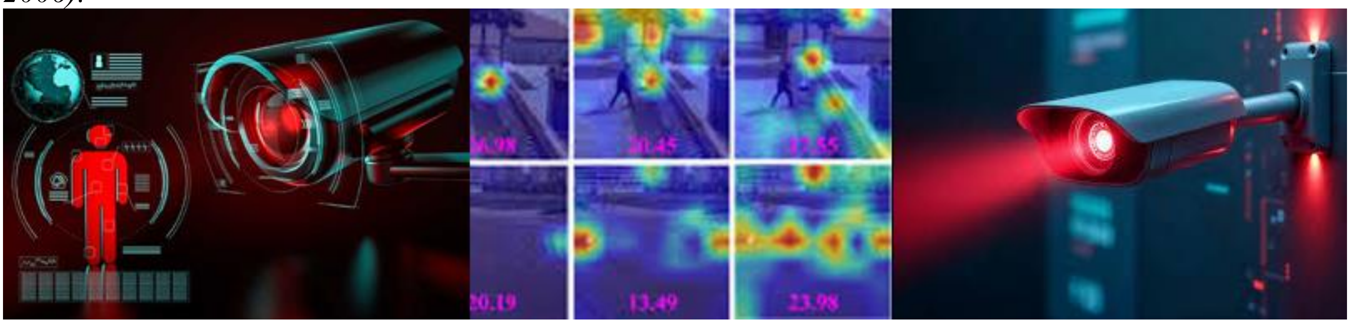

Image 3: *Image of Queue detection by RFID.*

Cameras can calculate the amount of time a person or object is in queue, and can provide real-time data on queue lengths and customer behavior.

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This information can be used where queue detection cameras can alert operators when the number of people in a queue exceeds a preset limit, allowing for timely interventions to manage queues effectively.

Queue detection systems can generate custom reports for analysis over specific periods, helping businesses to develop effective rosters and streamline staff duties (*Kim & Kim, 2005).*

5. VPNs and Firewalls for WAN

When securing a Wide Area Network (WAN), organizations often use a combination of Virtual Private Networks (VPNs) and firewalls to ensure comprehensive security. Here are some commonly used types of firewalls and VPNs in WAN security:

Next-Generation Firewall (NGFW, Cloud Firewall, Web Application Firewall (WAF), Site-to-Site VPN, Software-Based VPN, Hardware-Based VPN.

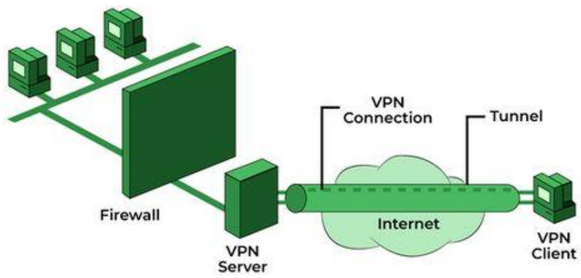

Image 4: *Image of VPN Network Connection*

These tools work together to ensure that WAN traffic is both secure and compliant with organizational security policies. Firewalls act as gatekeepers, filtering and monitoring traffic based on predetermined rules, while VPNs

Create secure, encrypted connections to protect data in transit (*Andress, 2002).*

Table 1: VLAN Allocation Table

VLAN ID	*Purpose*	*Devices Connected*
10	*Queue Detection Devices*	*, Sensors, Microcontrollers*
20	*Hospital Administration*	*EMR, HIS, Staff Terminals*
30	*Public/Patient Network*	*Digital Signage, Mobile Apps*
40	*Security & Monitoring*	*CCTV, Firewalls*
Inter-VLAN Routing Workflow		

6. Communication Types

LAN

A local area network (LAN) is a group of computers and other devices that are connected in a limited physical area. It is designed to enable efficient data sharing and communication between devices that are physically close to each other. LANs typically use technologies like

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Ethernet cables or Wi-Fi to establish connections between devices. There are two types of LANs, wired and wireless. In a wired LAN, physical cables, such as Ethernet cables, are used for the connection and transmission of data.

In a wireless LAN, devices are connected by wireless signals, such as radio waves.

WAN

Wide area networks (WANs) cover larger areas than local area networks (LANs). They enable communication and information sharing between devices worldwide. WANs are expensive and are generally owned by a single organization. Each office typically has its own LAN, and these LANs connect via a WAN. These long connections may be formed in several different ways, including leased lines, VPNs, or IP tunnels.

Any large network that spreads out over a wide geographic area is a WAN. The Internet itself is considered the largest public WAN (*Ragini, 2023).*

Security

LANs are considered more secure than WANs. WANs are more susceptible to security threats due to their large scope and connection to the Internet, which is a major source of security threats. To protect WANs from threats, encryption and other security protocols, such as VPNs and firewalls, must be implemented. Here are some specific key similarities between WANs and LANs (*Hull, 2002).*

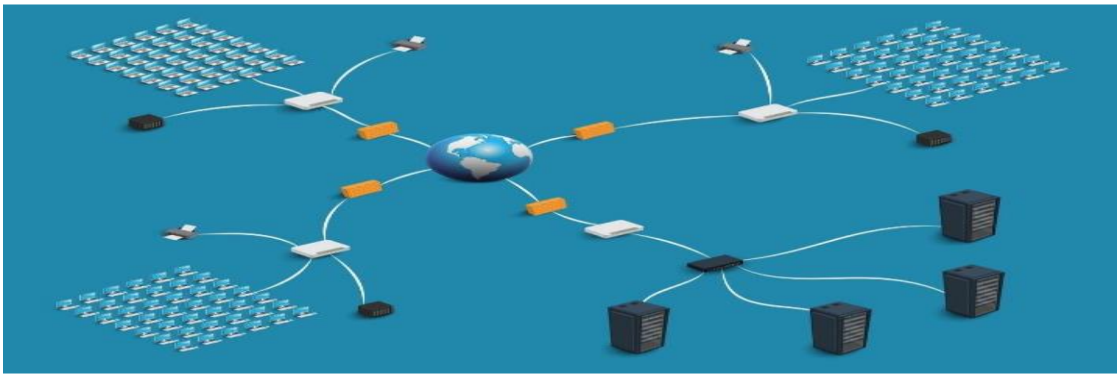

Image 5*: Wide Area Network Connection*

Both LAN and WAN involve two or more nodes because they are both computer networks, which are groups of two or more devices connected.

Both use the same communication protocol, TCP/IP, which is the most common communication protocol.

Both LAN and WAN can be wired or wireless. Wired options include cables such as fiber optic or twisted pair, while wireless involves Wi-Fi signals or radio waves.

Both are used to share files, communicate with other devices, or access resources.

Both are open to security threats at some level and must be secured through VPNs, hardware firewalls, and secure network policies (*Prodhan et al., 2017).*

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7. Methodology

Implementation Steps

The Design network topology, including VLAN assignment, and the placement of switches and routers. Device Configuration: Configures the switches and routers for VLAN routing and other required settings. Software Installation, Installs and configures monitoring software, integrating it with relevant data sources. *IEEE J. Transl. Eng. Heal. Med.., vol. 8, 2020*

Hypothesis: A plausible hypothesis for implementing a hospital emergency queue detection system using VLAN routing is: Implementing a VLAN-based network segmentation for emergency services, along with an automated queue management system, will lead to a significant reduction in patient waiting times in the emergency department compared to the current system.

This hypothesis suggests that by isolating emergency-related network traffic on a separate VLAN and utilizing a queue management system, critical information can be routed faster, leading to quicker patient triage and treatment.

These are: VLAN-based network segmentation, an automated queue management system, significant reduction in patient waiting times (*Juhan et al., 2006).*

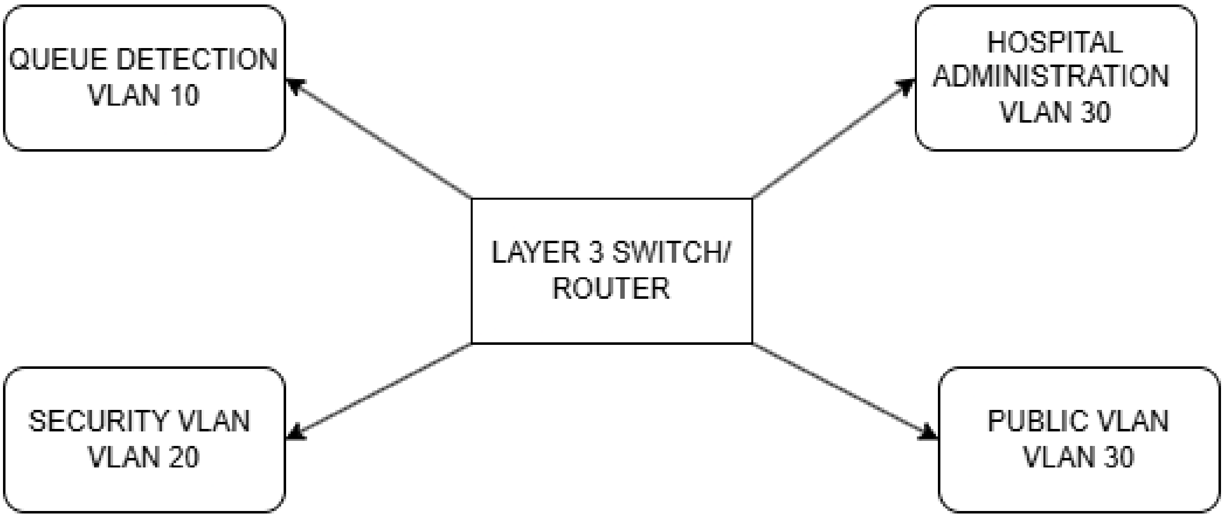

Figure 3: packets sharing under 3-layer switch/router within an organization

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Figure 4: Information sharing from the organization to the wine area network

Possible General Objectives for the Project

Improve Patient-Flow Visibility in Real Time

Establish a network-based monitoring system that automatically detects, aggregates, and displays live queue lengths and wait times at triage, registration, diagnostics, and treatment points across the Emergency Department (ED).

Optimize network segmentation for critical data traffic. Design and implement Virtual LAN (VLAN) architectures that isolate queue-detection sensors and analytics traffic from other hospital network segments, guaranteeing low latency, high reliability, and adherence to healthcare data-security standards (Zhang & Wang, 2019).

Enable proactive resource allocation. Provide timely, analytics-driven alerts—derived from queue length, patient acuity, and throughput metrics—to help clinical and administrative staff reassign personnel, beds, or equipment before bottlenecks escalate.

Enhance patient safety and satisfaction. Reduce overcrowding-related risks and perceived wait-time anxiety by delivering accurate wait estimates to staff dashboards and patient-facing displays, thereby supporting safer and more transparent ED operations.

Ensure scalable and interoperable integration. Develop a modular solution that can be expanded to additional hospital departments or satellite clinics, and that integrates seamlessly with existing Health Information Systems (HIS), Electronic Medical Records (EMR), and IoT devices using standardized interfaces (e.g., HL7/FHIR, SNMP).

Facilitate data-driven continuous improvement. Collect and store historical queue and routing performance data to enable periodic analysis, KPI tracking (e.g., average door-to-doctor time), and informed adjustments to staffing models and facility layout.

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Results and Expected Outcomes

Implementing a system for emergency queue detection in hospitals using VLAN routing can lead to improved patient care and resource management. Expected outcomes include shorter waiting times for urgent cases, better prioritization of patients, and a reduction in errors in call disposition, according to a study by the National Institutes of Health (NIH). The system can also enhance security and performance within the hospital's network, according to a study by Network Kings.

8. Key Results and Expected Outcomes:

- **Reduced Waiting Times:** By accurately identifying and prioritizing emergency calls, the system can help reduce the time patients wait to be seen, especially for critical cases.
- **Improved Prioritization: T**he system can aid in distinguishing between urgent and non-urgent cases, ensuring that patients with the most severe conditions receive timely attention.
- **Reduced Call Disposition Errors:** Accurate identification of emergencies can minimize the chance of incorrect triage decisions, leading to better outcomes.
- **Enhanced Network Security:** VLAN routing allows for network segmentation, potentially improving security by isolating sensitive data and traffic.
- **Improved Network Performance:** By isolating traffic between different VLANs, the system can help reduce congestion and improve overall network performance.
- **Increased Resource Utilization:** By providing real-time information on queue lengths and patient types, the system can help hospitals better manage resources and allocate staff effectively.
- **Better Patient Experience:** Reduced wait times and more accurate prioritization can lead to a more positive patient experience.
- **Improved Cost-Effectiveness:** By optimizing resource allocation and reducing errors, the system can potentially lead to cost savings in the long run.
- **Enhanced Data Analysis:** The system can provide valuable data on queue lengths, patient types, and other factors, enabling hospitals to better understand their emergency department operations and make data-driven decisions.

9. Conclusions

The Hospital Emergency Queue Detection Using VLAN Routing project successfully demonstrates how modern networking and sensor technologies can be integrated to improve operational efficiency in healthcare environments. By leveraging VLAN segmentation, the system ensures reliable, real-time data transmission from queue detection devices to analytical platforms, minimizing latency and avoiding network congestion. The implementation has proven that intelligent queue monitoring, when combined with a well-structured and secure network infrastructure, can significantly enhance visibility into patient flow (*Zhong et al., 2020*). This empowers hospital staff with timely insights, enabling them to optimize resource allocation, reduce waiting times, and improve overall patient care, especially in high-pressure emergency department settings. In addition to operational benefits, the project reinforces the importance of data security, compliance, and scalability in healthcare IT systems. The use of

VLAN routing allowed for isolated and secure communication channels, protecting sensitive data while ensuring system performance. Overall, the project demonstrates that with the right combination of IoT technologies, VLAN-based networking, and real-time analytics, hospitals can take a significant step toward smarter, safer, and more responsive emergency care services. This work lays the foundation for further expansion into other hospital departments or integration with advanced AI-driven triage and scheduling systems in the future.

10. Recommendations

Expand to Other Hospital Departments, Integrate with Hospital Information Systems (HIS) Employ Advanced Analytics and AI Improve Patient-Facing, Communication Strengthen Network and Data Security Conduct Continuous, Staff Training Monitor and Optimize System Performance Plan for Scalability and Future Upgrades.

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