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CHENNAI

Computer Networks
(BCSE308L)

Digital Assignment – 1

Slot: B1+TB1

Real-Time Ambulance to Hospital Emergency Communication System Using IoT and Computer Networks

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Abstract: In emergency medical scenarios, timely and reliable communication between ambulances and hospitals is critical for saving lives. Traditional emergency systems rely largely on voice communication or manual reporting, which often leads to delays, incomplete information, and poor preparedness at the hospital end. This project proposes a Real-Time Ambulance to Hospital Emergency Communication System that integrates IoT hardware with Computer Networks principles to ensure continuous, low-latency, and priority-based transmission of patient vital data. Real physiological parameters such as heart rate and blood oxygen saturation (SpO_2) are measured using medical-grade sensors connected to an ESP32 microcontroller and transmitted over TCP/IP networks to a central emergency server. The server applies emergency-aware data handling and forwards the information to a hospital dashboard in real time, enabling hospitals to prepare medical resources before patient arrival. The system demonstrates the practical application of core computer networking concepts such as client–server architecture, real-time communication, scalability, and quality of service, making it suitable for academic evaluation and Smart India Hackathon-level implementation.

Introduction: Emergency healthcare response depends heavily on the speed and accuracy of information exchange between ambulances and hospitals. In critical cases such as cardiac arrest, trauma, or respiratory failure, every second is valuable. Despite advances in medical equipment, communication systems used in ambulances remain limited, often relying on voice calls or delayed data transfer. These methods do not provide continuous insight into a patient's condition and do not allow hospitals to prepare in advance. With the rapid development of IoT technologies, wearable sensors can now measure vital physiological parameters in real time. However, simply collecting data is insufficient unless it is transmitted reliably and promptly to the hospital. Existing networks are best-effort in nature and do not distinguish between emergency and non-emergency traffic, which can lead to delays during congestion. This project addresses this challenge by combining real IoT-based patient monitoring with computer-network-aware communication techniques. The proposed system ensures that emergency patient data is transmitted efficiently, reliably, and meaningfully, thereby improving pre-hospital care and hospital readiness.

Literature Review

1. Traditional emergency medical communication systems

Traditional ambulance-to-hospital communication mainly depends on radio and voice calls to share patient information between paramedics and doctors. These methods support basic coordination but do not provide continuous, real-time monitoring of patient vital signs. As a result, hospitals rely heavily on what paramedics verbally report, which can lead to human error, miscommunication, and delays during high-pressure emergencies. Voice-based systems also prevent hospitals from analyzing the patient's condition in advance or arranging specialized equipment and medical teams before the ambulance arrives.

2. IoT-Based Remote Patient Monitoring Systems

IoT-based healthcare systems use wearable or bedside sensors to measure heart rate, oxygen saturation, temperature, and other physiological signals and send them to remote servers or mobile apps. These solutions have significantly improved home care and long-term monitoring for chronic patients by enabling doctors to track health data over time. However, most existing IoT health monitoring projects focus on stable environments such as homes or hospital wards, not on fast-changing emergency situations inside ambulances. They usually do not handle strict real-time delivery, emergency prioritization, or network congestion, which are critical when a patient is being transported in a moving vehicle.

3. Cloud-Centric Healthcare Monitoring Platforms

Cloud-based healthcare platforms collect data from IoT devices and offer scalable storage, analytics, and decision support. They allow multiple stakeholders to access patient information and enable advanced processing such as trend analysis and prediction. Despite these benefits, cloud-centric designs depend heavily on continuous internet connectivity and can introduce additional latency when data must travel through distant cloud servers. In time-critical ambulance scenarios, such delays and possible availability issues can reduce the effectiveness of real-time decision-making and emergency response.

4. Wireless Body Area Networks (WBANs) for Health Monitoring

Wireless Body Area Networks consist of several small sensors placed on or inside the body that communicate wirelessly over short range to collect physiological data. WBANs are optimized for low power consumption and efficient intra-body communication, making them suitable for continuous health monitoring near the patient. However, most WBAN research concentrates on local data aggregation and reliable communication within or around the body. The extension of WBAN data from a mobile ambulance environment to distant hospitals over public networks is often outside their primary scope.

5. Mobile Health (mHealth) Applications

Mobile health applications running on smartphones and tablets enable patients and caregivers to view health metrics, receive reminders, and communicate with healthcare providers. These apps improve accessibility and patient engagement in routine or chronic care scenarios. Nevertheless, many mHealth systems assume relatively stable network conditions and do not implement mechanisms for guaranteed reliability, low latency, or priority handling of life-critical medical data.

Therefore, their direct use in pre-hospital emergency care, where every second matters, is limited.

6. GPS-Enabled Smart Ambulance Systems

Several smart ambulance solutions integrate GPS modules and navigation services to track ambulance location and optimize routes toward hospitals. Such systems can reduce travel time, help avoid traffic congestion, and support coordination with traffic management infrastructure. Yet, many of these GPS-based systems focus mainly on vehicle tracking and routing, with little or no integration of real-time patient vital data. Without combining location information with physiological monitoring and network-aware communication, their contribution to overall emergency care remains partial.

7. Hospital Information Systems (HIS)

Hospital Information Systems manage electronic health records, clinical workflows, billing, and administrative operations inside the hospital. They significantly enhance hospital efficiency and data organization once the patient has been admitted. However, most HIS implementations are designed to receive patient information only after arrival, not while the patient is en route in an ambulance.

This reactive approach prevents hospitals from preparing intensive care units, operation theatres, or specialist teams in advance based on the patient's real-time condition during transport.

8. Quality of Service (QoS) Mechanisms in Computer Networks

Quality of Service techniques in networking prioritize certain traffic classes and provide guarantees related to bandwidth, delay, jitter, and packet loss for time-sensitive applications. Research has shown that QoS can significantly improve performance for multimedia streaming, industrial control, and other delay-critical services. Despite this, QoS is often implemented at lower network layers or in controlled environments and is rarely exposed or used directly at the application layer in practical emergency healthcare systems. As a result, medical IoT data in public networks still competes with ordinary traffic without explicit emergency-aware prioritization.

9. Real-Time Data Transmission Protocols for IoT

Protocols like HTTP, MQTT, and WebSockets are widely used to transmit IoT data between devices and servers. MQTT is known for its lightweight publish–subscribe model, making it suitable for constrained devices and low-bandwidth networks, while WebSockets support persistent, bidirectional communication ideal for continuous data streams. However, most existing implementations treat all messages similarly and rely on best-effort delivery, without built-in mechanisms to mark and handle emergency medical data with higher priority.
This limits their direct suitability for critical ambulance-to-hospital communication unless additional logic or QoS policies are applied on top.

10. Smart Ambulance and Emergency Healthcare Prototypes

Recent studies propose smart ambulance prototypes that combine IoT sensors, wireless communication, and cloud or edge platforms to share patient information with hospitals in near real time. These prototypes demonstrate that it is technically feasible to monitor vital signs, send data to remote servers, and provide doctors with dashboards before the patient arrives. However, many existing designs concentrate on sensor integration and data visualization, while giving less attention to core networking issues such as scalability to many ambulances, congestion handling in public networks, and explicit priority-based data transmission. This gap highlights the need for systems that not only collect medical data but also apply computer-network principles to ensure timely, reliable, and emergency-aware communication between ambulances and hospitals.

Novelty of the proposed system

The proposed system introduces a novel integration of real IoT hardware with computer-network-aware emergency communication. Unlike existing solutions, it uses real-time physiological data from patients, supports multiple ambulances concurrently, and applies priority handling for critical conditions. The system emphasizes core computer networks principles such as real-time streaming, client–server scalability, and emergency-aware data delivery, enabling hospitals to take proactive decisions before patient arrival. This combination of realism, network intelligence, and emergency focus distinguishes the project from existing works.

Methodology

The proposed Real-Time Ambulance to Hospital Emergency Communication System is engineered as a robust, multi-tier network application. The system transforms a standard physiological sensing setup into a real-time network communication framework by applying core computer networking principles, including client-server architecture, transport layer reliability, and application layer persistent streaming.

System Architecture and Topology

The network operates on a definitive Client-Server model. The ESP32 acts as a mobile edge client located inside the ambulance, while a centralized Node.js application functions as the receiving server. To enable direct and secure routing, both the edge node and the central server are assigned unique IP addresses on the network, preventing packet collisions and logical addressing conflicts.

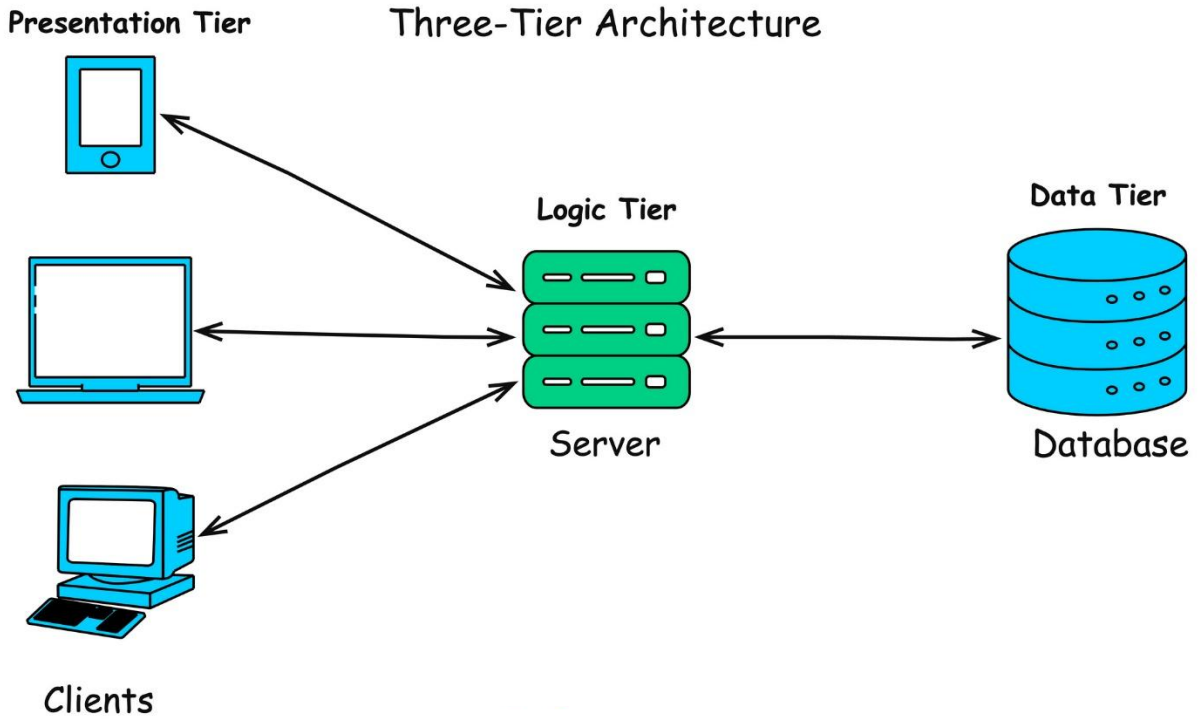


Figure 1: End-to-End Client-Server Architecture illustrating the flow of physiological and geographical data over the network.

Data Encapsulation and Multiplexing

Physiological data (Heart Rate and SpO_2) collected by the MAX30100/MAX30102 sensor is validated locally at the edge to filter out motion artifacts. Instead of initiating separate network streams for different data types, the ESP32 performs data multiplexing. It encapsulates the validated vital signs alongside simulated GPS coordinates into a single, lightweight JSON (JavaScript Object Notation) payload. This structured formatting minimizes bandwidth overhead and reduces the frequency of network transmissions.

```
      // Example of the Multiplexed JSON Payload sent over TCP
{
  "clientId": "AMB-101",
  "timestamp": 1708705200,
  "payload": {
    "vitals": {
      "heartRate": 85,
      "spo2": 98
    },
    "location": {
      "latitude": 12.8399,
      "longitude": 80.1545
    }
  },
  "qosLevel": 1
}
```

Protocol Selection: Transport and Application Layers

Given the critical nature of medical data, the system utilizes the Transmission Control Protocol (TCP) at the Transport layer. TCP ensures the reliable, ordered, and error-checked delivery of physiological parameters, guaranteeing that no vital health data is lost due to cellular network fluctuations during transit. To overcome the high latency and repeated request overhead associated with standard HTTP polling, the Application layer implements the WebSocket protocol. Operating over TCP, WebSockets establish a persistent, full-duplex communication channel. This allows for continuous, bidirectional, and real-time streaming of the multiplexed JSON payloads from the ambulance to the hospital without the need to repeatedly open and close network connections .

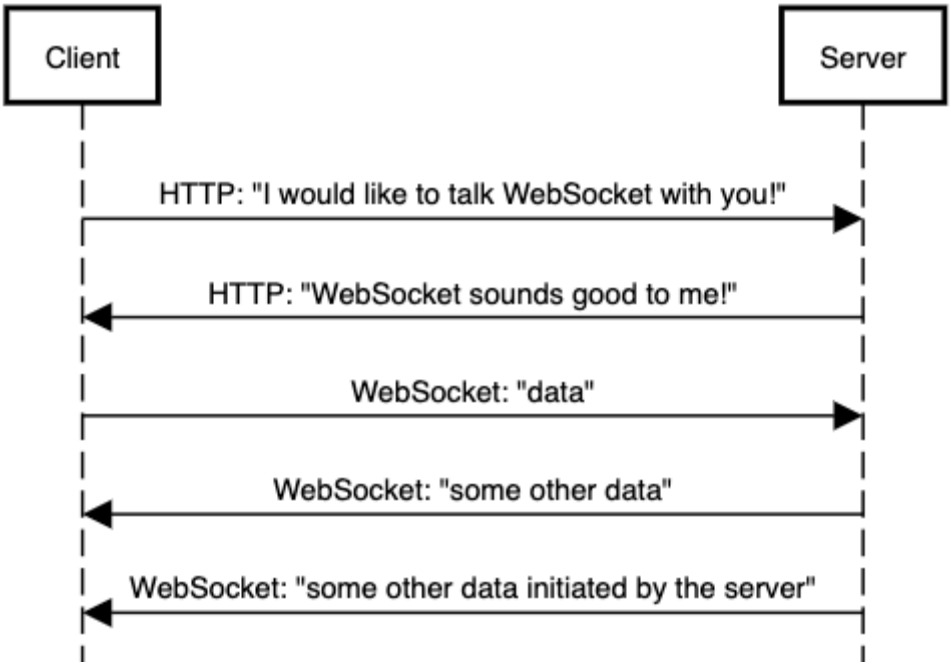


Figure 2: Sequence diagram demonstrating the initial HTTP handshake upgrading to a persistent WebSocket TCP connection for real-time streaming.

Remote Visualization and Multi-Client Routing

The Node.js server acts as an aggregator and router. Upon receiving the continuous stream of JSON packets, the server broadcasts the data to distinct web-based user interfaces. This dual-dashboard approach demonstrates the server's ability to handle multiple concurrent clients:

Doctor's Dashboard: Focuses strictly on high-frequency physiological data streams, dynamically plotting real-time charts for clinical analysis and triggering threshold-based alerts.

Hospital Admin Dashboard: Parses the multiplexed GPS data from the exact same payload to plot the ambulance's real-time geographical location and calculate dynamic Estimated Times of Arrival (ETAs), allowing the hospital to pre-allocate medical resources.

Client Type	Subscribed Data Stream	Primary Network Purpose	Update Frequency
Doctor's Dashboard	High-frequency Vitals (BPM, SpO_2)	Real-time clinical alerting	1 Hz (Every second)
Admin Dashboard	Multiplexed GPS & Status	Resource preparation & ETA	0.2 Hz (Every 5 seconds)

Implementation Status: 50% Completed Progress

The project execution is divided into sequential phases. Currently, the project stands at exactly 50% completion, having successfully integrated the physical data acquisition layer and the initial data-link configurations.

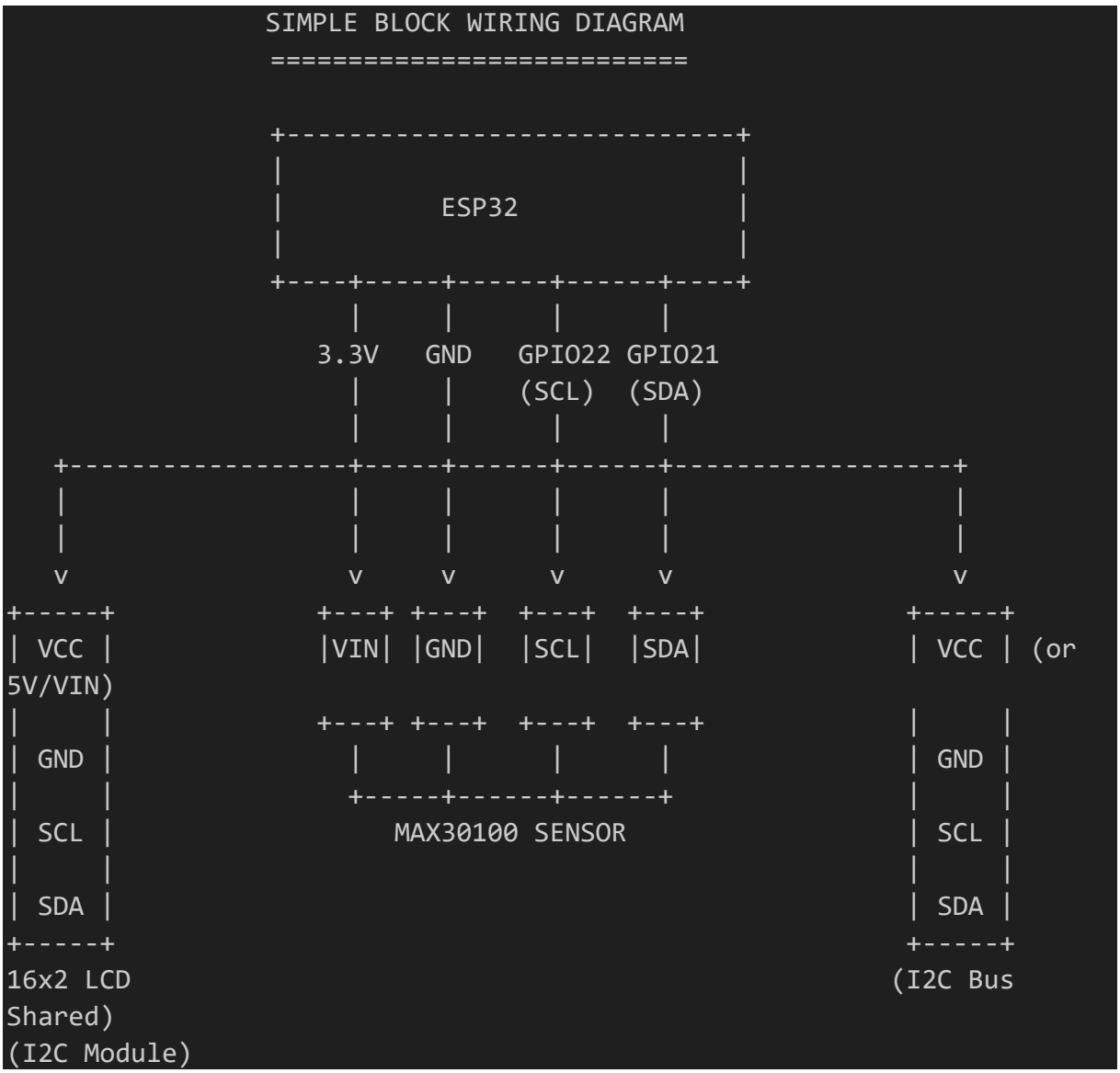
Milestones Achieved (Completed 50%):

Sensor Interfacing: Successfully integrated the MAX30100/MAX30102 sensor with the ESP32 microcontroller using the I2C protocol.

Edge Data Processing: Programmed the ESP32 to accurately capture, filter, and extract reliable Heart Rate (BPM) and Blood Oxygen Saturation (SpO_2) values from raw photoplethysmographic signals.

Local Redundancy Display: Wired and configured an OLED/LCD display to the ESP32 edge node to provide immediate, on-site visual feedback of patient vitals for ambulance paramedics.

Initial Network Connectivity: Verified the ESP32's ability to connect to a local WiFi network using the TCP/IP stack and successfully transmitted baseline data to a simple preliminary dashboard.



Component	Pin Function	ESP32 Pin Connection	Protocol
MAX30100/30102	SDA (Data)	GPIO 21	I2C
MAX30100/30102	SCL (Clock)	GPIO 22	I2C
OLED Display	SDA (Data)	GPIO 21 (Shared)	I2C
OLED Display	SCL (Clock)	GPIO 22 (Shared)	I2C
All Devices	VIN / GND	3.3V / GND	Power

{Circuit diagram yaha par main photo

}

```
// Edge Processing: Filtering invalid readings before network
transmission
void processAndSendVitals() {
  pox.update();
  if (millis() - tsLastReport > REPORTING_PERIOD_MS) {
    float currentBPM = pox.getHeartRate();
    int currentSpO2 = pox.getSpO2();

    // Data Validation Logic
    if (currentBPM > 30 && currentSpO2 > 50) {
      // Only valid human data is prepared for transmission
      displayOnOLED(currentBPM, currentSpO2);
      // prepareNetworkPayload(currentBPM, currentSpO2);
    }
    tsLastReport = millis();
  }
}
```

Pending Milestones (Remaining 50%):

WebSocket Integration: Upgrading the basic network connection to a persistent WebSocket channel for sub-second, full-duplex communication.

JSON Multiplexing: Coding the logic to combine the physiological data and simulated GPS tracking coordinates into unified JSON payloads.

Central Server Deployment: Developing and hosting the Node.js server to manage incoming client streams and route data effectively.

Application Dashboards: Building the multi-client UI, consisting of the Doctor's clinical dashboard (live charting) and the Hospital Admin dashboard (live map tracking).

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