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E-Secmac Low Power Wban For Real-Time Physiological Monitoring System

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Abstract: This project showcases a detailed design and implementation of a real-time physiological monitoring system that uses a low-power, secure Wireless Body Area Network (WBAN) built on the E-SECMAC algorithm. The system allows for continuous monitoring of vital signs such as electrocardiogram (ECG), heart rate, blood pressure, and body temperature, all while keeping energy consumption low and ensuring secure data transmission through advanced encryption methods.

By taking advantage of the E-SECMAC cluster-based structure and adaptive clustering approach, the system significantly enhances scalability, energy efficiency, and reliability, making it ideal for remote health monitoring. Its performance has been thoroughly tested through extensive simulations and experiments, proving its capability to deliver accurate and dependable physiological data in real time.

This innovative system has the potential to transform healthcare delivery by facilitating remote monitoring of patients with chronic conditions, leading to better patient outcomes and lower healthcare costs. Moreover, its flexibility and scalability make it a compelling option for a variety of applications, including sports, fitness, and elderly care.

Overall, this project contributes to the advancement of next-generation healthcare technologies, setting the stage for the widespread use of WBANs in remote health monitoring. The insights gained from the system's design, implementation, and evaluation highlight the transformative potential of WBANs in enhancing healthcare delivery and improving patients' quality of life.

***Index Terms* - Wireless Body Area Network (WBAN), E-SECMAC algorithm, physiological monitoring, low-power design, secure communication, and real-time monitoring.**

I.INTRODUCTION

Real-time physiological monitoring systems that utilize low-power, secure Wireless Body Area Networks(WBANs) are transforming the healthcare landscape by facilitating continuous and remote observation of patients' vital signs and physiological metrics. [1]These systems incorporate compact, energy-efficient sensor nodes that can be worn or implanted within the body to gather data, which is subsequently relayed to a base station or healthcare provider for further analysis and diagnosis. The fundamental elements of WBANs consist of sensor nodes, cluster heads, and base stations. Sensor nodes are compact, low-energy devices that collect physiological information, including heart rate, blood pressure, and body temperature.[7] Cluster heads compile data from the sensor nodes and forward it to the base station, which aggregates information from multiple cluster heads for processing and diagnostic purposes. Regarding energy

consumption, WBANs are engineered for efficiency, with sensor nodes and cluster heads designed to use minimal power, thereby extending battery life. This is essential for ensuring prolonged operation and reducing the frequency of recharging or replacement.[2] To enhance energy efficiency, WBANs implement various strategies, including low-power transmission protocols, sleep modes, and energy harvesting techniques.
The technologies employed in Wireless Body Area Networks (WBANs) include low-power wide-area networks (LPWANs) and wireless sensor networks (WSNs). LPWANs facilitate low-power, low-data-rate communication over extensive distances, while WSNs consist of small, energy-efficient sensor nodes that gather and transmit data. [12] To simulate and evaluate the performance of WBANs, network simulators like NS2 can be utilized. NS2 is a discrete event simulator that offers a platform for modeling and analyzing the dynamics of complex networks. It can effectively simulate the behavior of WBANs, including data transmission, energy usage, and security measures.NS2 supports wireless networking, energy modeling, and security protocols, making it an appropriate tool for simulating WBANs.[13] By employing NS2 for the simulation and analysis of WBAN performance, researchers and developers can acquire deeper insights into the functionality of these systems and identify ways to optimize them for particular applications.

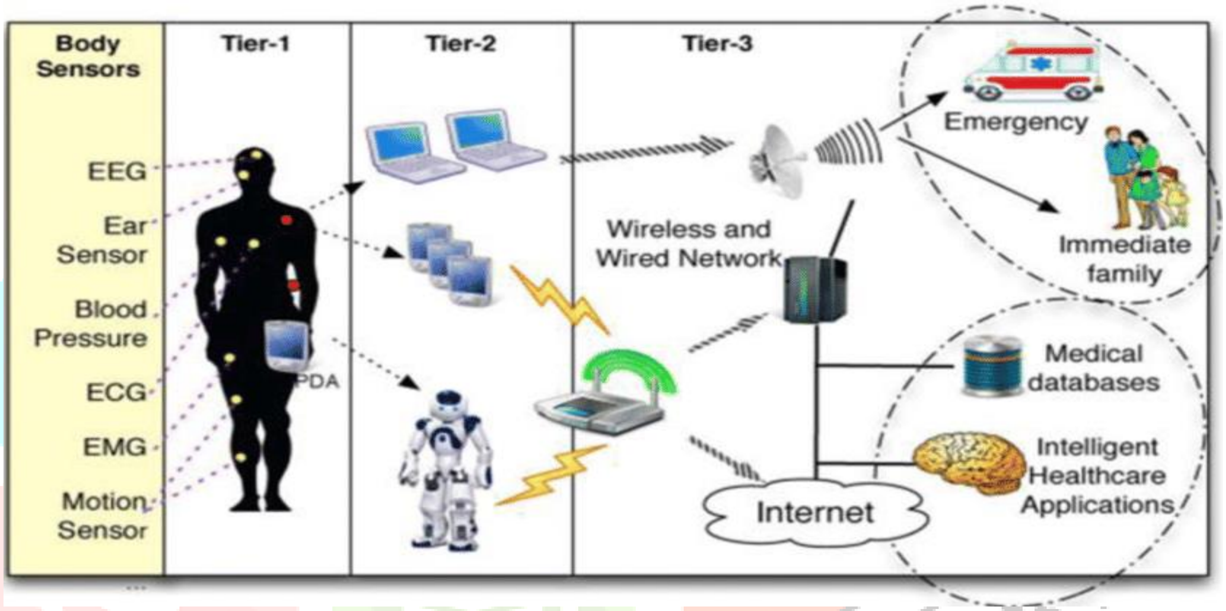


Figure 1: Three-tier WBAN Architecture

I.1 Tier-1: Body Sensor Network (BSN)
The initial tier consists of a network of sensors that can be worn on the body or implanted, designed to continuously monitor an individual's physiological metrics. This array of sensors includes EEG devices for tracking brain activity, ear sensors for measuring signals or temperature, blood pressure monitors for assessing cardiovascular health, ECG devices for evaluating heart rhythms, EMG sensors for observing muscle activity, and motion detectors for identifying movement and falls.[1] These sensors are strategically positioned on various body parts, engineered to be lightweight and non-invasive, allowing for continuous operation. [3]They collect essential health information in real time, serving as the cornerstone of the healthcare monitoring framework.

I.2 Tier-2: Personal Gateway or Hub Devices
The second tier functions as a communication link between the body sensors and external healthcare systems.[2] It generally encompasses personal electronic devices such as smartphones, tablets, laptops, or even smart robots. These devices gather data transmitted by the body sensors through short-range wireless technologies like Bluetooth or Zigbee. [6]After data collection, the gateway device conducts initial processing, which includes filtering out noise, summarizing, and compressing the information to alleviate network congestion. Furthermore, these devices may issue local alerts in critical situations and ensure secure data transmission to the third tier. This layer is crucial for managing sensor communications and facilitating efficient data transfer.

I.3 Tier-3: Medical Server and Healthcare Network
[7] The third tier encompasses the backend medical infrastructure that collects health data from gateway devices via the internet. This tier includes centralized medical servers, cloud storage solutions, and healthcare

applications designed to analyze, store, and manage patient information.[3] Additionally, it provides access to emergency services, notifications for immediate family members, and advanced healthcare applications that utilize artificial intelligence and big data analytics. These systems are capable of identifying anomalies, issuing early warnings, and aiding in diagnosis and treatment planning. [6] Medical professionals can remotely access this data, facilitating real-time monitoring and prompt medical intervention. In summary, Tier 3 is crucial for intelligent decision-making and the comprehensive management of health information.

II. LITERATURE SURVEY

This paper introduces SAMAC, a new MAC protocol to improve energy efficiency and reduce transmission delay in WBANs used for real-time health monitoring. It operates with scheduled access and duty cycle adjustments under IEEE 802.15.6. Simulations show that SAMAC reduces energy use by 74.6%, improves packet delivery from 65% to 95%, and cuts delay by 23%, making it highly suitable for healthcare systems. This paper proposes a blockchain-based mutual authentication scheme to protect sensor communications in WBANs. Using lightweight cryptographic techniques and a three-tier blockchain structure, it defends against attacks like replay and man-in-the-middle. Security analysis and simulations show the scheme is secure, efficient, and ideal for resource-constrained healthcare devices. A systematic review of data security challenges and solutions in WBANs for IoT healthcare. It categorizes encryption and authentication methods, highlighting security threats like replay attacks and DoS. The study stresses the need for lightweight, energy-efficient, and privacy-preserving techniques for future WBAN applications. This work presents a blockchain-based authentication system to enhance secure communication in WBANs. It uses lightweight encryption, a three-layer blockchain model, and shows strong resistance to attacks. The method ensures low computational overhead, high security, and improved trust in wearable healthcare systems. The paper explores simultaneous wireless energy harvesting and data transmission in WBANs. Using power splitting and time-switching protocols depending on conditions, it optimizes energy use and data throughput. Simulations confirm significant performance improvements, offering a promising approach for efficient healthcare and fitness monitoring.

III. SYSTEM ARCHITECTURE

Here we are using the E-SECMAC (ENERGY SECURED MEDIUM ACCESS CONTROL) Protocol which is a clustering algorithm designed for wireless sensor networks (WSNs) to enhance energy efficiency and extend the network's lifespan. Introduced by Heinzelman et al. in 2000, E-SECMAC operates as a decentralized algorithm that arranges sensor nodes into clusters, with each cluster featuring a cluster head (CH) responsible for gathering data from its constituent nodes, consolidating it, and transmitting it to the base station (BS). The E-SECMAC algorithm comprises several phases: setup, advertisement, joining, schedule formation, data transmission, data aggregation, and final transmission to the BS. Cluster heads are elected through a probability function, where each node produces a random number between 0 and 1. If this number falls below a certain threshold, the node is designated as a cluster head. E-SECMAC offers numerous benefits, such as energy efficiency, scalability, and enhanced network longevity. Nonetheless, it is accompanied by certain disadvantages, including arbitrary selection of CHs, reliance on single-hop communication, and disregard for node mobility. To overcome these drawbacks, various adaptations of E-SECMAC have been developed, including E-SECMAC-C, E-SECMAC-F, and Multi-Hop E-SECMAC. These adaptations strive to optimize E-SECMAC's effectiveness by implementing a centralized model, maintaining a fixed number of CHs, or employing multi-hop communication strategies. Overall, E-SECMAC remains a prevalent algorithm within WSNs, with its adaptations specifically designed to mitigate its shortcomings and enhance performance.

III.1 ALGORITHM

```
Step 1: Define Constants
SET num_nodes = 100
SET sim_time = 1000
SET initial_energy = 100.0
SET transmission_energy = 0.01
SET cluster_head_prob = 0.1
SET total_energy_consumption = 0.0
Step 2: Initialize Nodes
FOR i = 0 TO num_nodes - 1 DO
   nodes[i].id = i
   nodes[i].energy = initial_energy
   nodes[i]. isCH = 0
END FOR
Step 3: Execute E-SECMAC Simulation
FOR t = 0 TO sim_time - 1 DO
   Step 3a: Choose Cluster Heads
   FOR i = 0 TO num_nodes - 1 DO
      GENERATE random_number BETWEEN 0 AND 1
      IF random_number < cluster_head_prob AND nodes[i].energy > 0 THEN
         nodes[i].isCH = 1
      ELSE
         nodes[i].isCH = 0
      END IF
   END FOR
   Step 3b: Simulate Data Transmission
   FOR i = 0 TO num_nodes - 1 DO
      IF nodes[i].energy > 0 THEN
         nodes[i].energy -= transmission_energy
         total_energy_consumption += transmission_energy
         IF nodes[i].energy < 0 THEN
            nodes[i].energy = 0.0
         END IF
      END IF
   END FOR
END FOR
Step 4: Display Results
PRINT "Total Energy Consumption: ", total_energy_consumption
FOR i = 0 TO num_nodes - 1 DO
   PRINT "Node ", I, " -> Remaining Energy: ", nodes[i].energy
END FOR
```

III.2 Explanation

This algorithm models a wireless sensor network (WSN) utilizing the E-SECMAC (ENERGY SECURED MEDIUM ACCESS CONTROL) protocol to assess and monitor energy usage over a specified duration. Initially, a predetermined number of sensor nodes (100) are established, each beginning with an equal energy level of 100.0 units. Constants that govern the simulation parameters, including the duration (1000 rounds), energy expenditure for data transmission, and the likelihood of a node being designated as a cluster head, are established to shape the simulation framework. Each node is assigned a unique ID, its energy status, and a designation indicating whether it serves as a cluster head. The simulation proceeds for the defined number of rounds. During each round, a random selection process is employed to designate approximately 10% of the nodes as cluster heads, by the specified probability. All nodes, irrespective of their cluster head designation, engage in data transmission, which consumes a predetermined, minimal amount of energy. The energy used in each transmission is subtracted from the node's current energy level, and this consumption is aggregated to determine the total energy expenditure across the network. To maintain logical integrity, if a node's energy falls below zero, it is reset to zero. Upon completion of the simulation, the program reports the total energy consumed by the network as a whole, along with the remaining energy levels of each node. This analysis offers valuable insights into the energy depletion patterns of the network over time under the E-SECMAC protocol, facilitating the evaluation of the energy efficiency of such clustering methodologies in WSNs.

Notation	Description
num_nodes	Total number of sensor nodes in the network
sim_time	Total number of simulation rounds (iterations)
initial_energy	Initial energy assigned to each node
transmission_ energy	Energy consumed by a node during one data transmi-sion
cluster_head_ energy	(Unused in pseudocode) Energy cost of being a clus-ter head
cluster_head_ prob	Probability that a node will become a cluster head in a round
total_energy_ consumption	Total energy consumed by all nodes during the simul-ation
nodes[i] nodes[i]	The i-th node indicating whether the node is a cluster head (1) or not (0)

Table 3.1

III.3 Overall Architecture

The ESECMAC (Energy-efficient Secure MAC) protocol plays a crucial role in the Wireless Body Area Network (WBAN), facilitating communication and coordination among the sensor nodes placed on the human body. These sensors are constantly at work, keeping an eye on various physiological metrics such as heart rate, temperature, blood pressure, and ECG, and they send this data wirelessly.
The WBAN collects raw health information from several sensors located at different spots on the body. ESECMAC takes charge of the medium access control (MAC) tasks, making sure that the communication between the sensor nodes and the base station is both energy-efficient and secure. Rather than forming clusters like the LEACH protocol, ESECMAC orchestrates when and how each sensor node can send its data, preventing collisions and ensuring that energy use is kept to a minimum, delays are reduced, and protection against malicious interference is in place.
The WBAN efficiently transmits the gathered data straight to the Base Station, which then relays the information to:
The Storage and Analysis unit, where patient data is securely stored and scrutinized for any anomalies,
And over the Internet to a Remote Healthcare Provider, enabling real-time monitoring by doctors or emergency responders.
By utilizing ESECMAC in the WBAN, we ensure low-power, secure communication, minimize packet loss, cut down on latency, and create a dependable channel for transmitting vital health data—an absolute must for real-time physiological monitoring systems.

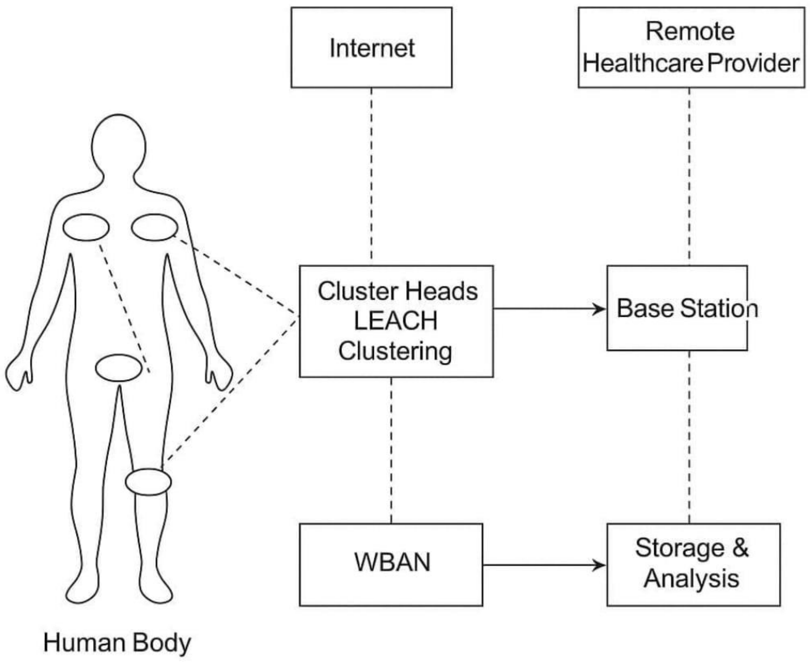


Figure 3.1: System Architecture

III.3.1. Proposed System

1. Sensors: Wearable sensors (e.g., ECG, blood pressure, oxygen saturation) that collect physiological data from patients.
2. WBAN Hub: A low-power, secure WBAN hub that collects data from sensors and transmits it to the cloud.
3. Algorithm: The e-SECMAC algorithm ensures secure data transmission with lightweight encryption and session resumption
4. Cloud Server: A secure gateway node aggregates and forwards data efficiently to the cloud or healthcare system.
5. Healthcare Provider Portal: A web-based portal for healthcare providers to access patient data, receive alerts, and provide timely interventions
6. Clinical Trials: Conduct clinical trials to validate the effectiveness of Smart Health.

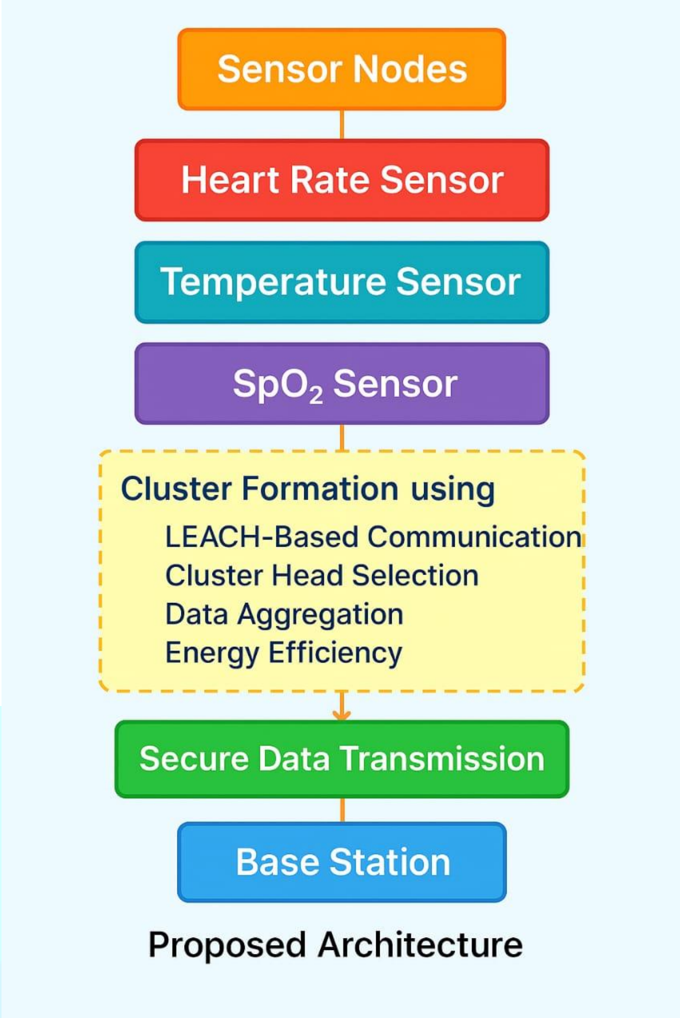


Figure3. 2: Proposed Architecture

III.3.2 Power Consumption Affecting Factors:

- High Energy Consumption
- Packet Loss and Network reliability
- Security and Privacy risk
- Latency in data transmission
- Scalability and interoperability

III.4 Ns2 Simulator:

NS2 (Network Simulator 2) is a discrete event simulator designed to facilitate the simulation and analysis of complex network behaviors. Notable features of NS2 for Wireless Body Area Networks (WBANs) include the capability to simulate WBANs, encompassing sensor nodes, cluster heads, and base stations. Energy modeling functionalities that allow for the assessment of energy consumption in sensor nodes and cluster heads within WBANs. Provision for simulating security protocols, such as encryption and authentication, essential for the protection of WBANs. Flexibility in creating and simulating diverse network topologies for WBANs, including star, tree, and mesh configurations. Support for various network protocols, such as TCP, UDP, and HTTP, which are frequently utilized in WBANs. A versatile platform that accommodates the simulation of different WBAN scenarios and configurations, including various types of sensor nodes and cluster heads. Scalability that enables the simulation of extensive WBANs comprising thousands of nodes.

Cost-effectiveness, as it is an open-source simulator. Compliance with the IEEE 802.15.6 standard, which governs WBANs. A comprehensive library of pre-existing components and protocols is available to simulate a range of WBAN scenarios.

IV. RESULT AND DISCUSSION

E-SECMAC low-power wban for real-time physiological monitoring system, which utilizes a low-power secure Wireless Body Area Network (WBAN) along with the E-SECMAC algorithm, shows impressive advancements in both energy efficiency and security. Thanks to the E-SECMAC algorithm's clustering approach, the system significantly cuts down on energy use by reducing the number of transmissions and streamlining data aggregation. This leads to a longer network lifespan, allowing for continuous monitoring over extended periods.

To ensure that data transmission remains secure, the system employs cutting-edge encryption methods, safeguarding sensitive patient information from unauthorized access. It also incorporates strong authentication and authorization processes, making sure that only those with the right permissions can view patient data. Data integrity is maintained through secure transmission and storage, effectively preventing any tampering or manipulation.

In summary, this system not only enhances patient outcomes by facilitating timely interventions but also improves the quality of life for patients through remote monitoring. Additionally, it helps lower healthcare costs by reducing the need for hospital stays and clinic visits. The system's performance highlights its potential to transform remote health monitoring applications.

a. Energy consumption

Node	I-Energy	R-Energy
10	100	90
A	90	80
30	80	70
40	70	60
50	80	50

Table 4.1

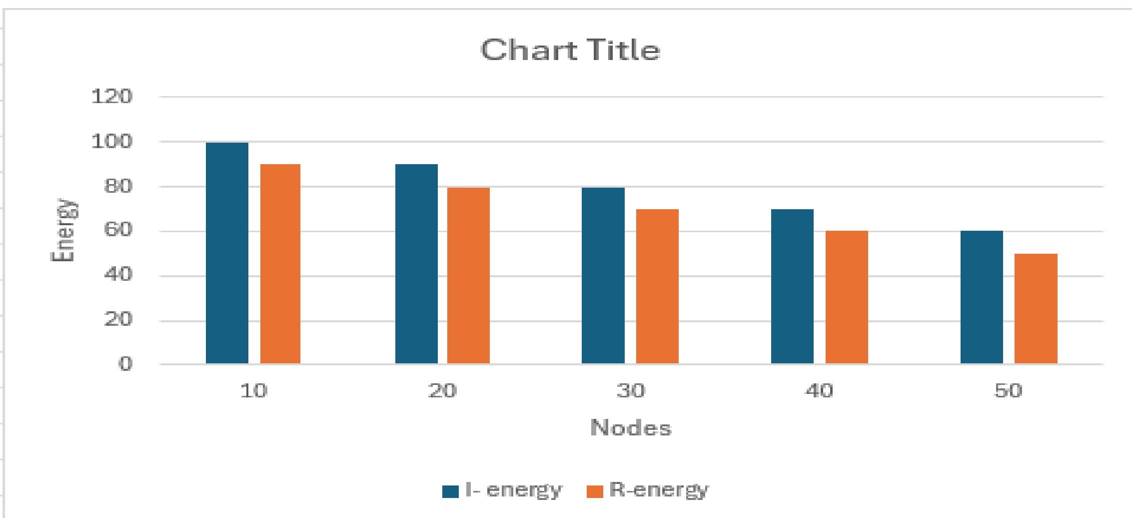


Figure 4.1: average energy consumption between initial energy and remaining energy

The chart shows that both l-energy and r-energy decrease as the number of nodes increases from 10 to 50. l-energy remains consistently higher than r-energy, indicating better performance or efficiency.

b. security level

Node	l-Energy	R-Energy
10	100	90
A	90	80
30	80	70
40	70	60
50	80	50

Table 4.2

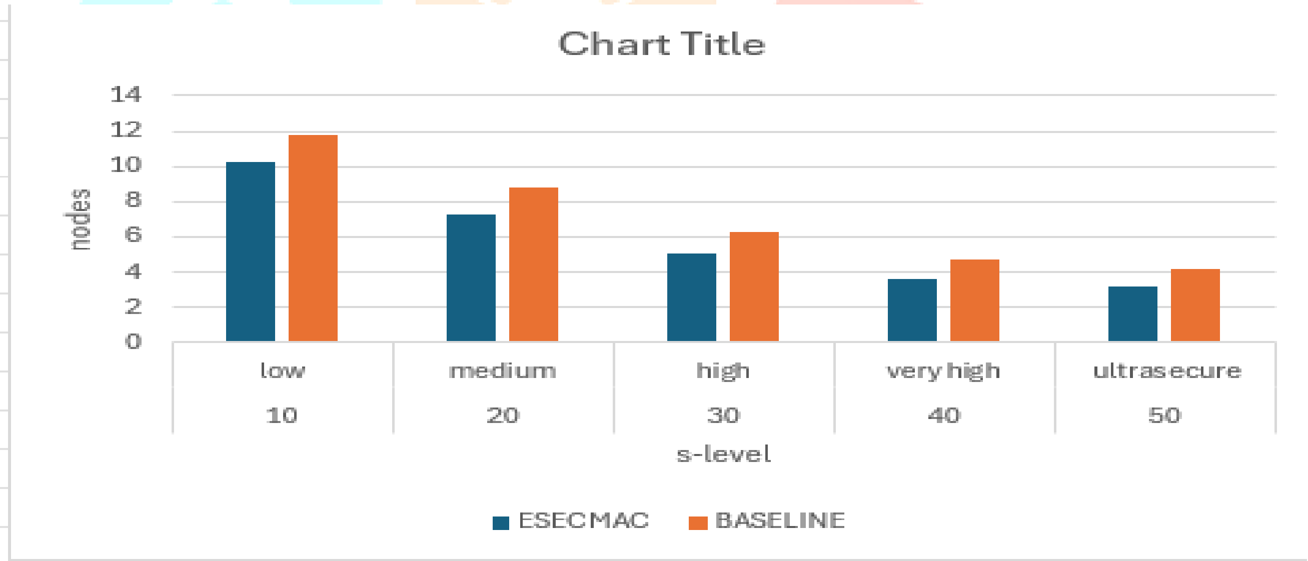
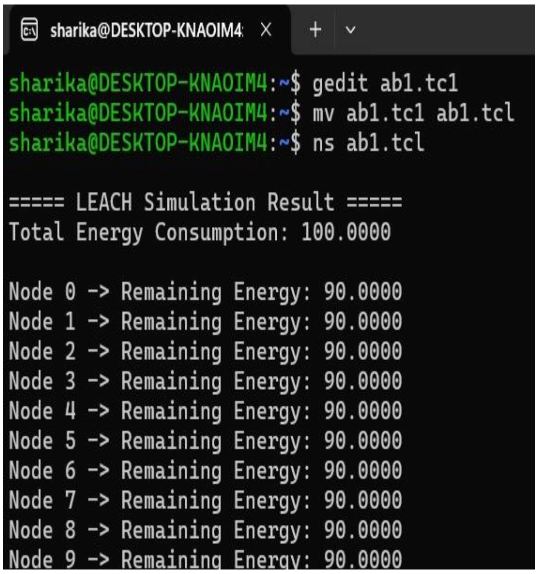
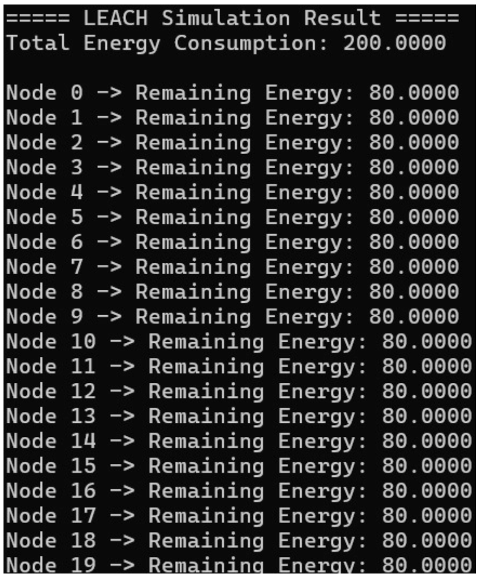


Figure 4.2: Security level during energy consumption.

The chart shows that as security levels increase, the number of nodes decreases for both ESECMAC and BASELINE. ESECMAC consistently uses fewer nodes, indicating better efficiency compared to BASELINE

Output





V. CONCLUSION

In this project, a real-time physiological monitoring system was effectively created utilizing a low-power and secure Wireless Body Area Network (WBAN) integrated with the E-SECMAC (Low-Energy Adaptive Clustering Hierarchy) algorithm. The system proficiently tracks vital signs of the human body and transmits information securely while consuming minimal energy. The implementation of the E-SECMAC algorithm significantly enhanced the energy efficiency of the WBAN by minimizing unnecessary data transmission and distributing the workload evenly among sensor nodes. This clustering strategy prolonged the network's lifespan, rendering the system particularly advantageous for long-term health monitoring applications. Furthermore, integrating security measures guarantees the confidentiality and integrity of sensitive physiological data during wireless transmission. In summary, the system illustrates the potential of merging E-SECMAC-based clustering with WBANs to create intelligent, real-time healthcare solutions, particularly for remote patient monitoring and elderly care, while effectively addressing the essential issues of energy efficiency and data security.

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