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Smart Healthcare Monitoring system using Wireless Sensor Networks

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Abstract: Wireless sensor networks (WSNs) have the potential to revolutionize healthcare by allowing for the continuous monitoring of patients and the rapid response to medical emergencies. In this study, we detail the planning and execution of a WSN-based smart healthcare monitoring system that can keep tabs on your vitals around the clock, including your pulse, oxygen saturation, blood pressure, and temperature. Every sensor node communicates with a central base station (sink) to analyze and act upon data sent by medical sensors and microcontrollers. Utilizing the DMAC (Data-Gathering MAC) protocol, which improves energy economy and reduces latency via staggered duty cycles, is a crucial aspect of the system. Focusing on the phases of shared and exclusive bandwidth between nodes, the research emphasizes the temporal dynamics of node transmissions. The system has been tested and shown to be reliable in data collecting, energy management, and network coordination via simulations. This shows that it has the capacity to be used in healthcare applications that are both scalable and responsive.

Keywords: Wireless sensor network, healthcare, system, monitoring, sensor

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INTRODUCTION

Digital electronics networks in homes have largely replaced their office-based predecessors as a result of lightning-fast wireless communications and computer hardware (Hwang and Yu, 2012). Particularly in the fields of remote monitoring and control, real-time applications built on home networks are booming in popularity and relevance. A growing number of healthcare applications are using wireless sensor networks (WSNs) for alerts and real-time monitoring. To save lives, time, and money, medical centers, physicians' offices, and patients may access real-time health information via the integration of medical sensors, microcontrollers, and smartphones that provide embedded systems.

Wireless sensor networks (WSNs) are an ideal tool for handling unexpected scenarios, such as the unusual symptoms experienced by sick people going about their daily lives. In order to better monitor healthcare facilities and identify diseases, several researchers have created WSNs. In their 2008 proposal, Chung et al. included electrocardiogram (ECG) and blood pressure (BP) monitoring into a healthcare monitoring system that would use a mobile phone to continuously analyze data and send it via A network of wireless sensors. Kumar et al. (2012) state that WSNs have had a big impact on healthcare systems this century and will be crucial to the future of healthcare as we know it. According to Yan et al. (2015), sensing, intelligent computing, and wireless networking are all part of the interdisciplinary job of monitoring human health problems. Saxena et al. (2003) found that patients with illnesses need continuous monitoring of biological signals relating to present cardiac function. In order for medical professionals to keep tabs on their patients' vitals, these online monitoring systems need software that can transmit health signals over the internet.

Reducing paperwork, expanding the number of monitored patients, improving accuracy, and shortening diagnostic times are just a few of the many benefits that healthcare apps that make use of computers, smart mobiles, and wireless technologies will provide. No longer is it necessary for patients to remain in the hospital for physicians to be able to monitor them 24/7 with these apps. Continuous monitoring, early identification of anomalous situations, monitored recovery, and possible knowledge acquisition via data mining of all collected dataare just a few of the many ways in which WSN technology can benefit patients, doctors, medical centers, and society at large. Actually, because of their built-in wireless networks, smart mobile phones may be used for remote sensing, data collecting, and monitoring of medical data. With the use of online scanned signals and the patient's medical history, this technology will aid physicians in identifying the health condition. Identifying unusual health issues in real-time and prompt response from the medical center are the major difficulties of health monitoring systems. Hospital testing may sometimes confirm that a patient's symptoms are normal even when they occur outside. However, without real-time monitoring, which requires the patient to remain in the hospital's intensive-care unit (ICU) for a few days, it is not simple to discover all sorts of aberrant activity. Consequently, it is possible to create a portable, wireless monitoring system that might aid doctors and hospitals in providing accurate care.

MEDICAL SENSORS

Using wireless communication technologies and medical sensors to monitor a patient's vitals as they go about their daily lives is a win-win situation for everyone involved. In this scenario, each patient is seen as a node in a wireless sensor network (WSN) that is connected via the internet to a central node located at a medical institution. The node, a portable medical device with a built-in microprocessor connected to a number of medical sensors, is seen in Figure 1.

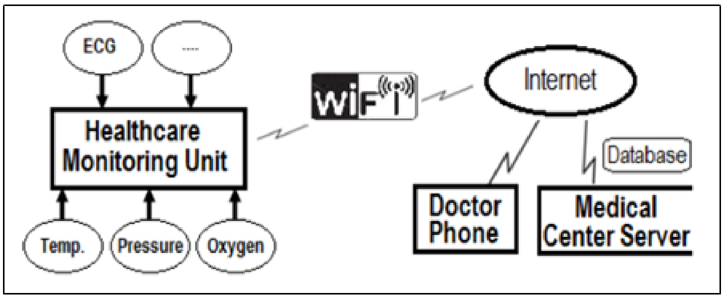


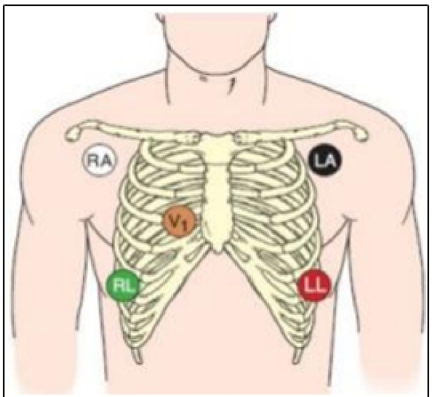
Figure 1: System architecture layout

Table 1: Features of medical sensors

Medical sensor	Signal range	Sampling frequency
Electrocardiograph (ECG)	0.01–5.0 mV	100 sample/sec
Finger pulse oximeter (SpO2)	45–200 beats/min, 12–40 breaths/min	100 sample/sec
Blood pressure	40–300 mmHg	1 sample/sec
Temperature	20–50 Celsius	1 sample/sec

The patient's medical history and the required sensors for health monitoring establish theability to assess health parameters in real-time. Reliable, compact, and power-efficient medical sensors were taken into account while designing the suggested healthcare system. The chosen sensors' broad features are shown in Table 1. Blood pressure, oxygen saturation, temperature, electrocardiogram (ECG) signals, and heart rate were all measured via four separate sensors.

- **ECG sensing:** ECG stands for electrocardiogram and describes the method of continuously measuring the electrical and muscular activities of the heart. There isthe fitted ECG machine only had five electrodes—RA, RL, LA, LL, and V1—attached to the human body. Every electrocardiogram (ECG) sensor converts it into an electrical signal with an amplitude between 1 and 5 mV as soon as it is recognized. Figure 2 shows a signal conditioning circuit that filters and amplifies the analogue signals produced by the electrocardiogram electrodes. An instrumentation amplifier, a low pass filter (with a 150 Hz cut-off), a gain amplifier, a notch filter, and a high pass filter make it up.



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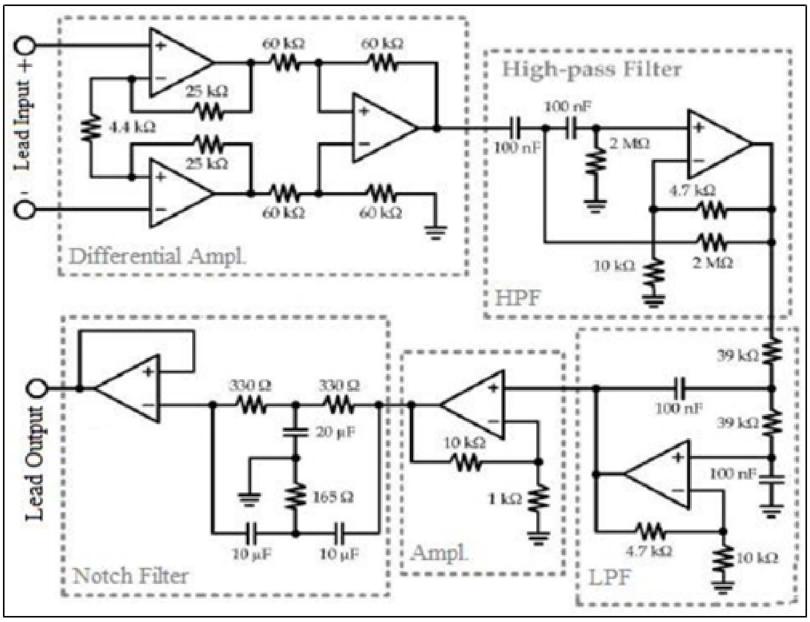
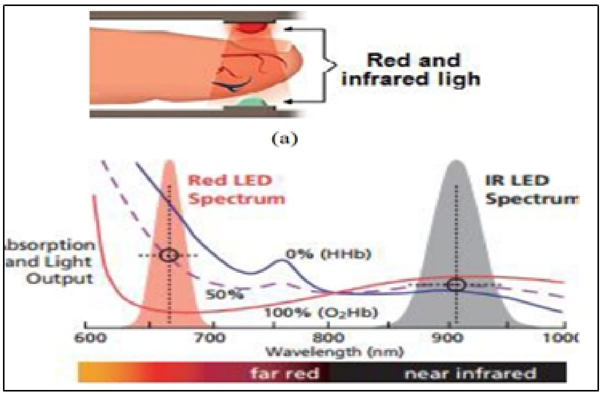


(b)

Figure 2 (a) Electrocardiogram lead insertion (b) signal conditioning unit (for colors, check online

- **Heart rate and oxygen level detection:** Oxygen saturation (SpO2) and heart rate may be measured using a finger pulse oximeter. An infrared or red light-emitting diode (LED) and a photodetector, which absorbs light from the measurement site—make it up. One way that pulse oximeter's function is by measuring the blood's hemoglobin absorption properties using red or infrared light. Figure 3 shows that different types of hemoglobin absorb different wavelengths of light. Red hemoglobin absorbs more red light, while infrared light absorbs more oxygenated hemoglobin. This aids in determining the ratios of red and infrared light transmittances, converting these numbers into absorbances, and comparing them to estimate blood oxygenation. A microcontroller receives pulses from a pulse oximeter and uses them to determine the patient's heart rate.



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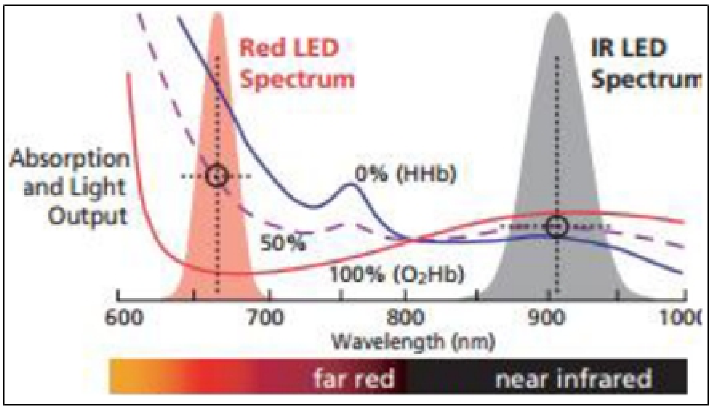

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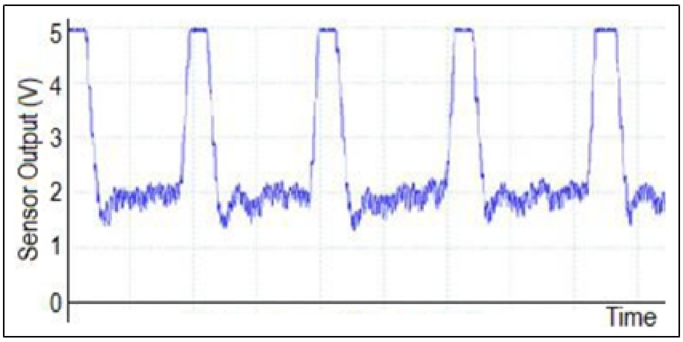

(c)

Figure 3: The workings of finger pulse oximeter sensor, including (a) the sensor itself, (b) the output and absorption of light, and (c) the pulse output of the sensor

- **Blood pressure sensing:** The blood pressure was measured using a Silicon pressure sensor (ASDX 015PDAA5). A digital interface is provided for communication as seen in Figure 4, with the integrated microprocessor. The pressure sensor is connected via an airline to a DC motor and adump valve. The blood pressure measurements are obtained by controlling the DC motor and dump valve with the help of the integrated microprocessor. The principle of the measurement is dependent on the pressure sensor picking up on changes in the arm cuff's pressure. With an accuracy of ±2.0% throughout the stated full scale pressure span, this sensor provides a high voltage output (4.0 Vdc span).

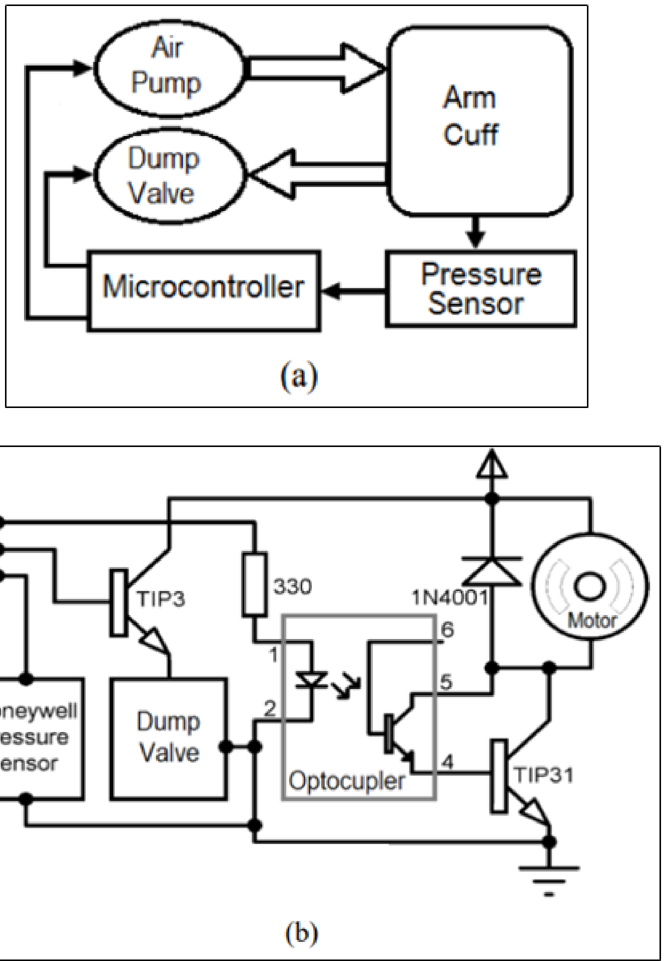

Figure 4:blood pressure monitor, (a) method of measurement, (b) circuit interface

- **Temperature sensing:** A compact, inexpensive, and infra-red thermopile detector and signal conditioner chip make up the MLX90614 non-contact temperature sensor. For continuous temperature monitoring, it provides a 10-bit PWM signal with a precision of 0.14°C. As seen in Figure 5, it may be directly attached to the input of the microcomputer.

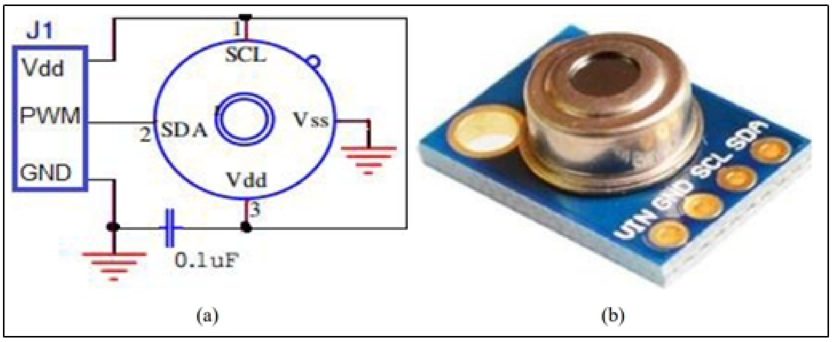

Figure 5: A temperature monitoring device

METHODOLOGY

The design of the mobile the architecture shown in the II-type environmental node, I-type environmental node, and node Figure 6. Due to the outside deployment of all nodes, solar energy harvesting is used to fulfill the lifespan requirements.

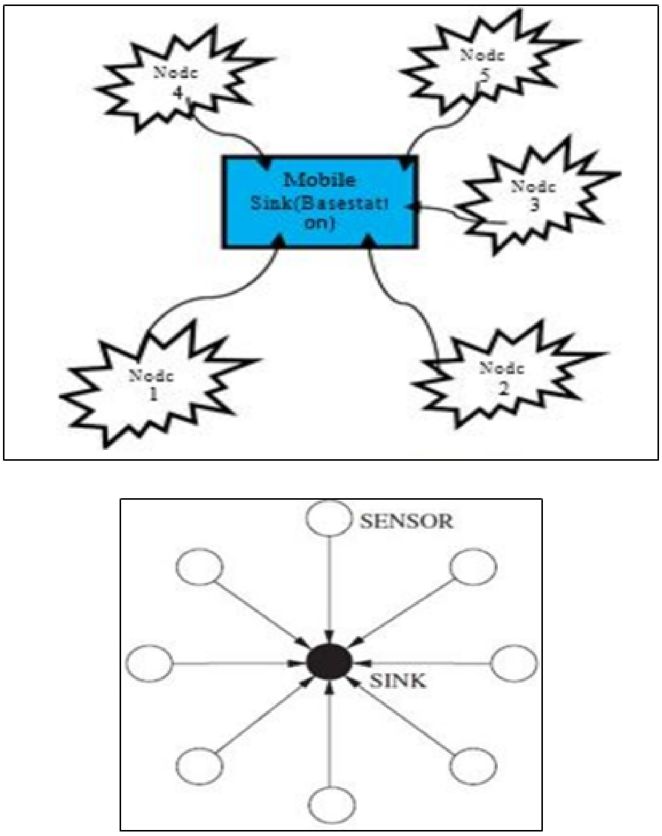

Figure 6: Single HOP Sensor

One common communication pattern The Data-Gathering MAC (DMAC) protocol is used in wireless sensor networks. It leverages the fact that data is collected at a single node, known as the "sink," in a data-gathering tree. DMAC seeks to transfer data throughout the data collecting tree with the least amount of delay and the highest possible energy efficiency. Nodes along the multi-hop path to the sink in DMA Chave their duty cycles "staggered"; in other words, they wake up progressively, like a chain reaction. With a simple toggle, nodes may go into a sleeping, transmitting, or receiving state. As part of its routing process, a node will transmit a packet to the next hop and then wait for an acknowledgment (ACK) while it is in the sending state. Additionally, the node at the following hop is in the receiving state before switching to the sending state to pass the packet on (unless it is the destination node). A node may enter a sleep state between packet transmission and reception, allowing it to save energy by turning off its radio.

RESULTS

Each node has been broadcast at a predetermined period. A monitoring system based on wireless sensor networks has been developed and put into operation to collect comprehensive data on the people and their environments that make up the mobile nodes. So far, a total of five nodes and one sink node (or base stations) have been installed for gathering data. To satisfy the requirements of certain applications, network protocols were developed using widely used components. Simulations and future field trials validated the efficacy of our monitoring system by assessing system functions and network performances.

Figure 7: Building Nodes

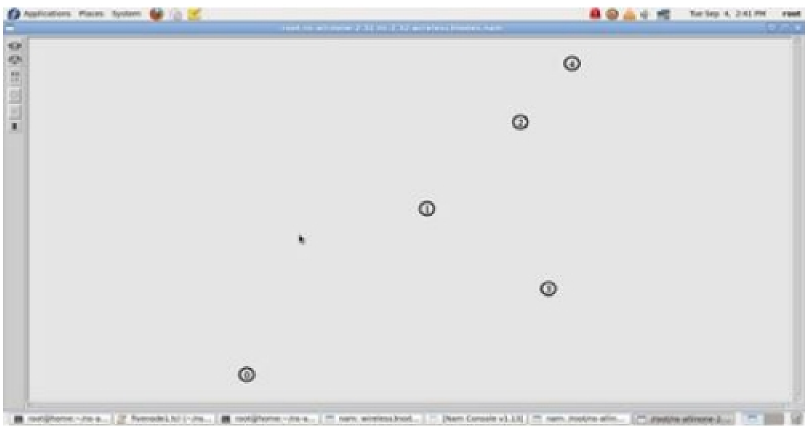

Figure 8: Node Communicating with Another Node

Analysis: Node 1 starts broadcasting at time T=1.4 seconds, while Node 2 starts at time T=10 seconds begins transmitting.

Node 1 is the only transmitter throughout the time interval [1.4, 10 seconds] making full use of the available bandwidth.

Table 2: Details Regarding Network Node Transmissions

Node ID	Transmission Start Time (sec)	Transmission End Time (sec)	Bandwidth Utilization	Transmission Status	Network Exclusivity
Node 1	1.4	10.0	100% of available	Active	Exclusive transmitter
Node 1	10.0	-	Partial (shared)	Active	Concurrent with Node 2
Node 2	10.0	-	Partial (shared)	Active	Concurrent with Node 1
Node 3	N/A	N/A	0%	Inactive	N/A
Node 4	N/A	N/A	0%	Inactive	N/A
Node 5	N/A	N/A	0%	Inactive	N/A

Table 3: Temporal Network State Analysis

Time Interval (sec)	Active Transmitting Nodes	Bandwidth Allocation	Network State
[0, 1.4)	None	0% utilization	Idle
[1.4, 10.0)	Node 1 only	Node 1: 100%	Single node transmission
[10.0, -)	Node 1 and Node 2	Shared (protocol dependent)	Multi-node transmission

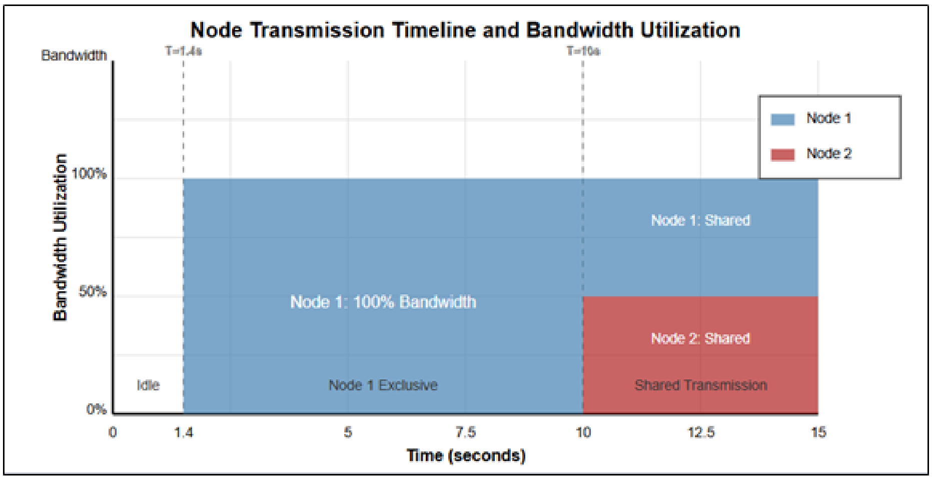

Figure 9: Node Transmission Timeline and Bandwidth Utilization

Node 1 has its own dedicated transmission window, and then Node 2 and Node 1 share the bandwidth for a while when they're both online, as shown in the graphic. The graphic shows that Node 1 uses all of the available bandwidth between [1.4 sec, 10 sec] before Node 2 starts transmitting, which causes the two nodes to share the bandwidth.

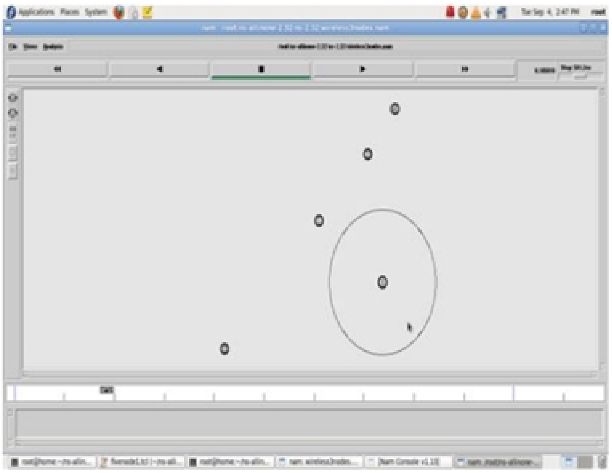

Figure 10: Analysis Node Using Health Monitoring.

Analysis: Node 1 starts broadcasting at time T=1.4 seconds, while Node 2 starts at time T=10 seconds begins transmitting.

There is a window of opportunity for Node 1 to make full use of the available bandwidth between [1.4 sec, 10 sec]. This proves that Node 1 was really quite effective over the allotted time frame. Node 2 begins transmitting when the time is 10 seconds.

Table 4: Features of Time-Related Transmission

Node ID	Start Time (sec)	Status During [1.4, 10] sec	Status After T=10 sec	Bandwidth Allocation [1.4, 10]	Bandwidth Allocation After T=10
Node 1	1.4	Sole Transmitter	Active (with contention)	100% of available bandwidth	Shared (reduced performance)
Node 2	10.0	Inactive	Active	0% (dormant)	Shared (initial transmission)

Table 5: Evaluation of Performance KPIs

Time Period (sec)	Active Nodes	Network Utilization	Node 1 Performance	Node 2 Performance	System State
[0, 1.4)	None	0%	Inactive	Inactive	Idle
[1.4, 10.0)	Node 1	100%	Optimal (High)	N/A (Inactive)	Single node optimization
[10.0, -)	Node 1, Node 2	100% (shared)	Degraded	Suboptimal	Contention state

Table 6: Criteria for Evaluating Performance

Factor	[1.4, 10.0) sec	After T=10.0 sec	Impact on Performance
Bandwidth Exclusivity	Exclusive to Node 1	Shared between nodes	Direct correlation with throughput
Transmission Collisions	None	Present	Increases latency and reduces efficiency

Processing Priority	Absolute	Competitive	Affects processing time and response rate
Resource Allocation	Unlimited access	Constrained access	Determines operational capacity

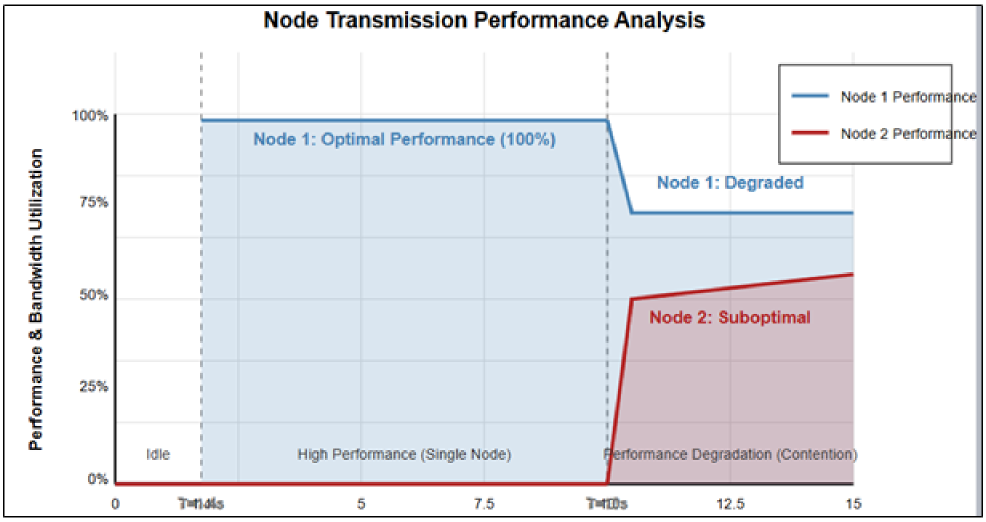

Figure 6: Assessing the Efficiency of Node Transmission

Tables 4, 5, and 6, together with Figure 6, provide the results of a comprehensive time-based evaluation of the node transmission performance in a wireless sensor network. Focusing on their start timings, operational stages, and bandwidth allocation, Table 4 details the temporal behavior of two active nodes, Node 1 and Node 2. Node 1 is allowed to use all of the available bandwidth until 10 seconds after it starts sending, which is 1.4 seconds from the start of transmission. Node 2 is dormant during this time. Node 2 becomes online after 10 seconds, leading to a situation where bandwidth is shared. As a result of competing priorities and limited resources, Node 1's performance starts to drop, and Node 2 starts transmitting under limited circumstances.

The network's performance across three time periods is further detailed in Table 5. There are no active nodes in the network during the first phase, which lasts from zero to one and a half seconds. Node 1 achieves peak performance and complete network usage by transmitting independently for 1.4 to 10 seconds. During this stage, there is no interference and the throughput is at its peak. Nevertheless, a shared network environment is established when Node 2 becomes active after 10 seconds and both nodes start transmitting at the same time. Due to increased latency and the possibility of data collisions, Node 2's performance is poor and Node 1's performance is worsened as a consequence of communication congestion caused by this shared state.

Table 6 compares the efficiency of transmission during exclusive and shared transmission times based on important criteria. When Node 1 is the only node in the network, it has all the advantages: unfettered access to resources, processing priority, bandwidth exclusivity, and no transmission collisions. All of these factors work together to make the system run better. The dynamics change after ten seconds due to resource competition between the two nodes. The system's resources are more scarce, processing priorities are more competitive, accidents are more likely, and bandwidth is shared. These alterations demonstrate the limits of concurrent node activity in the absence of effective coordination and have an immediate effect on operational efficiency, reaction time, and throughput.

Figure 6, which shows the nodes' transmission effectiveness with time, provides visual confirmation for these conclusions. The graph probably shows that Node 1's efficiency spikes during exclusive transmission and then drops dramatically when Node 2 starts talking to each other. Visualizations show that good performance is directly related to transmission exclusivity and that resource contention and bandwidth sharing have a detrimental effect on system efficiency.

The results show that the efficiency of data transmission in WSNs is greatly affected by the time of node activation and the exclusivity of bandwidth use. Particularly in multi-node settings where concurrent transmission might hinder performance, the results highlight the need of improved scheduling and protocol design to reduce contention.

CONCLUSION

The feasibility of A wireless sensor network-based healthcare monitoring system that can acquire and transmit data in real-time has been shown by this study. Continuous patient observation outside of typical clinical settings is made possible by integrating medical sensors for electrocardiogram (ECG), oxygen saturation (SaO2), blood pressure (BP), and temperature (temperature) into compact node architecture. The system optimizes bandwidth utilization and reduces delay by using energy-efficient protocols, including DMAC. Timing analysis of transmissions showed that Node 1 made the most of its capacity from 1.4 to 10 seconds, when it was at its peak performance, before Node 2 began sharing its bandwidth. The system's capacity to adjust dynamically in response to node activity was shown during this exclusive time. In order to aid in early diagnosis and emergency intervention, the study's results lend credence to the idea that such intelligent technologies might be useful in home-based or remote healthcare settings. Deploying the system in the real world and conducting extensive field tests to ensure its durability and compatibility with current healthcare systems are potential areas for future research.

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