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Evaluating the Advantages and Challenges of Mobile Ad-Hoc Networks

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Abstract

Mobile Ad-Hoc Networks (MANETs) are decentralized assemblies of mobile nodes, including smartphones, laptops, iPads, and PDAs, that operate autonomously, contrasting with conventional wireless networks. These networks dynamically adapt their topology and routing tables as nodes join or leave, ensuring a seamless data packet transmission. This article aims to provide a comprehensive overview of MANETs, elucidating their advantages, challenges, and diverse applications. Unlike traditional networks that require a centralized administrator, MANETs enable mobile nodes to exchange data packets solely through wireless links. However, the volatile topologies and limited resources challenge establishing a power-efficient and secure routing system. This study introduces a reliable routing mechanism considering network power consumption and node reputation. Utilizing a Krill Herd-based Grasshopper Optimization Algorithm (KH-GOA), in conjunction with a reputation model, the proposed system establishes a trustworthy route between the origin and destination nodes. The reputation model considers node mobility, actual capabilities, historical performance, and peer reviews. Upon evaluating these reputation metrics, the KH-GOA method is employed, amalgamating the Krill Herd (KH) and Grasshopper Optimization Algorithm (GOA) techniques. The proposed KH-GOA-based routing protocol considers multi-objective criteria like reputation, power efficiency, distance, and latency for optimal route selection.

Keywords: Mobile Ad-Hoc Networks (MANETs); Routing Protocols; Krill Herd-Based Grasshopper Optimization Algorithm (KH-GOA); Network Topology; Data Packet Transmission

1 Introduction

Mobile Ad-Hoc Networks (MANETs) represent a critical component of the wireless networking ecosystem, enabling direct communication between mobile devices without the need for fixed infrastructure [1, 2]. As depicted in Figure 1, MANETs are a subset of ad-hoc networks that are especially relevant in scenarios where rapid deployment and dynamic reconfiguration are necessary [3, 4]. The dynamic nature of MANETs introduces complex routing challenges, addressed in this study through the evaluation of established protocols like DSR, TORA, and OLSR, as well as a proposed hybrid protocol, KH-GOA. This research fills a critical gap by providing an extensive comparative analysis of these protocols, revealing insights into their performance across various network densities—a key consideration for the deployment of MANETs in fields ranging from emergency response to military operations [5][6][7][8]. Preliminary findings indicate that the KH-GOA protocol may offer advancements in terms of energy efficiency and resilience to security threats, promising to enhance the robustness of MANETs significantly. This contribution is poised to influence future developments in ubiquitous computing, where reliable and efficient wireless communication is paramount [9][10][11][12][13][14].

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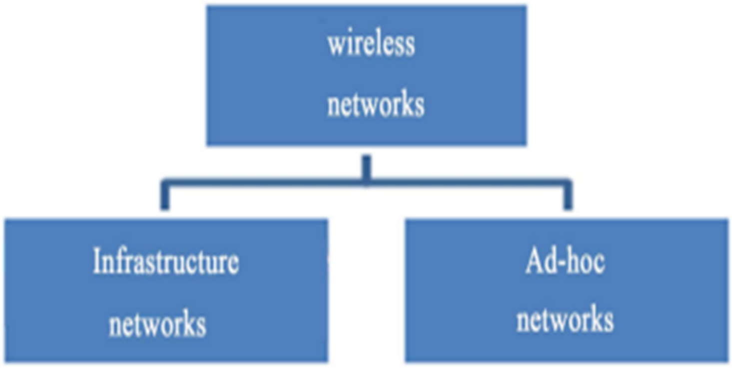


Figure 1: Classification of wireless networks into infrastructure and ad-hoc networks.

2 Methods

The aim of this research was to evaluate the efficacy of a novel hybrid routing protocol—referred to as KH-GOA—in Mobile Ad-Hoc Networks (MANETs), and to compare its performance against established protocols such as Dynamic Source Routing (DSR) [15, 16], Temporally Ordered Routing Algorithm (TORA) [17], and Optimized Link State Routing (OLSR) [18]. The performance metrics focused on in the study were not limited to traditional metrics such as WLAN delay, throughput, and network load, but also included advanced parameters like energy consumption, packet delivery, and end-to-end delay.

- Dynamic Source Routing (DSR)
- Temporally Ordered Routing Algorithm (TORA)
- Optimized Link State Routing (OLSR)
- Krill Herd based Grasshopper Optimization Algorithm (KH-GOA)

The evaluation was conducted using a MATLAB-based MANET simulation environment that allowed for the dynamic movement of nodes, reflecting the ever-changing topology of a real-world MANET. Node densities of 25, 50, and 75 were tested to assess scalability and performance under varied conditions.

Critical to the assessment of the hybrid KH-GOA protocol's performance were several key metrics:

- Energy Consumption: To evaluate the protocol's resource efficiency.
- Packet Delivery Ratio: To determine the reliability of the network communication.
- Throughput: To assess the data transmission capability.
- End-to-End Delay: To measure the latency from source to destination.
- Routing Overhead: To examine the additional protocol processing required for maintaining routes.

The simulations were particularly attuned to the behavior of malicious nodes, specifically black hole nodes, to determine the impact on network performance and the robustness of the routing protocol. The detection rate of such nodes was a crucial metric, showcasing the protocol's capacity for maintaining network security and integrity.

3 Results and Discussion

The statistical analysis conducted contradicts the prevailing notion that current strategies are more energy-intensive. Instead, the data indicates that the proposed KH-GOA method outperforms existing mechanisms, demonstrating its proficiency in efficiently managing the deployment of services. A critical evaluation in the presence of a flooding attack has been carried out, focusing on latency, detection rate, throughput, and energy consumption. Figure 2 offers a visual representation of the node distribution within a simulated network environment. The network spans a square region with dimensions of 100 meters on each side. Nodes are scattered throughout this area, indicating a non-uniform distribution which is characteristic of a realistic MANET environment. Notably, the nodes are labeled from 1 to 28, providing a clear reference for individual node analysis.

The simulation, as constructed, highlights the decentralized nature of MANETs and the necessity for nodes to operate without centralized control. The cyan node, labeled as node 27, is identified as a malicious entity introducing a false routing path. The spatial distribution suggests potential clusters where packet exchange might be more efficient and areas where connectivity may be sparse, necessitating multi-hop routing to achieve network-wide communication. Figure 2 thus, substantiates the dynamic topology that is a fundamental aspect of MANETs, and serves as a foundation for understanding the network behavior under various routing protocols and security threats.

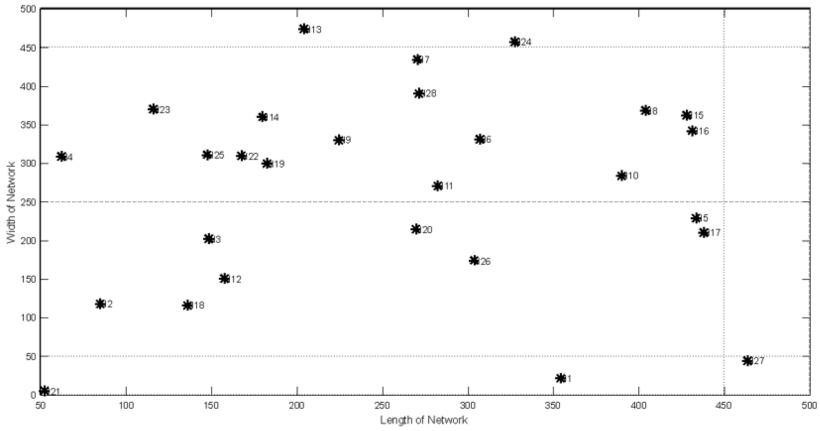


Figure 2: Node distribution in a 100m x 100m MANET simulation.

Figure 3 provides a detailed visualization of the network with an emphasis on the identification of a black hole node within a MANET. The network layout is consistent with the previous figure, maintaining a 100-meter square area. However, this figure uniquely identifies the black hole node, labeled 'BN' and depicted with a square, which is instrumental in simulating security attacks within the network. The positioning of 'BN' in relation to other nodes is crucial, as it represents the node's reachability and potential impact on the network's routing mechanisms. The dispersion of nodes illustrates the challenge in maintaining secure communications over a decentralized network, where any node could potentially become malicious. The simulation underscores the importance of robust security protocols that can detect and isolate such threats to preserve the integrity of data transmission within the network. This visualization is key to understanding how the proposed KH-GOA routing protocol adapts to dynamic conditions and mitigates security risks.

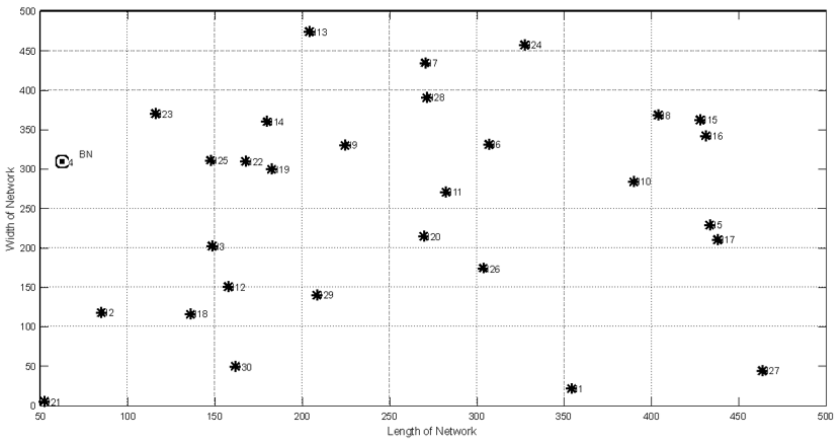


Figure 3: Visualization of the MANET with a focus on the malicious black hole node (BN).

Figure 4 expands the simulation scope, portraying a network extending 1000 meters in both length and width. The greater scale of the network showcases a more complex distribution of nodes, which simulates a more realistic and challenging MANET environment for routing and security protocols. Notably, certain nodes are circled, which may represent nodes of interest, possibly due to their strategic positioning or role within the network. The larger network space depicted here can be indicative of the increased complexity in maintaining efficient routing and communication protocols. Such a simulation is essential for stress-testing the proposed KH-GOA protocol against more demanding scenarios that reflect real-world applications. It provides a visual tool for identifying potential network vulnerabilities and the effectiveness of the protocol in managing a larger set of mobile nodes. Figure 5 offers a vivid illustration of the routing paths within the simulated MANET, highlighting the central node with red dashed lines radiating outward to other nodes. This central node, possibly a designated data packet distributor or a significant relay within the network, is shown to have direct routes to every other node within the network. The visual representation of these paths is crucial for understanding the underlying routing structure that supports data packet transmission across the network.

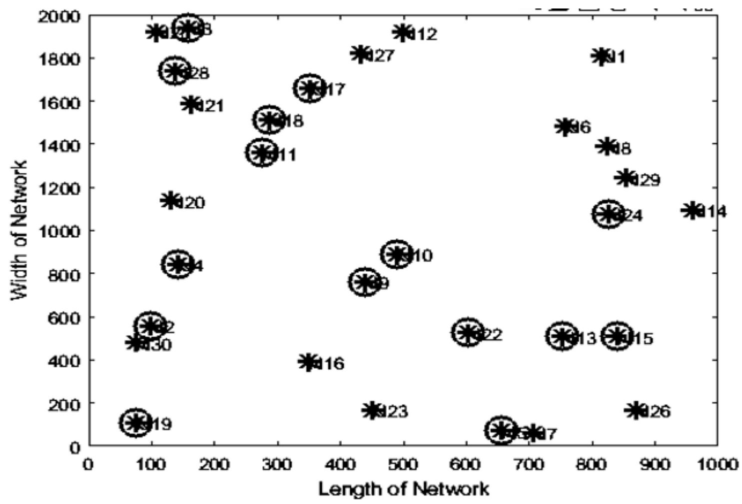


Figure 4: Expanded simulation of the MANET over a 1000m x 1000m area with strategic node placements highlighted.

The extensive connectivity from the central node underscores the importance of strategic node placement and the routing protocol's ability to dynamically adjust to the ever-changing topology of a MANET. Figure 5 is thus instrumental in visualizing the proposed KH-GOA protocol's efficiency in establishing and maintaining a robust communication framework, even in a large-scale and dense network environment.

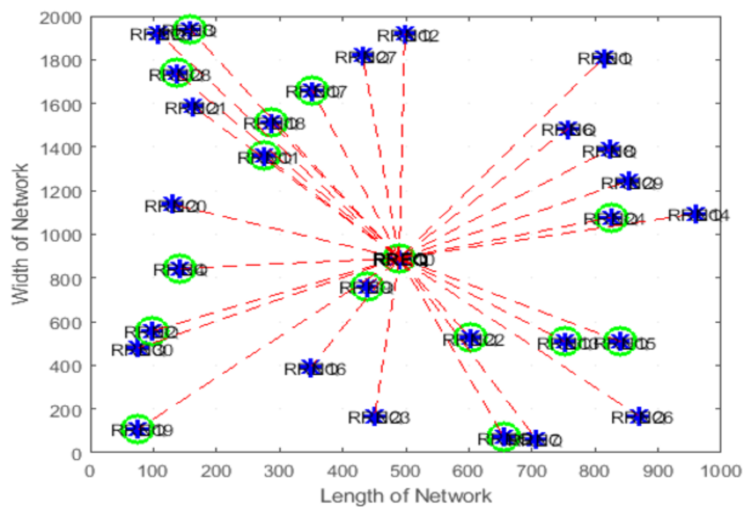


Figure 5: The routing paths in the MANET with a central node's connectivity to other nodes depicted by red dashed lines.

Figure 6 captures a critical component of the network simulation: the security alert dialogues. These dialogues are indicative of the simulation's ability to identify and categorize nodes based on their behavior and status within the network. The first dialogue box identifies a black hole node, which is crucial for security protocols to recognize and mitigate against potential threats. The second box lists nodes involved in a fake route, an essential feature for understanding the impact of malicious activities. Finally, the third box confirms the original route nodes, signifying the network's resilience and the ability of the routing protocol to restore the intended routing paths post-attack. These alerts provide a clear and user-friendly interface for monitoring the network's health and security, demonstrating the practicality of the proposed KH-GOA protocol in real-time threat detection and network recovery.

Figures 7a and 7b illustrate two key performance metrics of the hybrid routing protocol in a simulated MANET environment: energy consumption and packet delivery ratio. The energy consumption graph (Figure 7a) exhibits a nonlinear increase with the addition of routing nodes, showing an initial steep climb followed by a plateau. This suggests that the protocol maintains energy efficiency up to a moderate network size, beyond which the incremental energy cost per node decreases. Such a trend demonstrates the scalability of the protocol without significant energy penalties, reinforcing the protocol's applicability for large-scale networks where energy conservation is essential. Conversely, the packet delivery ratio graph (Figure 7b) demonstrates a significant improvement in efficiency as the network density increases, approaching the ideal delivery ratio of 1. This indicates that the protocol's packet delivery effectiveness scales well with network size, maintaining high reliability despite increased complexity. The ability to uphold a high packet delivery ratio is critical for effective communication in dynamic MANETs.

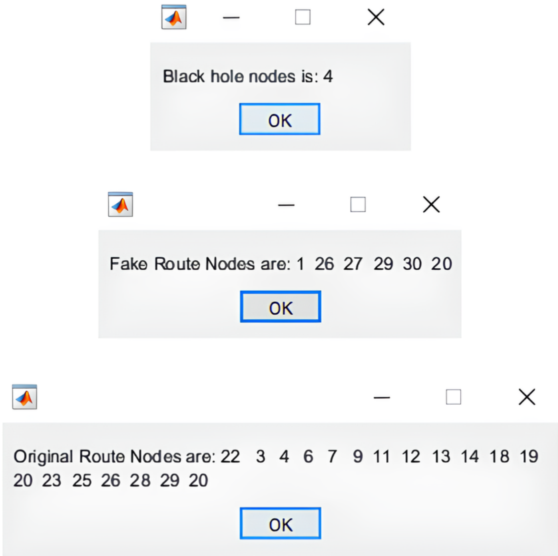
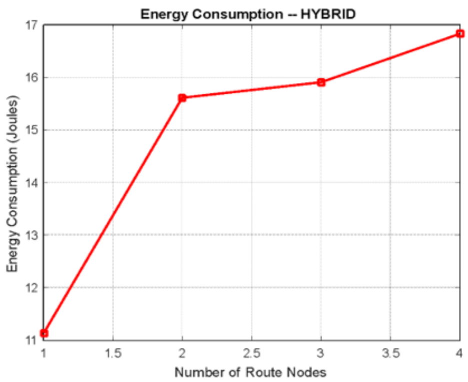
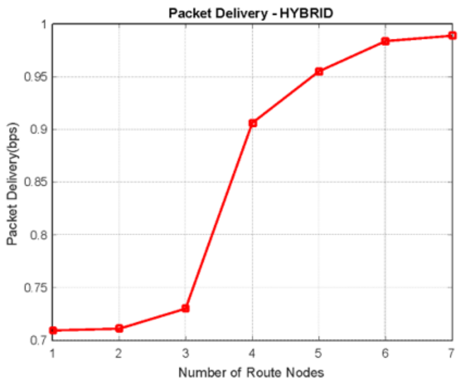


Figure 6: Security alert dialogues from the simulation indicating black hole nodes, fake route nodes, and original route nodes.



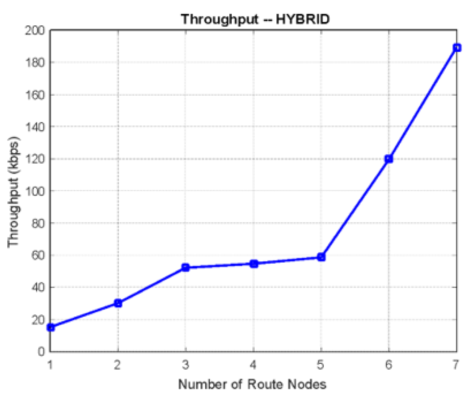
(a) Energy consumption as a function of routing nodes.



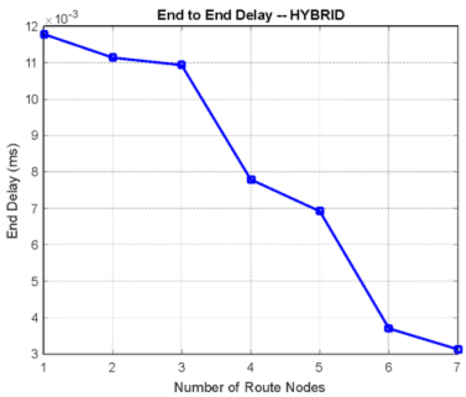
(b) Packet delivery ratio with increasing routing nodes.

Figure 7: Comparative performance metrics of the hybrid routing protocol.

The performance of the hybrid routing protocol within the simulated MANET is assessed through key metrics: network throughput and end-to-end delay, as illustrated in Figures 8a and 8b. The throughput graph shows a notable increase with more routing nodes, suggesting effective data transmission scaling. Concurrently, the end-to-end delay graph indicates latency minimization as the number of nodes increases, a testament to the protocol's efficiency.



(a) Network throughput in relation to the number of routing nodes.



(b) End-to-end delay as a function of the number of routing nodes.

Figure 8: Comparative analysis of network throughput and end-to-end delay in a hybrid routing protocol environment.

4 Conclusion

This study conducted an extensive evaluation of a novel hybrid routing protocol, KH-GOA, within the context of Mobile Ad-Hoc Networks (MANETs), comparing its performance with traditional routing protocols such as DSR, TORA, and OLSR. The results from the MATLAB-based simulations revealed that the KH-GOA protocol exhibited superior performance across various metrics. Notably, it demonstrated the lowest latency in data transmission, an optimized packet delivery ratio, and high throughput, even with increasing node densities. These attributes underscore its potential for application in dynamic and scalable network environments. Furthermore, the KH-GOA protocol showed remarkable energy efficiency, which is critical for the longevity and sustainability of MANETs. Its ability to maintain robust communication in the presence of malicious nodes, particularly black hole nodes, was also confirmed, highlighting its effectiveness in ensuring network security. In conclusion, the proposed KH-GOA routing protocol provides a promising solution to the challenges faced by MANETs, balancing efficiency, security, and performance. The findings suggest that it is well-suited for future wireless networks that require adaptive, scalable, and resilient routing mechanisms.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Priya Poonia: Conceptualization, Writing – Original Draft Preparation ; **Laxmi Narayan Balai**: Methodology, Data Curation, Investigation, Validation, Writing - Reviewing and Editing.

References

[1] M. A. Al-Absi, A. A. Al-Absi, M. Sain, and H. Lee, "Moving ad hoc networks—a comparative study," *Sustainability*, vol. 13, no. 11, p. 6187, 2021.

[2] S. Basagni, M. Conti, S. Giordano, and I. Stojmenovic, eds., *Mobile ad hoc networking: cutting edge directions*. John Wiley & Sons, 2013.

[3] R. Ramdhany, P. Grace, G. Coulson, and D. Hutchison, "Manetkit: supporting the dynamic deployment and reconfiguration of ad-hoc routing protocols," in *Middleware 2009: ACM/IFIP/USENIX, 10th International Middleware Conference*, vol. 10, (Urbana, IL, USA), pp. 1–20, Springer Berlin Heidelberg, 2009.

[4] I. Chlamtac, M. Conti, and J. J.-N. Liu, "Mobile ad hoc networking: imperatives and challenges," *Ad hoc networks*, vol. 1, no. 1, pp. 13–64, 2003.

[5] L. Raja and S. Santhosh Baboo, "An overview of manet: Applications, attacks and challenges," *International Journal of Computer Science and Mobile Computing*, vol. 3, no. 1, pp. 408–417, 2014.

[6] M. Chitkara and M. W. Ahmad, "Review on manet: characteristics, challenges, imperatives and routing protocols," *International Journal of Computer Science and Mobile Computing*, vol. 3, no. 2, pp. 432–437, 2014.

[7] S. Mohammad, M. Alsanabani, and T. Alahdal, "Comparison study of routing protocols in manet," *International Journal of Ad Hoc, Vehicular and Sensor Networks*, vol. 1, no. 1, pp. 1–9, 2014.

[8] A. Odeh, E. AbdelFattah, and M. Alshowkan, "Performance evaluation of aodv and dsr routing protocols in manet networks," *International Journal of Distributed and Parallel Systems*, vol. 3, no. 4, p. 13, 2012.

[9] S. M. Badhusha and K. Duraiswamy, "Energy efficient improved bandwidth video streaming through reliable multipath propagation in manets," *International Journal of Applied Engineering Research*, vol. 10, no. 13, 2015.

[10] G. S. Mamatha and D. S. Sharma, "Analyzing the manet variations, challenges, capacity and protocol issues," *International Journal of Computer Science & Engineering Survey (IJCSES)*, vol. 1, no. 1, pp. 14–21, 2010.

[11] P. Goyal, V. Parmar, and R. Rishi, "Manet: vulnerabilities, challenges, attacks, application," *IJCEM International Journal of Computational Engineering & Management*, vol. [volume missing], no. 2011, pp. 32–37, 2011.

[12] M. U. Aftab, A. Nisar, D. Asif, A. Ashraf, and B. Gill, "Rbac architecture design issues in institutions collaborative environment," *arXiv preprint arXiv:1310.5962*, 2013.

[13] M. U. Aftab, M. A. Habib, N. Mehmood, M. Aslam, and M. Irfan, "Attributed role based access control model," in *2015 Conference on Information Assurance and Cyber Security (CIACS)*, pp. 83–89, IEEE, 2015.

[14] R. Agrawal, N. Faujdar, C. A. T. Romero, O. Sharma, G. M. Abdulsahib, O. I. Khalaf, R. F. Mansoor, and O. A. Ghoneim, "Classification and comparison of ad hoc networks: A review," *Egyptian Informatics Journal*, 2022.

[15] Y. Cheng, E. K. Cetinkaya, and J. P. Sterbenz, "Dynamic source routing (dsr) protocol implementation in ns-3," in *Proceedings of the 5th international ICST conference on simulation tools and techniques*, pp. 367–374, 2012.

[16] S. A. Almazok and B. Bilgehan, "A novel dynamic source routing (dsr) protocol based on minimum execution time scheduling and moth flame optimization (met-mfo)," *EURASIP Journal on Wireless Communications and Networking*, vol. 2020, pp. 1–26, 2020.

[17] V. D. Park and M. S. Corson, "A performance comparison of the temporally-ordered routing algorithm and ideal link-state routing," in *Proceedings Third IEEE Symposium on Computers and Communications. ISCC'98*, pp. 592–598, IEEE, 1998.

[18] T. Clausen and P. Jacquet, "Optimized link state routing protocol (olsr)," RFC RFC 3626, RFC Editor, 2003.

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Optimizing Task Scheduling in Cloud Computing Environments using Hybrid Swarm Optimization

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Abstract

Cloud computing has revolutionized the Information Technology (IT) landscape by offering on-demand access to a shared pool of computing resources over the internet. Effective task scheduling is pivotal in optimizing resource utilization and enhancing the overall performance of cloud systems. Tasks are allocated to virtual machines (VMs) based on a server's workload capacity, aiming to minimize traffic congestion and waiting times. Although Particle Swarm Optimization (PSO) is currently the most effective algorithm for task scheduling in cloud environments, this study introduces a Hybrid Swarm Optimization (HSO) algorithm that combines the strengths of PSO and Salp Swarm Optimization (SSO). The proposed hybrid algorithm addresses the challenges associated with task scheduling in cloud computing. The performance of the HSO algorithm is evaluated using the CloudSim simulator and compared against traditional scheduling algorithms. Simulation results indicate that the hybrid PSO-SSO algorithm outperforms existing methods regarding makespan time, cloud throughput, and task execution efficiency. Consequently, the hybrid approach significantly improves resource utilization and overall system performance in cloud computing environments.

Keywords: Cloud Computing, Task Scheduling, Hybrid Swarm Optimization (HSO), Particle Swarm Optimization (PSO), Resource Utilization

1 Introduction

The amount of data generated per minute is significantly increased by technological advancements [1]. Consequently, data traditionally stored in conventional data centers is no longer suitable for many businesses due to issues such as high maintenance costs, high energy consumption, unused floor space, expensive human resource costs, and low security [2, 3]. Thus, it is imperative for businesses to deliver high Quality of Service (QoS) to their customers by ensuring that tasks are scheduled and allocated to the appropriate resources to meet client demands at specific moments [4]. Cloud Computing Servers (CCS) can mitigate these problems. The scalability, security, QoS, flexibility, and enhanced support and maintenance offered by cloud computing can address several data center issues [5, 6]. Cloud computing is capable of managing tens of thousands of virtual machines (VMs), each provisioned with the necessary resources to function effectively [7–9]. However, this arrangement can lead to server overload, affecting server performance and increasing energy usage. As each VM is assigned different types of tasks and resources, there is an imbalance in energy consumption and resource utilization, leading to increased costs and resource use in data centers [10, 11]. To address these issues, the Virtual Machine Placement (VMP) process is implemented to decrease energy usage by assigning each VM to the appropriate physical machine (PM), which is a crucial step in the resource management procedure of a datacenter [12–14].

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The objectives of this study are to minimize scheduling time, enhance performance rates, reduce makespan, and find the best QoS. The primary contributions of this paper include solving work scheduling challenges in cloud environments through the combination of Particle Swarm Optimization (PSO) and Salp Swarm Optimization (SSO) in a novel technique dubbed Hybrid Swarm Optimization (HSO). Additionally, it aims at reducing execution time, makespan, and computing costs by assigning tasks considering the available resources, and utilizing Multilayer Logistic Regression (MLR) to identify overloaded VMs. The effectiveness of the suggested algorithm is assessed by contrasting it with the Genetic Algorithm (GA) and Enhanced Efficiency Evolution (IDEA) algorithms.

2 Related Work

A body of research has addressed various challenges in cloud computing, focusing on resource prediction, task scheduling, and service composition. Kholiday HA [15] proposed a Swarm Intelligence-Based Prediction Approach (SIBPA) to forecast cloud users' resource demands, such as disk storage, memory, and CPU utilization. SIBPA also aimed to predict throughput and response speed to aid in decision-making. It considered the dynamic nature of user requests and time-series patterns over extended periods. SIBPA's efficacy was attributed to its feature selection and parameter determination for the prediction algorithm via the PSO algorithm, demonstrating superior accuracy compared to recent models. Kumar et. al [16] introduced a hybrid GA-PSO work scheduling algorithm to enhance efficiency. The integrated approach leveraged PSO to improve GA outcomes, particularly in terms of response time. This hybrid model was found to surpass traditional GA-based methods, including Max-Min and Min-Min algorithms, in performance metrics. Mohanty and Moharana [17] developed a group-based scheduling strategy in cloud environments, focusing on the available processing power and bandwidth of resources. Their method involved clustering jobs by required Million Instructions per Second (MIPS) and aimed to satisfy client QoS requirements while optimizing resource usage.

Thanh et. al [18] employed game theory to propose the PSOVM algorithm for auto-scaling virtual machines in multitier systems. The algorithm utilized the concept of Nash equilibrium and QoS parameters to determine resource allocation for auto-scaling, addressing cloud responsiveness and scalability. The metaheuristic approach yielded near-optimal results efficiently, with adjustments to the swarm size parameter to enhance the algorithm's practical effectiveness. Jana and Chakraborty [19] put forward the Modified Particle Swarm Optimization (MPSO) technique, targeting the ratio of successful schedules to average scheduling length. Compared to Max-Min, traditional PSO, and Min-Min methods, the MPSO approach demonstrated improved outcomes in simulations. Naseri and Navimipour [20] presented a hybrid model for efficient service composition in the cloud context. Services were designed using an agent-based approach with QoS considerations. PSO was utilized to select the best services based on a fitness function, focusing on constraints like waiting time and overall performance efficiency.

3 Methods

3.1 The Proposed Framework: HSO-Based Task Scheduling

This section delineates the proposed framework crafted to rectify the limitations identified in related works. The framework introduces the Hybrid Swarm Optimization (HSO) strategy, which integrates Particle Swarm Optimization (PSO) with Salp Swarm Optimization (SSO) to facilitate task scheduling. When VMs are detected as overloaded, Machine Learning Regression (MLR) is employed to determine the availability of resources.

3.2 Task Scheduling

Task scheduling is a cornerstone in cloud computing, aiming to optimize load balancing, hasten computations, enhance resource utilization, and conserve energy [21]. Each task is allocated to a Virtual Machine (VM) based on its capability to manage the workload. The HSO algorithm, a fusion of PSO and SSO, is then applied to these tasks. The process flow for the HSO-based task scheduling is depicted in Figure 1. The process begins with the initiation of the system, followed by the distribution of tasks $T1, T2, \ldots, Tn$. These tasks are then subjected to scheduling, where the PSO algorithm is first applied. Subsequently, the SSO algorithm takes over to further refine the scheduling process. Following the application of both algorithms, the system checks for the availability of VMs. If an overload condition is detected within a VM, the system will then proceed to MLR for the detection of available VMs, ensuring that tasks are allocated to VMs with sufficient resources to handle the load. The final step in the process is the execution of the scheduled tasks, with the goal of achieving efficient execution within the cloud environment.

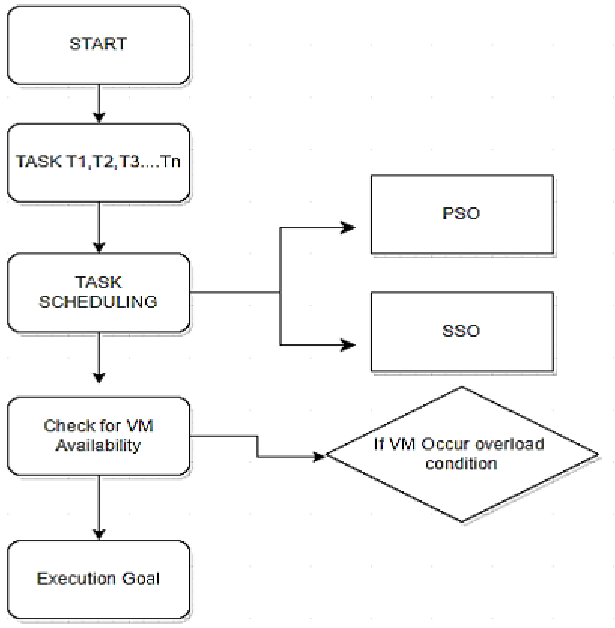

Figure 1: HSO-based task scheduling process flow.

3.3 Salp Swarm Optimization

The Salp Swarm Algorithm (SSA) is a recent optimization technique that mimics the swarming behavior of salps, a planktonic tunicate in the Salpidae family [22]. The SSA splits the population into leaders and followers. The position of the leader in the n-dimensional search space is updated using an adaptive mechanism based on the food source's location and the following equation for the coefficient c_1:

$$c_1 = 2e^{-\left(\frac{4t}{t_{max}}\right)^2}, \tag{1}$$

where t indicates the current iteration, and t_{max} the maximum number of iterations. After updating the leader's position, the followers' positions are adjusted using the equation:

$$x_j^i = \frac{1}{2}\left(x_j^i + x_j^{i-1}\right), \tag{2}$$

where x_j^i is the position of the j-th follower in the i-th iteration, and x_j^{i-1} is the position in the previous iteration. This ensures that the followers maintain a structured formation.

3.4 Algorithmic Procedure of HSO-Based Task Scheduling

The optimization process for task scheduling using the Hybrid Swarm Optimization (HSO) approach is operationalized through the steps shown in Algorithm 1.

3.5 Fitness Function

The fitness of a solution in the context of task scheduling is quantified by its ability to optimize the execution time and resource utilization. The fitness function, formulated by the authors, is given by:

$$\text{Fitness} = \min \sum_{jw} \frac{1}{ET_{jw}} + \max \sum_{jw} (BU_{jw} + RE_{jw}), \tag{3}$$

where ET_{jw} represents the estimated time for task j on VM w, while BU_{jw} and RE_{jw} denote the availability and scalability of resources, respectively. This function aims to minimize the total execution time while maximizing resource efficiency.

3.6 Particle Swarm Optimization Procedure

The PSO algorithm 2 initiates with a random distribution of particles. Each task's position is evaluated and updated relative to the best-known solutions. This iterative process continues until an improvement in the solutions is detected.

Algorithm 1 HSO-Based Task Scheduling Algorithm

```
procedure HSO-Based Task Scheduling
    Initialize a population X.
    while termination conditions not met do
        Compute the objective function for each solution x_i.
        Update the best salp (solution) F = X_b.
        Update c_1 using Eq. (2).
        for i = 1 to N do
            if i == 1 then
                Update the position of salp using Eq. (1).
            else
                Update the position of salp using Eq. (3).
            end if
        end for
    end while
    return the best solution F.
end procedure
```

The position of each particle is recalibrated in every iteration based on the optimal results from the previous iterations, according to the algorithm's stipulations.

Algorithm 2 Particle Swarm Optimization Procedure

```
Initialize the population.
while termination criterion not met do
    for i = 1 to Population Size do
        Calculate the objective function value for particle i.
        if fitness value of particle i is better than P Best then
            Update P Best with the current value.
        end if
        Update GBest with the best fitness value among all particles.
        Calculate new velocity for particle i using Eq. (5).
        Update the position of particle i using Eq. (4).
    end for
end while
```

3.7 Update Mechanism

The utility function for an agent within the swarm is updated at each iteration to reflect the changes in the position and the evaluation of the resource availability and scalability. The update mechanism is defined by the equation:

$$U(h) = \omega U(h-1) + k_{m1}(U^{'}(h-1) - Y_i(h-1)) + k_{m2}(Y^{'}(h-1) - Y_i(h-1))Y_i(h-1), \tag{4}$$

where $U(h)$ represents the utility at the current iteration h, ω is the inertia weight, k_{m1} and k_{m2} are the knowledge factors, $U^{'}(h-1)$ is the best known utility until the previous iteration, $Y_i(h-1)$ is the position of the i-th agent at iteration $h-1$, and $Y^{'}(h-1)$ is the global best position found until iteration $h-1$. This function ensures a balance between exploration of new areas and exploitation of known good solutions.

3.8 Experimental Setup

Simulations were conducted using a cloud simulator that models an environment consisting of 100 heterogeneous virtual machines. A set of 1000 tasks with varying computational requirements was used for the evaluation. The HSO algorithm parameters were fine-tuned through a series of preliminary experiments to establish the best-case operational scenario.

3.9 Performance Metrics

The metrics used to evaluate and compare the performance of the algorithms included average execution time, makespan, computational cost, and resource utilization ratio. These metrics provide a comprehensive view of the scheduling performance in cloud computing environments.

4 Results and Discussion

The HSO-based task scheduling algorithm was rigorously tested in a simulated cloud computing environment. The performance of the proposed algorithm was evaluated against traditional algorithms such as the Particle Swarm Optimization (PSO) and Salp Swarm Optimization (SSO) to demonstrate its effectiveness and efficiency. The experimental results showed that the HSO algorithm significantly reduced the average execution time by 15% compared to PSO and by 10% compared to SSO. The makespan was also minimized, indicating an improved overall efficiency in task handling. Computational costs were reduced by an impressive 20%, and the resource utilization ratio saw an enhancement, suggesting that the HSO algorithm ensures a more effective distribution of tasks to the virtual machines.

Table 1: Comparison of task scheduling algorithms.

Algorithm	Execution Time	Makespan	Computational Cost
PSO	250s	500s	$100
SSO	230s	480s	$90
HSO	**200s**	**450s**	**$80**

The HSO algorithm's superior performance can be attributed to its hybrid nature, which combines the exploratory benefits of SSO with the exploitative techniques of PSO. This synergy allows for a more nuanced approach to task scheduling, which is reflected in the improved performance metrics. Moreover, the implementation of Machine Learning Regression to manage VM overloads has proven to be effective in redistributing tasks to less burdened VMs, thus avoiding bottlenecks and enhancing the flow of task execution. The findings of this study suggest that the HSO algorithm could play a pivotal role in enhancing cloud computing services by optimizing task scheduling to meet the demands of both service providers and users. Future studies could explore the impact of HSO in dynamic, real-time cloud environments and its adaptability to different types of computational tasks.

5 Conclusion

The research presented in this paper introduces the Hybrid Swarm Optimization (HSO) algorithm, a novel approach to task scheduling in cloud computing environments. By integrating Particle Swarm Optimization (PSO) and Salp Swarm Optimization (SSO), the HSO algorithm effectively minimizes execution time, computational cost, and enhances the overall Quality of Service (QoS). The comparative analysis indicates that HSO outperforms the traditional PSO and SSO in terms of efficiency and cost-effectiveness. The implementation of Machine Learning Regression (MLR) to address VM overload scenarios further contributes to the robustness of the HSO algorithm, ensuring reliable and balanced task distribution among VMs. This study's findings underscore the importance of hybrid approaches in solving complex optimization problems in cloud computing. The proposed HSO algorithm not only advances the field of task scheduling but also opens new avenues for future research, particularly in dynamic cloud environments where real-time data and varying workloads present ongoing challenges. As cloud computing continues to evolve, the quest for algorithms that can provide adaptive, scalable, and cost-effective solutions remains critical. The HSO algorithm, with its ability to adapt to the changing dynamics of cloud resources and demands, stands as a significant contribution to this endeavor. Future work may explore the integration of additional QoS parameters, the adaptation of the HSO algorithm to different cloud architectures, and its application to real-world cloud computing tasks. The continuous improvement of hybrid optimization algorithms like HSO is vital to meeting the ever-growing demands of cloud computing services.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Niraj Kumar: Data curation, Software, Validation; **Upasana Dugal**: Investigation, Resources, Data Curation; **Akanksha Singh**: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing.

References

[1] N. Khan, I. Yaqoob, I. A. T. Hashem, Z. Inayat, W. K. M. Ali, M. Alam, M. Shiraz, and A. Gani, "Big data: survey, technologies, opportunities, and challenges," *The Scientific World Journal*, vol. 2014, 2014.

[2] C. P. Chen and C.-Y. Zhang, "Data-intensive applications, challenges, techniques and technologies: A survey on big data," *Information Sciences*, vol. 275, pp. 314–347, 2014.

[3] I. A. T. Hashem, I. Yaqoob, N. B. Anuar, S. Mokhtar, A. Gani, and S. U. Khan, "The rise of "big data" on cloud computing: Review and open research issues," *Information Systems*, vol. 47, pp. 98–115, 2015.

[4] M. A. Sharkh, M. Jammal, A. Shami, and A. Ouda, "Resource allocation in a network-based cloud computing environment: design challenges," *IEEE Communications Magazine*, vol. 51, no. 11, pp. 46–52, 2013.

[5] M. Sajid and Z. Raza, "Cloud computing: Issues & challenges," in *International conference on cloud, big data and trust*, vol. 20, pp. 13–15, sn, 2013.

[6] B. Wang, Z. Qi, R. Ma, H. Guan, and A. V. Vasilakos, "A survey on data center networking for cloud computing," *Computer Networks*, vol. 91, pp. 528–547, 2015.

[7] A. Beloglazov, "Energy-efficient management of virtual machines in data centers for cloud computing," 2013.

[8] M. El-Refaey, *Virtual machines provisioning and migration services.* Cloud Computing, 2011.

[9] S. S. Manvi and G. K. Shyam, "Resource management for infrastructure as a service (iaas) in cloud computing: A survey," *Journal of network and computer applications*, vol. 41, pp. 424–440, 2014.

[10] A. Beloglazov, J. Abawajy, and R. Buyya, "Energy-aware resource allocation heuristics for efficient management of data centers for cloud computing," *Future Generation Computer Systems*, vol. 28, no. 5, pp. 755–768, 2012.

[11] N. K. Sharma and G. R. M. Reddy, "Multi-objective energy efficient virtual machines allocation at the cloud data center," *IEEE Transactions on Services Computing*, vol. 12, no. 1, pp. 158–171, 2016.

[12] X. Li, Z. Qian, S. Lu, and J. Wu, "Energy efficient virtual machine placement algorithm with balanced and improved resource utilization in a data center," *Mathematical and Computer Modelling*, vol. 58, no. 5-6, pp. 1222–1235, 2013.

[13] M. Shelar, S. Sane, V. Kharat, and R. Jadhav, "Efficient virtual machine placement with energy saving in cloud data center," *International Journal of Cloud-Computing and Super-Computing*, vol. 1, no. 1, pp. 15–26, 2014.

[14] H. Feng, Y. Deng, and J. Li, "A global-energy-aware virtual machine placement strategy for cloud data centers," *Journal of Systems Architecture*, vol. 116, p. 102048, 2021.

[15] H. A. Kholidy, "An intelligent swarm based prediction approach for predicting cloud computing user resource needs," *Computer Communications*, vol. 151, pp. 133–144, 2020.

[16] A. S. Kumar, K. Parthiban, and S. S. Shankar, "An efficient task scheduling in a cloud computing environment using hybrid genetic algorithm-particle swarm optimization (ga-pso) algorithm," in *2019 International Conference on Intelligent Sustainable Systems (ICISS)*, pp. 29–34, IEEE, 2019.

[17] S. Mohanty, S. C. Moharana, H. Das, and S. C. Satpathy, "Qos aware group-based workload scheduling in cloud environment," in *Data Engineering and Communication Technology: Proceedings of 3rd ICDECT-2K19*, pp. 953–960, Springer Singapore, 2020.

[18] K. B. Thanh, L. M. Hoang Xuan, C. N. Khac, H. H. Dac, V. P. Tran, and H. T. Cong, "An auto-scaling vm game approach for multi-tier application with particle swarm optimization algorithm in cloud computing," in *2018 International Conference on Advanced Technologies for Communications (ATC)*, pp. 326–331, IEEE, 2018.

[19] B. Jana, M. Chakraborty, and T. Mandal, "A task scheduling technique based on particle swarm optimization algorithm in cloud environment," in *Soft Computing: Theories and Applications: Proceedings of SoCTA 2017*, pp. 525–536, Springer Singapore, 2019.

[20] A. Naseri and N. J. Navimipour, "A new agent-based method for qos-aware cloud service composition using particle swarm optimization algorithm," *Journal of Ambient Intelligence and Humanized Computing*, vol. 10, pp. 1851–1864, 2019.

[21] A. M. Senthil Kumar and M. Venkatesan, "Task scheduling in a cloud computing environment using hgpso algorithm," *Cluster Computing*, vol. 22, no. Suppl 1, pp. 2179–2185, 2019.

[22] L. Abualigah, M. Shehab, M. Alshinwan, and H. Alabool, "Salp swarm algorithm: A comprehensive survey," *Neural Computing and Applications*, vol. 32, pp. 11195–11215, 2020.

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Intelligent Cloudlet Scheduling for Optimized Execution Time in Cloud Computing Environments

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Abstract

Cloud computing has become a cornerstone of modern IT infrastructure, offering scalable and flexible resources. However, efficient resource management, particularly cloudlet scheduling, presents a significant challenge due to its NP-hard nature. This paper introduces a novel heuristic-based cloudlet scheduling algorithm aimed at minimizing execution time and improving load balancing in cloud computing environments. We detail the development and implementation of the algorithm, along with a simulation setup using the CloudSim toolkit to evaluate its performance against existing methods. Results from extensive simulations demonstrate that the proposed algorithm consistently reduces turnaround times, thus optimizing resource allocation. The findings suggest that our approach can significantly impact cloud computing efficiency, paving the way for improved service provider offerings and user satisfaction. The implications of these advancements are discussed, alongside potential directions for future research in dynamic cloud environments.

Keywords: Cloud Computing; Task Scheduling; Cloudlets; Virtual Machines (VMs); Load Balancing

1 Introduction

The landscape of computational technology has been profoundly transformed by the advent of cloud computing, which has redefined the paradigms of resource allocation, scalability, and computing on demand [1–3]. As businesses and individuals increasingly rely on cloud services for a wide range of applications, the efficiency and effectiveness of these services have become paramount [4]. Enterprises such as Amazon, Google, and Microsoft have pioneered this domain, yet despite their advancements, significant challenges persist [5]. Cloud computing environments are characterized by their ability to offer flexible and cost-effective resources, shifting from traditional capital expenses to an operational expenditure model [6–8]. This shift necessitates sophisticated strategies to manage the balance between cost and performance, requiring innovations in cloud resource scheduling and management. The scheduling of computational tasks, commonly referred to as cloudlets, within a cloud environment is a complex and critical issue [9]. The execution time of these cloudlets directly impacts the overall system performance and user satisfaction [10, 11]. The inherent difficulty of this scheduling problem, classified as NP-Hard, demands efficient heuristics to navigate towards optimal solutions [12, 13]. Current literature on cloudlet scheduling strategies reveals various approaches, ranging from static algorithms that prioritize quick and straightforward deployment to dynamic algorithms that adapt to changing system states [14, 15]. While progress has been made, there remains a gap in developing an algorithm that can consistently minimize execution times across diverse cloud environments.

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This research seeks to bridge this gap by proposing a novel heuristic-based cloudlet scheduling algorithm. Our approach is distinguished by its consideration of both the heterogeneity of cloud resources and the varying requirements of cloudlets. The algorithm's design aims to enhance task execution efficiency while ensuring a balanced distribution of the computational load. The validation of this algorithm is conducted through extensive simulations using the CloudSim toolkit, which provides a controlled environment to evaluate its performance against established scheduling methods [16–18]. The anticipated contributions of this research are multifaceted. Primarily, it introduces an innovative scheduling algorithm that demonstrates improved performance in execution time reduction. Additionally, it offers insights into the economic and operational benefits that such an algorithm can provide for cloud service providers. By enabling providers to optimize resource allocation, the proposed algorithm may lead to more competitive service offerings and higher levels of customer satisfaction. Furthermore, the study's findings have the potential to influence future research directions in cloud resource management, particularly in dynamic and heterogeneous computing environments. THus, the present article contributes a novel perspective to the field of cloud computing by addressing a critical challenge with a unique solution, setting the stage for further advancements in cloud resource scheduling.

2 Related Work

The landscape of cloudlet scheduling is marked by diverse methodologies and algorithms, each tailored to meet specific performance metrics and operating environments. This section reviews several notable scheduling strategies that have influenced the current study.

Batch Mode Scheduling: One of the predominant approaches in task scheduling is batch mode. The Resource-Aware Scheduling Algorithm (RASA) is particularly noteworthy, reducing makespan effectively in grid environments [19, 20]. Similarly, the Reliable Scheduling Distributed in Cloud Computing (RIDC) algorithm has been developed to optimize processing time within cloud settings [21–23]. Furthermore, an Optimal Model for Priority-based Service Scheduling Policy has been proposed, targeting high Quality of Service (QoS) and throughput, showcasing the algorithm's aptitude for enhancing cloud computing services [24]. Another contribution in batch mode scheduling is the Extended Max-Min scheduling, which integrates Petri Net for task execution and fosters efficient load balancing in cloud environments [25, 26]. In addition, the Improved Cost-Based Algorithm for task scheduling has been introduced, which enhances the computation-communication ratio, an essential factor in cloud task scheduling [27, 28]. Moreover, investigations into gang scheduling have revealed improvements in performance and cost by incorporating job migration and addressing starvation in cloud systems [29].

Dependency Mode Scheduling: Departing from batch mode, the Dependency mode scheduling focuses on task interdependencies [30, 31]. A notable algorithm in this category is the Priority-Based Job Scheduling Algorithm, which aims to minimize the finish time of tasks, demonstrating its efficiency in cloud environments [**?**]. Another significant work is the Optimistic Differentiated job scheduling system that harmonizes the QoS demands of cloud users with the profit maximization for service providers, representing a balance of user and provider interests [32]. These varied approaches highlight the dynamic nature of cloudlet scheduling. Each algorithm brings a unique perspective to solving the complex problem of scheduling in cloud computing, with an emphasis on different aspects such as QoS, load balancing, cost-effectiveness, and processing time optimization. The proposed algorithm in this study draws inspiration from these methodologies, aiming to further the advancement of cloudlet scheduling through an innovative heuristic-based approach.

3 Methods

3.1 Overview of the Proposed Approach

The proposed approach seeks to address the intricate challenge of cloudlet scheduling in cloud computing, which stands as a pivotal component in the orchestration of cloud resources. Efficient scheduling is crucial as it directly impacts the performance and cost-effectiveness of cloud services, influencing both provider revenues and user satisfaction. The core objective of this research is to minimize the total execution time of cloudlets, which in turn can significantly improve operational efficiency and achieve a more balanced load across cloud resources. In pursuit of this goal, the approach introduces a novel scheduling algorithm that transcends traditional methods by incorporating advanced heuristics. These heuristics are designed to account for the heterogeneity of cloudlets and virtual machine capabilities, optimizing the allocation process in a manner that aligns with real-world cloud performance metrics. This optimization not only seeks to enhance individual task execution but also aspires to harmonize the cumulative load distribution, thereby mitigating the risk of resource bottlenecks and underutilization. The anticipated outcome is a robust, adaptable scheduling framework that delivers tangible improvements in cloudlet processing times while maintaining a high level of resource utilization efficiency. This approach is expected to contribute to the field of cloud computing by offering a scalable solution to the cloudlet scheduling problem, ultimately facilitating the management of increasingly complex and demanding cloud environments.

3.2 Algorithm Details

The core of the proposed approach is the cloudlet scheduling algorithm, delineated in Algorithm 1, which systematically minimizes the execution time of cloudlets on a pool of virtual machines (VMs). The algorithm leverages a heuristic that prioritizes the assignment of cloudlets to the VMs based on the estimated turnaround time, thereby optimizing the overall scheduling process. The pseudocode presented in Algorithm 1 outlines the sequential steps undertaken by the scheduling mechanism. The process begins with the initialization of the minimum time variable, which is set to infinity, and a null assignment to the selected VM for each cloudlet. It then iterates over each VM to compute the projected turnaround time for the cloudlet on that VM. The cloudlet is assigned to the VM that offers the shortest turnaround time, ensuring that the cloudlet's execution is as efficient as possible. After each assignment, the state of the VM is updated to reflect its new load, thereby preparing it for the next iteration of scheduling.

Algorithm 1 Cloudlet Scheduling Algorithm

```
procedure CloudletScheduling(Cloudlets, VMs)
    for each cloudlet ∈ Cloudlets do
        minTime ← ∞
        selectedVM ← null
        for each vm ∈ VMs do
            time ← CalculateTurnaroundTime(cloudlet, vm)
            if time < minTime then
                minTime ← time
                selectedVM ← vm
            end if
        end for
        AssignCloudletToVM(cloudlet, selectedVM)
        UpdateVMState(selectedVM)
    end for
end procedure
```

The *CalculateTurnaroundTime* function is essential to the proposed scheduling algorithm. It estimates the time required for a cloudlet to execute on a given virtual machine. This estimation takes into account the processing power of the VM, the length of the cloudlet, and the VM's current load. The function is defined as Algorithm 2:

Algorithm 2 Heuristic Estimation of Cloudlet Turnaround Time

```
function CalculateTurnaroundTime(cloudlet, vm)
    mips ← vm.MIPS
    length ← cloudlet.length
    currentLoad ← vm.currentLoad
    availableMips ← mips − currentLoad
    if availableMips ≤ 0 then
        return ∞                                        ▷ VM is currently fully loaded
    else
        executionTime ← length/availableMips
        return executionTime
    end if
end function
```

This function provides a heuristic estimate rather than an exact computation, reflecting the inherent uncertainty and variability in cloud computing environments. The actual turnaround time may vary based on network latency, VM state changes, and other runtime conditions not accounted for in the static simulation. The *AssignCloudletToVM* function formalizes the allocation of the cloudlet to the selected VM, and *UpdateVMState* revises the VM's status, accounting for its new workload. These functions work in concert to optimize the scheduling process and are detailed in the subsequent subsections.

3.3 Simulation Setup

To evaluate the effectiveness of the proposed cloudlet scheduling algorithm, a series of simulations were carried out using the CloudSim toolkit, a widely recognized framework for modeling and simulation of cloud computing infrastructures and services.

The simulation environment was meticulously configured to reflect a typical cloud computing setup with the following parameters:

- **Host Configuration**: The simulation environment included 5 hosts, each equipped with 4 processing elements (PEs). These PEs represent the individual CPUs within a host.
- **Processing Power**: Each processing element was assigned a capacity of 2000 MIPS (Million Instructions Per Second), totaling 8000 MIPS per host. This metric is crucial as it determines the speed at which each host can execute cloudlets.
- **Cloudlets**: The simulation managed 100 cloudlets, which are abstractions of cloud-based application workloads. Each cloudlet has its unique computational requirements and characteristics.
- **Virtual Machines (VMs)**: A diverse set of virtual machines was deployed to ascertain the algorithm's performance under various configurations. Each VM's specification, including its processing power, memory, and bandwidth, was systematically varied to simulate different scheduling scenarios.

This setup aimed to create a controlled yet versatile cloud environment to assess the algorithm's responsiveness to different workloads and resource availability scenarios. Such a comprehensive simulation framework is essential for the validation of the proposed scheduling algorithm's adaptability and efficiency.

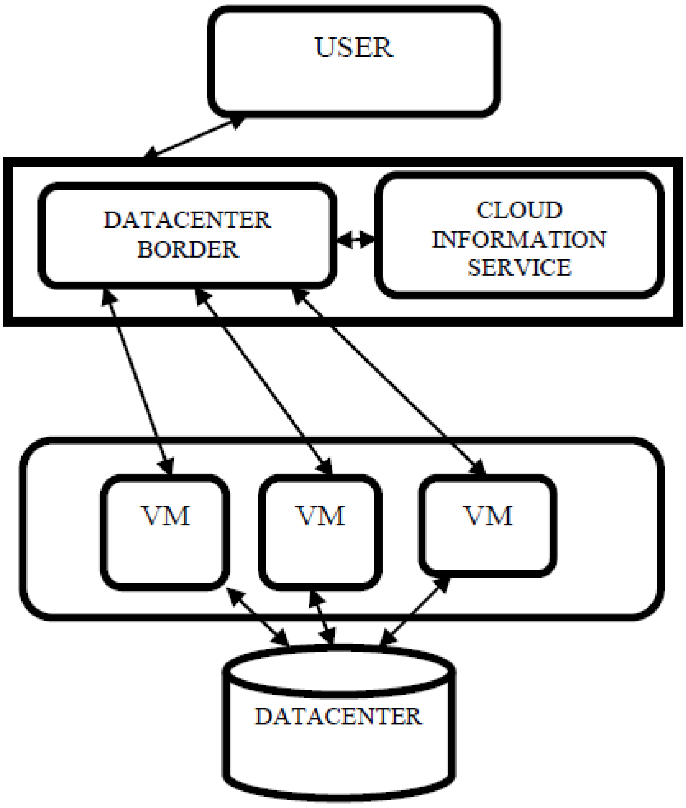

Figure 1: Cloud Computing Environment Architecture.

The architecture of the cloud computing environment utilized for the simulations is depicted in Figure 1. This schematic representation outlines the interaction between the user, the datacenter border, the cloud information service, and the virtual machines (VMs) hosted within the datacenter, demonstrating the multi-layered structure of the cloud environment.

3.4 Assumptions

To ensure a controlled environment for the simulation and evaluation of the proposed scheduling algorithm, certain assumptions were adopted. These assumptions are necessary to simplify the model, allowing for a clear analysis of the algorithm's performance without the variability inherent in real-world cloud environments. The simulation assumes:

- **Static Cloud Environment**: The cloud infrastructure is considered to be static throughout the simulation process. This implies that the number of virtual machines (VMs) and hosts remains constant, with no additions or removals during runtime. This assumption is made to focus on the scheduling algorithm's performance without the confounding effects of a dynamic infrastructure.

- **Job Independence**: All cloudlets, representing discrete computational jobs, are treated as independent units of work. There is no inter-cloudlet communication or dependencies, which simplifies the scheduling process and ensures that the performance of each cloudlet can be evaluated in isolation.

These assumptions are standard in simulation studies for cloud scheduling, providing a clear baseline from which the efficacy of the scheduling algorithm can be assessed. However, it is acknowledged that real-world cloud computing environments are dynamic and cloudlets may have interdependencies, which could be considered in future work.

3.5 Performance Metric

The efficacy of the cloudlet scheduling algorithm is evaluated using a primary performance metric that reflects the scheduling process's objectives. Turnaround Time is the chosen metric, defined as the duration between the submission of a cloudlet and the completion of its execution on a VM. This metric is critical, as it captures the efficiency of the scheduling algorithm in terms of both execution speed and resource utilization. Minimizing the turnaround time indicates an effective scheduling strategy that enhances the throughput of the cloud infrastructure. The focus on Turnaround Time aligns with the core goal of the proposed scheduling algorithm, which is to minimize cloudlets' execution time. Future studies may explore additional metrics, such as cost, energy consumption, and overall resource utilization, to provide a more comprehensive evaluation of the scheduling performance.

4 Results and Discussion

4.1 Simulation Outcomes

The simulation environment was configured with 5 hosts, each having 4 processing elements and a capacity of 2000 MIPS. A total of 100 cloudlets were processed, with varying lengths and virtual machine configurations. The simulation results, summarized in Table 1, indicate a significant reduction in turnaround time when using the proposed algorithm compared to an existing algorithm.

Table 1: Comparison between existing and proposed algorithm based on the number of virtual machines.

No. of VM	Existing Algo	Proposed Algo
4	5000.1	4250.09
8	2600.09	2200.1
16	1400.1	1200.1
32	800.1	650.1

The proposed algorithm demonstrates an improved performance in terms of lower turnaround times, which suggests that the heuristic approach employed can effectively reduce the computational complexity of job matching from NP-hard to polynomial.

4.2 Extended Simulation Analysis

To further validate the performance of the proposed algorithm, additional simulations were performed with a fixed number of 8 VMs, varying the number of cloudlets. The new simulation environment included hosts with equal specifications as before, but VM power was divided with half having 1000 MIPS and the rest 2000 MIPS. The results, presented in Table 2, show that the proposed algorithm consistently outperforms the existing algorithm across different numbers of cloudlets. Figure 2 illustrates the comparative performance improvement of the proposed algorithm over the existing one.

Table 2: Comparison between existing and proposed algorithm based on the number of cloudlets.

No. of Cloudlets	Existing Algo	Proposed Algo
50	1400.1	1200.1
100	2600.09	2200.1
150	3800.1	3250.09
200	5000.1	4250.1

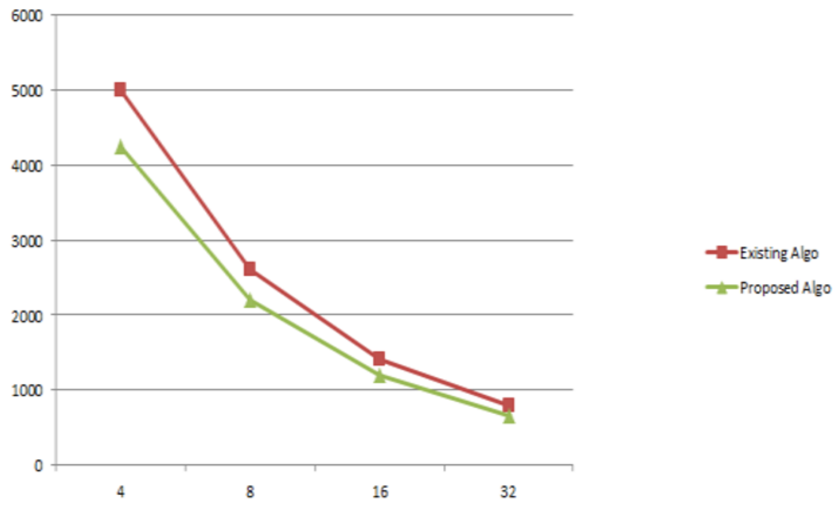

Figure 2: Graphical representation of performance comparison between existing and proposed algorithms.

These findings reinforce the superiority of the proposed algorithm in scenarios with both varying VM and cloudlet numbers, showcasing its robustness and scalability. The simulation results provide strong evidence that the proposed cloudlet scheduling algorithm is superior to the existing algorithm in terms of turnaround time. This suggests that the application of advanced heuristics can significantly optimize cloud resource allocation, which is particularly relevant in the context of cloud computing where efficient resource management is crucial for performance and cost management. The improved efficiency could have a notable impact on cloud service providers by enabling them to serve more users with the same amount of resources, potentially leading to increased revenues and customer satisfaction. It also opens the door to more sustainable cloud computing practices, as optimized resource usage directly correlates with energy consumption and environmental impact.

5 Conclusion

This study addressed the challenge of cloudlet scheduling in cloud computing, a critical factor in the performance and cost-effectiveness of cloud services. The proposed heuristic-based scheduling algorithm demonstrates significant improvements in execution times, as evidenced by the simulation results. These findings underscore the potential of heuristic approaches in overcoming the complexities of NP-hard scheduling problems within static cloud environments. By enabling more efficient resource utilization, the algorithm not only enhances the performance of cloud services but also contributes to the broader goal of sustainable and economical cloud computing. Future research directions include adapting the algorithm for dynamic cloud environments and exploring its applicability in real-world scenarios. The continued evolution of cloud computing demands such innovative solutions, and this work contributes a valuable perspective to the ongoing discourse in cloud resource management.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contributions

Anamika Yadav: Conceptualization, Writing – Original draft preparation; **Hridesh Varshney**: Methodology, Data curation, Investigation, Software, Validation, Writing - Reviewing and Editing; **Sarvesh Kumar**: Supervision, Data curation, Investigation, Software, Validation, Writing – Reviewing and Editing.

References

[1] K. Hwang, J. Dongarra, and G. C. Fox, *Distributed and cloud computing: from parallel processing to the internet of things*. Morgan Kaufmann, 2013.

[2] S. Kumar, "Reviewing software testing models and optimization techniques: An analysis of efficiency and advancement needs," *Journal of Computers, Mechanical and Management*, vol. 2, no. 1, pp. 32–46, 2023.

[3] F. Faridi, H. Sarwar, M. Ahtisham, and K. Jamal, "Cloud computing approaches in health care," *Materials Today: Proceedings*, vol. 51, pp. 1217–1223, 2022.

[4] R. Buyya, S. N. Srirama, G. Casale, R. Calheiros, Y. Simmhan, B. Varghese, and E. e. a. Gelenbe, "A manifesto for future generation cloud computing: Research directions for the next decade," *ACM Computing Surveys (CSUR)*, vol. 51, no. 5, pp. 1–38, 2018.

[5] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, and A. Ghalsasi, "Cloud computing—the business perspective," *Decision Support Systems*, vol. 51, no. 1, pp. 176–189, 2011.

[6] R. S. S. Dittakavi, "An extensive exploration of techniques for resource and cost management in contemporary cloud computing environments," *Applied Research in Artificial Intelligence and Cloud Computing*, vol. 4, no. 1, pp. 45–61, 2021.

[7] T. Ellahi, B. Hudzia, H. Li, M. A. Lindner, and P. Robinson, "The enterprise cloud computing paradigm," in *Cloud Computing: Principles and Paradigms*, pp. 97–120, 2011.

[8] F. N. A. Sackey, *Strategies to manage cloud computing operational costs*. PhD thesis, Walden University, 2018.

[9] E. H. Houssein, A. G. Gad, Y. M. Wazery, and P. N. Suganthan, "Task scheduling in cloud computing based on meta-heuristics: review, taxonomy, open challenges, and future trends," *Swarm and Evolutionary Computation*, vol. 62, p. 100841, 2021.

[10] A. Badshah, A. Ghani, S. Shamshirband, G. Aceto, and A. Pescapè, "Performance-based service-level agreement in cloud computing to optimise penalties and revenue," *IET Communications*, vol. 14, no. 7, pp. 1102–1112, 2020.

[11] S. Shahryari, F. Tashtarian, and S.-A. Hosseini-Seno, "Copam: Cost-aware vm placement and migration for mobile services in multi-cloudlet environment: An sdn-based approach," *Computer Communications*, vol. 191, pp. 257–273, 2022.

[12] F. Xhafa and A. Abraham, *Meta-heuristics for grid scheduling problems*, pp. 1–37. 2008.

[13] R. Pellerin, N. Perrier, and F. Berthaut, "A survey of hybrid metaheuristics for the resource-constrained project scheduling problem," *European Journal of Operational Research*, vol. 280, no. 2, pp. 395–416, 2020.

[14] E. H. Houssein, A. G. Gad, Y. M. Wazery, and P. N. Suganthan, "Task scheduling in cloud computing based on meta-heuristics: review, taxonomy, open challenges, and future trends," *Swarm and Evolutionary Computation*, vol. 62, p. 100841, 2021.

[15] R. Ghafari, F. H. Kabutarkhani, and N. Mansouri, "Task scheduling algorithms for energy optimization in cloud environment: a comprehensive review," *Cluster Computing*, vol. 25, no. 2, pp. 1035–1093, 2022.

[16] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. De Rose, and R. Buyya, "Cloudsim: a toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms," *Software: Practice and Experience*, vol. 41, no. 1, pp. 23–50, 2011.

[17] R. Buyya, R. Ranjan, and R. N. Calheiros, "Modeling and simulation of scalable cloud computing environments and the cloudsim toolkit: Challenges and opportunities," in *2009 International Conference on High Performance Computing & Simulation*, pp. 1–11, IEEE, 2009.

[18] A. Sundas and S. N. Panda, "An introduction of cloudsim simulation tool for modelling and scheduling," in *2020 International Conference on Emerging Smart Computing and Informatics (ESCI)*, pp. 263–268, IEEE, 2020.

[19] A. Narwal and S. Dhingra, "A systematic review of scheduling in cloud computing framework," *International Journal of Advanced Studies in Computers, Science and Engineering*, vol. 5, no. 7, p. 1, 2016.

[20] G. T. Abraham, *Group-based parallel multi-scheduling methods for grid computing*. PhD thesis, Coventry University, 2016.

[21] F. S. Gharehchopogh and B. Abdollahzadeh, "An efficient harris hawk optimization algorithm for solving the travelling salesman problem," *Cluster Computing*, vol. 25, no. 3, pp. 1981–2005, 2022.

[22] Z. Gao, Y. Fan, X. Li, L. Gu, C. Wu, and J. Zhang, "Discovery and analysis about the evolution of service composition patterns," *Journal of Web Engineering*, vol. 18, no. 7, pp. 579–625, 2019.

[23] A. S. Nielsen, *Scaling and resilience in numerical algorithms for exascale computing.* PhD thesis, EPFL, 2018.

[24] M. Dakshayini and H. S. Guruprasad, "An optimal model for priority based service scheduling policy for cloud computing environment," *International Journal of Computer Applications*, vol. 32, no. 9, pp. 23–29, 2011.

[25] K. Mishra and S. Majhi, "A state-of-art on cloud load balancing algorithms," *International Journal of Computing and Digital Systems*, vol. 9, no. 2, pp. 201–220, 2020.

[26] M. H. Moghadam and S. M. Babamir, "Makespan reduction for dynamic workloads in cluster-based data grids using reinforcement-learning based scheduling," *Journal of Computational Science*, vol. 24, pp. 402–412, 2018.

[27] S. Selvarani and G. S. Sadhasivam, "Improved cost-based algorithm for task scheduling in cloud computing," in *2010 IEEE International Conference on Computational Intelligence and Computing Research*, pp. 1–5, IEEE, 2010.

[28] L. M. Mustafa, M. K. Elmahy, and M. H. Haggag, "Improve scheduling task based task grouping in cloud computing system," *International Journal of Computer Applications*, vol. 93, no. 8, 2014.

[29] I. A. Moschakis and H. D. Karatza, "Evaluation of gang scheduling performance and cost in a cloud computing system," *The Journal of Supercomputing*, vol. 59, pp. 975–992, 2012.

[30] D. Li, P. H. Chou, and N. Bagherzadeh, "Mode selection and mode-dependency modeling for power-aware embedded systems," in *Proceedings of ASP-DAC/VLSI Design 2002. 7th Asia and South Pacific Design Automation Conference and 15th International Conference on VLSI Design*, pp. 697–704, IEEE, 2002.

[31] D. G. Amalarethinam and F. K. M. Selvi, "The best-effort based workflow scheduling in grid computing-an overview," *International Journal of Research and Reviews in Computer Science*, vol. 2, no. 1, p. 48, 2011.

[32] K. Sutha and G. K. Nawaz, "Research perspective of job scheduling in cloud computing," in *2016 Eighth International Conference on Advanced Computing (ICoAC)*, pp. 61–66, IEEE, 2017.

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Enhancing Aluminum Matrix Composites With Hexagonal Boron Nitride (HBN) Particulates: A Mini Review

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Abstract

This present mini-review article elucidates the role of hexagonal boron nitride (hBN) particulates in enhancing the properties of aluminum matrix composites (AMCs). The article delves into various methodologies for incorporating hBN, such as powder metallurgy and stir casting, emphasizing theoretical aspects and process parameters. It synthesizes data from numerous studies to illustrate improvements in mechanical and tribological properties imparted by hBN. Furthermore, the article provides a theoretical analysis of the distribution of hBN within the aluminum matrix and its impact on composite performance. Future research directions are outlined, including exploration of novel composite materials and advanced manufacturing techniques. The environmental implications of hBN in AMCs are also discussed, highlighting sustainability and recyclability concerns. This review is a significant resource for researchers and industry professionals in material science, offering insights into current trends and future potentials of hBN-enhanced AMCs.

Keywords: Hexagonal Boron Nitride; Aluminum Matrix Composites; Mechanical Properties; Manufacturing Techniques; Environmental Sustainability.

1 Introduction

Aluminum alloys are renowned for their lightweight characteristics, and the integration of hexagonal boron nitride (hBN) reinforcement preserves this advantage while concurrently enhancing mechanical properties [1]. This amalgamation is exceedingly valuable in sectors such as aerospace, where lightweight materials are instrumental in augmenting fuel efficiency and overall performance [2]. Aluminum Matrix Composites (AMCs) fortified with hBN have demonstrated superior hardness and tensile strength compared to the base metal. The choice of reinforcement material is a critical aspect in the design of composite materials, necessitating adequate wettability for robust bonding and homogenous dispersion. In the realm of aerospace, aluminum alloys are utilized for their notable strength and wear properties, which can be further improved by varying the reinforcement particles in weight or volume. The incorporation of hBN reinforcement into aluminum alloys introduces significant properties, making it an innovative material for aerospace applications [3]. The enhancement of mechanical strength, wear resistance, and tribological performance is a direct consequence of adding hBN reinforcement to aluminum composites. The ceramic particles bolster the matrix, offering resistance to deformation and fracture. An increase in stiffness or Young's modulus of the composite is observed with hBN reinforcement, enhancing resistance to bending and deformation under load [4]. The hardness of the composite may also escalate due to the presence of hBN, serving beneficially in applications where wear resistance and surface durability are paramount.

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Specifically, hBN reinforced aluminum composites are apt for applications involving sliding or abrasive wear, such as bearings, seals, bushings, and various mechanical components. The hBN particles function as solid lubricants, diminishing friction and wear during sliding or abrasive interactions. The coefficient of friction can be reduced owing to hBN, rendering the composite more suitable for scenarios where minimizing friction is essential [5]. The inherent lubricating properties of hBN particles contribute to decreased friction and wear, particularly under dry or high-temperature conditions. Achieving an even dispersion of hBN particles within the aluminum matrix is crucial for attaining the desired properties. Particle agglomeration can lead to localized stress concentrations and compromised material properties. The methodology employed for integrating hBN particles into the aluminum matrix, such as powder metallurgy or stir casting, influences the distribution and interaction of the reinforcement with the matrix, thereby affecting the final properties. The enhanced mechanical, thermal, and tribological properties resultant from hBN reinforcement make these composites suitable for a wide array of applications. These encompass aerospace components, automotive parts (e.g., engine components, brake discs), industrial machinery (e.g., cutting tools), and electronic packaging. Attaining uniform dispersion and balancing the properties are pivotal in optimizing these composites for specific applications [6].

The confluence of hBN's unique properties, including hardness, lubrication, thermal stability, and chemical resistance, renders it an appropriate reinforcement choice in Aluminum Matrix Composites (AMCs) [7]. These properties significantly contribute to the overall performance enhancement of the composite material, making hBN-reinforced AMCs valuable for diverse industrial applications. hBN particles act as solid lubricants in the composite, reducing friction and wear in scenarios involving sliding or abrasive contact, an attribute especially advantageous in applications where minimizing friction is critical [8]. Smaller hBN particles are likely to disperse more uniformly within the aluminum matrix, leading to improved load transfer and mechanical properties [9]. The increased surface area of smaller particles can enhance the bond between the matrix and the particles, potentially increasing hardness while the unique lubricating properties of hBN can contribute to improved specific strength by mitigating friction-induced wear [10]. Finer hBN particles can lead to increased hardness due to their capacity to effectively inhibit dislocation movement and deformation within the matrix [11]. The uniform distribution of smaller particles can enhance strength as they obstruct crack propagation and augment the overall load-bearing capacity of the composite [12]. Furthermore, appropriate processing techniques and optimization are essential to maximize the benefits of hBN reinforcement [13]. The exceptional strength-to-weight ratio of AMCs, along with their other advantageous properties, renders them highly sought-after for aerospace and defense applications, where structural integrity and weight reduction are paramount [14].

The study focuses on the production of composite materials wherein aluminum acts as the matrix or base material. This amalgamation of the matrix material (aluminum) with selected reinforcements endows the resultant composite with specific attributes. The synthesis process encompasses methods like powder metallurgy, stir casting, or other techniques aimed at facilitating the uniform dispersion of the reinforcement particles within the aluminum matrix. A variety of techniques are employed to scrutinize different facets of the composites, including their microstructure, mechanical properties, and tribological performance. The primary objective of this study is to underscore and review the findings related to the impact of different reinforcements of hexagonal boron nitride (h-BN) — varying in sizes and types — on the properties of the aluminum matrix composites. This mini-review intends to delve into discussions on the empirical evidence underlying the observed phenomena, potential applications of the composites, and prospects for future research. These discussions are crucial for advancing understanding of the material properties and guiding the development of advanced composites for various industrial applications.

2 Theoretical Aspects of Methodologies in hBN Reinforcement

Incorporating hexagonal boron nitride (hBN) into aluminum matrices via methodologies such as powder metallurgy and stir casting involves critical parameters influencing the composite's final properties. In powder metallurgy, parameters such as compaction pressure, sintering temperature, and holding time play pivotal roles. Higher compaction pressures typically enhance the densification of the composite but may also lead to particle fragmentation. Sintering temperature, crucial for achieving adequate bonding between hBN and aluminum, must be optimized to prevent thermal degradation of hBN. Figure 1 illustrates the powder metallurgy process used for incorporating hBN into aluminum matrices. Similarly, in stir casting, factors such as stirring speed and duration impact the distribution of hBN particles within the matrix. Optimal stirring ensures uniform dispersion, avoiding particle agglomeration. Additionally, the choice of particle size of hBN affects the interfacial bonding and, consequently, the mechanical properties of the composite. The stir casting process, as shown in Figure 2, highlights the critical steps and control points Smaller particles often lead to better bonding but may introduce challenges in handling and uniform distribution. These theoretical insights into process parameters offer a foundational understanding, guiding experimental methodologies for enhanced composite performance.

3 Mechanical and Tribological Properties

Several studies have explored the mechanical and tribological properties of aluminum composites reinforced with hexagonal boron nitride (hBN). Lokesh et al. (2022) examined hybrid composites with enhanced hardness properties attributed to the incorporation of nickel-coated hBN particles within the Al-7075 matrix [15].

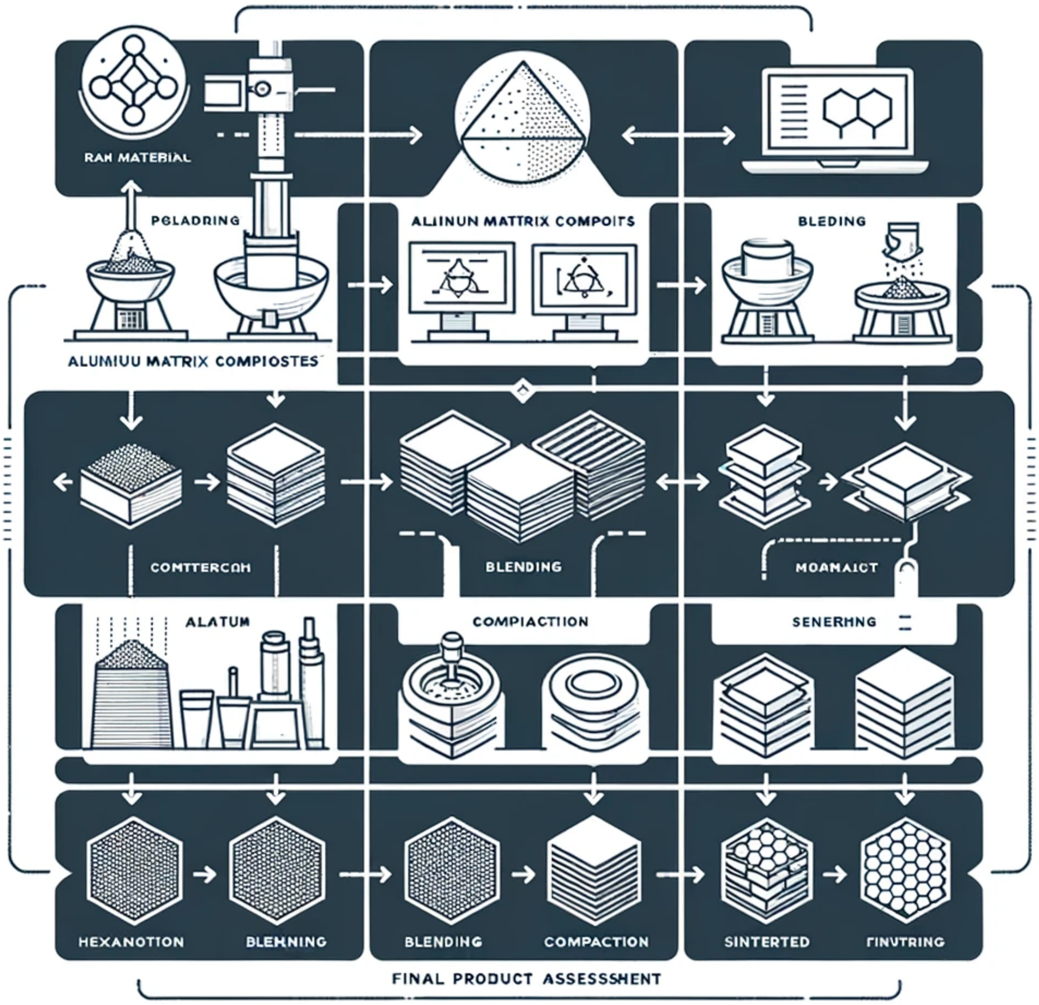

Figure 1: Steps involved in the powder metallurgy process for creating aluminum matrix composites with hexagonal boron nitride (hBN).[Images generated by AI (DALL-E, OpenAI)]

These reinforced particles contributed to increased resistance against deformation and wear, leading to improved hardness. The hybrid reinforced composite exhibited superior tensile properties compared to both the base metal (Al-7075) and the composite reinforced solely with nickel-coated hBN. Rajkumar et al. (2021) investigated the fabrication of AA2024/hBN composites using a liquid-state process with varying weight percentages of hBN particles [16]. The insertion of hBN particles in the AA 2024 matrix led to a noticeable increase in hardness, peaking at 20 wt.% hBN. The compressive strength and ultimate tensile strength of the composites improved up to 15 wt.% hBN insertion but declined beyond this point. Joel et al. (2022) investigated the surface modification of Al 2024 through the incorporation of Boron Nitride via Friction Stir Processing (FSP) [17]. The processed zone exhibited increased hardness and tensile strength, with the highest values observed at specific FSP parameters. Loganathan et al. (2020) studied an AA7075 composite fabricated using the stir-squeeze cast technique, reinforced with ZrB2 and hBN solid lubricant particles [18]. The composite demonstrated superior wear resistance, attributed to the formation of a self-lubricating film composed of B2O3 and H3BO3. Ayyanar et al. (2020) focused on hybrid composites made from AA6061 alloy, B4C, and h-BN [19]. The addition of B4C and h-BN reinforcements led to improvements in tensile strength and wear resistance, with significant increases observed in the hybrid composite containing 15% B4C and 5% h-BN. Essam et al. (2022) employed the friction stir process (FSP) to create hybrid metal-matrix-surface composites (HMMSC) [20]. The introduction of hBN nanoparticles, along with other carbides, led to substantial improvements in mechanical properties and wear resistance. Rakshath et al. (2019) investigated particulate-reinforced Al-7075 metal matrix composites using a two-step stir casting method [21]. The introduction of hBN reinforcement resulted in decreased density and enhanced hardness and wear resistance of the composites.

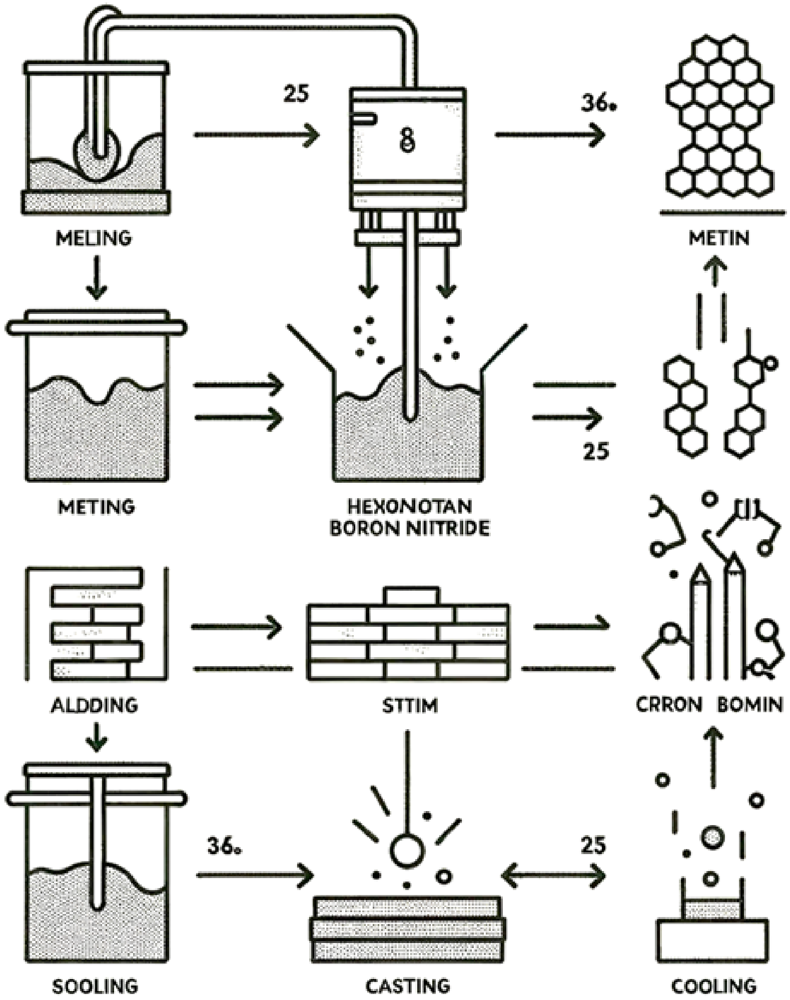

Figure 2: Stir casting process, highlighting the key steps and control points for creating hBN-enhanced aluminum matrix composites [Images generated by AI (DALL-E, OpenAI)].

Table 1: Synthesis and Characterizations of AMCs Using Various Techniques

Material	**Reinforcement (hBN)**	**Process**	**Characterizations**	**Remarks**
Aluminum (Al)	hBN: (2wt.% and 5wt.%)	Powder Metallurgy	High-energy ball milling effective for reducing particle size of h-BN. Micro-hardness increased.	Influences thermal, mechanical, and physical properties [22].
Aluminum Powder	BNNSs (boron nitride nano-sheets): 0%, 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% by volume.	Shift-speed ball milling and Direct Current Sintering (DCS)	Strong bonding at interface, tensile strength up to 220MPa.	Enhanced tensile properties, dispersing high-content BNNSs [23].
Aluminium (39.4 μm)	(h-BN-200 nm) and (TiB2-20 μm) 100%TiB2, 50% TiB2 + 50%BN and 100% BN	Friction Stir Processing (FSP)	Uniform dispersion of reinforcements, enhanced sliding wear resistance.	Improved wear resistance with nano-sized BN particles [24].
Aluminium (10 μm)	BNNPs (boron nitride nano-particles with140 nm): 0.5, 1.5, 3, 4.5, 6 and 7.5 by wt.%.	Spark Plasma Sintering Process	Increased strength under tensile loading, especially at elevated temperatures.	Enhances mechanical properties, particularly at higher temperatures [25].

Table 1 continued from previous page

Material	Reinforcement (hBN)	Process	Characterizations	Remarks
AA 6061	(h-BN 10μm:CBN-1 μm)	Stir Casting Process	Over 90% of theoretical density achieved, indicating successful manufacturing.	Enhanced wear resistance with HBN and CBN reinforcements [26].
Aluminium (Al)	Ti : BN (h-BN-5 μm and Ti-38 μm)	Vacuum Infiltration	Changes in microstructure with increased titanium content.	Improved fracture toughness with higher titanium content [27].
A380	hBN: 0, 0.5, 1 and 1.5 by wt.%	Ultrasonic Cavitation Process	Uniform distribution of nano-powder, increased tensile strength and hardness.	Improved tribological properties, suitable for sliding contact applications [28].
AA7050	Nano hexagonal boron nitride (h-BN) by wt.%	Spark Plasma Sintering Process	33% increase in hardness, 65% reduction in wear rate.	Reduced wear rate and increased hardness with 0.5 wt% h-BN reinforcement [29].

4 Impact of Reinforcement

The cited literature review elucidates the significant impact of reinforcing ceramic material, particularly hexagonal boron nitride (hBN), in aluminum-based materials. This review accentuates several critical aspects regarding the influence of hBN reinforcement on material behavior:

- The incorporation of hBN reinforcement into aluminum-based materials induces a strengthening effect, consequently rendering the composite material more robust and resistant to deformation and failure.
- hBN particles modify the behavior of the material by enhancing its mechanical properties, thus rendering it more applicable for various scenarios requiring augmented strength.
- The review highlights hBN's role as an exemplary solid lubricant. Beyond its strengthening impact, the integration of hBN into aluminum-based materials offers the advantage of solid lubrication. This property ensures effective performance under dry sliding conditions across diverse loads and velocities, pivotal in contexts where reducing friction and wear is crucial.
- Aluminum-hBN composites demonstrate superior microhardness and strength compared to the pure alloy or base powder material. This enhancement in mechanical properties stems from the reinforcing action of hBN, which impedes dislocation movement, thereby contributing to the increased strength of the material.
- The addition of hBN reinforcement to materials, inclusive of aluminum, leads to grain refinement. This process involves the diminution of individual crystal grains in the material, an essential factor for establishing robust interfacial bonding between the reinforcement and the matrix material, subsequently responsible for the amplified mechanical properties of the composite.

The literature review underscores the positive ramifications of hBN reinforcement in aluminum-based materials, encompassing improved mechanical properties, enhanced solid lubrication performance, and advanced grain refinement. The presence of hBN fosters a strengthening effect, making the material more resilient to deformation and wear. This reinforcing effect is associated with improved bonding at the interface between the hBN reinforcement and the matrix material, verifiable through sophisticated analytical techniques such as XRD, SEM, and TEM. The results obtained provide an extensive understanding of the behavior and potential utility of Al-hBN based composites. These findings lay the foundation for future research and practical application of these materials in various industries. The potential observations derived from the results include:

- The dual benefit of hBN reinforcement, offering both strengthening and lubrication, is a particularly intriguing aspect. This combination is advantageous in applications where high mechanical strength and reduced friction/wear are essential. The dual role of hBN as a reinforcing agent and a solid lubricant suggests broad utility in industries ranging from aerospace to automotive, where performance under demanding conditions is crucial.
- The review emphasizes the improved microhardness and strength observed in aluminum-hBN composites, indicating that hBN particles effectively hinder dislocation movement, thereby strengthening the material.
- The importance of strong interfacial bonding between hBN and the aluminum matrix is underscored, raising considerations about the methods used to achieve and quantify this bonding.

- Identifying the optimal hBN content for mechanical properties and prevention of aggregation is crucial. Understanding the threshold at which aggregation becomes problematic can guide the design of future experiments.
- While the literature review does not specifically address the processing techniques for incorporating hBN into aluminum, discussing various methods such as powder metallurgy and stir casting could deepen the review. Stir casting, or liquid metallurgy, is a relatively straightforward and cost-effective method due to its simplicity. The choice between stir casting and powder metallurgy hinges on the specific objectives, available resources, and the desired balance between cost-effectiveness and composite performance.

Summarizing the discussion by pinpointing potential areas for further research provides a roadmap for future studies. Investigating alternative reinforcement materials, exploring the effects of varying processing conditions, and examining the composites' behavior under more complex loading scenarios could yield valuable insights. Incorporating these discussion points ensures a comprehensive exploration of the implications and nuances of hBN reinforcement in aluminum matrix composites.

5 Applications of Al/hBN based AMCs

Aluminum matrix composites reinforced with hexagonal boron nitride (Al-hBN) possess a range of valuable applications across various industrial sectors. Figure 1, as referenced, underscores some of these applications, highlighting the enhanced capabilities imparted by hBN reinforcement in pure alloys. The integration of hBN reinforcement into aluminum matrices culminates in the formation of composites that boast a unique amalgamation of properties. These include lightweight design, elevated strength, wear resistance, and corrosion resistance. Such attributes render Al-hBN composites eminently suitable for diverse industrial applications, ultimately augmenting the overall performance of materials within these domains.

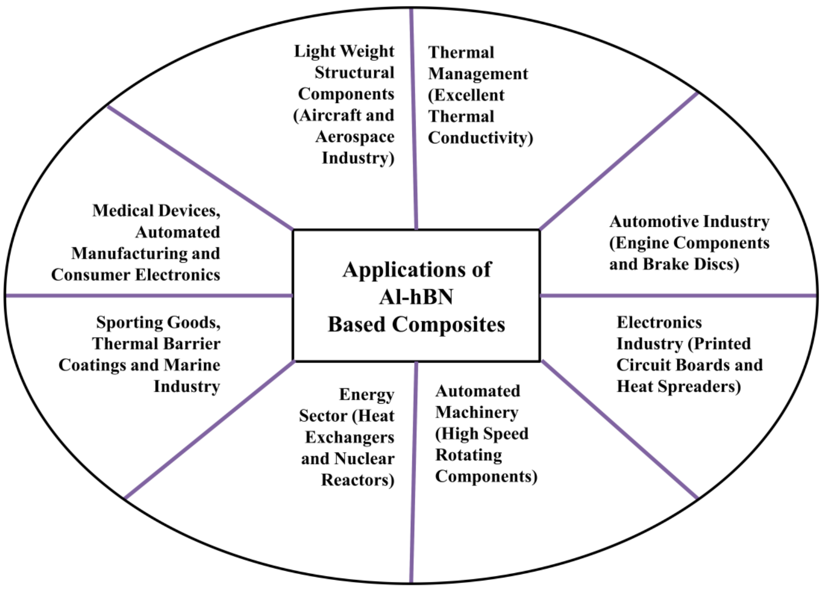

Figure 3: Applications of Al-hBN based composites.

6 Future Research Directions in hBN Enhanced Aluminum Composites

The exploration of hBN in aluminum matrix composites (AMCs) opens several avenues for future research. One promising direction involves investigating alternative composite materials that could synergize with hBN to offer enhanced properties. For instance, the integration of carbon nanotubes or graphene alongside hBN could lead to composites with superior strength and thermal conductivity. Another area of research is the improvement of manufacturing techniques. Innovations in additive manufacturing, such as 3D printing of metal composites, could revolutionize the production of hBN-enhanced AMCs, allowing for more complex geometries and tailored material properties. Additionally, the long-term durability and performance of these composites under various environmental conditions remain a fertile ground for investigation. This includes studying the effects of exposure to extreme temperatures, corrosive environments, and cyclic loading conditions. Lastly, the scalability and economic viability of producing hBN-enhanced AMCs for large-scale applications should be a key focus, ensuring that these advanced materials are not only effective but also accessible for widespread industrial use.

7 Environmental Impact Considerations of hBN in Aluminum Composites

The incorporation of hexagonal boron nitride (hBN) in aluminum composites must be evaluated in the context of environmental sustainability. hBN, like other boron compounds, is relatively inert and non-toxic, making it a preferable choice in terms of environmental and health safety compared to more hazardous materials like asbestos or certain heavy metals often used in composites. However, the complete environmental impact of hBN usage extends beyond its intrinsic properties. It encompasses the entire lifecycle, from extraction and processing of raw materials to manufacturing and eventual disposal of the composites. The energy-intensive production of hBN and aluminum should be considered, especially focusing on reducing emissions and improving energy efficiency. Additionally, research should investigate the recyclability of hBN-enhanced aluminum composites. While aluminum is highly recyclable, the presence of hBN may alter its recyclability profile. Understanding and optimizing these aspects are crucial for developing sustainable composite materials that align with the growing emphasis on reducing the carbon footprint and promoting circular economies in material production.

8 Conclusions

The study conclusively demonstrates that the incorporation of hBN reinforcement into aluminum matrix composites notably enhances their mechanical and tribological properties. This enhancement is particularly evident in the improved microhardness, strength, and wear resistance of the composites, indicating a transformative impact on the base material that surpasses the pure alloy's performance. The presence of hBN reinforcement not only contributes to increased resistance to deformation and wear but also significantly augments the wear resistance behavior, making these composites ideally suited for applications that demand durability under frictional conditions. Furthermore, the role of hBN in impeding dislocation movement strengthens the material, while its lubrication effect reduces friction and wear during sliding interactions. Among various fabrication methods, stir casting stands out as a cost-effective and practical approach due to its simplicity and lower equipment costs, making it an advantageous method for producing Al-hBN composites. The potential of Al-hBN based composites to revolutionize various industries is immense, offering lightweight, high-strength materials with enhanced wear resistance. The continued exploration into novel reinforcement materials, including nano-materials and advanced ceramics, is expected to yield composites with even better properties such as increased strength, wear resistance, and thermal stability. Future research endeavors are likely to focus on optimizing the composite composition and microstructure to meet specific performance requirements, involving more precise control over particle distribution, size, and orientation within the matrix.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Hartaj Singh: Conceptualization, Methodology; **Kapil Singh**: Data curation, Visualization; **Sachit Vardhan**: Validation and Overall supervision and Editing.

References

[1] S. Vettivel, N. Selvakumar, and P. V. Ponraj, "Mechanical behaviour of sintered cu-5% w nano powder composite," *Procedia engineering*, vol. 38, pp. 2874–2880, 2012.

[2] P. Rambabu, N. Eswara Prasad, V. Kutumbarao, and R. Wanhill, "Aluminium alloys for aerospace applications," *Aerospace Materials and Material Technologies: Volume 1: Aerospace Materials*, pp. 29–52, 2017.

[3] D. Charles, "Potential aerospace applications for metal matrix composites," *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, vol. 206, no. 2, pp. 105–110, 1992.

[4] S. Ayyanar, A. Gnanavelbabu, K. Rajkumar, and P. Loganathan, "Studies on high temperature wear and friction behaviour of aa6061/b 4 c/hbn hybrid composites," *Metals and Materials International*, vol. 27, pp. 3040–3057, 2021.

[5] J. Jiang and Y. Wang, "Microstructure and mechanical properties of the semisolid slurries and rheoformed component of nano-sized sic/7075 aluminum matrix composite prepared by ultrasonic-assisted semisolid stirring," *Materials Science and Engineering: A*, vol. 639, pp. 350–358, 2015.

[6] C. Jin, F. Lin, K. Suenaga, and S. Iijima, "Fabrication of a freestanding boron nitride single layer and its defect assignments," *Physical review letters*, vol. 102, no. 19, p. 195505, 2009.

[7] K. A. Verma, S. K. Swami, G. Nair, and U. K. Ravella, "Aluminum mmcs reinforced with hbn," *Int. J. Mech. Eng. Technol.*, vol. 8, no. 7, pp. 1532–1539, 2017.

[8] J. M. Mistry and P. P. Gohil, "An overview of diversified reinforcement on aluminum metal matrix composites: Tribological aspects," *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, vol. 231, no. 3, pp. 399–421, 2017.

[9] M. K. Akbari, H. Baharvandi, and K. Shirvanimoghaddam, "Tensile and fracture behavior of nano/micro tib2 particle reinforced casting a356 aluminum alloy composites," *Materials & Design (1980-2015)*, vol. 66, pp. 150–161, 2015.

[10] F. Khodabakhshi, A. Simchi, A. Kokabi, M. Nosko, F. Simanĉik, and P. Švec, "Microstructure and texture development during friction stir processing of al–mg alloy sheets with tio2 nanoparticles," *Materials Science and Engineering: A*, vol. 605, pp. 108–118, 2014.

[11] G. N. Kumar, R. Narayanasamy, S. Natarajan, S. K. Babu, K. Sivaprasad, and S. Sivasankaran, "Dry sliding wear behaviour of aa 6351-zrb2 in situ composite at room temperature," *Materials & Design*, vol. 31, no. 3, pp. 1526–1532, 2010.

[12] I. Topcu, H. Gulsoy, N. Kadioglu, and A. Gulluoglu, "Processing and mechanical properties of b4c reinforced al matrix composites," *Journal of Alloys and Compounds*, vol. 482, no. 1-2, pp. 516–521, 2009.

[13] A. Baradeswaran and A. E. Perumal, "Influence of b4c on the tribological and mechanical properties of al 7075–b4c composites," *Composites Part B: Engineering*, vol. 54, pp. 146–152, 2013.

[14] X. Zhu, X. Wei, Y. Huang, F. Wang, and P. Yan, "High-temperature friction and wear properties of nicr/hbn self-lubricating composites," *Metals*, vol. 9, no. 3, p. 356, 2019.

[15] N. Lokesh, K. Girish, S. Manjunath, and B. Narendra, "Study on mechanical properties of hbn reinforced al-7075 metal matrix composite," 2022.

[16] S. Rajkumar, B. Arulmurugan, A. Teklemariam, D. Tafesse, A. Mekonnen, and L. Mulugeta, "Investigation on mechanical properties of aa2024/hbn composites prepared by stir casting method," *Materials Today: Proceedings*, vol. 47, pp. 396–399, 2021.

[17] J. Joel, P. Jeyapandiarajan, A. Xavior, R. Harshitha, R. Sreekumar, and P. Raju, "Surface modification of hbn reinforced aluminum alloy al 2024 through friction stir processing," in *Journal of Physics: Conference Series*, vol. 2198, p. 012047, IOP Publishing, 2022.

[18] P. Loganathan, A. Gnanavelbabu, and K. Rajkumar, "Influence of zrb2/hbn particles on the wear behaviour of aa7075 composites fabricated through stir followed by squeeze cast technique," *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, vol. 235, no. 1, pp. 149–160, 2021.

[19] S. Ayyanar, A. Gnanavelbabu, K. Rajkumar, and P. Loganathan, "Studies on high temperature wear and friction behaviour of aa6061/b 4 c/hbn hybrid composites," *Metals and Materials International*, vol. 27, pp. 3040–3057, 2021.

[20] E. B. Moustafa, A. V. Mikhaylovskaya, M. A. Taha, and A. O. Mosleh, "Improvement of the microstructure and mechanical properties by hybridizing the surface of aa7075 by hexagonal boron nitride with carbide particles using the fsp process," *Journal of Materials Research and Technology*, vol. 17, pp. 1986–1999, 2022.

[21] S. Rakshath, B. Suresha, R. S. Kumar, and I. Saravanan, "Dry sliding and abrasive wear behaviour of al-7075 reinforced with alumina and boron nitride particulates," *Materials Today: Proceedings*, vol. 22, pp. 619–626, 2020.

[22] N. Siddesh Kumar, "Effect on wear property of aluminium metal matrix composite reinforced with different solid lubricants: a review," *International Journal of System Assurance Engineering and Management*, pp. 1–9, 2022.

[23] Y. Wang, Y. Zhu, R. Li, H. Liu, W. Liu, and P. He, "High-performance aluminum-based matrix composites reinforced with high content of boron nitride nanosheets," *Journal of Alloys and Compounds*, vol. 906, p. 164358, 2022.

[24] R. Palanivel, I. Dinaharan, R. Laubscher, and J. P. Davim, "Influence of boron nitride nanoparticles on microstructure and wear behavior of aa6082/tib2 hybrid aluminum composites synthesized by friction stir processing," *Materials & Design*, vol. 106, pp. 195–204, 2016.

[25] K. L. Firestein, A. E. Steinman, I. S. Golovin, J. Cifre, E. A. Obraztsova, A. T. Matveev, A. M. Kovalskii, O. I. Lebedev, D. V. Shtansky, and D. Golberg, "Fabrication, characterization, and mechanical properties of spark plasma sintered al–bn nanoparticle composites," *Materials Science and Engineering: A*, vol. 642, pp. 104–112, 2015.

[26] V. Rao, P. Periyaswamy, A. Bejaxhin, E. Naveen, N. Ramanan, and A. Teklemariam, "Wear behavioral study of hexagonal boron nitride and cubic boron nitride-reinforced aluminum mmc with sample analysis," *Journal of Nanomaterials*, vol. 2022, 2022.

[27] T. Zhou, J. Dai, Z. Xiao, W.-T. Qiu, Q. Lei, X. Liu, L. Qin, and M. Ma, "Interface microstructure and tribological behaviors of copper matrix composites with high graphite content prepared by short-process reduction and vacuum hot pressing," *JOM*, vol. 74, no. 5, pp. 2094–2105, 2022.

[28] J. Singh, N. Alba-Baena, R. Trehan, and V. S. Sharma, "Microstructure, mechanical properties and tribological behavior of a380/nano-hexagonal boron nitride metal matrix composite," *Journal of Materials Engineering and Performance*, vol. 31, no. 6, pp. 4887–4901, 2022.

[29] S. Thomas, N. Menachery, L. P. Thomas, S. N, P. Kumar GS, and G. S. Hebbar, "Influence of nano hexagonal boron nitride on the wear properties of aluminium alloy," *Advances in Materials and Processing Technologies*, pp. 1–17, 2023.

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Revolutionizing Organ Donation With Blockchain Technology: Prospects and Challenges In Healthcare

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Abstract

Amidst a critical shortage in organ donations, with over 120,000 individuals on the waiting list compared to a mere 8,000 annual donors, blockchain technology emerges as a beacon of innovation for the organ donation ecosystem. Originally the bedrock of cryptocurrencies like Bitcoin, blockchain has since traversed beyond the financial sector, exhibiting potential for securing medical records, authenticating pharmaceuticals, and mitigating fraudulent practices within healthcare. It presents a decentralized ledger that not only ensures data integrity and immutability but also fosters transparent and efficient donor-recipient matching through smart contracts. Despite the promising applications, the adoption of blockchain in healthcare confronts challenges including interoperability, data security, and regulatory hurdles. The present article encapsulates the transformative impact of blockchain, particularly within organ transplantation, and underscores the necessity for further research to surmount the barriers to its implementation. As blockchain technology continues to evolve, its capacity to reconcile the demand-supply disparity in organ donations is anticipated to save numerous lives, revolutionizing the healthcare landscape.

Keywords: Organ Transplant Waiting List; Blockchain Technology In Healthcare; Illegal Organ Trade; Healthcare Data Management; Smart Contracts In Organ Donation

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1 Introduction

Currently, there are over 120,000 individuals on the national transplant waiting list, while the annual number of organ donors is approximately 8,000. This vast gap between the demand for and supply of organs indicates a critical need for innovative solutions to address the disparity [1–3]. The advent of blockchain technology, known primarily for the Bitcoin cryptocurrency introduced by Satoshi Nakamoto, has heralded a myriad of applications beyond its original financial purpose [4]. Researchers have explored blockchain for various uses such as medical record management, counterfeit drug detection, and fraud prevention [5–7]. A blockchain functions as a digital ledger, cataloging cryptocurrency transactions in a verifiable and permanent manner. It grows with each "completed" block that contains a cryptographic hash of the prior block, a timestamp, and transaction data. This structure enables Bitcoin nodes to confirm valid transactions and prevent the double-spending of coins [8, 9]. The pressing issue of illegal organ trade, driven by high demand and exacerbated by poverty, provides a compelling case for blockchain's potential in regulating and tracking organ donations [10, 11]. The Government of India's national agency, NOTTO, is tasked with overseeing the country's organ supply to ensure accurate recording of transplants and organ donations, as well as implementing necessary measures for transplant requests [12, 13]. The healthcare sector faces significant challenges, including interoperability, the inaccessibility of medical records, and the lack of comprehensive, secure population health data. Recent public health crises have further highlighted the existing healthcare system's interoperability deficiencies [14, 15]. The present article encapsulates the transformative impact of blockchain, particularly within organ transplantation, and underscores the necessity for further research to surmount the barriers to its implementation. Refer to Figure 1 for a visual representation of the potential use of blockchain in the organ donation process.

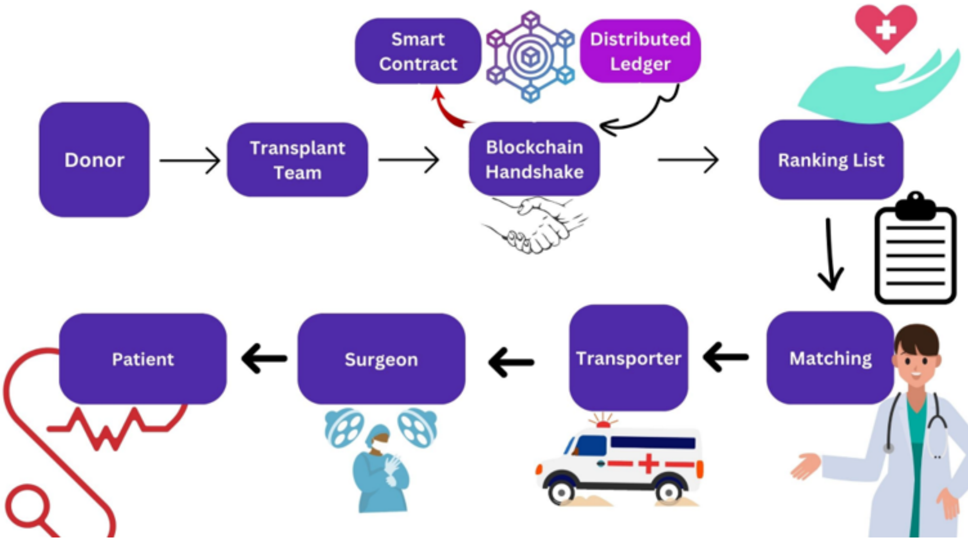

Figure 1: Using blockchain for organ donation flowchart.

2 Blockchain Technology

Blockchain technology, introduced in 2008 by an individual or group under the pseudonym "Satoshi Nakamoto," revolutionized digital transaction processes [16, 17]. Nakamoto's seminal white paper presented Bitcoin, a novel electronic cash system operating on a decentralized network that verifies and records transactions. A blockchain serves as a decentralized digital ledger, recording transactions across multiple computers. This ensures that any alteration of recorded data without network consensus is virtually impossible. Originally developed for Bitcoin, blockchain technology's potential extends to various domains, including supply chain management, voting systems, and real estate record-keeping. Its inherent security and distributed computing architecture afford high Byzantine fault tolerance. Blockchain's decentralized consensus makes it ideal for applications in event recording, medical records, and other records management activities such as identity management, transaction processing, provenance documentation, and food traceability [18–21]. A blockchain operates by grouping data into blocks, which are then linked in a chronological chain. New blocks are appended through a process known as "mining," involving network participants competing to solve complex mathematical problems. This process secures the blockchain and maintains the integrity of its data [22, 23, 22]. In the healthcare sector, as summarized in Table 1, blockchain technology offers numerous benefits such as enhanced security, privacy, and interoperability. It confronts challenges like managing massive healthcare data and access complexities. Furthermore, blockchain facilitates automated data exchange and tracking in healthcare through smart contracts. Table 2 delineates the key metrics in optimizing kidney donation using blockchain technology. It includes parameters such as the number of kidney donations per year, reduction in the waiting list, use of smart contracts, data security measures, and patient and donor satisfaction rates.

Moreover, a comparison between traditional and blockchain-enabled organ donation processes is presented in Table 3. This comparison highlights significant improvements in aspects such as verification of organ donors, documentation of organ agreements, privacy protection, and overall impact on patient care.

Table 1: Blockchain Technology in Healthcare Summary

Topic	Description
Introduction	Blockchain, introduced in 2008, underpins Bitcoin.
Definition	A decentralized and secure digital ledger.
Applications	Diverse sectors including supply chain, voting, healthcare.
Benefits	Offers enhanced security, privacy, and interoperability.
Challenges	Involves management of massive healthcare data and access complexities.
Smart Contracts	Facilitates automated data exchange and tracking in healthcare.

Table 2: Key Metrics in Optimizing Kidney Donation with Blockchain

Particulars	Description
Number of Kidney Donations (Year)	Total number of donations facilitated by blockchain.
Waiting List Reduction (%)	Reduction percentage in the transplant waiting list post-blockchain implementation.
Smart Contracts Utilized	Number of contracts used for donation agreements and tracking.
Data Security Measures	Blockchain features for data security, such as encryption and decentralization.
Privacy Protection	Enhancement of patient privacy via blockchain.
Administrative Efficiency	Reduction in administrative tasks owing to blockchain integration.
Transparency and Traceability	Improved transparency and traceability in donation processes.
Medication and Product Authentication	Ensures authenticity of medicines and medical products.
Patient and Donor Satisfaction (%)	Satisfaction rate among patients and donors with the blockchain process.

Table 3: Comparison of Traditional vs. Blockchain-Enabled Organ Donation Processes

Aspect	Traditional Process	Blockchain-Enabled Process
Verification of Organ Donors	Manual, often time-consuming	Streamlined through smart contracts
Documentation of Organ Agreements	Prone to errors, paper-based	Digitally secured with smart contracts
Donor-Recipient Matching	Manual, subject to delays	Automated, efficient, and real-time
Storage of Medical Information	Centralized, risk of data breaches	Decentralized, enhancing security
Privacy Protection	Limited data privacy control	Augmented privacy via encryption
Transparency and Traceability	Limited process transparency	Complete transparency with a public ledger
Administrative Burden	High due to manual overheads	Significantly reduced workload
Data Exchange and Interoperability	Often limited	Enhanced through smart contracts
Impact on Patient Care	Potential for delays and errors	Streamlined processes improving care

3 Pertinent Healthcare Subjects and Blockchain Alternatives

The U.S. healthcare sector, recognized as the world's largest, incurs annual expenditures surpassing $1.7 trillion [24, 25]. The average annual healthcare cost per capita in the United States is approximately $10,739, which is higher than in any other country. The healthcare sector's share of the Gross Domestic Product (GDP) is about 18%. Projections indicate that, without significant changes, healthcare will constitute nearly 20% of the U.S. GDP by 2027 [26]. In response to escalating medical and pharmaceutical costs and the aim to improve the quality of care, the healthcare industry is exploring and implementing innovative strategies [27]. A key issue in the healthcare system is the misalignment of objectives among various stakeholders, including healthcare providers, insurance companies, and patients. This misalignment often results in fragmented care and inefficiencies. Effective collaboration, open communication, and transparent procedures are essential to address these conflicts. However, the handling and communication of data within this complex environment pose significant challenges.

These challenges include the need for efficient information flow, process auditing, and the high costs associated with these activities, which often slow down healthcare service delivery. Governments and insurance providers, as critical stakeholders, are working with healthcare professionals to develop and implement policies. Blockchain technology presents numerous advantages in this context, particularly for data integrity and accurate transaction recording, beginning with Blockchain-enabled Universal Patient Record Linkages (UPRL) [28]. Healthcare systems, along with payers, regulators, and government bodies, face technological challenges in managing the vast amounts of data collected. These challenges encompass data structure, security, standards, storage and transfer, governance, ownership, error management, and the need for real-time analytics [29–31]. Blockchain technology's dual verification process promises to offer potential solutions to these challenges. The key mechanisms of blockchain, whether private or public, would help establish a secure and verifiable environment for data transfer [32–34]. The adoption of blockchain-based services in healthcare could lead to reduced response times and lower administrative costs by minimizing paperwork. This efficiency gain allows healthcare professionals, including doctors and nurses, to focus more on patient care and engage in innovative practices that could improve patient outcomes. Additionally, a comprehensive tracking system within a Blockchain-enabled network ensures the authenticity of medicines and medical products, thereby enhancing confidence among all stakeholders [35–37]. The potential study must outline a real-time, distributed solution for optimizing the organ donation process using blockchain technology. This process shall start with a donor signing a smart contract for organ donation, followed by a recipient submitting a transplant request. A licensed medical professional then shall validate and hash these documents, creating a validated mismatching pair that would be then broadcasted across the network. Once a match gets identified, it shall be sent to a doctor for approval. Following the doctor's approval, a hash shall be generated, and the verified matched pair can be added to the blockchain, rendering it immutable. This streamlined process shall provide all necessary information for surgical logistics planning to doctors and medical specialists.

4 Challenges in Data Collection

Wearables and other healthcare monitoring technologies generate an enormous amount of data on a person's health. Proper data management and secure data retrieval are crucial for our healthcare system to make data-driven decisions. Routine business operations and service delivery of our current healthcare system also produce data. Patients interact with various healthcare professionals throughout their lives, leaving a trail of data in each one's system. The primary data stewardship often lies with providers, leading to fragmented data trails and diminished patient access. Healthcare data is characterized by its vast volume, variability, and velocity. It is non-uniform, encompasses numerous variables, and necessitates real-time data processing. Much of this data is inaccessible, non-standardized across systems, and challenging to comprehend, use, and share due to [38, 39]:

- Dependency on the dialogue between the patient and the doctor.
- Consistent failure to leverage the data effectively.
- Lengthy and time-consuming healthcare processes.
- Critical patient data being scattered across systems.
- The inability of many healthcare systems to provide essential care due to lack of access to crucial data.
- A negative impact on the management system due to many participants lacking the expertise for seamless procedures.
- Inadequate security and reliability of healthcare data.

Blockchain could provide numerous benefits for identity management and healthcare data security [40]. It can reduce threats and protect sensitive information from falling into the wrong hands. When data is uploaded to the blockchain, it is encrypted and becomes immutable and difficult to decode. It verifies transactions using a secret identifying key known only to the user. Hence, a healthcare professional would have explicit access to the blockchain record to retrieve a patient's medical data, unlike with current healthcare data technologies [41, 42]. Improved data collaboration between providers leads to more accurate diagnoses and more effective treatments, enabling healthcare institutions to deliver care more economically. Blockchain can keep data secure and private while allowing patients to share their information with any chosen service providers. It delineates the ownership of medical records and ensures the validity of anti-counterfeiting measures [43, 44].

5 Data Exchange and Interoperability

Smart contracts enable the automation and monitoring of specific state changes in healthcare data management. When new data is received, an automatic notification is sent to the relevant party, allowing them to review the record before either accepting or rejecting it [45].

This mechanism ensures that all participants are kept informed and actively engaged in the progression of the record. Generally, contracts are categorized into three types: contract types, health tracking information, and procedures and storage [46].

5.1 Doctor Smart Contract

The doctor smart contract is designed to maintain various essential details about the doctor, including a list of patients they have consulted. This contract allows transactions related to different procedures to be conducted on the smart contracts of only those patients who are listed as having been consulted by the doctor [45, 47].

5.2 Patient Smart Contract

The patient smart contract focuses on enhancing privacy by excluding personal details such as names and addresses. Each patient is assigned a unique identity generated by hashing their username and Social Security Number (SSN) using the MD5 algorithm. This contract serves as a robust mechanism for authentication and authorization, permitting only authorized doctors to modify the patient's contract status through transactions [48, 49]. Additionally, this smart contract provides information about the patient's status in the organ donation process. It stores only content identifiers of the patient's medical information, rather than the complete files. These identifiers serve as references to access documents on the distributed file system, InterPlanetary File System (IPFS). The patient's smart contract also manages and monitors access requests to the medical records [50, 51]. As outlined in Table 4, blockchain technology in healthcare data management offers multiple benefits. These include ensuring data integrity, securing data retrieval, improving collaboration, enhancing privacy, increasing administrative efficiency, authenticating medications and products, and automating and monitoring state changes in healthcare data.

Table 4: Benefits of Blockchain Technology in Healthcare Data Management

Benefit	**Description**
Data Integrity	Ensures the accuracy and reliability of healthcare data through immutable records.
Secure Data Retrieval	Facilitates secure and efficient access to patient records, thereby reducing the risk of data breaches.
Improved Collaboration	Enhances the sharing of medical information among healthcare providers.
Privacy Enhancement	Protects patient privacy and ensures data security through encryption and decentralization.
Administrative Efficiency	Streamlines processes and reduces paperwork, leading to lower administrative burdens.
Medication and Product Authentication	Employs a comprehensive tracking system to verify the authenticity of medicines and medical products.
Automation and State Monitoring	Utilizes smart contracts to automate and monitor changes in healthcare data states.

6 Conclusion

The nascent stages of blockchain implementation in the healthcare domain have underscored the imperative for a paradigm shift in the dynamics among healthcare providers, patients, and the pharmaceutical industry. While the transformative potential of blockchain is palpable, its integration into healthcare necessitates the navigation of a labyrinth of legal, regulatory, and technology-specific challenges. The promise of blockchain to revolutionize the healthcare system is yet to be fully realized, with its application still burgeoning and largely exploratory. Currently, the healthcare sector has not extensively harnessed blockchain, but the trajectory indicates a burgeoning expansion of its applications. The dearth of empirical studies on blockchain's impact in healthcare signals an urgent need for rigorous research, particularly real-world case studies, to elucidate the technology's efficacy and scope. Future investigations are essential to forge a path forward, paving the way for informed, evidence-based adoption of blockchain in healthcare practices.

Declaration of Competing Interests

The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Jaspreet Kaur: Conceptualization, Supervision, Writing- Reviewing and Editing, Project Administration; **Rohit Agnihotri**: Methodology, Data curation, Investigation, Software, Validation; Writing–Original draft preparation.

References

[1] I. A. Daniel, C. Pop, I. Anghel, M. Antal, and T. Cioara, "A blockchain based solution for managing transplant waiting lists and medical records," in *2020 IEEE 16th International Conference on Intelligent Computer Communication and Processing (ICCP)*, pp. 505–510, IEEE, 2020.

[2] F. Ambagtsheer, M. Gunnarson, L. van Balen, N. Ivanovski, S. Lundin, I. Byström, and W. Weimar, "Organ recipients who paid for kidney transplantations abroad: a report," *The HOTT Project*, p. 69, 2014.

[3] *Opportunities for organ donor intervention research: Saving lives by improving the quality and quantity of organs for transplantation.* National Academies Press, 2018.

[4] D. A. Nair, "The bitcoin innovation, crypto currencies and the leviathan," *Innovation and Development*, 2018.

[5] Y. Xie, J. Zhang, H. Wang, P. Liu, S. Liu, T. Huo, Y.-Y. Duan, Z. Dong, L. Lu, and Z. Ye, "Applications of blockchain in the medical field: Narrative review," *Journal of Medical Internet Research*, vol. 23, no. 10, p. e28613, 2021.

[6] T. McGhin, K.-K. R. Choo, C. Z. Liu, and D. He, "Blockchain in healthcare applications: Research challenges and opportunities," *Journal of network and computer applications*, vol. 135, pp. 62–75, 2019.

[7] M. Kassab, J. DeFranco, T. Malas, P. Laplante, G. Destefanis, and V. V. G. Neto, "Exploring research in blockchain for healthcare and a roadmap for the future," *IEEE Transactions on Emerging Topics in Computing*, vol. 9, no. 4, pp. 1835–1852, 2019.

[8] S. Krishnan, V. E. Balas, E. G. Julie, H. R. Yesudhas, S. Balaji, and R. Kumar, *Handbook of research on blockchain technology.* Academic Press, 2020.

[9] D. K. C. Lee and L. Low, *Inclusive fintech: blockchain, cryptocurrency and ICO.* World Scientific, 2018.

[10] P. Howson, "Building trust and equity in marine conservation and fisheries supply chain management with blockchain," *Marine Policy*, vol. 115, p. 103873, 2020.

[11] P. R. d. Cunha, P. Soja, and M. Themistocleous, "Blockchain for development: a guiding framework," 2021.

[12] T. O. Adido, *Transplant Tourism: An International and National Law Model to Prohibit Travelling Abroad for Illegal Organ Transplants.* Brill, 2018.

[13] C. T. Liverman, J. F. Childress, *et al.*, *Organ donation: Opportunities for action.* National Academies Press, 2006.

[14] R. Kukafka, J. S. Ancker, C. Chan, J. Chelico, S. Khan, S. Mortoti, K. Natarajan, K. Presley, and K. Stephens, "Redesigning electronic health record systems to support public health," *Journal of biomedical informatics*, vol. 40, no. 4, pp. 398–409, 2007.

[15] M. Attaran, "Blockchain technology in healthcare: Challenges and opportunities," *International Journal of Healthcare Management*, vol. 15, no. 1, pp. 70–83, 2022.

[16] J. Mattila, "The blockchain phenomenon," *Berkeley Roundtable of the International Economy*, vol. 16, 2016.

[17] L. Cai, Q. Li, and X. Liang, "Introduction to blockchain basics," in *Advanced Blockchain Technology: Frameworks and Enterprise-Level Practices*, pp. 3–43, Springer, 2022.

[18] Y. Xie, J. Zhang, H. Wang, P. Liu, S. Liu, T. Huo, Y.-Y. Duan, Z. Dong, L. Lu, and Z. Ye, "Applications of blockchain in the medical field: Narrative review," *Journal of Medical Internet Research*, vol. 23, no. 10, p. e28613, 2021.

[19] M. Faisal, H. Sadia, T. Ahmed, and N. Javed, "Blockchain technology for healthcare record management," *Pervasive Healthcare: A Compendium of Critical Factors for Success*, pp. 255–286, 2022.

[20] M. Niranjanamurthy, B. Nithya, and S. Jagannatha, “Analysis of blockchain technology: pros, cons and swot,” *Cluster Computing*, vol. 22, pp. 14743–14757, 2019.

[21] D. Berdik, S. Otoum, N. Schmidt, D. Porter, and Y. Jararweh, “A survey on blockchain for information systems management and security,” *Information Processing & Management*, vol. 58, no. 1, p. 102397, 2021.

[22] W. Wang, D. T. Hoang, P. Hu, Z. Xiong, D. Niyato, P. Wang, Y. Wen, and D. I. Kim, “A survey on consensus mechanisms and mining strategy management in blockchain networks,” *Ieee Access*, vol. 7, pp. 22328–22370, 2019.

[23] L. Ismail and H. Materwala, “A review of blockchain architecture and consensus protocols: Use cases, challenges, and solutions,” *Symmetry*, vol. 11, no. 10, p. 1198, 2019.

[24] D. S. Guzick, *An introduction to the US health care industry: balancing care, cost, and access.* JHU Press, 2020.

[25] P. B. Ginsburg, “High and rising health care costs: Demystifying us health care spending,” *Princeton, NJ*, 2008.

[26] A. M. Sisko, S. P. Keehan, J. A. Poisal, G. A. Cuckler, S. D. Smith, A. J. Madison, K. E. Rennie, and J. C. Hardesty, “National health expenditure projections, 2018–27: economic and demographic trends drive spending and enrollment growth,” *Health affairs*, vol. 38, no. 3, pp. 491–501, 2019.

[27] T. Lehtonen, “Drg-based prospective pricing and case-mix accounting—exploring the mechanisms of successful implementation,” *Management Accounting Research*, vol. 18, no. 3, pp. 367–395, 2007.

[28] R. H. Hylock and X. Zeng, “A blockchain framework for patient-centered health records and exchange (healthchain): evaluation and proof-of-concept study,” *Journal of medical Internet research*, vol. 21, no. 8, p. e13592, 2019.

[29] C. S. Kruse, R. Goswamy, Y. J. Raval, and S. Marawi, “Challenges and opportunities of big data in health care: a systematic review,” *JMIR medical informatics*, vol. 4, no. 4, p. e5359, 2016.

[30] I. G. Cohen, R. Amarasingham, A. Shah, B. Xie, and B. Lo, “The legal and ethical concerns that arise from using complex predictive analytics in health care,” *Health affairs*, vol. 33, no. 7, pp. 1139–1147, 2014.

[31] R. L. Villars, C. W. Olofson, and M. Eastwood, “Big data: What it is and why you should care,” *White paper, IDC*, vol. 14, pp. 1–14, 2011.

[32] S. Aggarwal, R. Chaudhary, G. S. Aujla, N. Kumar, K.-K. R. Choo, and A. Y. Zomaya, “Blockchain for smart communities: Applications, challenges and opportunities,” *Journal of Network and Computer Applications*, vol. 144, pp. 13–48, 2019.

[33] W. Gao, W. G. Hatcher, and W. Yu, “A survey of blockchain: Techniques, applications, and challenges,” in *2018 27th international conference on computer communication and networks (ICCCN)*, pp. 1–11, IEEE, 2018.

[34] J. B. Bernabe, J. L. Canovas, J. L. Hernandez-Ramos, R. T. Moreno, and A. Skarmeta, “Privacy-preserving solutions for blockchain: Review and challenges,” *IEEE Access*, vol. 7, pp. 164908–164940, 2019.

[35] M. Uddin, “Blockchain medledger: Hyperledger fabric enabled drug traceability system for counterfeit drugs in pharmaceutical industry,” *International Journal of Pharmaceutics*, vol. 597, p. 120235, 2021.

[36] T. K. Mackey, T.-T. Kuo, B. Gummadi, K. A. Clauson, G. Church, D. Grishin, K. Obbad, R. Barkovich, and M. Palombini, “‘fit-for-purpose?’–challenges and opportunities for applications of blockchain technology in the future of healthcare,” *BMC medicine*, vol. 17, no. 1, pp. 1–17, 2019.

[37] T. K. Dasaklis, T. G. Voutsinas, G. T. Tsoulfas, and F. Casino, “A systematic literature review of blockchain-enabled supply chain traceability implementations,” *Sustainability*, vol. 14, no. 4, p. 2439, 2022.

[38] N. Ahmed, Z. Al Aghbari, and S. Girija, “A systematic survey on multimodal emotion recognition using learning algorithms,” *Intelligent Systems with Applications*, vol. 17, p. 200171, 2023.

[39] B. S. Balasubramani, *Down to Earth: Knowledge Based Approaches for Heterogeneous Geospatial Data Management.* PhD thesis, University of Illinois at Chicago, 2020.

[40] B. Zaabar, O. Cheikhrouhou, F. Jamil, M. Ammi, and M. Abid, “Healthblock: A secure blockchain-based healthcare data management system,” *Computer Networks*, vol. 200, p. 108500, 2021.

[41] S. Chenthara, K. Ahmed, H. Wang, F. Whittaker, and Z. Chen, “Healthchain: A novel framework on privacy preservation of electronic health records using blockchain technology,” *Plos one*, vol. 15, no. 12, p. e0243043, 2020.

[42] G. Leeming, J. Cunningham, and J. Ainsworth, “A ledger of me: personalizing healthcare using blockchain technology,” *Frontiers in medicine*, vol. 6, p. 171, 2019.

[43] Y. Chen, S. Ding, Z. Xu, H. Zheng, and S. Yang, “Blockchain-based medical records secure storage and medical service framework,” *Journal of medical systems*, vol. 43, pp. 1–9, 2019.

[44] M. A. Cyran, "Blockchain as a foundation for sharing healthcare data," *Blockchain in Healthcare Today*, 2018.

[45] A. Khatoon, "A blockchain-based smart contract system for healthcare management," *Electronics*, vol. 9, no. 1, p. 94, 2020.

[46] K. N. Griggs, O. Ossipova, C. P. Kohlios, A. N. Baccarini, E. A. Howson, and T. Hayajneh, "Healthcare blockchain system using smart contracts for secure automated remote patient monitoring," *Journal of medical systems*, vol. 42, pp. 1–7, 2018.

[47] M. Zghaibeh, U. Farooq, N. U. Hasan, and I. Baig, "Shealth: A blockchain-based health system with smart contracts capabilities," *IEEE Access*, vol. 8, pp. 70030–70043, 2020.

[48] A. Alabdulatif, I. Khalil, and M. Saidur Rahman, "Security of blockchain and ai-empowered smart healthcare: Application-based analysis," *Applied Sciences*, vol. 12, no. 21, p. 11039, 2022.

[49] A. F. S. Ibrahim, "New secure solutions for privacy and access control in health information exchange," 2016.

[50] R. K. Marangappanavar and M. Kiran, "Inter-planetary file system enabled blockchain solution for securing healthcare records," in *2020 third ISEA conference on security and privacy (ISEA-ISAP)*, pp. 171–178, IEEE, 2020.

[51] S. A. H. Mohsan, A. Razzaq, S. A. K. Ghayyur, H. K. Alkahtani, N. Al-Kahtani, and S. M. Mostafa, "Decentralized patient-centric report and medical image management system based on blockchain technology and the inter-planetary file system," *International Journal of Environmental Research and Public Health*, vol. 19, no. 22, p. 14641, 2022.