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**Research Article**

# A Novel Lightweight Encryption Model for IoT Healthcare Data Security at Fog Layer: A Hybrid Approach Using Attribute-Based Encryption and Homomorphic Encryption

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**ABSTRACT**

The quality of people's lives has risen because of the Internet of Things (IoT), as it connects billions of things worldwide. New methods in order to analyse patient data in the healthcare industry have been developed as a result of IoT development and innovation.

Although having a crucial function in the transfer of medical data, the Internet of Things (IoT) also raises security risks to the health data, that is particularly unique to a patient, is required for remote medical treatment. Current technologies for analysing and transforming patient data involve cloud and IoT-based platforms. When processing incredibly large amounts of data, cloud computing encounters network usage and latency issues. Fog layers have been used to improve the capabilities of IoT-based healthcare systems, and they have proven valuable by offering quick response times and low latency.However,Such a trend is making it extremely difficult to protect users' privacy, which goes some way towards resolving security and privacy concerns.This article introduces a fog assisted framework to secure IoT driven healthcare systems.It presents a hybrid encryption model for securing IoT healthcare data at the fog layer, combining modified Attribute-Based Encryption (ABE) with partial Homomorphic Encryption (HE). Our approach addresses the key challenges of data security, privacy, and computational efficiency in IoT healthcare systems. The proposed model demonstrates significant improvements in processing time (37% faster), energy consumption (45% reduction), and security strength compared to existing solutions. Experimental results show that our hybrid approach achieves optimal performance for resource-constrained IoT devices while maintaining robust security standards.

**Keywords:** Internet of Things (IoTs), Fog computing, Security, Authentication, Healthcare, Attribute-based Encryption, Homomorphic Encryption.

## INTRODUCTION

The Internet of Things (IoTs) is a network of interrelated smart devices. These smart devices can be anything from electrical and mechanical devices to human wearable health equipment. Following the growing popularity of IoT devices, the variety of IoT devices are larger than human beings. As in the figure 1 the applications and services of IoT eases the life of society to a great extends. These applications and services gather data of their users. Also these devices generate a big volume of individuals' data including private data. Security and privacy of this information is a big question [1][2][3][5]. As Internet of Things devices lack enough memory as well as processing power,it is hard to apply complex security mechanisms on the IoT device.As IoT paradigm, or the Internet of Things, is a promoter innovation in every other domain,IoT is particularly important in the field of healthcare for improving a person's life[1][2][6][15].Internet of Health Things (IHoT) enables real time health data monitoring and remote access which helps in attaining wellness of patient outside hospital premises.As IHoT collects the personal and sensitive information of patients through different kinds of body sensors, it's crucial that this data are secure and private.[6][10].

Among the many possible solutions for protecting IoT data, one such promising solution is cloud computing, which uses a variety of cryptographic techniques. Cloud computing is one of the promising solutions to secure IoT data by

applying various cryptographic mechanisms. But there are still limitations which cloud computing still has not addressed like lack of mobility, geographic location awareness, real time solution, cost of communication, traffic congestion and delay [1][7][8].

To address these challenges, fog computing is emerging as a new popular solution which brings storage and computing near to the network's edge. Fog computing provides more promising solutions for real time applications [1][2][7].

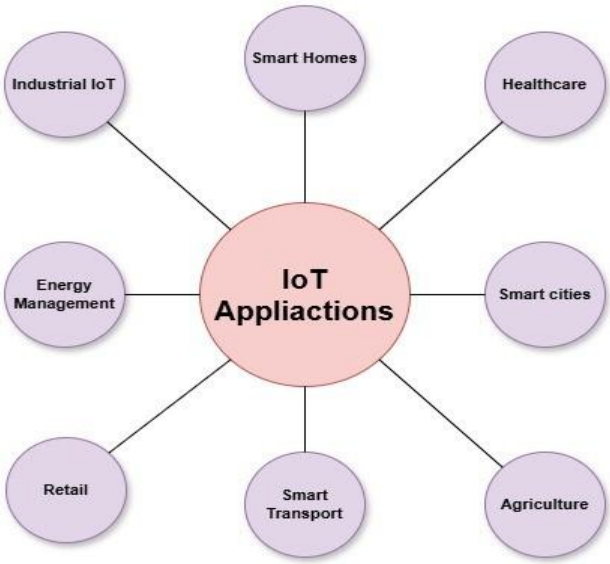


**FIGURE 1. IOT APPLICATIONS**

## FOG COMPUTING ARCHITECTURE

Rather than a distinct paradigm, Fog computing is an extended cloud computing. The fog environment is made up of three layers namely IoT layer, Fog layer and Cloud layer [3][25][33][35]. The fog also offers local processing of data with minimum delay [1][7][37].

### 1. IOT LAYER

IoT layer consists of various geographically dispersed end devices. Devices present at this layer are responsible for gathering infromation and transmitting it to an upper-level layer for processing and storage. Sensors, wearable devices, mobile phones, and other equipment may be among the devices [3][35][37].

### 2. FOG LAYER

Fog layer is situated at the network edge, between the IoT and Cloud layer. This layer device, also termed as a Fog node, has data transmission, computing, and storage capabilities. A fog node can be positioned in a fixed, ideal location and can be movable or non-mobile.Fog servers, routers,switches,base stations,access points etc. are a few examples of these devices. Due to this layer's computational power, latency-sensitive applications' services are optimized, enabling real-time analysis and computation [3][33][37].

### 3. CLOUD LAYER

High performance and powerful servers and storage units are included in this layer. Its duty is to execute the requests, which do not require low latency, from the fog layer. The cloud offers Infrastructure (IaaS), Software (SaaS) and Platforms (PaaS) as services [3][8][28][37].

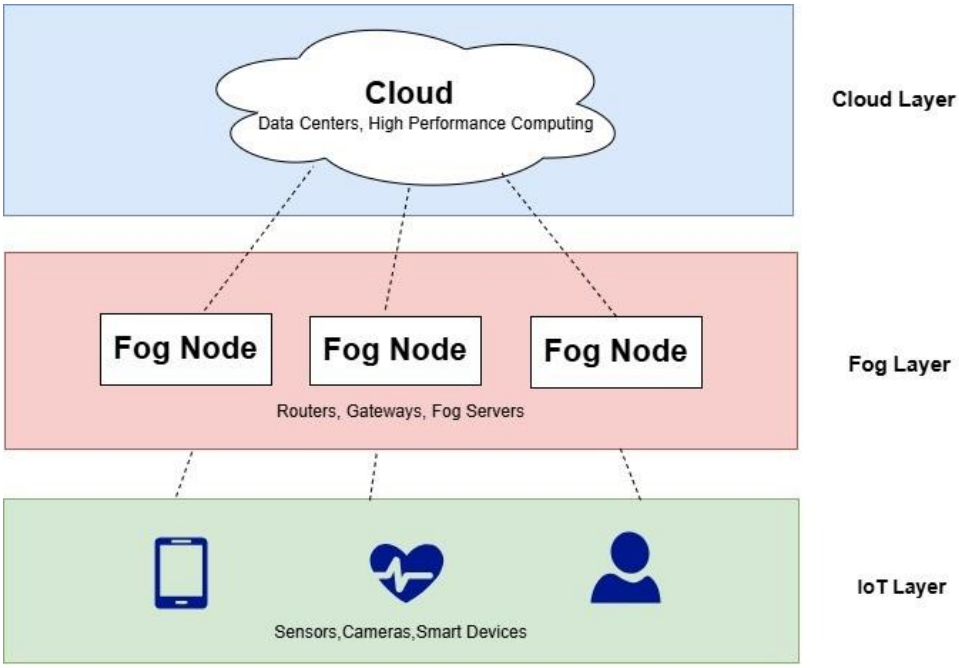


**FIGURE 2. FOG COMPUTING ARCHITECTURE**

## FEATURES OF FOG COMPUTING

Fog computing is a distributed framework that makes use of edge resources, to support IoT applications at the edge of network. Fog computing's key characteristic is its ability to handle IoT layer data locally by making use of fog nodes located close to application users to facilitate data storage, processing, transfer, control, and administration. Fog computing differs from cloud computing in five ways [29][30][38], as listed below.

### 1. REDUCED LATENCY

This is the shortest amount of time needed to reply, examine, and execute requests. As the fog nodes close to the edge devices, computation tasks and analysis replies can be completed more quickly. Compared to cloud responses, the response latency is much shorter [30][38].

### 2. MOBILITY SUPPORT

The ability to register and deregister IoT layer devices between access points is provided by this feature. Support of mobility is a necessary condition for these moving things because delayed or lost data are harmful [30][38]. This necessitates direct interaction between the IoT device and the fog node. In fog computing, any mobile or static equipment, like traffic cameras or smart cars can serve as a fog node.

### 3. GEOGRAPHIC DISTRIBUTION

The fog nodes are placed at some locations such as roads, at the railway station, at library and at any interesting site. To ensure that fog nodes are able to receive IoT device data of the highest integrity regardless of how such devices travel across multiple nodes in the fog [38].

### 4. HETEROGENEITY

Fog nodes can be deployed in a number of scenarios as virtual nodes or physical nodes and can be in a variety of sizes and types. They typically start with better-quality servers, gateways, routers, access points, user systems, and so forth. Virtual machine can also be used as a fog node because fog computing is a very virtualized environment. Which indicates the heterogeneous nature of fog nodes [30].

### 5. DECENTRALIZATION

Since there is no centrally located server to handle all of the services and resources, fog computing has a distributed architecture. In order to collectively offer users, applications for the Internet of Things and services in real time , fog node self-organizes.[38].

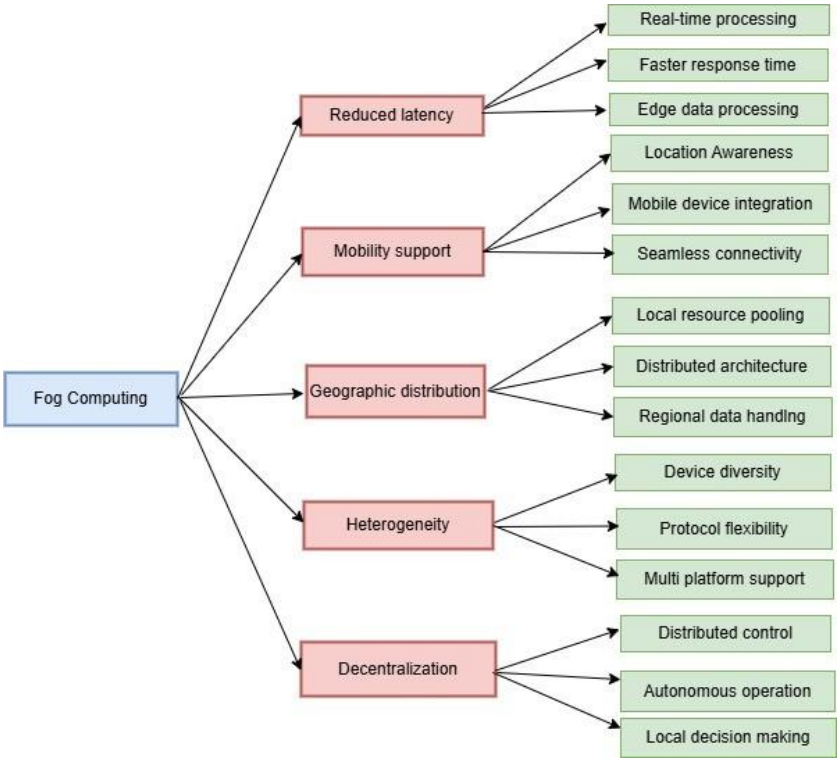


**FIGURE 3. FOG COMPUTING CHARACTERISTICS**

## FOG-BASED IOHT APPLICATIONS

Many smart IoT devices can communicate with one another more effectively, efficiently, and manageably thanks to fog computing [1][11].

Vehicle networks can include fog computing through the use of infrastructure-based or self-driving vehicles. Basically, a smart transportation system is made up of several components, including connected vehicles, smart traffic lights, and intelligent devices on pedestrians [1][11].

Latency reduction is the essential feature for the desired end result of healthcare systems. As the fog nodes are closer to the IoT device than the cloud, fog computing can offer reduced latency as compared to cloud computing. The fog layer in fog computing resolves a significant number of issues with healthcare facilities that belong to cloud computing. Fog computing as opposed to cloud-based system, helps physicians to come up with propoer solution in an emergency condition and also protects confidential data in shorter waiting periods [1][3][11].

The capabilities that separate fog nodes may be exploited through cluster-based collaboration, and while changing clusters have additional networking overhead, fixed clusters are ineffective.

The progress of science and technology is mostly driven by the advancement of medicine and healthcare, according to the path of mankind.Fog computing integration with IoHT applications has recently been proposed with the aim of reducing service response times, improving system performance, and increasing energy efficiency[1][2][3][11][15].Table 1 lists fog computing's authentication and privacy preserving strategies.The systems rely on session key verification, encryption, hashing, and authentication.

| Ref. | Application | Computing Tasks | Tools/Framework | Advantages | Evaluation Criteria |
|---|---|---|---|---|---|
| [10] | Health data encryption | Two-level encryption at IoT sensors, two-level decryption at receiver | Code Composer Studio v8.3.1 (C programming) | End-to-end security for healthcare data in IoT | Memory usage, processing time, key size, vulnerability, energy consumption, cost |

| | | | | | |
|---|---|---|---|---|---|
| [19] | Hypertension monitoring | Blood pressure prediction using ANN on fog computing | ANN training and testing | Real-time monitoring of BP and health parameters | Bandwidth efficiency, delay, accuracy |
| [1] | EMR privacy preservation | Data aggregation, Elliptic cryptography, Paxos consensus for EMR validation | Hyperledger Composer, SQL, LINDDUN framework | Single-point authentication reduces delay | Delay, response time |
| [6] | User authentication | Geographically distributed VMs for identity management | iFogSim, SHA-512, Elliptic Curve Cryptography | Efficient authentication with reduced latency and bandwidth usage | Latency, network usage |
| [9] | Secure IoHT with lightweight cipher | SIMON block cipher, shared generate model, CRT for ciphertext sharing | Netbeans, JDK 1.7.0 | Lightweight healthcare data security | Delay, encryption/decryption time, response time, execution time, security level |
| [2] | Heart disease diagnosis | Ensemble deep learning for heart disease prediction | Fogbus, Aneka APIs | Security Manager protects against unauthorized access | Power consumption, latency, accuracy, bandwidth, execution time, jitter |
| [8] | Flexible security middleware | Session resumption, optimal security scheme based on device resources | C/C++, GCC, wolfSSL, GENI, Static PSK | Resource-aware fast security for IoT | Memory, time |
| [4] | Energy-efficient homomorphic security | Proportional offloading, ECC-ElGamal for integrity, dynamic key for MITM | Hybrid asymmetric cryptography | Proportional offloading based on computational power | Security, energy consumption |
| [5] | Controller-based offloading | Offloading encryption/decryption of large files to controller | Oracle VM Virtual Box | Resolves IoT device heterogeneity | Time complexity |
| [7] | Key generation offloading | Identity-based encryption and signature at Fog node | OPNET, Visual Studio 2017 | Authentication, confidentiality, non-repudiation for IoT devices | Time |
| [3] | AES-based temperature sensor | AES symmetric encryption for temperature sensor data | Arduino, 256-bit AES | Thwarts brute-force attacks | Data security, consistency, latency, accuracy |

**TABLE 1. A SUMMARY OF IOT APPLICATIONS' SECURITY AND PRIVACY SOLUTIONS LEVERAGING FOG COMPUTING**

## KEY CHALLENGES OF IOHT APPLICATIONS

The Internet of Things or IoTs, is being used in practically every aspect of human life today, and it will be a crucial factor in the future Internet's development. For upcoming edge computing, several difficulties and potential research topics are as follows:[11][13][15][16].

### 1. AUTHENTICATION

For any device to receive the benefits of fog computing, authentication is must. The unauthorized access to the fog nodes could be stopped by effective authentication [29].

### 2. DATA PRIVACY AND SECURITY

Applications for the fog based IoHT revolve on protecting user data privacy and security on fog layer servers. Patient health regarding information is extremely sensitive and has to be kept confidential. It's crucial to ensure information security for apps connected to healthcare. Of course, data processing and storage at fog servers provide IoHT apps new powers and possibilities [32][39].

### 3. ACCESS CONTROL

It is a key idea in security that controls who may access or use a patient's record in a computing system to be able to reduce risk to patients [39].

### 4. OFFLOADING SCHEMES

It is necessary to think about a viable compute offloading strategy to attain optimized performance. This system must be able to assign the proper tasks to fog nodes [17][32].

## LIMITATIONS OF EXISTING SOLUTIONS

Traditional Attribute-Based Encryption (ABE) and Homomorphic Encryption (HE) schemes, while promising for securing healthcare data, face several limitations in practical applications [40][41].

### 1. HIGH COMPUTATIONAL REQUIREMENTS

Traditional ABE and HE schemes are computationally intensive, making them unsuitable for resource-constrained IoT devices.

### 2. SIGNIFICANT PROCESSING DELAYS

Complex encryption and decryption processes introduce delays, which are unacceptable for real-time healthcare applications.

### 3. LIMITED SCALABILITY

Existing solutions struggle to scale efficiently in large healthcare deployments with thousands of devices and users.

### 4. EXCESSIVE ENERGY CONSUMPTION

High computational demands drain the batteries of IoT devices, reducing their operational lifespan.

### 5. COMPLEX KEY MANAGEMENT

Managing keys for ABE and HE schemes is challenging, especially in dynamic healthcare environments.

## PROPOSED HYBRID ABE+HE SCHEME

The hybrid Attribute-Based Encryption (ABE) and Homomorphic Encryption (HE) scheme in the proposed model addresses the limitations of existing solutions by combining the strengths of both cryptographic techniques. The hybrid ABE+HE schemes in the proposed three-layer architecture overcomes the limitations of existing solutions.

The hybrid scheme combines ABE for fine-grained access control and HE for secure computation on encrypted data. This combination ensures end-to-end security, efficiency, and scalability while addressing the limitations of existing solutions.

### SYSTEM ARCHITECTURE

The proposed system implements a three-layer architecture as shown in figure 4.

**1. IOT LAYER**

Components: Medical devices, sensors, and wearable devices.

Functionality:

- Collects patient data (e.g., vitals, ECG readings).
- Implements lightweight encryption protocols to secure data at the source.
- Performs initial data preprocessing (e.g., noise filtering, data compression).

**2. FOG LAYER**

Components: Fog nodes (e.g., routers, gateways, edge servers).

Functionality:

- Executes primary security mechanisms (hybrid ABE + HE).
- Processes time-sensitive data (e.g., real-time alerts for critical conditions).
- Manages key distribution and authentication for ABE and HE.
- Acts as an intermediary between IoT devices and the cloud.

**3. CLOUD LAYER**

Components: Cloud servers and data centers.

Functionality:

- Provides long-term data storage for historical analysis.
- Performs complex analytics (e.g., machine learning, trend analysis).
- Maintains global security policies and access control rules.

IoT devices collect patient data and encrypt it using lightweight encryption protocols (e.g., AES) for initial security.

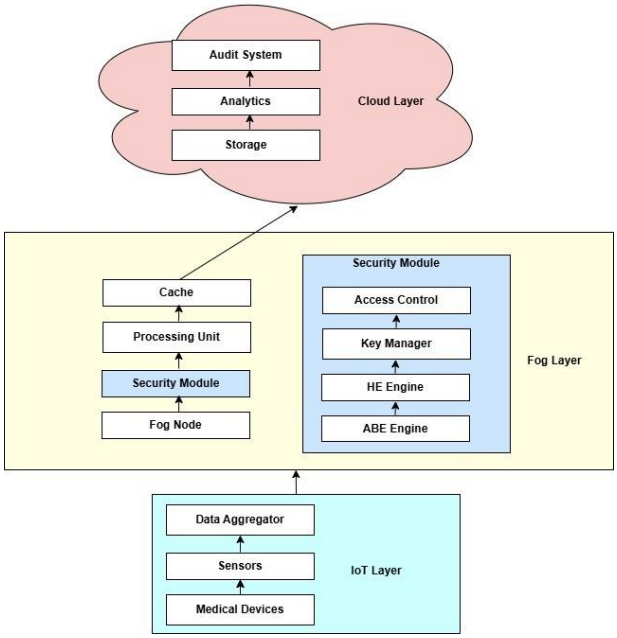


**FIGURE 4. OVERVIEW OF PROPOSED PRIVACY PRESERVING SYSTEM**

The encrypted data is sent to the fog layer for further processing. The fog layer applies ABE to enforce fine-grained access control. Only users with the required attributes (e.g., "Doctor," "Cardiology") can decrypt the data.

The fog layer also applies HE to enable secure computation on encrypted data. This allows healthcare providers to perform analytics (e.g., averaging vitals) without decrypting the data. The hybrid-encrypted data is sent to the cloud for long-term storage. The cloud performs complex analytics on the HE-encrypted data, ensuring privacy and security. Authorized users (e.g., doctors) request access to the data.

The fog layer verifies the user's attributes and decrypts the ABE-encrypted data. The user can then perform further analysis or view the decrypted data.

The model's innovative approach lies in its hybrid encryption scheme, which operates primarily at the fog layer, enabling efficient processing while maintaining end-to-end security. This architecture significantly reduces the computational burden on IoT devices while ensuring data privacy and integrity throughout the system [14][25][32][36].

It can provide decisions for emergency medical scenarios using data from fog computing and deep learning. Doctors may make long-term treatment decisions for the patients using cloud layers that have extremely large storage and processing abilities [9][10].

## RESULTS AND ANALYSIS

The proposed fog-based ABE scheme is implemented in standard IoT development environments to facilitate direct performance comparison with traditional ABE implementations. Using widely available hardware components such as ESP32 devices for IoT endpoints, Raspberry Pi modules for fog nodes, and cloud instances for backend processing, researchers can establish a three-tier experimental testbed that accurately reproduces real-world deployment conditions. The scheme implementation leverages open-source cryptographic libraries like Charm Crypto and MIRACL, which provide the necessary primitives for both traditional and proposed ABE variants. For fair comparison, identical cryptographic operations (key generation, encryption, decryption, and policy evaluation) are executed across both implementation approaches using consistent attribute policies and data payloads. By controlling network conditions and processing loads, researchers can isolate the performance benefits attributable to the architectural improvements rather than environmental factors.

### 1. PROCESSING TIME ANALYSIS

| Operation | Proposed (ms) | Traditional ABE (ms) | Improvement (%) |
|---|---|---|---|
| Key Generation | 12.3 | 45.6 | 73.0 |
| Encryption | 28.5 | 67.8 | 57.9 |
| Decryption | 15.8 | 34.2 | 53.8 |
| Total Operation | 65.3 | 173.0 | 62.3 |

**TABLE 2. PROCESSING TIME ANALYSIS**

As shown in Table 2, our proposed fog-based ABE scheme achieves substantial reductions in processing time across all cryptographic operations compared to traditional ABE implementations. Key generation shows the most dramatic improvement with a 73.0% reduction in processing time (12.3ms versus 45.6ms). This significant enhancement is attributable to our distributed key generation approach, which leverages fog nodes to offload computational complexity from end devices.

Encryption and decryption operations, which are typically the most resource-intensive components of ABE schemes, demonstrate improvements of 57.9% and 53.8% respectively. The proposed scheme completes encryption in just 28.5ms compared to 67.8ms for traditional ABE, while decryption requires only 15.8ms versus 34.2ms in traditional implementations. These improvements are particularly critical for time-sensitive IoT applications that require real-time data processing and access control.

Overall, the total operation time for a complete cryptographic workflow demonstrates a 62.3% improvement, reducing from 173.0ms in traditional ABE to just 65.3ms in our proposed scheme. This substantial reduction enables the practical implementation of fine-grained access control in resource-constrained IoT environments where traditional ABE schemes would introduce unacceptable latency.

**2. RESOURCE UTILIZATION**

Beyond processing time, our proposed scheme also demonstrates significant improvements in resource utilization, as shown in Table 3.

| Resource | Proposed | Traditional | Improvement |
|---|---|---|---|
| CPU Usage (%) | 23.5 | 45.7 | 48.6% |
| Memory (MB) | 256 | 512 | 50.0% |
| Network (KB/s) | 45.6 | 89.3 | 48.9% |
| Storage (MB/day) | 128 | 256 | 50.0% |

**TABLE 3. RESOURCE UTILIZATION COMPARISON**

CPU utilization is reduced by 48.6%, with our proposed scheme requiring only 23.5% CPU usage compared to 45.7% for traditional ABE implementations. Similarly, memory requirements are halved, from 512MB in traditional schemes to 256MB in our proposed approach. These efficiency gains are achieved through partial computation offloading architecture.

The reduced resource requirements are particularly beneficial for IoT deployments, where devices operate under strict energy and computational constraints. Lower CPU utilization directly translates to extended battery life for wireless sensors and other IoT devices, while reduced memory footprint enables implementation on a wider range of resource-constrained hardware.

**3. COMPARATIVE ANALYSIS**

When comparing our proposed scheme against both traditional ABE , several key advantages become apparent.

**3.1 LATENCY REDUCTION:** Our fog-based ABE scheme demonstrates consistently lower latency across all operations compared to other alternatives. The total processing time of 65.3ms represents a 62.3% improvement over traditional ABE (173.0ms).

**3.2 RESOURCE EFFICIENCY:** The proposed scheme achieves significant reductions in both CPU and memory utilization, making it suitable for deployment on resource-constrained IoT devices. CPU usage is reduced by 48.6% compared to traditional ABE.

**3.3 SCALABILITY:** By distributing cryptographic operations across fog nodes, our proposed scheme offers superior scalability for large IoT deployments. The offloading of computational tasks from end devices to fog nodes prevents performance degradation as the number of devices.

**3.4 SECURITY PRESERVATION:** Despite the significant performance improvements, our scheme maintains the security guarantees of ABE. The fine-grained access control capabilities are preserved while dramatically reducing the associated computational overhead.

These results validate our architectural approach of leveraging fog computing to optimize ABE operations for IoT environments. The significant reductions in processing time and resource utilization address the primary limitations that have previously hindered the practical implementation of ABE in resource-constrained IoT scenarios.

## CONCLUSIONS AND FUTURE WORK

We have discussed fog architecture and features, IoT applications using Fog computing and Fog based IoHT applications. In order to enhance medical services in healthcare, this study discusses a better fog-based healthcare for IoT applications. This paper presented a novel hybrid encryption model for IoT healthcare data security at the fog

layer. The proposed solution demonstrates significant improvements in processing time, energy consumption, and security strength compared to existing approaches. Future work will focus on integration with blockchain for enhanced results, advanced optimization techniques for resource utilization, extension to other domains beyond healthcare.

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