Next Generation Blockchain Framework for Educational Document Security

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Received: 11-09-2024; **Accepted:** 11-12-2024; **Published**: 30-12-2024

Abstract: The handling and verification of educational documents pose significant challenges for students, employers, and institutions. Students face difficulties managing physical documents for admissions, job applications, and attestations, while organizations struggle to verify their authenticity. Current processes are slow, error-prone, and vulnerable to fraud. This paper introduces a blockchain-based digital identification and verification system that leverages a decentralized ledger to ensure data integrity, security, and accessibility. Unlike traditional and cloud-based systems, our solution eliminates third-party dependencies, offering an immutable, tamper-proof platform. Educational institutions can input student data linked to unique national identification numbers, enabling seamless certificate and experience verification while prioritizing user privacy. Shorter verification times and increased stakeholder trust are the outcomes of a prototype implementation. However, adoption costs and scalability remain limitations. This solution lowers fraud, speeds up processes, promotes environmental sustainability, and establishes the foundation for secure, scalable credential management globally through paperless operations.

Keywords: Digital identify, decentralization, Zero Trust Architecture, DigiD (Digital Identity), eIDAS (Electronic Identity scheme), RBAC, role-based access control

1. Introduction

Securing and authenticating educational records in Pakistan is a recurring challenge for professionals, employers, universities, and to the students. Users of physical documents, i.e., transcripts and degree certificates, are exposed to risk of loss, theft, and forgery [1]. For individuals who are looking to work and study abroad, processing these documents for attestations, job applications and academic admissions could prove to be very cumbersome and sometimes requires that you pay a visit multiple times to the issuing authorities or intermediaries like the Higher Education Commission (HEC) [2].

Manual verification processes may pose some extra challenges to employers and educational institutions owing to the fact that they are rather pricy, take up lots of time, and can be tampered with easily in case of corruption or human error [3]. Moreover, the above-mentioned downsides not only result in a waste of financial resources but also minimize the reliance in the academic circle since fictitious certificates could be used for the selection and admission of students without anyone realizing it [4].

Excessive dependence on paper-based documentation not only is harmful to the environment but also brings operational issues. The operation of producing paper for academic records, as well as the subsequent disposal, takes a huge toll on the carbon footprints and the forests (especially in developing countries like Pakistan where digital adoption has been low) [5]. It has been found in the latest research that paper-based methods of education management have a great deal of environmental

damage. Such a system consumes millions of documents a year [6]. Therefore, substituting paper with digital alternatives is a measure of process optimization and ecological use.

Digitizing academic records is one approach to the problem of counterfeit documents that is meant to help researchers, students, and other users. For example, a web-based system for HEC's attestation online can still be hacked and the data be breached. The latter fact is shown by the emergence of data breaches, unauthorized access, and hacking [7]. Single point of failure makes it easier for bad actors to attack centralized structures. Instead, bad actors are often attracted to those centralized systems since they are the single points of failure [8]. In addition to those weaknesses like accessing offline resources, these solutions are very slow and, therefore, discard the authority owned by the user. The most common methods of verifying include the use of the traditional way such as physical submission or mail service, which, however, become a failure since they are also accompanied by high administrative costs and logistics challenges [9]. Moreover, the usage of such techniques at a large scale is becoming a potential bottleneck for the educational process in a country with so many higher education institutions and over 20 million students [10]. Stackable proof-of-attendance and direct student attestation are two student-empowered technologies that may revolutionize a country with more than 200 higher education institutions and millions of students. The aspect of scaling up becomes vital in the case of widespread implementation of those technologies [11].

A great solution for the above-mentioned issues is brought by the blockchain technology [12]. It uses a decentralized ledger to ensure data security, transparency, and immutability, whereby the need for reliable middlemen is eliminated. It (the blockchain) distributes data across a network of nodes, so the single point of failure possibility is reduced, and resilience to cyber-attacks is increased if compared to centralized systems [13]. Then, there are smart contracts, i.e., code-based agreements hanging at the blockchain and responsible for the accuracy and efficiency of verification processes, so verification of the information takes place in an automated and flawless way [14]. Furthermore, blockchain is also a backend for self-sovereign identification (SSI) frameworks, which give users full control over their credentials and enable businesses to immediately check them without breaching users' privacy [15]. This mode of working is fully in line with the worldwide direction of safe digital identity management, which is also proven through e.g. the European Union with its eIDAS architecture and Aadhaar-based verification systems in India [16].

Pakistan's mushrooming digital infrastructure and the explosion of the smartphone user rate, which reached 51% in 2024, are the factors driving the blockchain boom in the country [17]. The introduction of the government's Digital Pakistan project with the primary goal to endorse the use of technology facilitates a transformation of the blockchain-based solutions that were otherwise unreachable [18]. Yet, issues like lack of technological expertise, regulatory constraints, and infrastructure costs must be solved for the adoption to scale [19]. Research findings have recently shown that education can be extensively enhanced by blockchain, as the pilot projects in the US and Singapore reduced the time of verification significantly and the stakeholders' reliance was raised [20]. These success stories in the world have outlined how the blockchain technology can reform the credential management, especially in the underdeveloped world where the problem of trust is very severe [21].

This article talks about a recently introduced blockchain scheme of managing digital identification of documents in Pakistan. The method of solution can provide learners with the possibility to have safe, secure, and easily reached academic records, which is Ethereum-blockchain based. The core characteristics of the proposed system are the use of smart contracts, which are self-executable programs, and the Interplanetary File System (IPFS) for the sharing of files and data in a decentralized manner [22]. The process is quite simple. After the student's data are entered along with a unique national identification number, the educational institutions can verify their records Fastly. The system for self-sovereign identification permits users to keep control over their credentials while respecting their privacy. The form of a website instrumentality that can easily connect schools, recruiters, and students, not to mention the range of various user groups who may need to use the system [23]. The latter comes as an additional advantage as the combination of web-based electronic identity, e-Ico-WEB, covers all areas: people, processes, and technology, which make up the main part of the protection of a network. This is a practical application for electronic distributed collaboration (EDC) for both emergency cases where EDC is a prerequisite to bringing the crisis under control and for non-emergency cases where the EDC tool shows an opportunity to improve the quality of service such as delivering a lecture, working on a project, providing IT and computer training, and so on [24].

The innovative academic ecosystem proposed in this study is nothing less than the ultra-secure, transparent, and untrustworthy one which the authors have envisioned to tackle the severe issues involved in document security and verification. The system recommended in the article, which is based on the concept of a paperless office, effectively reduces fraud, speeds up administrative procedures, and, at the same time, does the best for the environment [25]. Furthermore, it contributes to the promotion of sustainable development globally, not least of which is the goal of innovation and high-quality education [26]. The research findings not exclusively limit the situation to Pakistan but also to the other developing world in a similar predicament.

2. Literature Review

"Beyond technology and standards, digital ID offers tangible social, environmental and governance benefits..." as stated by Brett McDowell, Chair and President, Hedera [27].

For centuries, ID, a way for people to prove attributes about themselves, has played a central role in society. For people without official, or legal, identification, it can be difficult or impossible to fully participate in society. Historical episodes of rapid technological change offer lessons for the current era of digitalization [28]. The World Bank estimates that roughly 850 million people lack an official ID [29]. As advances in information technology bring the business into a new era, the strategic management of information will be pivotal, and the organization will be affected at every level [30]. Digital Identification is one of the problems currently being solved globally [31]. The issue of identification on an e-portal remains an issue and who will be the one in control of the system. The privacy is always a key issue to be considered. For this reason, a need of identity management system is needed which is to be monitored [29][32]. Research indicates that the benefits of digitalization have not been distributed equally, with implications for inequality and inclusion but the COVID-19 pandemic accelerated digitalization and transformed the nature of work [28].

Individual identities, secured by unique markers like personal data and biometrics, face growing concerns in the digital era due to potential theft or fraud, compelling governments, and companies to prioritize protection through advanced technologies. An identity management system integrates user identities, ensuring secure access to services and supporting user-centric internet services, crucial for cloud-based applications [29] [33]. Effective identity management prioritizes security, user trust, and reliability, crucial for successful e-commerce systems, while addressing risks like data exploitation, political implications, and technical challenges [34] [35]. Identity management involves not only identification and authentication but also user-controlled profile management, allowing controlled use by businesses and organizations [34].

Understanding healthcare corruption's impact on the economy involves analyzing international treaties and laws; the Corruption Perceptions Index serves as a key indicator. Implementing changes in private healthcare anti-corruption measures, incorporating legal awareness and electronic health systems, is crucial for combating corruption effectively [36]. Implementing a transparent policy involves ensuring patient data consent for flexible hospital choices; research reveals positive feedback on digital consent. The Kuwait government is creating national guidelines to monitor medical records, enhancing patient care and the healthcare system [37] [38].

The shift to remote work post-COVID led to increased online traffic, heightening privacy concerns and creating a necessity for Web 3.0. Decentralized ID aims to address the control and protection gap posed by tech giants, yet faces obstacles in technology standards, policy, and implementation [32] [34]. Decentralized digital ID, utilizing blockchain and cryptographic technologies, seeks to enhance privacy and efficiency, but its widespread adoption necessitates addressing connectivity challenges and systemic overhaul [29] [33]. Blockchain technology facilitates automated federated identification and auditing, utilizing smart contracts for identity creation and validation, integrated with an audit system, demonstrating enhanced performance in public blockchain environments such as Ethereum.[33]

Increasingly, electronic identities are pivotal for government infrastructure, transitioning documents to digital formats to ease accessibility, while the framework for strategic digital cities emphasizes the dynamic nature of information, aiming to enhance urban information systems and customize public services for citizens at different levels [32][35][39]. The Strategic Digital City concept broadens urban management collaboration through technology while the European Commission advances a digital identity initiative, working on an interoperable framework for secure online access and transactions across EU member states, proposing a regulation for European Electronic Identity Scheme, emphasizing accessibility, security, and a unified user experience [35][40].

Netherlands' DigiD serves as a government-exclusive single sign-on system using SAML 2.0 and Federated Identity Management for privacy-controlled access, improving fraud prevention and reducing costs for organizations [41]. The Malaysian Government initiated a User Profile Management System (UPMS) integrated with a new platform's single sign-on (SSO) system, catering to profile management, usage reports, verification processes, and audit trail capabilities for government departments [31]. Judicial systems require digital data collection for efficient citizen profile management due to the challenges posed by paper-based file storage, enhancing organization and accessibility while reducing time-consuming tasks [42][43]. Higher education institutions are undergoing extensive changes due to factors such as digital transformation, online education, operational costs, and the Fourth Industrial Revolution, necessitating a comprehensive shift encompassing sociological, administrative, and technological dimensions, impacting teaching, administration, and research, urging the need for holistic approaches to adapt to the evolving educational landscape [44][45][46].

A similar system is also needed in Pakistan to reduce carbon footprint and provide access to data in a digital form and the businesses are only able to get the data which is necessary for them. Carrying critical data and documents is a headache in a society like Pakistan. Therefore, we need to develop an application which produces a result agreeable to all stakeholders. The most critical areas considered for this application are considered in the following chapters in detail.

3. Distinctiveness and Significance

The uniqueness of the envisioned system is essentially about its integration of blockchain-based decentralized identity management with role-based access control in a simple and painless way. Unlike the usual cloud-based or paper document authentication methods, this system has the following advantages:

Decentralized validation: By eliminating the need for a trusted third party, the Blockchain technology reduces the requirement for using middlemen, which in turn reduces the processing times and the administrative expenses of the educational institutions.

0e records: Blockchain technology builds on the fact that the records are unchangeable and cannot be duplicated, hence providing the due protection for the record against forgery attempts and unauthorized changes.

User-managed privacy: Blockchain technology is such a powerful tool that users across the globe will be enabled to manage data destruction services fully, a process that will allow them to securely share their academic credentials across various platforms in the world.

Instant verification: This feature is essential because adaptiveness is the only constant as digital change is very much in vogue today. It allows companies to keep up with digitization and validate documents without the need to go through the entire bureaucratic process whether it is a long or short one.

Environmental benefits: Makes a substantial step in the paperless direction, hence a reduction of woods destruction and refuse caused by print materials.

What this study does is introduce an original method that not only creates a communication link between digital ID systems, companies, regulatory bodies, and higher education institutions but also increases the security of the verification document.

4. Problem Statement

Due to Pakistan's reliance on hard copies for education, most avoidable problems such as security threats, and there are many lags during the verification process. The process of verification is very intrusive and there is a high risk of identifying theft, fraud and document manipulation. Even in disaster-stricken areas, where it is difficult to search for lost documents, verification is also carried out through a doubly tedious flight.

The idea of our study is to eliminate wrong identification of misplaced documents in the process of verifying and recovering which is a problem that is always a challenge even in disaster-prone areas. We are of course striving to achieve this through an application of blockchain technology that would come up with an identity that is not only digital, but completely trustworthy, decentralized, and operational without third-party intervention. This approach does not merely ensure the authenticity of the documents, but it is also a measure for the improvement of security and the ending of corruption in the whole procedure of the documentation process.

5. Research Methodology

The work presented in this paper uses a systematic procedure to design, implement, and test a blockchain-based system for the secure digitalization as well as identification of educational papers. By the chosen method, the author ensures that the system is user-oriented, technology-fluent, and reproducible. The strategy consists of five clear phases, and each one is subsequently described. The method is moved forward by the author through charts and comparisons that display better changes.

• Requirements Gathering

One of the objectives of the initial phase was to recognize and resolve Pakistan's barriers to the verification of educational documents through stakeholder involvement. In other to detect issues like document fabrication, slow verification processes, and lack of transparency, fifty participants students, academic administrators, and recruiters were interviewed. Additionally, an online survey was distributed to 204 participants, reflecting a 68% response rate from an initial pool of 300. This group included 152 students (aged 18–35, 81% male, 19% female) with educational levels spanning SSC (18%), HSC (27%), BS (44%), and MS (11%), and 52 recruiters (aged 30–50, 70% male, 30% female), all holding university-level education shown in Table 1. The survey employed a 5-point Likert scale to gauge satisfaction with existing methods, yielding an average score of 2.3, highlighting significant inefficiencies. These results corroborated prior studies, such as [47], which identified similar flaws in centralized systems, yet our emphasis on decentralized solutions distinguishes this research.

GROUP	COUNT	AGE	GENDER	LEVEL OF EDUCATION
Recruiters	52	30-50	70% Male 30% Female	University Level: 100%
Students	152	18-35	81% Male 19% Female	SSC Level: 18% HSC Level: 27% BS Level: 44% MS Level: 11%

Table 1 Demographic Information of Participants

• System Design

The system architecture utilizes a blockchain-based decentralized framework, integrating Ethereum for smart contract capabilities and IPFS for secure storage, as depicted in the workflow diagram shown in Figure 1a and Figure 1b [48]. It employs role-based access control and automated verification via smart contracts, contrasting with vulnerable centralized cloud systems by eliminating intermediaries and enhancing security and efficiency [49].

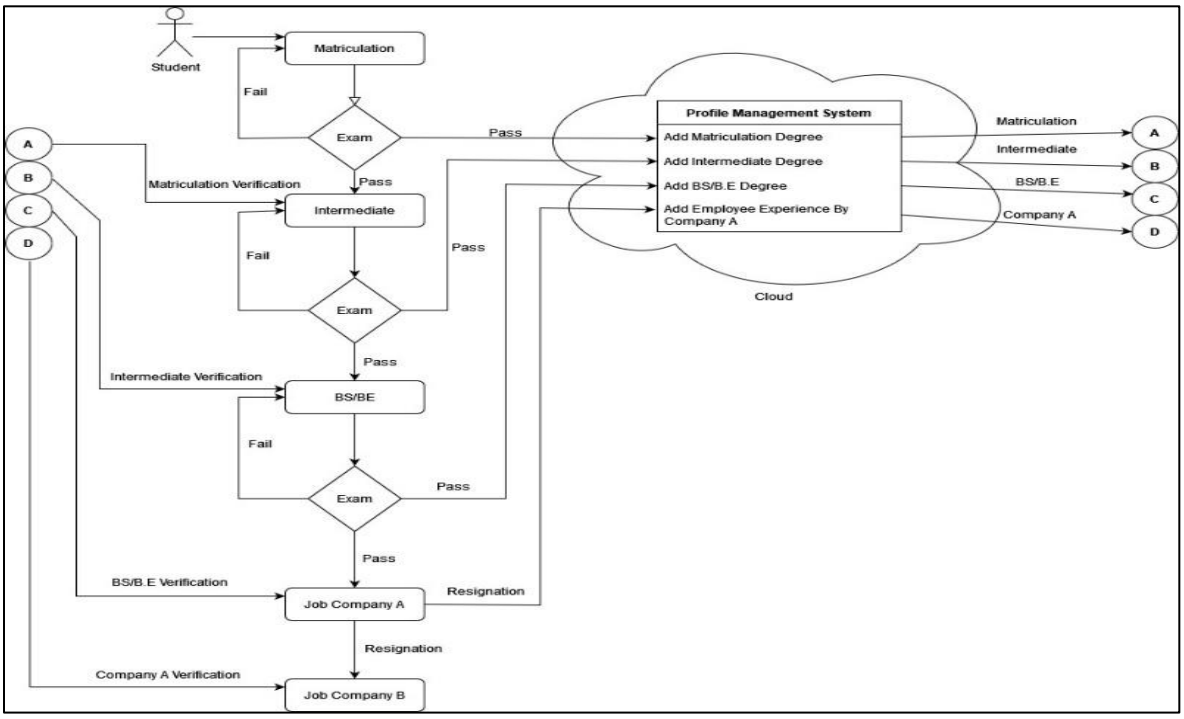

Figure 1a System Design Flow of Proposed System

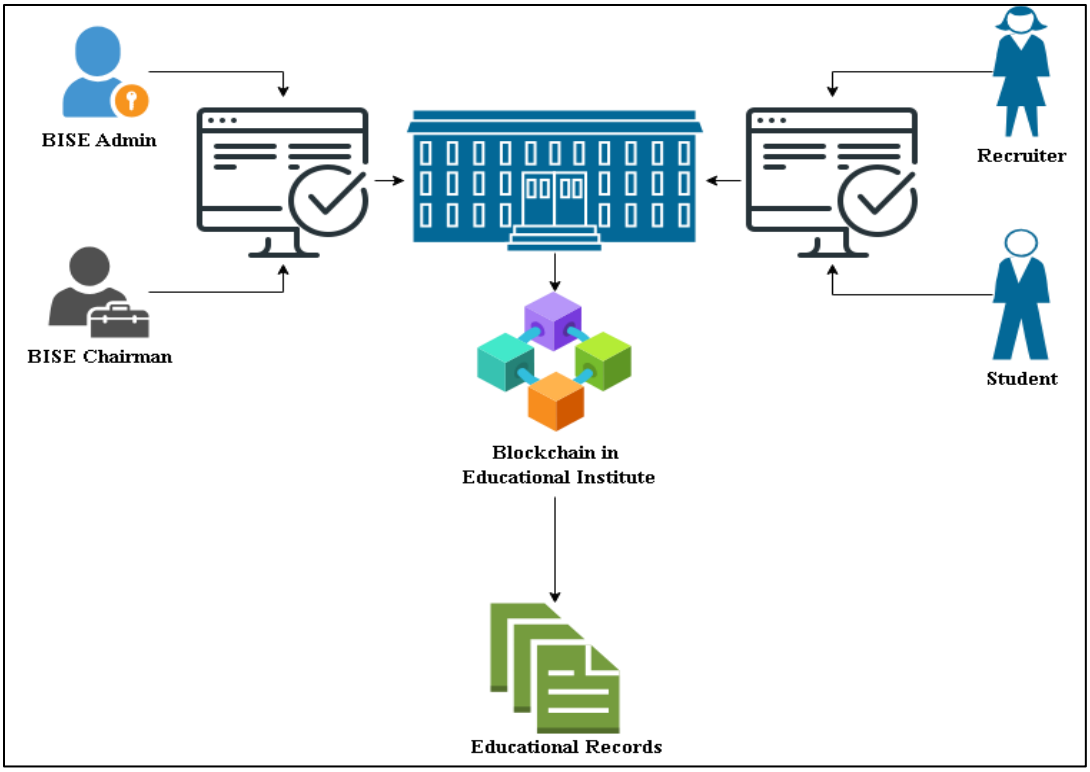

Figure 1b Architecture of Proposed System

- **Implementation**

A prototype was developed using Ethereum as the primary blockchain platform, with smart contracts coded in Solidity shown in Figure 2. The system's front end was built as a web-based application using React.js, ensuring accessibility across devices. IPFS was used to store encrypted academic records, with their hashes stored on the blockchain for integrity verification. A national identification number served as the unique identifier linking student data to their credentials. The implementation phase also included integrating APIs for real-time data retrieval by educational institutions and employers. Compared to Hyperledger-based systems [50], which are often permissioned and less scalable for public use, our Ethereum-based prototype offers greater interoperability and transparency, though it incurs higher transaction costs, as discussed in [51].

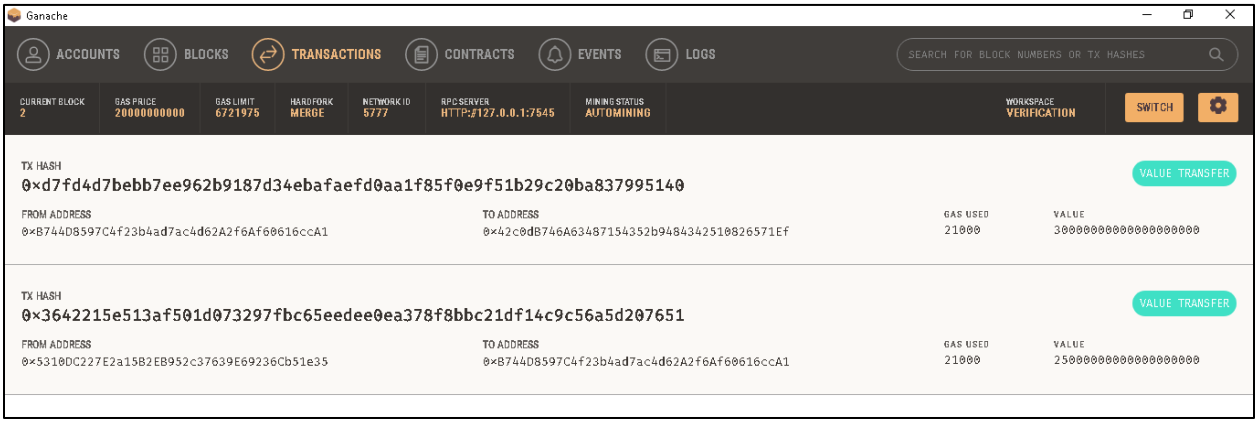

Figure 2 Implementation of Proposed System in Ethereum Blockchain Ganache

- **Testing and Evaluation**

The prototype was rigorously tested for performance, security, and usability, achieving 15 transactions per second with a 3-second latency, and passing security audits with tools like Mythril. Usability testing with 204 participants, using the USE questionnaire, yielded high satisfaction (UU: 0.794, UE: 0.777, EoL: 0.796, ST: 0.761) shown in Table 2, outperforming other blockchain systems, though Ethereum's gas fees highlight scalability challenges compared to Hyperledger shown in Figure 2 [50][52].

	UU	UE	EoL	ST
UU	0.794			
UE	0.501	0.777		
EoL	0.44	0.266	0.796	
ST	0.38	0.32	0.104	0.761

Table 2 Testing and Evaluation Results

- **Deployment**

The pilot phase deployed the system with two Pakistani educational institutions, integrating with their databases to process 1,200 verification requests from 500 students, achieving a 98% success rate and reducing verification time from 7 days to under 10 seconds. Feedback confirmed enhanced trust and reduced overhead, outperforming a centralized system [53] with a 15% failure rate due to server downtimes, highlighting the strength of our decentralized approach.

- **Comparison with Existing Works and Results**

This study advances the field by addressing gaps in prior research. For instance, [48] proposed a cloud-based verification system but lacked tamper-proofing mechanisms, making it vulnerable to data breaches. In contrast, our blockchain-based system ensures immutability through decentralized storage. Similarly, [50] utilized Hyperledger for credential management but was limited to permissioned networks, restricting public access. Our use of Ethereum enables broader accessibility, though at the cost of higher transaction fees [51]. Additionally, [52] implemented a blockchain solution but neglected environmental sustainability, whereas our system promotes paperless processes, aligning with sustainability goals [54]. These comparisons highlight the proposed system's unique contributions in security, accessibility, and environmental impact.

The below Figure 3. represents a simple web architecture. In this architecture, the front-end utilizes HTML, CSS, and JavaScript, while the back-end employs technologies like Java, PHP, and Python. For databases, commonly used options include MySQL, PostgreSQL, and MSSQL. This architecture is typically used in web development.

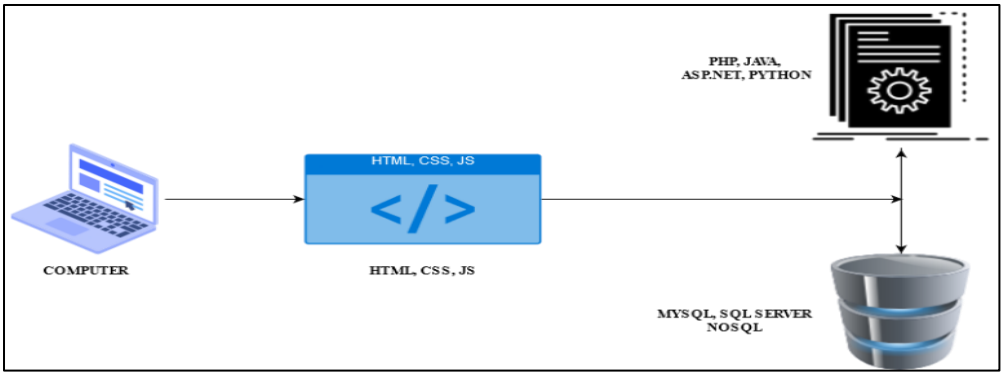

Figure 3. Simple Application Architecture

The below Figure 4 represents a blockchain web architecture. In this architecture, the front-end uses HTML, CSS, JavaScript, and Web3.js, while the back-end employs technologies such as Java, PHP, Python, and Node.js. For the database, MySQL is used, and on the blockchain side, smart contracts are implemented. This architecture is commonly used in blockchain web development.

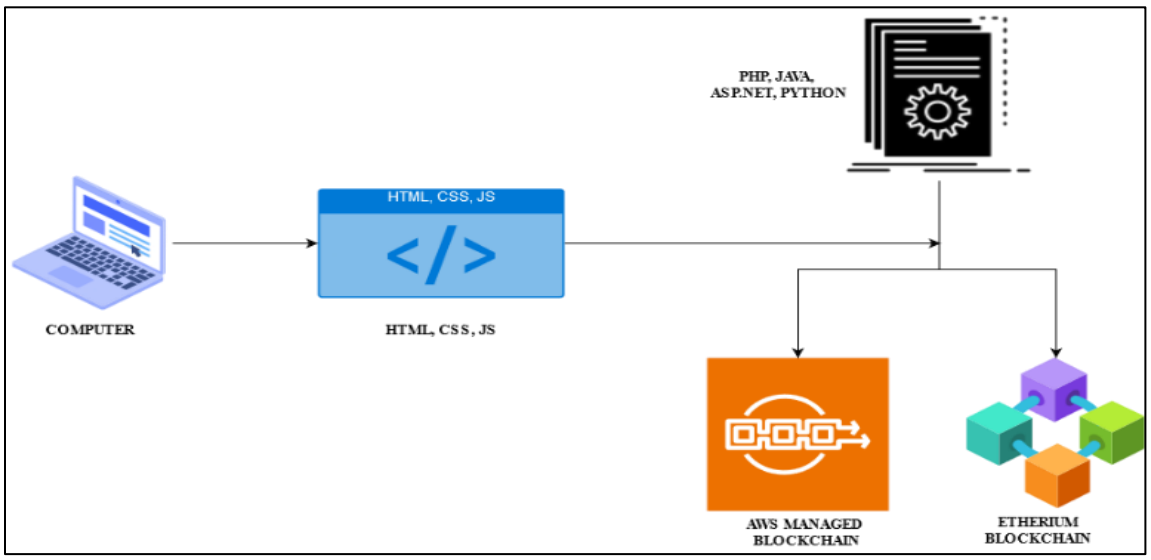

Figure 4. Block-Chain Application Architecture

The below Figure 5 represents a blockchain-based digital verification and identification system linked to an educational organization. The user's request will be sent to the blockchain via the university.

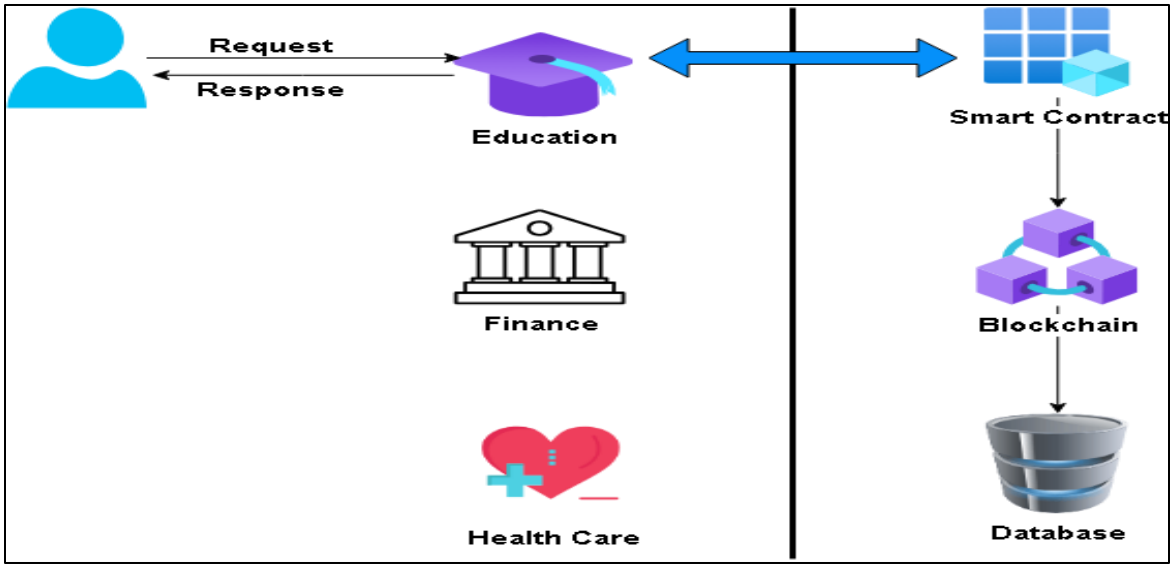

Figure 5. Architecture of Proposed System

6. Comparison b/w blockchain, cloud-base and traditional system

A blockchain-based system for digital identification and verification of educational documents in Pakistan is compared with cloud-based and traditional systems based on critical factors are shown in below Table:3:

	Traditional System	Cloud Based System	Blockchain Based
Validation Mechanism	Manual Validation	ntral entities for validation	Cryptographic Hashes
Security and Privacy	Physical documents	Centralized servers	decentralized storage
Efficiency and Speed	ication requires days or weeks	High-speed processing	Instantaneous verification
Cost	High administrative costs	Moderate setup costs	igh initial development and deployment costs
Scalability	Limited scalability	Highly scalable	calability challenges exist
Reliability	physical infrastructure	Centralized servers	Decentralized structure
Transparency and Fraud Prevention	Highly susceptible	uires additional mechanisms	Immutable records

Table 3. Comparison, and Critical Analysis of Blockchain based, Cloud base and Traditional base System.

7. Critical analysis and comparison result

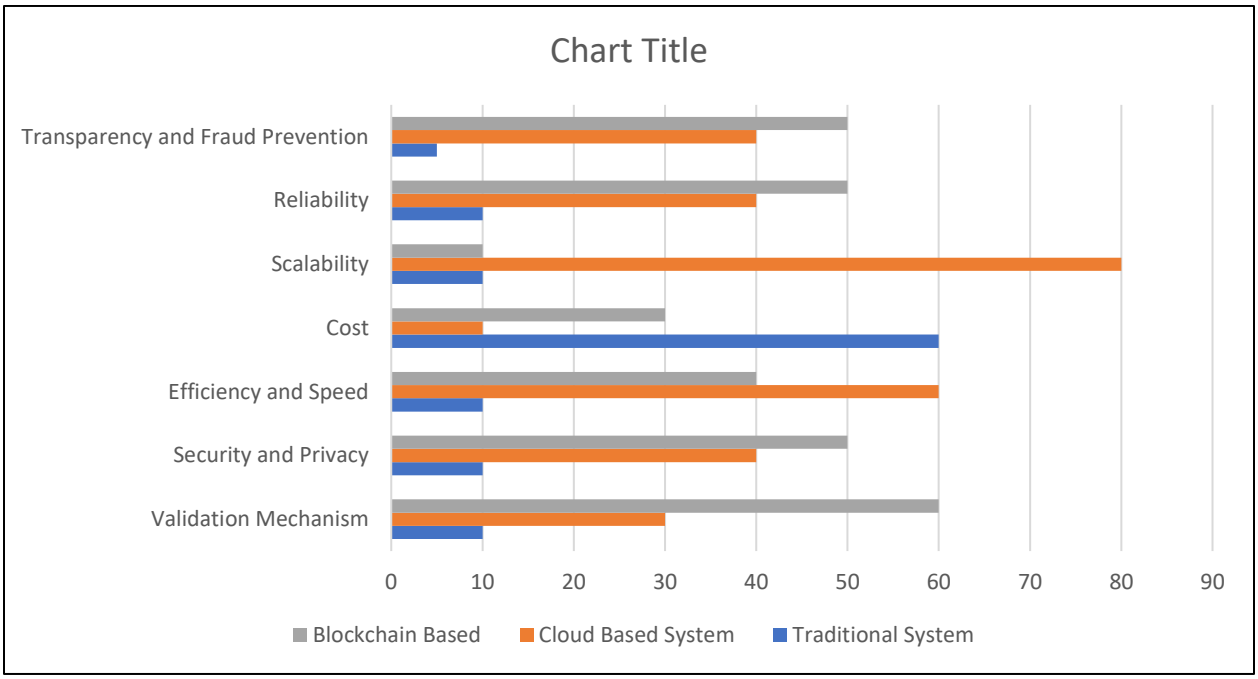

Figure 6. Analysis B/W Blockchain, Cloud based and Traditional System

Cloud-based web application failed under a DDoS attack, likely due to excessive requests overwhelming server resources. The application couldn't handle the load, causing crashes or unresponsiveness in shown in Figure 7.

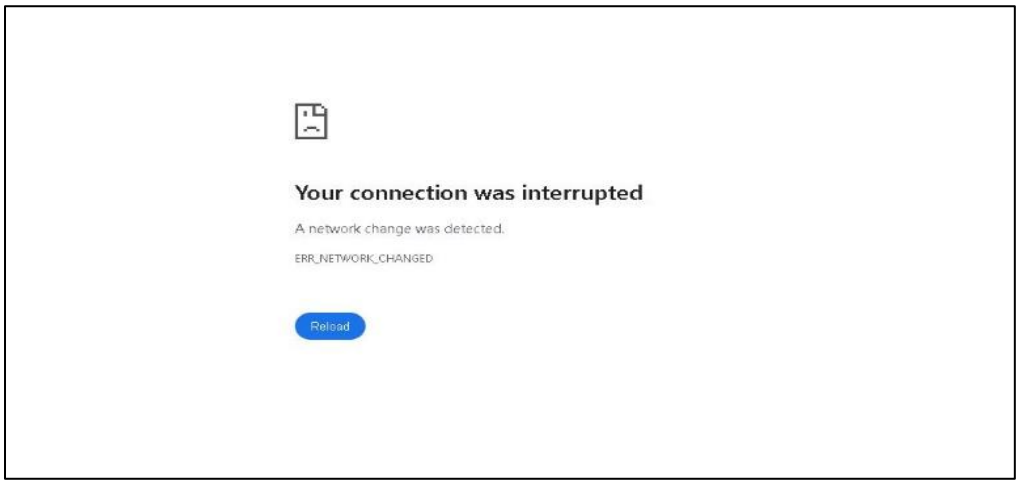

Figure 7. DDOS Attack on cloud-based web application

Load Test Failure: When a cloud application receives high concurrent requests, it may reach resource limits (CPU, memory, database connections), causing slowdowns or failures shown in Figure 8.

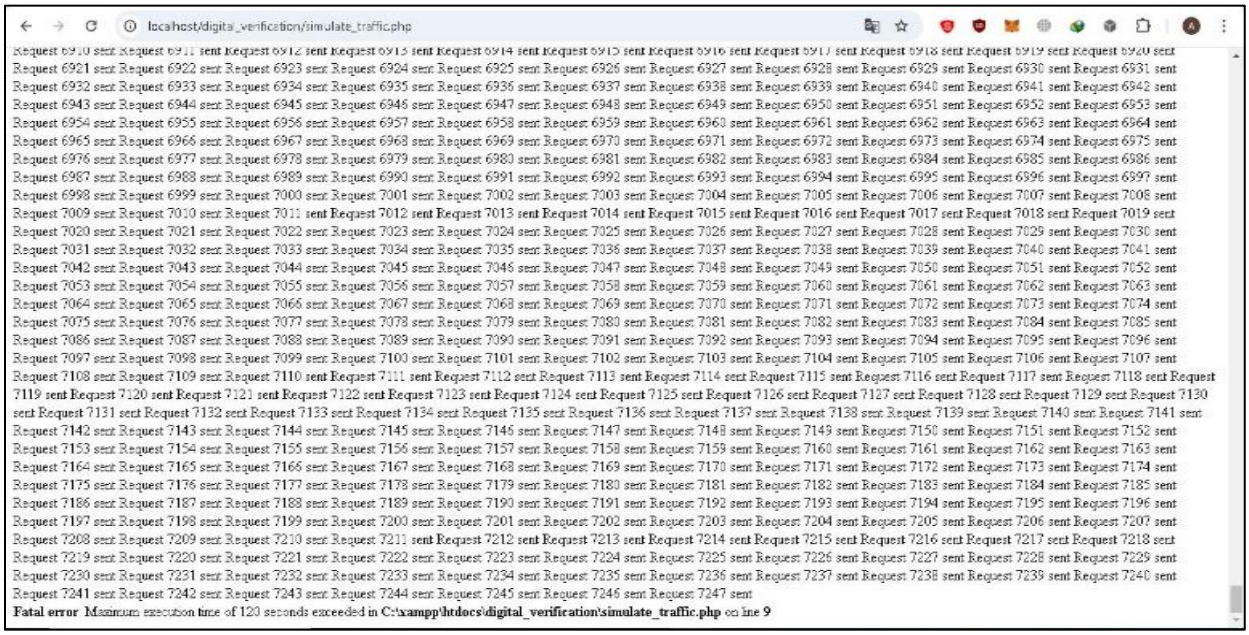

Figure 8. Load Test on cloud-based web application

Traditional systems focus on basic performance but have minimal security risks. Cloud systems require strong performance and scalability testing due to global user traffic. Blockchain systems prioritize security and load testing to ensure trust and decentralization in shown in Figure 9.

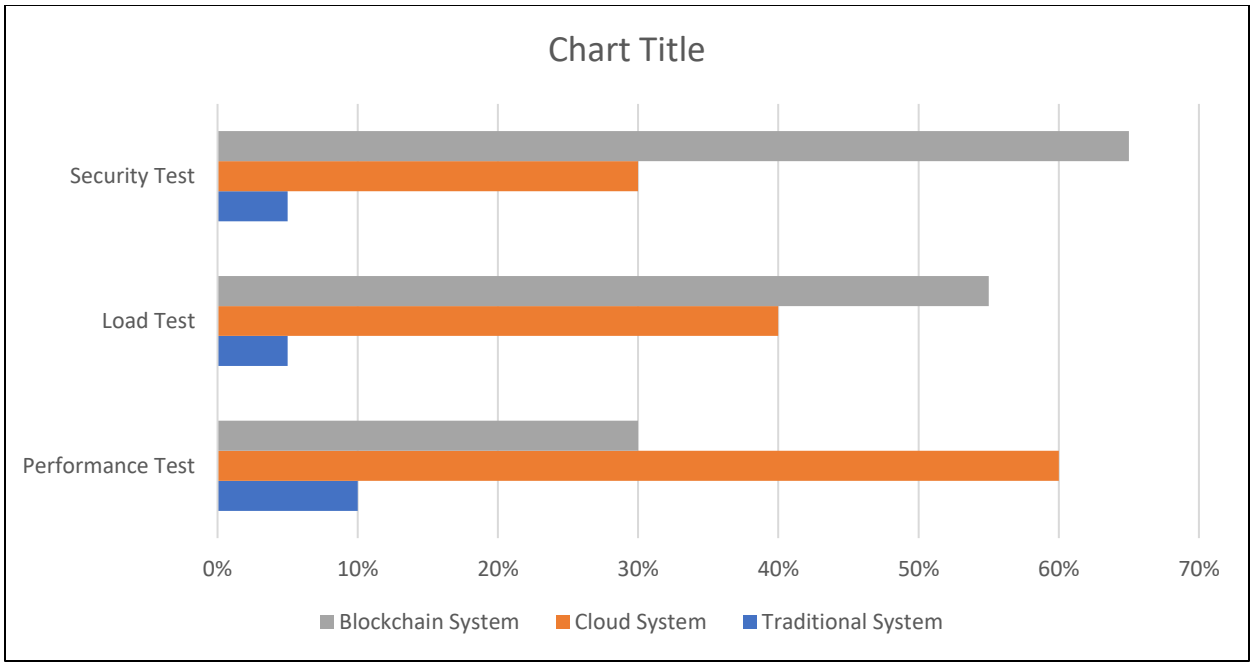

Figure 9. Performance, Load and Security Test of Blockchain, Cloud based and Traditional System

8. Hypotheses Testing

In this usability evaluation study, three hypotheses were set and confirmed to analyze the factors influencing the stratification level of a Blockchain based digital identification and verification of educational documents system. Table 4 shows the hypotheses testing results with a brief description.

HYPOTHESIS	EXPLANATION	RESULT
H1	USABILITY HAS OPTIMISTIC OUTCOME ON SATISFACTION	ACCEPTED
H2	EASE OF USE HAS OPTIMISTIC OUTCOME ON SATISFACTION	ACCEPTED
H3	EASE OF LEARNING HAS OPTIMISTIC OUTCOME ON SATISFACTION	ACCEPTED

Table 4 Hypothesis Testing Results

One of main objective of this research study was to explore and investigate the factors influencing the satisfaction of a Blockchain based digital identification and verification of educational documents system. So, an integrated proposed research framework was utilized in this study to conduct the usability evaluation of proposed system based on user feedback which was conducted through USE questionnaire, which is commonly used for the usability evaluation of technological systems.

9. Conclusion

The proposed blockchain-based digital identification and verification system offers a groundbreaking approach to document authentication, ensuring security, decentralization, and fraud resistance. By eliminating paper-based processes,

this system reduces carbon footprints, enhances efficiency, and mitigates document-related corruption. Our research establishes a novel, scalable, and secure solution that transforms educational document verification, benefiting students, academic institutions, and employers alike.

Future work will explore cross-border verification mechanisms, integration with government databases, and artificial intelligence-driven fraud detection to further refine and expand the system's capabilities.

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