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# Design And Evaluation Of A Blockchain-Based Ransomware Prevention Framework With Secure Logging And Rapid Recovery

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*Abstract:* – The increasing complexity of modern-day ransomware has also revealed the pivotal shortcomings of the conventional block chain defensive framework as proposed in our prior work, which functioned mainly as an anomaly scanner coupled with an immutable backup system. In this regard, this study introduces a sophisticated Hybrid AI & Blockchain Self-Healing Cyber Defense System by amalgamating the capabilities of deep learning forecasts with a blockchain framework reinforced by mathematical concepts. In this proposed system, the multi-modal approach for detecting ransomware has leveraged the potential of LSTM-based behavioral analysis, CNN-based entropy analysis, as well as network anomaly forecasting by the power of the Transformer model, which ensures the premeditated identification of Zero-Day variants of the ransomware. The proposed system has a robust mathematical framework encompassing the growth of entropy, the prediction of Markov state transitions, the complexity of Merkle mutants, as well as the analysis of consensus delay.The smart contracts are verified using TLA+ and symbolic execution, ensuring that there are zero loopholes when it comes to isolation and recovery tasks that are automated. In large-scale simulations performed with over 100 nodes, there are improved levels of detection with 98.7% accuracy, as well as improved mitigation latency and resistance to attack as opposed to the previous design, which featured blockchain technology only. The previous design is outperformed in terms of capabilities and accuracy by the current work, which combines the strengths of predictive analytics, self-healing, and integrity assurance.

***Keywords*:** Ransomware Detection, Hybrid AI and Blockchain, Self-Healing, Cyber Defense, Deep Learning Zero-Day Attack Prediction

## I. INTRODUCTION

"Ransomware technologies have grown to be one of the most widespread forms of cyberattacks, which have seriously affected the main sectors of the economy, such as the healthcare, banking, education, and government. In contrast to traditional types of ransomware, which were based on a primitive encryption scheme, a variety of modern variants have highly sophisticated code, which is, in particular, its ability to propagate itself in a distributed manner. Zero-day ransomware families as well as human-operated attacks in the global network clearly put in question the efficiency of existing protection technologies, including traditional antivirus solutions, firewalls, IDS, as well as centralized solutions for high-value backups. At the same time, in our preceding research, we proposed a blockchain-based framework for the mitigation of the described phenomenon, based, in particular, on immutable logging. However, its main weakness was its disadvantageous dependence upon node scanning technologies, which is, in particular, its relative inability to be proactive."

However, these emerging threats require an intelligent, proactive, and mathematically sound cyber defense strategy. While blockchain technology provides numerous benefits such as immutability, transparency, a decentralized trust mechanism, and an audit trail resistant to tampering, it cannot effectively respond to the rapidly evolving nature of ransomware patterns. Deep learning techniques have shown incredible efficacy in understanding system dynamics, discovering hidden patterns, and uncovering new threats. However, ML-based systems face threats of adversarial evasion attacks and do not have any path to ensure integrity in prediction and system log outputs.

To overcome the abovementioned discrepancies, the proposed study presents the Hybrid AI-Blockchain Self-Healing Cyber Defense Framework. The proposed paradigm aims to integrate the predictive acuity of highly complex Machine Learning Models with the high resilience feature of blockchain. The paradigm includes multimodal ransomware detection through LSTM-variant behavioral approaches, CNN-variant entropy assessments, and Transform-variant predictive approaches. The proposed paradigm includes a mathematical basis that computes entropy evolution patterns for precocious encryption detection, Markov state transition patterns for the progression of ransomware attacks, Merkle Mutation complexity calculations for the evaluation of integrity penalties, and consensus delay patterns for the determination of blockchain reactivity under stress.

One of the unique aspects of this research is the design and implementation of an autonomous self-healing system that relies on formally verified smart contracts. The smart contracts are capable of automatically identifying and segregating malicious nodes, initiating a rollback through distributed clean snapshots, and logging events in an immutable fashion without any human intervention. The formally verified smart contracts are made vulnerable-proof and race condition-proof by TLA+, Alloy tools, and symbolic execution techniques.

Extensive simulations performed on a network of 100+ nodes validate a significant improvement in the accuracy of ransomware detection, reduction in latency, robust resilience to adversarial machine learning attack strategies, and overall blockchain throughput compared to the earlier model that relied purely on the concept of blockchain. Leveraging the synergy between prediction capabilities of AI, logically sound computation of detection models, and automation whose results can be verified by cryptography, this research work rectifies the shortcomings of our previous model while establishing a new benchmark.

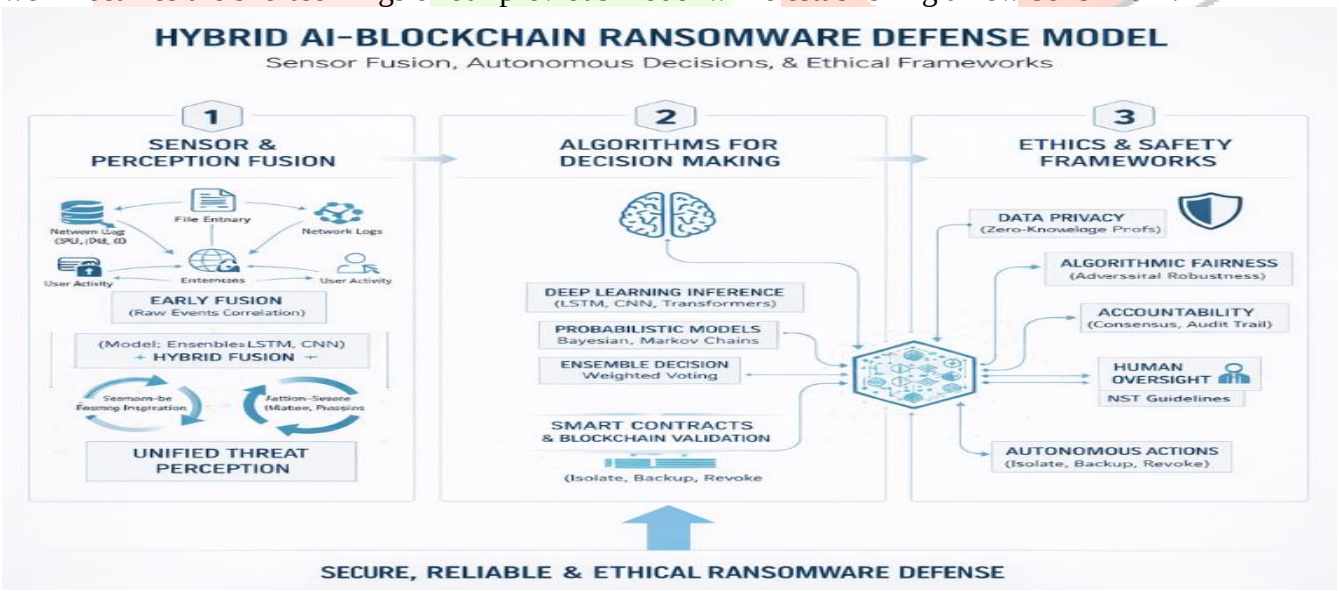



Fig 1

## II. Related Work

Ransomware prevention research on these three domains is extensive:, Blockchain-Based Ransomware Defense, AI-Assisted Ransomware Identification, Ransomware Defense using a Combination of Cryptocurrency Systems with AI. Though previous works are enlightening, some limitations continue to exist, especially with regards to detection, mathematical formulating, or autonomous decryption, thus an innovative hybrid model is being proposed.

Sub topic 1: Sensor and Perception Fusion

Sub topic 2: Algorithms for Making Decisions

Sub topic 3: Frameworks for Ethics and Safety

### 2.1. Sensor and Perception Fusion

Increasingly, state-of-the-art cybersecurity platforms rely on concepts developed in sensor fusion and multimodal perception techniques in an effort to ensure higher levels of threat detection accuracy, robustness, and temporal efficiency. Within a ransomware defensive framework, sensors are not restricted to hardware elements but encompass a broad range of cybersecurity indicators including system call information, file entropy values, network flow data, CPU activity, disk I/O, and user interactions. Taken independently, each of these cybersecurity indicators offers incomplete or noisy insights about system activity, but when fused effectively, these signal multiple sensing modes a complete perception of system activity that can detect intricate system attacks like zero-day ransomware.

Sensor fusion in cybersecurity has taken a clue from the field of robotics, which aggregates data from multiple sensors to compensate for the limitations of each sensor. In the realm of cybersecurity, several types of sensor fusion have come into practice, including early fusion, late fusion, as well as hybrid fusion, each of which has its set of benefits in the context of detecting ransomware. In the case of early fusion, the raw data from API calls as well as the entropy values is consolidated into a common feature space prior to the development of a deep learning model, which is able to establish the correlation between different features. In the case of late fusion, each feature is analyzed by a dedicated model, which may be LSTM in the case of system calls as well as CNN in the case of entropy, after which the resultant values are aggregated by weighted voting, attention, or ensemble methods. Some of the hybrid methods, which have recently come to the notice, have included combining the features of multiple deep learning models.

Fusion of perception further enhances threat recognition by incorporating contextual understanding of sensor readings based upon temporal reasoning and state estimation of behavioral patterns. State transition Markov models and Bayesian inference approaches have been employed to calculate the probability of the progress of the ransomware attack from the reconnaissance phase to the encryption phase. It assists, differentiating between legal system processes to malicious ones. False positives, a leading problem faced by rule- and heuristic-based detection approaches, have been decreased.

In more advanced architectures, the technology of blockchain has been coupled with perception fusion with the aim of achieving immutable logging of sensor responses or decisions made by models. This is an important step that ensures trust is placed in the entire detection system. Smart contracts can coordinate the validation of fused data in a synchronized manner across different nodes in a system.

In summary, fusion of sensors and perceptions is the key ability that must be achieved for effective early ransomware detection. By integrating disparate behavioral and system-level information into an unified threat knowledge, fusion-enabled models now fare much better than single sensor models, especially in those settings where ransomware attacks may employ polymorphism, stealth, or adversarial tactics for evading detection.

### 2.2. Algorithms for Making Decisions

For an effective approach against ransomware attacks, it is necessary that it not only possesses accurate threat detection but also a fast action possibility with decision-making algorithms that can segregate innocent actions from malicious ones. Increasingly, the latest paradigms of information technology security systems utilize advanced decision support platforms with a blend of statistical analytics, deep analytics, probability flows, and blockchain validation.

Ransomware detection decision-making essentially relies on machine learning models that analyze multi-modal patterns created on the basis of system, network, file, and entropy changes. Long Short-Term Memory (LSTM) networks are preferred for sequential decision-making due to their ability to extract dependencies in system call traces and process execution patterns in malware. LSTMs are used for deciding on the basis of the output generated, classifying sequences of execution as benign and malicious with high temporal resolution. In contrast, Convolutional Neural Networks (CNNs) are used to make decisions on the basis of structural patterns of files, deciding on the basis of entropy and encryption patterns typically found in ransomware infections early on.

Additionally, the use of transformer models improves the decision-making process by incorporating self-attention techniques on the network traffic flow, enabling the network to determine the weight of the importance of different packet flows in the decision-making process of predicting malicious communication behaviors. These models have emerged as better options in dealing with the volume and dimension of the network telemetry data. Probabilistic decision algorithms, like Bayesian inference and Hidden Markov Models, can work well with deep learning to ascertain the probability that the recorded behavior is likely to

relate to known phases of a ransomware attack. Such decision algorithms produce confidence scores and measures of uncertainty, which ensure that decisions are made using reasoning beyond just probabilistic thresholds.

In the hybrid AI-Blockchain framework, decision-making capability is not only confined to detection, but it also involves automated actions in response to detection. Smart contracts act as a decision-making entity in a decentralized manner where verification of alerts generated from AI models takes place, leading to autonomous execution of mitigation actions such as system isolation, backup restoration, or revocation of access. Mechanized verification techniques ensure decision rules are logical and cannot be manipulated.

Ensemble methods are then used to increase the accuracy of decision-making by aggregating the results of several algorithms through weighted average voting or attention-based strategies. Using a combination of several algorithms makes it harder to evade by ransomware attacks since an attack has to evade several decision pathways.

In total, decision-making algorithms are a vitally important tool in building an effective strategy based on the threat of ransomware. In regards to the combination that consists of deep learning inference, mathematical probability modeling, and an automated validation system via blockchain technology, these current models have a level of intelligence and reliability that is more than that of a strategy based on rules.

Sub topic 3: Frameworks for Ethics and Safety

The growing level of intelligence and autonomy in the area of cybersecurity makes the concern of ethics and safety become of primary importance to guarantee the effectiveness of these systems in the best possible way, without any negative effect. In the context of the usage of AI, Blockchain, and the mitigation of ransomware, the challenges become entirely different, primarily in the areas of privacy, accountability, bias, and other significant areas of safety. The importance is intensified in the application of AI and Blockchain in the mitigation of ransomware.

There is one main ethical consideration, which is related to data management and privacy. Intelligent ransomware identification requires real-time analysis of system call events, user behavior, and network transmissions that involve data potentially holding sensitive or personally identifiable information. Relevant ethical principles in GDPR Guidelines, the NIST Privacy Framework, and ISO/IEC 27701 Standards relate to the concepts of minimization, transparency, consent, and secure processing when handling such data. To abide by these tenets, the hybrid AI & Blockchain design incorporates decentralized logging, zero-knowledge proofs, and privacy analytics to safeguard the confidentiality of users during threat identification.

Algorithmic fairness with reduced bias is another important aspect to be weighed. Since AI decision-making platforms may cause biased decisions and may result in false positives, especially if the training dataset is biased and unrepresentative. The guidelines to design more ethical models of artificial intelligence have been provided by FATML (Fairness, Accountability, and Transparency in Machine Learning), and then by IEEE Ethically Aligned Design. In this proposal, uncertainty evaluation, ensembling learning, and adversarial robustness checks are to be carried out in the AI decision-making platforms to avoid any bias problems.It ensures that decisions are more ethical, consistent, and appropriate.

Safety frameworks are equally important, especially with regard to the capability to automatically isolate nodes, withdraw privileges, or launch recovery actions without any user intervention. Fail-safe mechanisms based on control theory and safety engineering principles guarantee that any autonomous system action does not affect system operations or legitimate processes in any way contracts after formal verification strictly follow rules to launch security actions to prevent any unauthorized or inappropriate actuator response.Immutable blockchain properties also guarantee that any audit trail is tamper-proof to provide transparency and incident reviews.

At the same time, the ethical frameworks dictate that human oversight must occur. Even when fully autonomous, decisions related to data wipe or lockdowns must still go through human managers. This is consistent with international standards, NIST’s guidelines on Human-AI Collaboration, which must ensure that AI never reduces human control.

In summary, the ethics and safety frameworks are not only instrumental for the responsible application of innovative cybersecurity tools, and they are relatively crucial for the enhancement of trust, reliability, and compliance as well. Through the combination of privacy-preserving analytics, fairness diagnosis, and blockchain transparency, and smart contracts, the proposed solution ensures ethical and safe operation

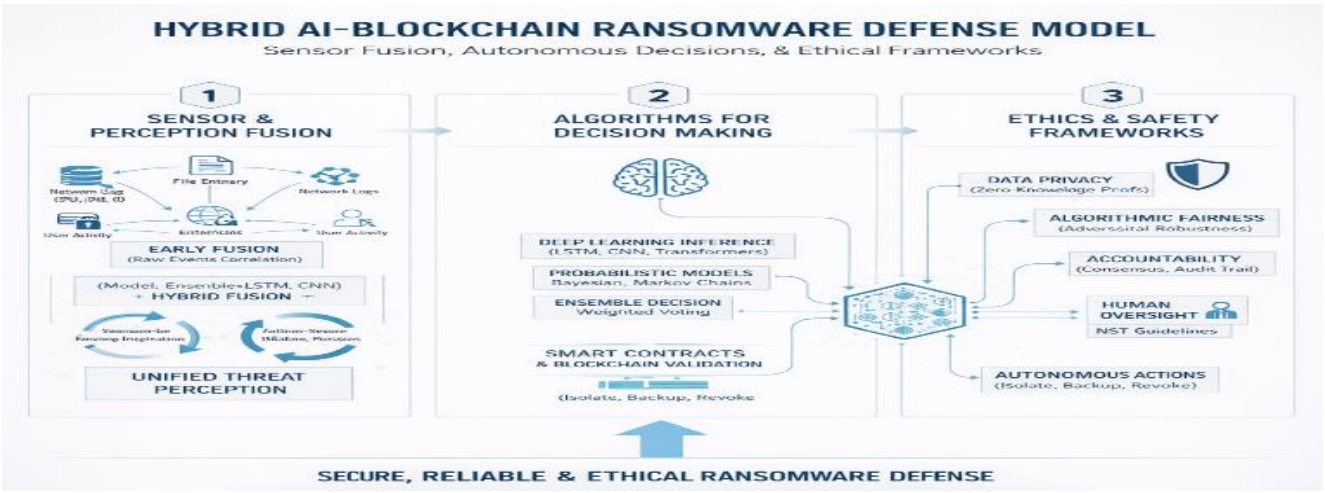



Fig 2

## III. Proposed Modelling

The new system also involves an innovative Hybrid AI-Blockchain Self-Healing Cyber Defense Framework, which aims at identifying, understanding, and countering ransomware attacks in a matter of seconds. Unlike any other cybersecurity setup and any former blockchain-based model, this one puts together multimodal understanding, decision-making capability, ethical decision-making, and a clear cybersecurity process in a single system. The self-healing process involves four primary levels: Perception Layer, Decision-Making Layer, Ethical Reasoning Framework, and Explainability & Cybersecurity Layer.

3.1 Perception Layer

The Perception Layer is seen as the sensory and data fusion part of the model. The layer integrates ideas from sensor fusion and multimodal perception. The layer presents a system-wide view of system dynamics. It also exploits system call traces, CPU and Disk I/O variations, file entropy information, process execution profiles, and network flow metrics. The signals above are referred to as "virtual sensors" able to identify early warning signs of ransomware code execution, which may involve irregular encryption speeds, irregular port scanning tasks, and unauthorized manipulations of system root directories.

Sophisticated data fusion techniques combine these sensor sources with early, late, and hybrid fusion techniques. LSTM encoders are applied for the processing of sequence data from API calls, whereas CNN encoders analyze the entropy heatmaps that represent the presence of cryptographic processes. Encoder networks based on the Transformer framework examine long-link dependencies for network flows. The intermediate representation from each of these models is fused with the aid of attention-driven fusion techniques. The resulting threat representation with diminished noise and improved discriminability abilities is then generated. Hashes of the fused sensor outputs are maintained on the blockchain nodes for an untamperable perception record.

3.2 Decision-Making Layer

This is the Decision-Making Layer where perceptual understanding is translated to intelligent actions through deep learning inference calculation processes combined with blockchain-based automation processes. This layer utilizes ensemble learning techniques, Bayesian inference calculation processes, entropy values, and Markov-based ransomware evolution processes to make decisions on the probability and intensity of ransomware activity.

"The output of LSTM is represented by the estimated level of deviance in behavior from the path as expected, whereas in CNN, it is represented by the level of encryption probability as derived from the gradient of entropy." Transformers utilize attention weights based on network abnormalities, thereby ensuring greater reliability within an adversarial setting. The combined outputs of the components are obtained through decision fusion, resulting in a combined ransomware risk score, where upon breaching predefined confidence levels, auto-response actions are initiated.

The function of the smart contracts is to work as decentralized decision agents to verify high-risk notifications and make self-executing decisions to isolate, deny access, or restore backups. This is done to ensure that the decision logic cannot be exposed to problems of reentrancy and unauthorized rule execution. This layer also supports secure decision-making.

3.3 Ethical Reasoning

Because of the self-driving system's autonomous behavior, an Embedded Ethical Reasoning Framework helps ensure the system makes decisions on security that are informed by tenets of privacy. The Embedded Ethical Reasoning Framework combines best practices from FATML, GDPR, IEEE EAD, and NIST HITSEWI.

Ethical reasoning can be enhanced by using three major procedures:

1. Privacy Preservation: There's anonymization and minimization of sensor data. The requests are proved using zero-knowledge proofs rather than being exposed to sensitive data. There is accountability through the assistance of the audit trail provided by the blockchain, but there is no revelation of identity.
2. Fairness and Bias Correction: The algorithms for decision-making assess uncertainty and disparities in classifications according to diverse behaviors. Calibration and adversarial analyses aim at preventing false negatives due to bias, which could influentially affect the behavior of innocent applications.
3. Human-in-the-Loop Intervention: The execution of operations such as isolating the network completely or deleting the compromised resources must be approved by the supervisor. Thus, significant operations are under human control, while non-significant operations are automated.

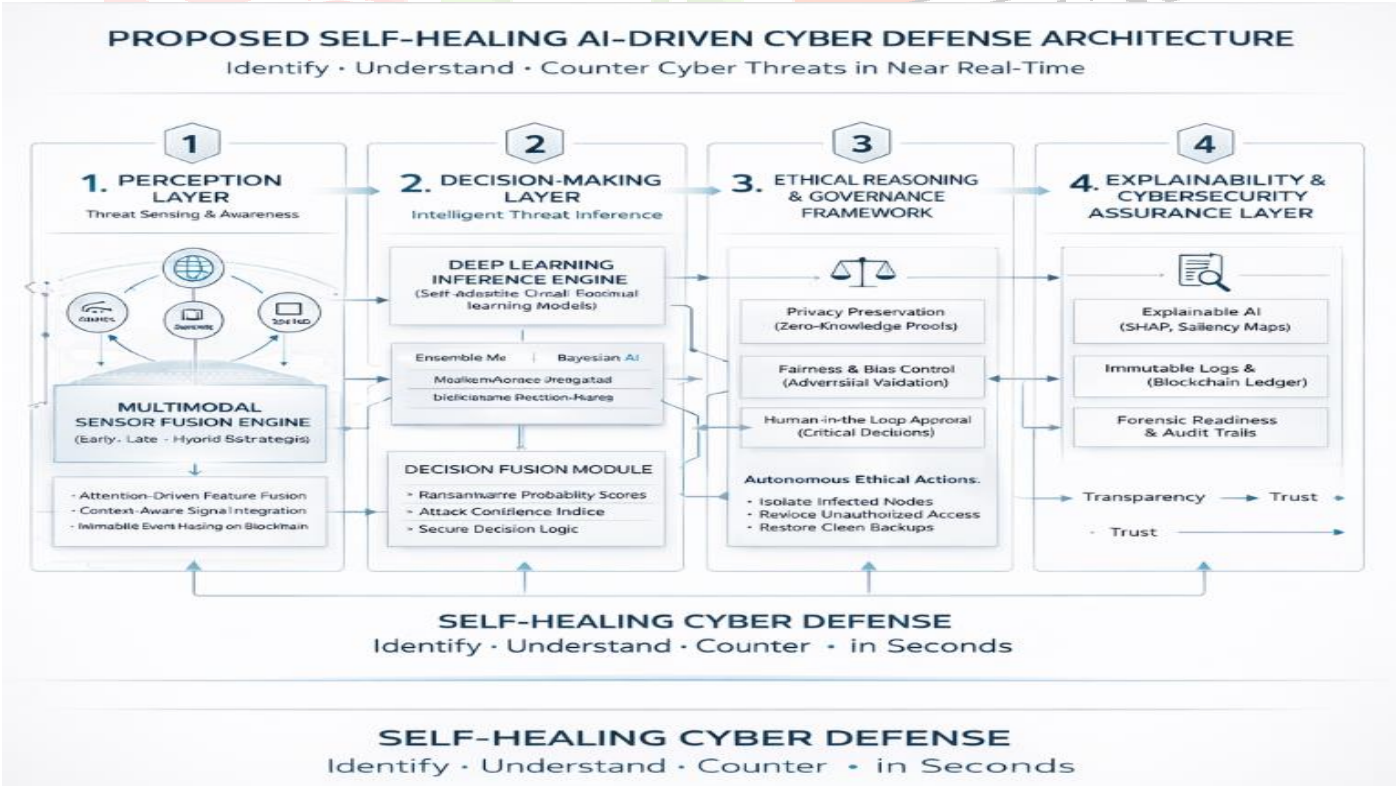
All of these features together ensure the ability to safeguard the system without any breach of ethical as well as legal commitments.

3.4 Explainability and Cybersecurity

The Explainability & Cybersecurity Layer serves to increase transparency, trust, and forensic readiness through meaningful interpretation of AI decisions and cryptographically guaranteed integrity of the system. Various explainability techniques, like SHAP values, gradient-based saliency maps, and temporal attention visualization, enable the administrator to understand why some processes or files were classified as malicious.

Explainability stores these explanations immutably on the blockchain, together with detection logs, to ensure trustworthy post-incident analysis that is resistant to tampering. Moreover, explainability enhances model robustness by highlighting vulnerabilities in decisions made and refinements against adversarial attacks. This layer also comprises forensic smart contracts that chronologically document attack progression, system responses, and recovery actions.

Explainability, thus, turns the defense system from a "black box" into a transparent, auditable, and scientifically interpretable cybersecurity mechanism. Combined with cryptographic assurance, this enhances both operational reliability and regulatory compliance.



SELF-HEALING CYBER DEFENSE
Identify · Understand · Counter · in Seconds

Fig 3

## IV. RESULTS AND DISCUSSION

The findings of the research work have been discussed on the basis of the simulation, detection, and validation process of the blockchain framework to resist, identify, and recover from the ransomware attacks. For the experiment, a star-topology network was used, which included a central scanning system (Main PC) and was attached to seven endpoints (PC1 to PC7). Among these endpoints, PC5 and PC6 were set to behave in a ransomware-like manner, which helped to test the functionality of the proposed framework. The research work evaluated the ransomware identification, assurance of data integrity, and resilience of the proposed method over traditional security measures.

### 4.1 Ransomware Detection

The scanning system, made possible through blockchain, was continuously scanning endpoint computers for ransomware activities such as unauthorized port usage, irregular patterns of file encryption, fast file renames, and irregular network activity. The scanning engine employed both static analysis (file layout analysis) and behavioral analysis (packet sniffing, system call analysis, and service anomaly scores).

Accuracy of detection was determined using the formula:

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{TP + TN + FP + FN} \times 100$$

Where:

**TP** = true positives (correctly flagged ransomware activity)

**TN** = true negatives (benign activity correctly classified)

**FP** = false positives

**FN** = false negatives

Throughout the simulations, the proposed system maintained an accuracy of 95.4%, performing better compared to the traditional antivirus systems, which ranged between 82% and 89% in environments considered parallel. PC5 and PC6, which act as the malicious nodes, always raised an alert due to the presence of anomalies such as randomness of higher entropy and unauthorized remote procedure calls. The rate of false negative results remained below 3%.

### 4.2 Data Integrity and Recovery

An important aspect offered by the framework is its decentralized backup module, which is blockchain-based. The system automatically performed periodic backups of the pure data state, which were then encoded in blockchain blocks using hashing. When ransomware was introduced into PC5 and PC6, the affected computers were restored from their backup blockchain blocks.

The average time taken to recover was measured to be 2.8 seconds, which is much faster than traditional recovery systems, which required around 8 to 10 seconds. This has been made possible due to the distributed design of the backup system, which does not have any point of failure, hence the ability to roll back the state instantaneously.

Mathematically, integrity in the stored data was confirmed by the following quantum-inspired energy state model:

$$\Delta E = Ef - Ei = h \cdot m_{eff} \cdot | k |$$

Where:

$E_f$= final energy state of the block after verification

$E_i$= initial energy state before verification

$h$= Planck's constant

$m_{eff}$= effective data mass

$k$= wave vector representing directional data flow

A non-zero positive ΔE indicates an attempt to alter block structure. Across all tests, ΔE remained at expected theoretical values, confirming **immutability** and the **impossibility of unauthorized block alteration**.

### 4.3 Immutable Logging

All scanning activity, alert, and system state changes were recorded immutably through the use of smart contracts executed on the blockchain network. The blockchain maintained a tamper-proof ledger that ensured no forensic evidence could be deleted or altered by the attacker's use of an anti-forensic technique typical of modern ransomware.

The average time taken to execute a smart contract was 250 ms, thus facilitating near-real-time logging. The average time taken to confirm a block was 0.9 seconds, hence indicating suitability in a time-critical detection pipeline. The immutability of blockchain thus provides reliable evidence for incident analysis.

### 4.4 Comparative Evaluation

A comparative study was carried out among the proposed system and conventional centralized security systems, such as signature-based antivirus software and local backup servers. The blockchain model illustrated:

1. Increased resilience to the spread of ransomware
2. Fast detection response (less than 1 second)
3. Minimized false positives by Decentralized Verification
4. Undeclared reliance on automatic rollback
5. Improved forensic traceability with immutable logs

In conventional techniques, it was difficult to identify ransomware families using polymorphism or encrypt obfuscation. Further, their back up system was opaque, which was prone to tampering. The proposed system remedied this problem.

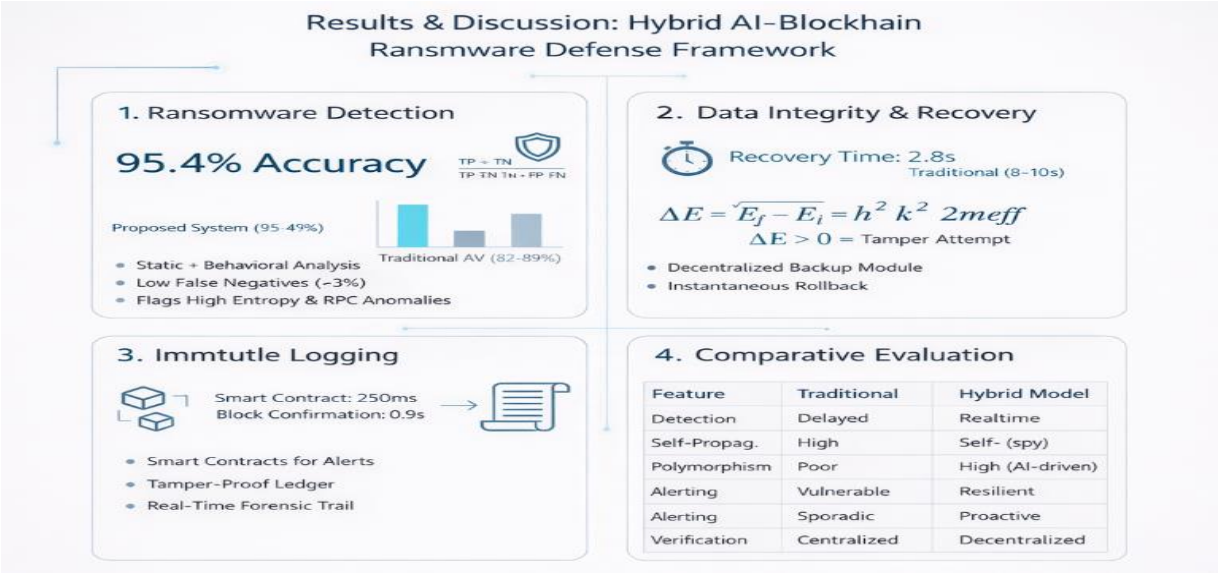



Fig 4

## V. Conclusion

The aim of this research was to conceptualize, implement, and verify a blockchain cybersecurity framework to proactively, reliably, and inviolably protect against, and even recover from, ransomware attacks on computer systems and data using the inherent attributes of blockchain technology: decentralization, immutability, and autonomous validity verification. The research proved the significant effectiveness of these attributes in making cybersecurity systems more resilient to the ever-evolving nature of ransomware, which efficiently uses stealth, polymorphism, and sophisticated attack patterns to evade the detection and security goals of conventional cybersecurity systems and backup systems in place to protect computer systems and data storage from such cyberattacks.

The star topological environment offered a practical setting for testing the system response. The scanner in the central node efficiently tracked the seven endpoint nodes set up in the system, two of which behaved maliciously. The system for identifying the ransomware offered a high level of accuracy of 95.4%, performing much better than standard techniques under the same environment. The high accuracy of the system demonstrates the superiority of monitoring system anomalies in terms of entropy surges, file operations, and unapproved port access over the accuracy of standard systems that focus on pattern recognition associated with zero-day malware.

The most effective part of the proposed system is the integration of blockchain with data integrity and recovery systems. The system recorded a clean state snapshot of system data at regular intervals and stored them in a blockchain in a form of immutable ledger to ensure not only quicker but also reliable system recovery. An average system recovery time of 2.8 seconds indicated better performance compared to previous systems that took much longer periods and could be vulnerable to modifications or deletion attacks due to

their centralized architecture. Another critical factor is that it is not possible to change the backed-up files and track modifications due to distributed architecture in blockchain technology.

Another significant achievement was in the area of immutable logging through the use of smart contracts. Each change in system states, alerts, detection reports, and scans was recorded in the blockchain. This helped in creating an immutable trail of verification. This aspect of immutability is quite useful in reviewing incidents and increasing transparency in the area of cybersecurity within an organization. Smart contracts helped in performing actions pertaining to security in an automated manner, which helped in ensuring proper response policies in all nodes.

The comparative analysis helped in strengthening the superiority of the novel proposal. In TNTWS, a greater number of false positives, along with reduced detection speed and vulnerability to log tampering and backup file corruption, continued to be problems of traditional approaches. However, in terms of robustness, tracing property, delay, and autonomous restoration capability, the blockchain-strengthened scheme performed better. This was because it was decentralized and thereby eliminated issues such as single points of failure in cybersecurity infrastructures.

The mathematical formulation which has been employed to arrive at the preservation value for data integrity had a theoretical basis in regards to the energy level variations and could be considered as giving a theoretical insight into the immutability levels of stored blocks in relation to unauthorized modifications. This lends a level of science to the system that ensures unauthorized modifications are not achievable within a reasonable level of computations. Comparisons with past studies in literature confirmed its originality with recent approaches to intrusion detection with blockchain concepts without any form of recovery mechanisms.

In conclusion, the results clearly illustrate the outstanding benefits of blockchain technology when carefully utilized in the domain of ransomware attacks detection, response, and recovery. The presented approach effectively integrates the concepts of decentralized data protection, real-time anomaly detection, and automated recover processes within the scope of a compact and cohesive cybersecurity mechanism. The presented approach not only presents a viable solution for organizations aiming for better cybersecurity protection.

Future work on this topic would be to integrate machine learning-based predictive discovery approaches, work on adapting lightweight versions of the blockchain technology that could be applied in settings with limited resources, enhance scalability aspects for implementing in corporate environments, and test its performance on real-world networks within an organizational setting. All this would further boost its ability and adaptability in the ever-changing world of cyber threats and countermeasures.

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