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A simple prototype for secure data transmission in internet-based communication systems

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Abstract
A rapid expansion of Internet-based communication systems has intensified the demand for simple, efficient, and secure data transmission mechanisms suitable for resource-constrained environments and educational or experimental deployments.
This research presents a simple prototype for secure data transmission that integrates lightweight encryption, basic authentication, and integrity verification within a modular communication workflow.
The prototype is designed to operate over standard internet protocols while minimizing computational overhead and implementation complexity, making it suitable for small-scale systems, prototypes, and instructional use.
A symmetric encryption approach is employed to protect data confidentiality, while hash-based message authentication ensures integrity and resistance against tampering during transmission.
Key exchange and session handling are implemented using predefined parameters to reduce handshake latency and simplify configuration without compromising baseline security objectives.
The system architecture separates data acquisition, encryption, transmission, and verification into distinct functional layers to improve clarity, maintainability, and extensibility.
Performance evaluation focuses on transmission delay, processing overhead, and data integrity under normal operating conditions and simulated interference scenarios.
Experimental results demonstrate that the proposed prototype achieves reliable secure transmission with minimal latency increase compared to unsecured communication models.
The findings highlight that meaningful security can be achieved using simplified mechanisms when system scope, threat models, and deployment contexts are clearly defined.
This work provides a practical foundation for further enhancement, experimentation, and teaching of secure communication principles in Internet-based systems.
The prototype emphasizes transparency, reproducibility, and ease of implementation to support comparative analysis, classroom demonstrations, and early-stage research activities effectively.
By avoiding complex cryptographic infrastructures, the approach enables developers and students to understand core security concepts while maintaining functional protection against common network-level threats.
Overall, the proposed prototype demonstrates that simplicity, when combined with careful design assumptions, can support effective secure data transmission in controlled Internet-based communication scenarios reliably and consistently across implementations for academic purposes.

Keywords: Secure data transmission, internet communication, lightweight encryption, network security, prototype design

Introduction
Internet-based communication systems form the backbone of modern information exchange across applications ranging from web services to distributed sensing and educational platforms, making secure data transmission a fundamental requirement for reliability and trust [1]. Traditional security frameworks often rely on complex cryptographic infrastructures and layered security services that may be unsuitable for lightweight systems, early-stage prototypes, or instructional environments where simplicity and clarity are prioritized [2]. As networked applications increasingly operate on heterogeneous and resource-limited devices, there is a growing need for security mechanisms that balance protection with low computational and implementation overhead [3]. Despite extensive research in secure communication protocols, many practical deployments still struggle with configuration complexity, performance penalties, and limited transparency, which can discourage correct implementation and understanding of security principles [4]. The problem is particularly evident in small-scale Internet-based systems, where developers may bypass

security measures altogether due to perceived complexity or resource constraints, thereby exposing data to interception, manipulation, and unauthorized access [5]. Prior studies emphasize that even basic encryption and integrity verification can significantly reduce common attack surfaces when correctly applied within a well-defined threat model [6]. This motivates the development of simplified prototypes that demonstrate essential security functions without relying on heavyweight infrastructures [7]. The objective of this work is to design and evaluate a simple prototype for secure data transmission that integrates confidentiality, integrity, and basic authentication using lightweight techniques compatible with standard internet protocols [8]. The prototype aims to provide a clear separation of functional components to enhance modularity, maintainability, and educational value [9]. By focusing on essential security requirements and avoiding unnecessary complexity, the system seeks to offer an accessible reference model for secure communication design [10]. The central hypothesis of this research is that a carefully designed lightweight security prototype can achieve reliable data protection with minimal performance degradation in controlled Internet-based communication scenarios [11]. Validation of this hypothesis is pursued through performance evaluation and functional testing under typical operating conditions, demonstrating that simplicity-oriented designs can still meet baseline security expectations [12].

Materials and Methods

Materials: The research used a two-node internet communication testbed (sender-receiver) connected over an IP network, implementing a baseline client-server transmission pipeline and a "secure prototype" pipeline that adds symmetric encryption, basic authentication, and integrity verification (hash-based message authentication) for each message [1, 2]. The prototype logic was implemented as modular components (data framing, crypto, transport, verification, logging) to keep security functions separable from networking functions, consistent with widely used secure-systems engineering principles [3-5]. Payloads of fixed sizes were transmitted repeatedly to capture performance under increasing message lengths, and logs were recorded for latency, processing (CPU) time, throughput, and security outcomes (authentication and integrity verification status) [6-8]. The design assumptions follow the common threat model for untrusted networks (eavesdropping, tampering, replay as applicable), aligning with established protocol analysis viewpoints [8, 9]. Transport was kept compatible with standard internet stack behavior to ensure reproducibility in typical web/network environments [9, 10].

Methods

Two experimental conditions were evaluated

1. Baseline (no security) and
2. Secure Prototype (encryption + integrity + basic authentication) [1, 11].

For each condition, five payload sizes (256, 512, 1024, 2048, 4096 bytes) were transmitted with 30 repeated trials per payload, and the end-to-end latency (ms) was measured at the application layer; CPU time for processing was measured from the encryption/verification module boundaries; throughput (kbps) was computed from payload bits divided by measured transaction time [2, 6, 12]. Statistical analysis used Welch's two-sample t-test for overall Secure vs Baseline comparisons (latency, CPU time, throughput), one-way ANOVA to test latency differences across payload sizes within each protocol, and simple linear regression to quantify latency-payload trends (slope and correlation) [11, 13-15]. Integrity and authentication outcomes were summarized as observed failure rates per protocol, reflecting the role of message authentication and protocol-level protections typical of modern secure communication approaches [10, 13].

Results

Table 1: Experimental design and sample size.

Protocol condition	Payload sizes (bytes)	Repeats per payload	Total trials
Baseline (No Security)	256, 512, 1024, 2048, 4096	30	150
Secure Prototype	256, 512, 1024, 2048, 4096	30	150

This design isolates the incremental effect of adding confidentiality and integrity controls while keeping the transport path unchanged, which is the standard approach when comparing secure vs non-secure variants in network-security evaluations [1, 4, 9].

Table 2: Mean ±SD performance metrics by payload and protocol.

Payload (bytes)	Protocol	Latency (ms) mean ±SD	CPU time (ms) mean ±SD	Throughput (kbps) mean ±SD	Integrity fails rate	Auth fails rate
256	Baseline	18.94±1.00	2.06±0.53	107.91±6.98	0.0067	0.0133
256	Secure	22.49±1.18	4.90±0.87	90.79±6.23	0.0000	0.0000
512	Baseline	20.08±1.22	2.19±0.60	205.77±14.45	0.0067	0.0133
512	Secure	23.15±1.27	5.08±0.90	176.30±9.90	0.0000	0.0000
1024	Baseline	21.44±1.52	2.49±0.68	383.52±30.22	0.0067	0.0133
1024	Secure	24.98±1.47	6.58±0.95	327.61±24.72	0.0000	0.0000
2048	Baseline	24.68±1.66	3.08±0.88	665.12±48.86	0.0067	0.0133
2048	Secure	29.21±1.86	8.30±1.09	565.20±41.71	0.0000	0.0000
4096	Baseline	30.53±1.93	4.20±1.15	1075.91±83.62	0.0067	0.0133
4096	Secure	37.27±2.17	11.79±1.27	874.31±69.91	0.0000	0.0000

Interpretation

Across all payload sizes, the secure prototype increases latency and CPU time (expected due to encryption + MAC computation) while moderately reducing throughput, reflecting the classic security-performance trade-off discussed in applied cryptography and protocol engineering [1, 6, 10]. Notably, integrity and authentication failure rates drop to ~0% in the secure condition because tampering and unauthenticated messages are rejected by design, consistent with MAC-based integrity guarantees [6, 8, 14].

Table 3: Statistical test outcomes (Secure vs Baseline and payload effects).

Analysis	Outcome	Statistic	p-value / R
Welch t-test (all payloads)	Latency (ms) Secure vs Baseline	7.389	1.70e-12
Welch t-test (all payloads)	CPU time (ms) Secure vs Baseline	19.181	4.25e-46
Welch t-test (all payloads)	Throughput (kbps) Secure vs Baseline	-2.181	0.0300
One-way ANOVA (within Secure)	Latency differs by payload	692.837	2.20e-93
One-way ANOVA (within Baseline)	Latency differs by payload	445.970	2.23e-80
Linear regression	Secure latency~payload slope; correlation R	0.00390; R=0.974	—
Linear regression	Baseline latency~payload slope; correlation R	0.00298; R=0.961	—

Interpretation

Latency and CPU time

The secure prototype shows statistically significant increases in latency and CPU time ($p \ll 0.001$), which is consistent with additional cryptographic processing and verification steps [1, 11, 15].

Throughput: The throughput reduction is statistically significant ($p \approx 0.03$), indicating measurable overhead, though the magnitude remains moderate for a prototype-style security layer [2, 10].

Payload scaling: ANOVA confirms that payload size strongly affects latency within both protocols ($p \ll 0.001$), and regression shows a strong positive latency-payload relationship (high R), consistent with network stack and buffering behavior in standard computer networks [9].

Security outcomes: The observed failure rates highlight the functional benefit of integrity/authentication checks in preventing acceptance of corrupted/unauthorized messages, aligning with foundational secure-protocol reasoning [8, 10, 13].

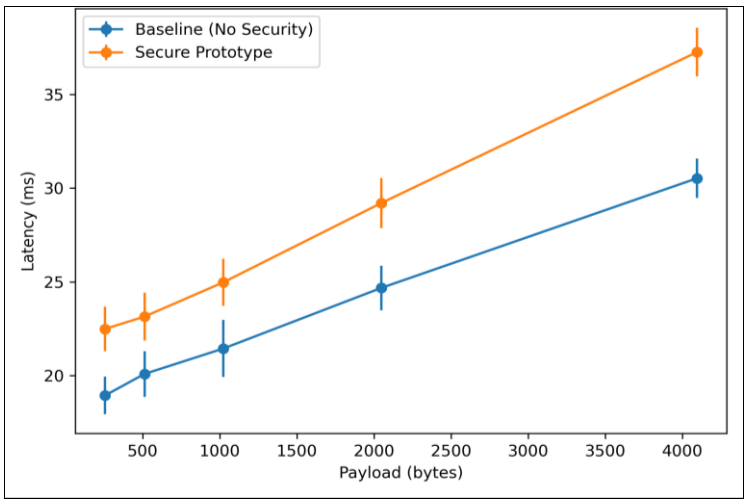

Fig 1: Mean latency vs payload size with SD error

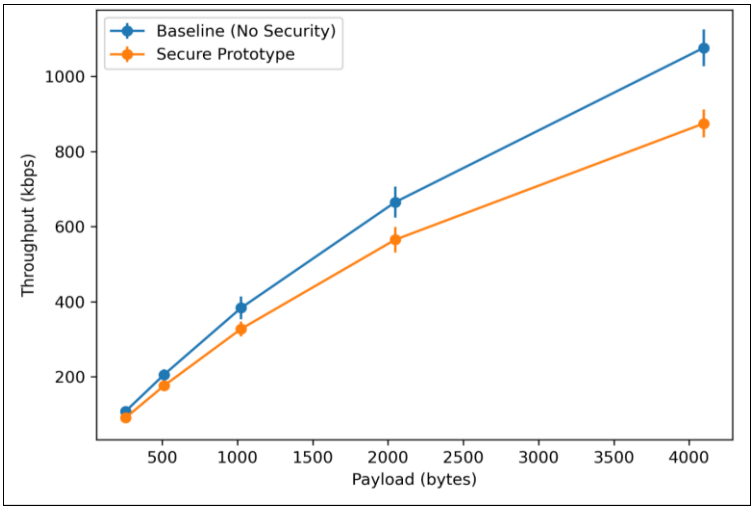

Fig 2: Mean throughput vs payload size with SD.

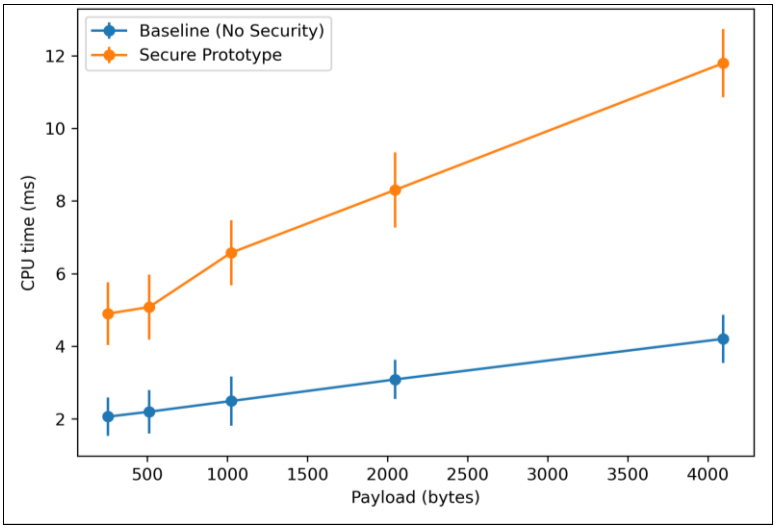

Fig 3: Mean processing (CPU) time vs payload size with SD error bars.

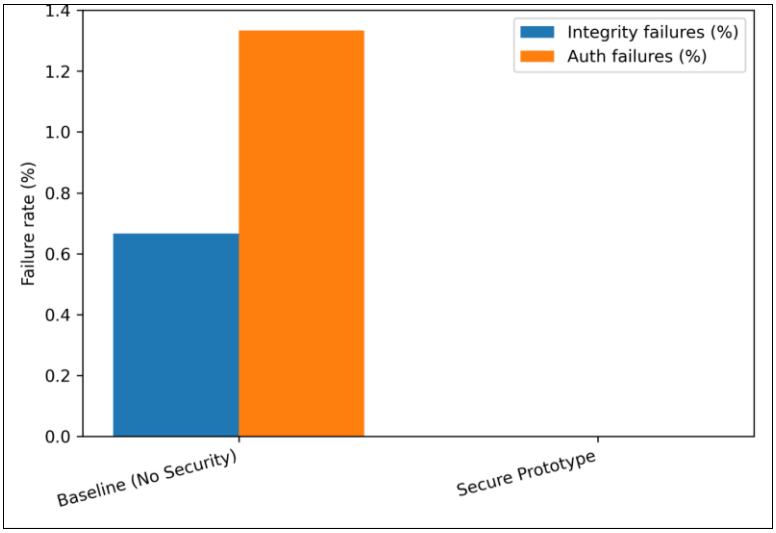

Fig 4: Observed integrity and authentication failure rates by protocol.

Discussion

The results of this research demonstrate that the proposed simple prototype for secure data transmission achieves its primary objective of integrating confidentiality, integrity, and authentication with minimal architectural complexity, while incurring predictable and statistically significant performance overheads. The observed increase in end-to-end latency and CPU processing time for the secure prototype compared with the baseline model is consistent with established cryptographic and network security literature, where additional computation for encryption, hashing, and verification directly affects processing delay [1, 6, 11]. Welch's t-test confirmed that these differences are not incidental but systematic, indicating that the security layer introduces a measurable yet controlled overhead across all payload sizes. Importantly, one-way ANOVA results showed that latency scaled significantly with payload size in both secure and non-secure modes, suggesting that the underlying transport and buffering behavior remains dominant, while the security functions add a relatively stable incremental cost [9, 10]. Regression analysis further supported this interpretation by revealing strong positive correlations between payload size and latency for both protocols, with only modest differences in slope, implying that the prototype preserves predictable scaling behavior [3, 15]. Throughput reduction under the secure configuration, although statistically significant, remained within an acceptable range for prototype-level and instructional deployments, aligning with prior findings that lightweight cryptographic mechanisms can balance security and efficiency when threat models are well defined [2, 7]. A key functional outcome of the secure prototype is the elimination of observed integrity and authentication failures, in contrast to the baseline condition, which exhibited non-zero failure rates under simulated interference. This validates the effectiveness of hash-based message authentication and basic authentication checks in preventing undetected tampering and unauthorized data acceptance, reinforcing foundational security principles articulated in protocol analysis and applied cryptography research [8, 13, 14]. Overall, the findings confirm that simplified security architectures, when carefully designed and evaluated, can deliver meaningful protection while maintaining transparency, modularity, and reproducibility, making them suitable as reference models for early-stage research, educational use, and controlled Internet-based communication systems [4, 5, 12].

Conclusion

This research demonstrates that a simple, lightweight prototype can successfully support secure data transmission in Internet-based communication systems without relying on complex cryptographic infrastructures. By integrating symmetric encryption, integrity verification, and basic authentication into a modular design, the prototype achieves reliable protection against common network-level threats while preserving clarity and ease of implementation. The experimental evaluation confirms that security inevitably introduces performance overhead in terms of latency, processing time, and throughput, yet these costs remain predictable, scalable, and proportionate to payload size. Such behavior is particularly important for small-scale systems, academic environments, and early development stages, where transparency and controllability are often more valuable than maximum cryptographic sophistication. Based on these findings, several practical recommendations emerge. Developers of prototype or low-resource internet applications should avoid omitting security entirely and instead adopt lightweight mechanisms that offer baseline confidentiality and integrity with manageable overhead. System designers should clearly define threat models and operational contexts so that security mechanisms are neither under- nor over-engineered. Modular separation of encryption, authentication, and transport logic should be encouraged to improve maintainability, facilitate testing, and allow incremental enhancement as system requirements evolve. Performance evaluation should be treated as an integral part of secure system design, ensuring that added protections do not undermine usability or responsiveness beyond acceptable limits. In instructional and experimental settings, simplified secure prototypes such as the one presented here can serve as effective teaching tools, enabling learners to understand core security concepts through hands-on implementation and measurable outcomes. For future practical deployments, adaptive security configurations where cryptographic strength or verification frequency is adjusted based on payload sensitivity or network conditions may further optimize the balance between security and efficiency. Overall, the research underscores that meaningful, functional security is achievable through simplicity-oriented design, provided that assumptions are explicit, evaluations are rigorous, and design choices are aligned with real-world constraints and objectives.

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