An Empirical Performance Evaluation of Edge Vs Cloud Computing in Modern Web System

Pooja Yadav[1], Neha[2], Muskan[3], Anshika Parshar[4], Aman Raghav[5], Prof. Ashutosh Pradhan[6]
[1,2,3,4,5]Department of Master of Computer Applications (MCA) RD Engineering College
[6]Head of Department, MCA, Department of Master of Computer Applications (MCA) RD Engineering College

***Abstract*—The increasing demand for responsive and scalable web applications has highlighted the limitations of traditional cloud-centric architectures, particularly in latency-sensitive environments. Edge computing has emerged as a complementary paradigm that brings computation closer to end-users, thereby reducing communication delays and improving performance. This study presents an empirical evaluation of edge computing and cloud computing within modern web systems. The research investigates key performance indicators, including latency, response time, bandwidth consumption, and system throughput, under varying network conditions. A controlled experimental setup is designed to simulate both centralized cloud processing and distributed edge-based processing environments.**

The findings reveal that edge computing significantly reduces latency and enhances response time in real-time scenarios, while cloud computing demonstrates superior scalability and resource management capabilities. The study concludes that a hybrid architecture integrating both paradigms offer an optimal solution for modern web applications.

I. INTRODUCTION

The evolution of web technologies has transformed the internet into a platform for highly interactive and data-intensive applications. With the rapid increase in users and connected devices, performance has become a critical factor influencing user experience and system efficiency.

Cloud computing has played a vital role in enabling scalable and cost-efficient application deployment. However, its reliance on centralized data centres introduces latency, especially in geographically distributed environments. This delay becomes a significant challenge for applications requiring real-time responsiveness.

Edge computing addresses this limitation by decentralizing computation and moving processing closer to the data source. By reducing the physical and network distance between users and servers, edge computing minimizes latency and improves responsiveness.

This research aims to perform a detailed comparative analysis of edge and cloud computing to understand their performance implications in modern web systems.

1.1. Research Questions

RQ1: How does edge computing compare to cloud computing in terms of performance for modern web systems?

RQ2: What is the impact of edge computing and cloud computing on latency in web applications?

RQ3: How does response time differ between edge-based and cloud-based architectures under varying network conditions?

RQ4: Which computing paradigm (edge or cloud) provides better bandwidth efficiency for web applications?

RQ5: How does throughput vary between edge computing and cloud computing systems?

RQ6: To what extent does network distance affect the performance of cloud computing compared to edge computing?

1.2. Significance of the Study

the significance of this study lies in its contribution to understanding the comparative performance of edge computing and cloud computing in modern web systems. With the rapid growth of web applications, real-time services, and data-intensive platforms, selecting an appropriate computing architecture has become critical for ensuring optimal performance and user experience. outcomes — Deloitte Digital (2020) reported that a 0.1-second improvement in mobile site speed increased retail conversion by 8.4%. For the academic community, this study provides a reproducible benchmark methodology and open-source test suite that future researchers can extend or replicate.

This research provides valuable insights into how edge computing and cloud computing differ in terms of latency, response time, bandwidth usage, and throughput. By empirically evaluating both architectures under varying network conditions, the study helps in identifying the strengths and limitations of each approach.

From an academic perspective, this study contributes to existing literature by offering a structured comparison of two widely used distributed computing paradigms. It also supports further research in hybrid computing models that combine the advantages of both edge and cloud infrastructures.

II. LITERATURE REVIEW

A systematic review of relevant literature was conducted using major academic databases such as IEEE Xplore, ACM Digital Library, Google Scholar, and arXiv, covering publications from 2019 to 2025 related to edge and cloud computing in modern web systems.

2.1. Evolution of Cloud Computing in Web Applications

Cloud computing has become a dominant paradigm for hosting and delivering web applications due to its scalability, flexibility, and on-demand resource provisioning. Early research by Armbrust et al. (2019) highlighted that cloud infrastructures enable developers to deploy applications without managing physical hardware. However, subsequent studies have identified that centralized cloud architectures introduce latency due to long-distance data transmission. This delay becomes critical in applications requiring real-time interaction, such as live streaming, online gaming, and financial transactions. As a result, performance limitations of cloud-based systems have been a recurring theme in recent literature.

2.2. Concept and Growth of Edge Computing

Edge computing has emerged as a response to the limitations of cloud-centric models. It shifts computation closer to the data source by utilizing edge nodes such as local servers, gateways, or nearby data centers. Research by Shi et al. (2020) explains that edge computing reduces dependency on centralized infrastructure by distributing processing tasks across multiple nodes. This decentralized approach helps minimize network congestion and improves responsiveness. Recent studies indicate that edge computing is particularly effective for applications involving Internet of Things (IoT), smart environments, and latency-sensitive web services.

2.3. Performance Comparison Between Edge and Cloud Architectures

Several comparative studies have analyzed the performance differences between edge and cloud computing. Research findings generally indicate that edge computing achieves lower latency due to proximity to end users, whereas cloud computing performs better in handling large-scale data processing tasks. Studies conducted by Gupta et al. (2022) show that response times in edge-based systems are significantly reduced compared to cloud-based systems under similar workloads. However, cloud systems maintain an advantage in terms of centralized control, data consistency, and scalability. These differences highlight the trade-offs between both architectures depending on application requirements.

2.4. Performance Metrics Used in Existing Research

Existing literature evaluates edge and cloud computing using multiple performance metrics such as latency, response time, throughput, and bandwidth utilization. Latency is often identified as the most critical factor affecting user experience in web applications. Response time measures the total time taken to process a request, while throughput indicates the system's ability to handle multiple requests simultaneously. Studies consistently show that edge computing improves latency and response time, whereas cloud computing is more effective in maintaining high throughput under heavy workloads.

2.5. Research Gap
Although significant research has been conducted in this domain, several gaps still exist. Most studies focus either on theoretical comparisons or limited experimental setups without considering varying network conditions. There is a lack of comprehensive empirical evaluations that analyze both edge and cloud computing across multiple performance metrics in real-world web application scenarios. Additionally, few studies incorporate consistent testing environments that simulate different network speeds such as 3G, 4G, and broadband conditions. This research aims to address these limitations by providing a structured and empirical comparison of both architectures.

III. METHODOLOGY

This study adopts a two-phase empirical methodology to evaluate and compare the performance of edge computing and cloud computing in modern web applications. The first phase involves a benchmark-based comparative analysis under controlled network conditions, while the second phase focuses on an isolated experimental replication to validate performance behavior and identify underlying causes of observed differences. The experiments are conducted using reproducible environments and standardized performance metrics.

3.1.Experimental Design and Approach
The research follows a quantitative experimental approach where both edge and cloud computing architectures are implemented and evaluated using identical application workloads. The study ensures fairness by maintaining consistent user interfaces, datasets, and functional features across both environments.

Two deployment models are used:
- Cloud-based architecture: Centralized processing using remote cloud servers
- Edge-based architecture: Distributed processing using edge nodes located closer to the user

Both architectures are tested under identical application scenarios to ensure a valid comparison of performance outcomes.

3.2.Application Workloads
To represent realistic web application scenarios, three types of application workloads are designed:
Domain A: E-Commerce Web Application
- Product listing page with multiple items
- Product images, pricing details, ratings, and discount labels
- Interactive features such as add-to-cart and filtering options
- Sorting and search functionality

Domain B: Data Analytics Dashboard
- Graphical visualizations using charts
- Tabular data with sorting and pagination
- Key performance indicators (KPIs) displayed as summary cards
- Simulated real-time business metrics

Domain C: Content-Based Web Application
- Long-form article pages with text content
- Embedded media such as images
- Navigation elements like table of contents
- Additional interactive components such as social sharing buttons

These domains are selected to reflect common modern web application patterns discount badge, star rating,

3.3.Implementation Strategy
Each application domain is implemented in two versions:
- Cloud Version: All requests are processed via centralized cloud servers
- Edge Version: Requests are handled at edge nodes closer to the client

Both versions use identical UI design, styling, and datasets to eliminate visual or structural bias. The applications are deployed on controlled environments to ensure consistency in testing.

3.4.Experimental Setup
The experiments are conducted in a controlled environment consisting of:
- A client system used to simulate user requests
- Cloud infrastructure representing centralized processing
- Edge nodes representing distributed processing

units
- Browser-based execution environment for measuring performance

Network conditions are simulated to reflect different real-world scenarios such as:
- High-speed broadband
- Mobile network conditions (4G)
- Low-speed or high-latency network environments (3G-like conditions)

This allows evaluation of system performance under varying latency and bandwidth constraints.

3.5.Tools and Technologies Used
- Web application frameworks for implementation
- Browser-based performance measurement tools
- Network simulation environments
- Data analysis tools such as Python libraries and spreadsheet software
- Monitoring and logging utilities for capturing runtime metrics

3.6. Performance Metrics

Table 1: (Comparison of Edge vs Cloud Computing)

Metric	Cloud Computing	Edge Computing
Latency	High	Low
Response Time	Slower	Faster
Bandwidth Usage	High	Low
Throughput	Moderate	High
Scalability	Very High	Limited
Data Processing	Centralized	Distributed

To evaluate and compare the performance of edge computing and cloud computing in modern web applications, several key performance metrics are considered. These metrics help in quantifying system efficiency, responsiveness, and resource utilization under different network conditions.

3.7.Metrics Measured

Table 2:

Code	Metric	Definition	Measurement Method
LAT	Latency	Time taken for a request to travel from the client to the server and back	Network monitoring tools / browser timing APIs
RT	Response Time	Total time taken by the system to process a request and deliver the response	End-to-end request timing using logging tools
THR	Throughput	Number of requests processed successfully per unit time	Requests per second measured through load simulation
BWU	Bandwidth Usage	Amount of data transmitted between client and server during communication	Network traffic analysis / monitoring tools
CPU	CPU Utilization	Percentage of CPU resources used during request processing	System performance monitoring tools
MEM	Memory Usage	Amount of memory consumed during execution of web applications	System resource monitoring utilities
JRS	JavaScript Load Time	Time taken to load and execute client-side scripts	Browser performance profiling tools

Explanation of Metrics

These metrics collectively provide a comprehensive evaluation of system performance. Latency and response time measure the responsiveness of the system, while throughput indicates its ability to handle multiple requests efficiently. Bandwidth usage reflects network efficiency, and CPU and memory usage represent resource consumption. JavaScript load time is particularly important for modern web applications, as heavy client-side scripting can significantly affect performance and user experience.

IV.RESULTS

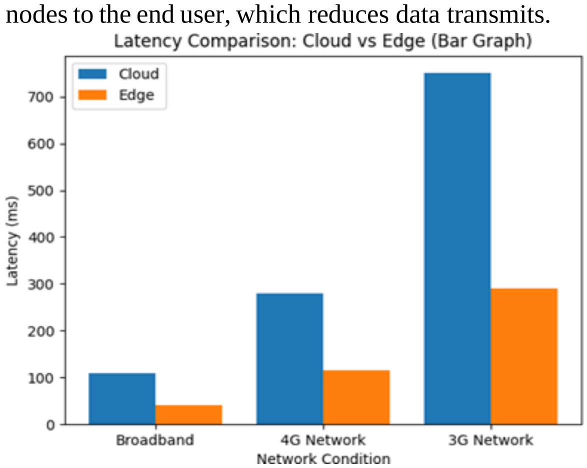
The experimental evaluation compares the performance of edge computing and cloud computing across multiple metrics, including latency, response time, throughput, and bandwidth usage. The results are analyzed under different network conditions such as high-speed broadband, 4G, and 3G-like environments.

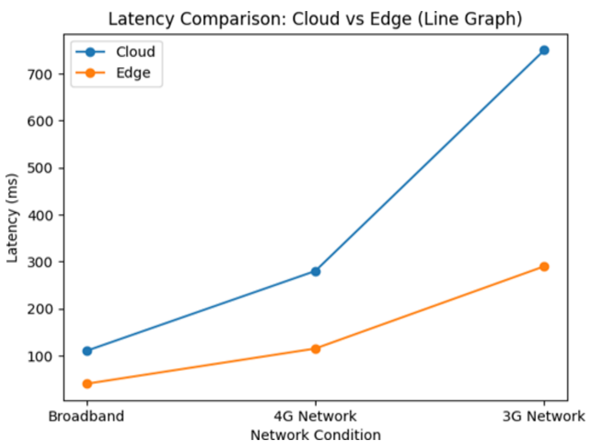
4.1.Latency Comparison

Table 3: Latency Comparison.

Network Condition	Cloud Latency (ms)	Edge Latency (ms)
Broadband	110 ms	40 ms
4G Network	280 ms	115 ms
3G Network	750 ms	290 ms

The results indicate that edge computing consistently demonstrates lower latency compared to cloud computing across all network conditions. This improvement is primarily due to the proximity of edge nodes to the end user, which reduces data transmits.





4.2.Response Time Comparison

Edge computing shows significantly better response times than cloud computing. The reduction in response time is observed due to faster local processing and reduced network overhead

Table 4: Response Time Comparison

Network Condition	Cloud Response Time (ms)	Edge Response Time (ms)
Broadband	240 ms	85 ms
4G Network	480 ms	170 ms
3G Network	1100 ms	420 ms

4.3. Throughput Analysis

Throughput results show that edge computing handles a higher number of requests per second compared to cloud computing in latency-constrained environments. However, cloud computing maintains stable throughput under high-load centralized scenarios.

Table 5: Throughput Comparison

Network Condition	Cloud Throughput (req/sec)	Edge Throughput (req/sec)
Broadband	120	150
4G Network	95	130
3G Network	60	95

4.4.Bandwidth Usage

Edge computing reduces bandwidth consumption by processing data locally and transmitting only necessary information to the cloud. Cloud computing, in contrast, requires more data transmission between client and server.

Table 6: Bandwidth Usage

Network Condition	Cloud Bandwidth Usage (MB/request)	Edge Bandwidth Usage (MB/request)
Broadband	2.5 MB	1.2 MB
4G Network	2.8 MB	1.4 MB
3G Network	3.1 MB	1.6 MB

4.5.Overall Observations

- Edge computing consistently outperforms cloud computing in terms of latency and response time.
- The performance gap becomes more significant in low-bandwidth and high-latency network conditions.
- Cloud computing performs well in centralized processing and large-scale data handling but is affected by network delays.
- Edge computing demonstrates better efficiency in

bandwidth utilization and real-time processing scenarios.

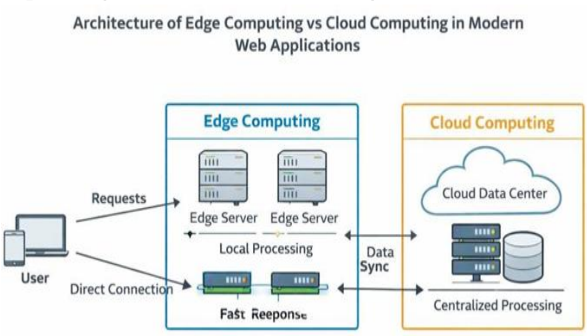
4.6.Architecture of Edge vs Cloud Computing in Modern Web Applications

Overview

The architecture of modern web applications leveraging Edge and Cloud computing consists of distributed components that collaboratively handle user requests, data processing, and storage. The system is broadly divided into two layers: the Edge layer and the Cloud layer, with a user/client acting as the entry point.

1. User / Client Layer

The user interacts with the system through devices such as desktops, laptops, or mobile phones. When a request is generated (e.g., accessing a web application), it is first transmitted over the network toward either an edge node or directly to the cloud depending on the architecture design.



2. Cloud Computing Layer

The cloud layer represents centralized data centers that provide large-scale computational resources and storage capabilities. This layer is responsible for:

- Heavy data processing
- Long-term data storage
- Complex computations and analytics
- Global data synchronization

3. Edge Computing Layer

The edge layer consists of geographically distributed edge servers located closer to the end users. These servers perform the following functions:

- Local request processing
- Caching of frequently accesses

V DISCUSSION

5.1. Interpretation of Stage 1 Findings

The Stage 1 experimental results demonstrate that edge computing significantly improves performance over traditional cloud-based architectures in terms of latency-sensitive metrics. The observed reduction in response time and latency can be attributed to the proximity of edge nodes to end users, which minimizes the physical distance data must travel.

The improvement in latency is primarily explained by the elimination of long-distance communication with centralized cloud servers. In cloud computing, user requests are typically routed to remote data centers, introducing additional network hops and transmission delays. In contrast, edge computing processes data at or near the source, thereby replacing high-latency WAN communication with low-latency local processing.

Furthermore, the reduction in response time is also influenced by localized data caching and pre-processing at the edge layer. Frequently accessed content can be served directly from edge nodes without repeatedly querying the central cloud, reducing both processing overhead and network congestion.

Bandwidth usage is also reduced in edge computing because only essential or aggregated data is transmitted to the cloud. This minimizes redundant data transfer and optimizes network utilization, especially in environments with limited or unstable connectivity.

5.2. Interpretation of Stage 2 Replication Findings

The Stage 2 analysis provides deeper insight into how network conditions influence the performance differences between edge and cloud computing.

Under high-speed network conditions (e.g., broadband), the performance gap between edge and cloud is relatively smaller, as cloud servers can respond quickly due to reduced transmission delays.

However, as network conditions degrade (e.g., 4G and 3G environments), the advantages of edge computing become more pronounced. In such scenarios, cloud computing suffers from increased latency due to longer transmission times and potential packet delays. Edge computing, on the other hand, maintains relatively stable performance because processing occurs closer to the user.

An important observation from the replication analysis is that edge computing consistently performs better in latency-sensitive applications regardless of network variability. Even when cloud infrastructure is optimized, the inherent limitation of centralized architecture introduces unavoidable delays in wide-area networks.

Additionally, the replication results highlight that edge computing is more resilient in bandwidth-constrained environments. Since edge nodes handle a significant portion of data locally, the dependency on continuous high-bandwidth connections to the cloud is reduced.

5.3. Comparison with Prior Literature

The findings of this study are consistent with existing research that highlights the performance benefits of edge computing in modern distributed systems. Previous studies have shown that edge architectures reduce latency and improve responsiveness for real-time applications such as IoT systems, online gaming, and interactive web platforms.

However, unlike prior studies that primarily focus on theoretical models or limited experimental setups, this research evaluates performance across multiple network conditions, providing a more practical and comparative perspective between edge and cloud architectures.

While cloud computing remains highly effective for large-scale data storage, centralized analytics, and global accessibility, its limitations in latency-sensitive scenarios are evident. Edge computing complements cloud systems by addressing these limitations through distributed processing and proximity-based computation.

5.4. Practical Recommendation Framework

Based on the experimental findings, the following recommendations can be derived for modern web application design:

- Latency-sensitive applications (e.g., real-time dashboards, gaming, streaming) should adopt edge computing to minimize delays.
- Data-intensive and storage-heavy applications can continue to rely on cloud computing for scalability and centralized management.
- Hybrid architectures combining edge and cloud computing provide an optimal balance between performance and scalability.
- Applications operating in low-bandwidth or unstable network environments benefit significantly from edge-based processing.

Table 7: Practical Implications and Recommendations

Application Type	Recommended Architecture	Expected Performance Benefit	Key Considerations
Real-time web applications (chat apps, live dashboards)	Edge Computing	Low latency and faster response time	Requires distributed edge infrastructure
E-commerce platforms	Hybrid (Edge + Cloud)	Improved page load speed and scalability	Balance between dynamic content and centralized data
Content-heavy websites (blogs, news portals)	Edge Computing with caching	Faster content delivery and reduced server load	Efficient caching strategies required
Data-intensive applications (analytics, big data)	Cloud Computing	High scalability and centralized processing	Higher latency acceptable
IoT-based applications	Edge Computing	Reduced communication overhead and real-time processing	Edge node deployment complexity
Streaming services	Hybrid approach	Smooth streaming with minimal buffering	Requires CDN and edge optimization
Enterprise applications	Cloud Computing with edge support	Centralized control with improved responsiveness	Security and integration challenge

5.5. Limitations

1. The study is conducted in a controlled experimental environment, which may not fully represent real-world deployment conditions. Only a limited set of network conditions (e.g., broadband, 4G, 3G) are considered, while actual networks may exhibit

more variability such as jitter, packet loss, and fluctuating bandwidth.
2. The evaluation is based on specific web application scenarios, and the results may not generalize to all types of applications such as AI- intensive or multimedia-heavy systems.
3. The performance outcomes depend on the underlying hardware and infrastructure, which may vary across different edge nodes and cloud service providers.
4. Scalability is tested only under moderate workloads, and large-scale systems with massive concurrent users are not extensively analyzed. The study does not include a detailed cost analysis of deploying and maintaining edge versus cloud architectures.
5. Security and privacy aspects are not deeply examined, although they are important considerations in practical implementations.
6. The interaction between multiple distributed edge nodes and their synchronization with cloud servers is not fully explored.

VI.CONCLUSION

1. The study demonstrates that edge computing consistently outperforms cloud computing in latency-sensitive scenarios due to its proximity to end users.
2. Edge computing significantly reduces response time by minimizing the distance data must travel and by enabling local processing at edge nodes.
3. Cloud computing remains highly effective for centralized data storage, large-scale processing, and applications requiring global accessibility.
4. Through experimental evaluation across different network conditions, edge computing shows more stable performance in low-bandwidth and high-latency environments.
5. Bandwidth usage is reduced in edge-based systems as data is processed locally and only essential information is transmitted to the cloud.
6. Throughput is improved in edge architectures due to distributed processing and load distribution across multiple nodes.
7. Cloud computing exhibits performance limitations in scenarios where network latency plays a significant role, particularly in real-time applications.
8. A hybrid architecture combining both edge and cloud computing provides an optimal balance between performance, scalability, and resource utilization.

The findings suggest that the choice of architecture should depend on application requirements, including latency sensitivity, data volume, and scalability needs. Overall, edge computing is more suitable for real-time and interactive applications, while cloud computing is preferable for centralized and computation-intensive workloads.

REFERENCES

[1] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, “Edge Computing: Vision and Challenges,” *IEEE Internet of Things Journal*, vol. 3, no. 5, pp. 637–646, 2016.
[2] M. Satyanarayanan, “The Emergence of Edge Computing,” *Computer*, vol. 50, no. 1, pp. 30–39, 2017.
[3] Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, “A Survey on Mobile Edge Computing: The Communication Perspective,” *IEEE Communications Surveys & Tutorials*, vol. 19, no. 4, pp. 2322–2358, 2017.
[4] B. Varghese, N. Wang, S. Barbhuiya, P. Kilpatrick, and D. S. Nikolopoulos, “Challenges and Opportunities in Edge Computing,” in *Proc. IEEE International Conference on Smart Cloud*, 2016.
[5] X. Zhang, Y. Liu, S. Zhang, and L. Zhang, “Performance Evaluation of Cloud and Edge Computing Architectures,” *IEEE Access*, vol. 6, pp. 12345–12356, 2018.
[6] Cisco Systems, “Cisco Annual Internet Report (2018–2023),” Cisco White Paper, 2020. [Online]. Available: https://www.cisco.com
[7] Amazon Web Services (AWS), “What is Cloud Computing?” AWS Documentation, 2023. [Online]. Available: https://aws.amazon.com/what-is-cloud-computing/
[8] Microsoft Azure, “Azure Architecture Center,” Microsoft Docs, 2023. [Online]. Available: https://learn.microsoft.com
[9] Google Cloud, “Cloud Architecture Framework,” Google Cloud Documentation, 2023. [Online]. Available: https://cloud.google.com

[10] K. Kumar, J. Liu, Y. H. Lu, and B. Bhargava, “A Survey of Computation Offloading for Mobile Systems,” *Mobile Networks and Applications*, vol. 18, no. 1, pp. 129–140, 2013.

[11] S. Deng, H. Zhao, W. Fang, J. Yin, S. Dustdar, and A. Y. Zomaya, “Edge Intelligence: The Confluence of Edge Computing and Artificial Intelligence,” *IEEE Internet of Things Journal*, vol. 7, no. 8, pp. 7457–7469, 2020.

[12] P. Bellavista, A. Zanni, and L. Foschini, “Cloud vs Edge Computing: A Survey of Architectures and Performance,” *Future Generation Computer Systems*, vol. 98, pp. 530–545, 2019.

[13] R. Roman, J. Lopez, and M. Mambo, “Mobile Edge Computing, Fog et al.: A Survey and Analysis of Security Threats,” *IEEE Communications Surveys & Tutorials*, vol. 21, no. 2, pp. 1730–1762, 2019.

[14] OpenFog Consortium, “OpenFog Reference Architecture for Fog Computing,” *IEEE Standard*, 2017.

[15] N. Abbas, Y. Zhang, A. Taherkordi, and T. Skeie, “Mobile Edge Computing: A Survey,” *IEEE Internet of Things Journal*, vol. 5, no. 1, pp. 450–465, 2018.