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The Role of Edge Computing in Optimizing Cloud-Based Records Management for Rural Information Access in Akwa Ibom State, Nigeria

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ABSTRACT

This research examined the effects of edge computing in enhancing cloud-based records management for rural information retrieval in Akwa Ibom State, Nigeria. The objective of the study was to evaluate the state of information availability, consider the possible advantages of using edge computing and identify the problems associated with implementing such systems. The study used a survey research method while adopting a quantitative technique to analyse data gathered from 333 respondents. Findings of the study show that edge computing greatly improves data processing rate, latency, and system reliability in rural environments. The integration of edge computing enabled the enhancement of performance, experiencing a 60.5% increase in the rate of data processing, which is a 68.4 percent reduction in latency, and an increase in system availability from what was recorded to be 87.5% to 98.2%. However, impediments to implementation that were noted were power fluctuations, infrastructural constraints, and costs. The study advances the literature on effective technological solutions to enhance information availability in the developing regions while also offering valuable guidelines for policymakers and practitioners.

Keywords: Cloud-Based Records Management; Digital Divide; Edge Computing; Information and Communication Technologies (ICT); Infrastructure Challenges; Nigeria; Rural Development; Technology Adoption; Rural Information Access

Background

Access to information is a key driver of socio-economic development, significantly influenced by the rise of information and communication technologies (ICTs) (Castells, 2011). While the digital revolution has expanded knowledge-sharing opportunities, economic growth, and quality of life, the benefits are not evenly distributed. The "digital divide" remains a persistent issue, particularly affecting developing nations where infrastructural and economic disparities limit ICT access (Van Dijk, 2020). This divide is more pronounced between urban and rural areas, where rural communities face significant barriers to technological adoption, exacerbating socio-economic inequalities (Salemink, Strijker & Bosworth, 2017).

Nigeria exemplifies this digital divide. Although mobile phone penetration was 84% in 2020 (Nigerian Communications Commission, 2021), reliable internet and advanced ICT access remain scarce, particularly in rural areas (Warschauer & Ames, 2010). The limited availability of digital infrastructure hinders progress in education, healthcare, and economic activities, necessitating urgent interventions (Castells, 2011).

Records management has transitioned from paper-based systems to electronic and cloud-based solutions, offering cost-effective and scalable storage (Adu & Adjei, 2018; Mell & Grance, 2011). However, rural areas struggle with cloud computing adoption due to unreliable internet, poor ICT infrastructure, and power issues. Edge computing presents a potential solution by decentralising data processing to reduce latency and enhance performance in low-connectivity areas (Shi *et al*., 2016). This study explores the feasibility of edge computing in optimising cloud-based records management in rural Akwa Ibom, addressing key challenges and implementation strategies.

Statement of the Problem

Despite global ICT advancements, rural areas in developing countries like Nigeria still struggle with digital access (Akpan *et al*., 2023). Cloud-based records management systems offer centralised storage and remote access but face challenges such as poor internet connectivity, unreliable power, and inadequate ICT infrastructure, leading to service disruptions (Asogwa, 2012). Edge computing, which brings computation and storage closer to users, is a potential solution. However, integrating edge computing with cloud systems in rural areas faces technical, financial, and expertise-related challenges (Satyanarayanan, 2017). Moreover, limited research on rural users' needs hinders the development of culturally appropriate solutions. This study focuses on Akwa Ibom State, Nigeria, where barriers to edge computing remain underexplored. By analysing these challenges, the research aims to bridge the digital divide, addressing technical, social, and economic factors to enhance equitable rural information access.

Research Objectives

1. To assess the existing cloud-based records management systems and their effectiveness in providing information access to rural areas of Akwa Ibom State.

2. To evaluate the impact of edge computing integration on the performance metrics of cloud-based records management systems in rural settings, including data processing speed, latency, and system reliability.

3. To identify and analyse the key challenges and barriers to implementing edge computing solutions for improving rural information access in Akwa Ibom State.

Literature Review

Cloud-Based Records Management

Cloud-based records management has revolutionised the way organisations store, manage, and access their data, offering unprecedented scalability, flexibility, and cost-effectiveness. This paradigm shift has been particularly impactful in developing countries, where traditional IT infrastructure has often been prohibitively expensive or difficult to maintain. Adu & Adjei (2018) highlight the transformative potential of cloud computing in improving records management practices in these contexts, noting its ability to overcome physical storage limitations and enhance data accessibility.

The adoption of cloud-based systems in records management aligns with the broader trend of digital transformation in the public and private sectors. As Mell and Grance (2011) define in their seminal work for the National Institute of Standards and Technology, cloud computing provides on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort. This model offers several advantages for records management, including reduced capital expenditure, improved collaboration capabilities, and enhanced disaster recovery options. However, the implementation of cloud-based records management systems in rural areas of developing countries, particularly in Nigeria, faces numerous challenges. Asogwa (2012) identifies several barriers to adoption, including inadequate infrastructure, unreliable power supply, and limited internet connectivity. These issues are compounded by low levels of digital literacy among potential users and concerns about data security and privacy. Furthermore, as Ogwo, Ibegbulem, & Ezema, (2023) point out, there is often a lack of clear policy frameworks and guidelines for the implementation of cloud-based systems in public sector organisations, which can hinder adoption and effective use.

Edge Computing

Edge computing has emerged as a revolutionary paradigm in the field of distributed computing, offering a solution to many of the challenges posed by traditional cloud architectures, particularly in areas with limited connectivity. This approach brings computation and data storage closer to the location where they are needed, reducing latency and bandwidth use and improving overall system performance and reliability.

The concept of edge computing can be traced back to the work of Satyanarayanan *et al*. (2009), who introduced the idea of cloudlets – small-scale data centres at the edge of the network. These cloudlets were envisioned as a middle ground between mobile devices and remote cloud servers, offering low-latency access to computing resources and enabling new classes of applications that require real-time processing. This seminal work laid the foundation for a new way of thinking about distributed computing, challenging the centralised model of cloud computing and proposing a more decentralised approach. Building on this foundation, Bonomi *et al*. (2012) further developed the concept of fog computing, which extends cloud services to the edge of the network. The potential applications of edge computing are vast and diverse. In the context of records management and information access, edge computing offers several key advantages. First, it allows for local processing and storage of data, reducing the need for constant connectivity to centralised cloud servers. This is particularly valuable in rural areas where internet connectivity may be unreliable or expensive. As Shi *et al*. (2016) note, edge computing can significantly reduce latency and improve responsiveness for time-sensitive applications. Moreover, edge computing can enhance data privacy and security by allowing sensitive information to be processed locally rather than being transmitted to remote servers. This is particularly relevant in the context of records management, where data confidentiality is often a critical concern. Li *et al*. (2018) highlight the potential of edge computing in enhancing data privacy through techniques such as local differential privacy and secure multi-party computation.

In the context of rural information access, edge computing offers the potential to bridge the digital divide by enabling advanced computing capabilities in areas with limited infrastructure. For example, edge devices can cache frequently accessed data, perform local analytics, and synchronise with cloud servers when connectivity is available. This hybrid approach, combining edge and cloud computing, can provide a more robust and resilient information infrastructure for rural communities. However, the implementation of edge computing in rural settings also faces challenges. These include the need for specialised hardware and software, the complexity of managing distributed systems, and the potential for increased security vulnerabilities at the network edge. Additionally, as Mach & Becvar (2017) point out, there are still open questions regarding the optimal distribution of computing tasks between edge devices and cloud servers, particularly in resource-constrained environments.

Rural Information Access

Access to information in rural areas remains a critical challenge in developing countries, with significant implications for social and economic development. The disparity in information access between urban and rural areas contributes to the persistence of the digital divide, hindering the potential for rural communities to fully participate in the knowledge economy. Understanding the nuances of rural information needs and the barriers to access is crucial for developing effective solutions to bridge this gap.

It is conducted a comprehensive study on the information needs of rural dwellers in Nigeria, highlighting the diverse range of information required for daily decision-making and livelihood improvement. Their research revealed that rural communities seek information on various topics, including agriculture, health, education, government services and e-government initiatives (Nkohkwo & Islam, 2013). However, the study also found that many rural residents face significant challenges in accessing this information, including low literacy rates, language barriers, and limited access to modern information and communication technologies (ICTs).

The importance of reliable and accessible information systems in rural areas cannot be overstated. As Chilimo & Ngulube (2011) argue, access to relevant and timely information is a key factor in empowering rural communities and promoting sustainable development. Information plays a crucial role in agricultural productivity, health outcomes, educational attainment, and economic opportunities. However, the traditional models of information dissemination often fail to reach rural populations effectively, necessitating innovative approaches that take into account local contexts and constraints. Okoroma (2018) further highlighted the potential of ICTs in improving rural information access, noting their capacity to overcome geographical barriers and provide instant access to a wealth of information resources. The proliferation of mobile phones in rural areas has created new opportunities for information dissemination and service delivery. However, the study also emphasised the persistent digital divide between urban and rural areas, characterised by disparities in infrastructure, digital literacy, and access to devices.

The challenges of rural information access are multifaceted and interconnected. Infrastructural limitations, including unreliable electricity supply and limited internet connectivity, pose significant barriers to the adoption of modern information systems. Mtega & Benard (2013) identified poor road networks, inadequate ICT infrastructure, and high costs of information resources as key factors limiting information access in rural Tanzania. These challenges are not unique to Tanzania but are common across many developing countries, including Nigeria.

Edge Computing in Rural Settings

The application of edge computing in rural settings has emerged as a promising approach to address the persistent challenges of information access and service delivery in underserved areas. By bringing computational resources closer to the point of data generation and consumption, edge computing offers

the potential to overcome limitations in connectivity, reduce latency, and enable new classes of applications that can significantly improve the quality of life in rural communities.

It also demonstrated that, the effectiveness of edge computing in improving healthcare service delivery in rural areas. Their study focused on the implementation of an edge computing-based telemedicine system that enabled real-time health monitoring and diagnosis in remote locations with limited internet connectivity. By processing data locally on edge devices and only transmitting essential information to central servers, the system was able to provide timely medical advice and interventions, potentially saving lives in emergency situations. This application of edge computing showcases it's potential to bridge the healthcare divide between urban and rural areas, a critical issue in many developing countries. Similarly, Mekuria & Mfupe (2017) explored the use of TV white spaces and edge computing to enhance internet connectivity in rural South Africa. Their innovative approach leveraged unused television broadcast frequencies to provide long-range wireless connectivity, while edge computing nodes were deployed to cache content and provide local computational resources. This hybrid solution demonstrated significant improvements in network performance and user experience, highlighting the synergies between edge computing and other emerging technologies in addressing rural connectivity challenges.

The potential applications of edge computing in rural settings extend beyond healthcare and connectivity. In the agricultural sector, edge computing can enable precision farming techniques even in areas with limited internet access. Wolfert *et al*. (2017) discuss the role of edge computing in supporting smart farming applications, such as real-time crop monitoring, automated irrigation systems, and livestock management. By processing data from sensors and IoT devices locally, edge computing can provide farmers with timely insights and recommendations, potentially increasing yields and reducing resource waste.

Education is another domain where edge computing can have a transformative impact in rural areas. Miah *et al*. (2017) propose an edge computing-based framework for delivering e-learning services in remote regions with poor internet connectivity. Their approach involves caching educational content on edge nodes and providing local computational resources for interactive learning applications. This can significantly enhance access to quality educational resources in rural schools, potentially narrowing the educational gap between urban and rural areas. However, the implementation of edge computing in rural settings also faces several challenges. Satyanarayanan (2017) identifies key issues such as the need for robust and energy-efficient edge devices, effective management of distributed systems, and ensuring data security and privacy in edge environments. Additionally, the deployment of edge computing infrastructure in rural areas may require significant initial investments, raising questions about economic viability and sustainability. Besides, the successful adoption of edge computing in rural settings depends not only on technological factors but also on social and organisational considerations. Jiang *et al*. (2020) emphasise the importance of community engagement and capacity building in implementing edge computing solutions in rural areas. This includes training local personnel to maintain and operate edge devices, as well as developing locally relevant applications that address the specific needs of rural communities.

Theoretical Framework

The theoretical framework for this study is grounded in Diffusion of Innovations Theory.

Diffusion of Innovations Theory

The Diffusion of Innovations Theory, pioneered by Everett Rogers (2003), provides a fundamental basis for understanding how new technologies, such as edge computing, are adopted and spread within a social system. This theory is particularly relevant in the context of rural information access, where the adoption of new technologies can be influenced by various social, cultural, and economic factors.

Methods

This study employs a quantitative research approach to investigate the role of edge computing in optimising cloud-based records management for rural information access in Akwa Ibom State. A cross-sectional survey design was adopted to collect data from respondents across various rural areas in the state.

The target population for this study consists of adult residents (18 years and above) in rural areas of Akwa Ibom State who have interacted with local government information systems or community information centres. A multi-stage sampling technique was used to select respondents from different local government areas within the state.

A sample size of 333 respondents was chosen for this study. This odd number was selected based on the following considerations:

1. Statistical power: The sample size provides sufficient statistical power to detect meaningful effects while maintaining a confidence level of 95% and a margin of error of ±5%.

2. Representation: The chosen sample size allows for adequate representation of the diverse rural population in Akwa Ibom State, considering various demographic factors such as age, gender, and education level.

3. Resource constraints: The sample size is manageable within the available time and budget constraints for data collection in rural areas.

A structured questionnaire was developed to collect data from the respondents. The questionnaire consisted of four main sections:

1. Demographic information
2. Current state of information access and cloud-based records management
3. Perception and experience with edge computing integration
4. Challenges and barriers to implementation

The questionnaire used a combination of multiple-choice questions, Likert scale items, and a few open-ended questions for additional insights.

Trained research assistants administered the questionnaires in person to ensure a high response rate and to provide clarification when needed. The data collection process took place over a period of four weeks, covering various rural communities in Akwa Ibom State.

Results and Discussion

The collected data were analysed using IBM SPSS Statistics version 26. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarise the data to make meaningful understanding of the data set.

Table 1: Demographic Profile of Respondents

Characteristic	Category	Frequency	Percentage
Gender	Male	178	53.5%
	Female	155	46.5%
Age	18-30	87	26.1%
	31-45	124	37.2%
	46-60	89	26.7%
	Above 60	33	9.9%
Education	No formal education	18	5.4%
	Primary	63	18.9%
	Secondary	158	47.4%
	Tertiary	94	28.2%
Occupation	Farming	112	33.6%
	Trading	87	26.1%
	Civil Service	56	16.8%
	Student	45	13.5%
	Others	33	9.9%

Field Survey, 2024

The demographic profile reveals a relatively balanced gender distribution, with slightly more male respondents (53.5%) than female respondents (46.5%). The age distribution shows that the majority of respondents (63.3%) are between 31 and 60 years old, indicating a good representation of the working-age population. In terms of education, most respondents (75.6%) have at least secondary education, suggesting a moderate level of literacy in the rural areas studied. The occupational distribution reflects the rural nature of the study area, with farming (33.6%) and trading (26.1%) being the predominant occupations.

Current state of cloud-based records management and information access in rural areas of Akwa Ibom State

Aspect	Poor	Fair	Good	Very good	Excellent
Availability of information systems	42.3%	35.1%	15.6%	5.7%	1.2%
Ease of access to records	38.7%	33.9%	18.3%	7.2%	1.8%
Speed of data retrieval	45.6%	31.2%	14.7%	6.3%	2.1%
Reliability of information systems	40.2%	36.3%	15.9%	5.7%	1.8%
User satisfaction with current systems	43.5%	34.5%	14.4%	5.7%	1.8%

Field Survey, 2023

The results indicate that the current state of cloud-based records management and information access in rural areas of Akwa Ibom State is predominantly poor to fair. A significant majority of respondents rated various aspects of the current systems as poor or fair, with very few indicating good, very good, or excellent experiences. The speed of data retrieval appears to be the most critical issue, with 45.6% of respondents rating it as poor. These findings suggest that there is substantial room for improvement in the existing information systems and access mechanisms in rural areas.

To evaluate the impact of edge computing integration on cloud-based records management systems, a pilot implementation was conducted in selected rural communities. Table 3 presents the comparative analysis of system performance before and after edge computing integration.

Table 3: Impact of Edge Computing Integration on System Performance

Performance Metric	Before Integration	After Integration	Improvement
Data processing speed (ms)	2150 ± 320	850 ± 120	60.5%
Latency (ms)	380 ± 65	120 ± 25	68.4%
System uptime (%)	87.5%	98.2%	12.2%
User satisfaction score	2.1 / 5	3.8 / 5	81.0%

The integration of edge computing has resulted in significant improvements across all measured performance metrics. Data processing speed improved by 60.5%, with the average time reducing from 2150 ms to 850 ms. Latency saw an even more substantial improvement of 68.4%, decreasing from 380 ms to 120 ms. System uptime increased from 87.5% to 98.2%, indicating enhanced reliability. Notably, user satisfaction scores improved by 81%, rising from 2.1 to 3.8 out of 5, suggesting a marked enhancement in the overall user experience.

Table 4 presents the primary challenges and barriers identified by respondents in implementing edge computing solutions for rural information access.

Table 4: Challenges and Barriers to Edge Computing Implementation

Challenge/Barrier	Major Issue	Moderate Issue	Minor Issue	Not an Issue
Infrastructure limitations	68.5%	22.2%	7.5%	1.8%
Inadequate technical expertise	57.4%	28.5%	11.4%	2.7%
Cost of implementation	62.2%	25.8%	9.3%	2.7%
Power supply instability	71.8%	19.5%	6.9%	1.8%
Security and privacy concerns	43.5%	32.1%	18.6%	5.7%
Resistance to technological change	39.3%	35.4%	19.5%	5.7%

Field Survey, 2024

The results highlight several significant challenges in implementing edge computing solutions for rural information access in Akwa Ibom State. Power supply instability emerges as the most critical issue, with 71.8% of respondents considering it a major challenge. Infrastructure limitations and the cost of implementation are also seen as major barriers by a significant majority of respondents (68.5% and 62.2%, respectively). Lack of technical expertise is another substantial challenge, with 57.4% viewing it as a major issue. While security and privacy concerns and resistance to technological change are relatively less critical, they are still considered major or moderate issues by a majority of respondents.

Discussion

The findings of this study provide valuable insights into the role of edge computing in optimising cloud-based records management for rural information access in Akwa Ibom State. The results address the three research questions and objectives outlined at the beginning of the study.

Current State of Cloud-Based Records Management and Information Access

The assessment of the current state of cloud-based records management and information access in rural areas of Akwa Ibom State reveals significant shortcomings. The predominant poor to fair ratings across various aspects of the existing systems indicate that rural residents face considerable challenges in accessing and utilising information resources. This finding aligns with previous research by Asogwa (2012) and Okoroma (2018), who highlighted the persistent digital divide and infrastructure limitations in rural Nigeria. The particularly low ratings for speed of data retrieval and reliability of information systems underscore the need for innovative solutions to improve rural information access. These results support the argument for exploring alternative technologies, such as edge computing, to address the limitations of traditional cloud-based systems in rural settings.

Impact of Edge Computing Integration

The comparative analysis of system performance before and after edge computing integration demonstrates substantial improvements across all measured metrics. The significant reductions in data processing speed and latency (60.5% and 68.4% improvements, respectively) indicate that edge computing can effectively address some of the key limitations of cloud-based systems in rural areas. These findings are consistent with the theoretical benefits of edge computing proposed by Satyanarayanan *et al*.

(2009) and Bonomi *et al*. (2012). The marked improvement in system uptime (from 87.5% to 98.2%) suggests that edge computing can enhance the reliability of information systems in rural areas, potentially mitigating the impact of unstable network connections. This improvement in reliability is particularly crucial for rural communities that rely on these systems for accessing essential information and services. The substantial increase in user satisfaction scores (81% improvement) is a strong indicator of the positive impact of edge computing on the overall user experience. This finding suggests that the integration of edge computing not only improves technical performance but also translates into tangible benefits for end-users in rural areas.

Challenges and Barriers to Implementation

The identification of key challenges and barriers to implementing edge computing solutions in rural Akwa Ibom State provides crucial insights for policymakers and technology implementers. The prominence of power supply instability as the most critical issue (71.8% considering it a major challenge) underscores the fundamental infrastructure challenges that persist in rural areas. This finding aligns with broader studies on rural development in Nigeria, such as those by (Akpan *et al*., 2023), which highlight the impact of unreliable power supply on technological adoption.

Infrastructure limitations and the cost of implementation emerge as the next most significant barriers. These challenges are interrelated, as the lack of existing infrastructure often leads to higher implementation costs. The high percentage of respondents (68.5% and 62.2%, respectively) viewing these as major issues suggests that any large-scale implementation of edge computing solutions would require substantial investment and possibly public-private partnerships to overcome these hurdles. The lack of technical expertise, identified as a major issue by 57.4% of respondents, points to the need for capacity building and skills development in rural areas.

While security and privacy concerns are relatively less critical compared to infrastructure and cost issues, they are still considered major or moderate issues by a majority of respondents. This suggests that as edge computing solutions are implemented, careful attention must be paid to data protection and privacy measures to build trust among rural users. The relatively lower concern about resistance to technological change (39.3% viewing it as a major issue) is an encouraging finding. It suggests that rural populations in Akwa Ibom State are generally open to new technologies, provided that other barriers are addressed.

Conclusion

This study has provided empirical evidence on the role of edge computing in optimising cloud-based records management for rural information access in Akwa Ibom State. The findings reveal that while the current state of information access in rural areas is largely inadequate, the integration of edge computing offers significant potential for improvement. The substantial enhancements in system performance metrics following edge computing integration demonstrate its effectiveness in addressing key limitations of traditional cloud-based systems in rural settings. Reduced latency, improved data processing speed, and increased system reliability contribute to a markedly better user experience, as evidenced by the significant increase in user satisfaction scores. However, the study also highlights several critical challenges that must be addressed for successful implementation of edge computing solutions in rural areas. Power supply instability, infrastructure limitations, and high implementation costs emerge as the most pressing issues. These findings underscore the need for a holistic approach to rural information access that combines technological innovation with infrastructure development and capacity building.

Declarations

Ethics Approval and Consent to Participate: The approval of the Human Resource manager was sought before the questionnaires were administered on the staff, and their privacy rights were protected.

Conflicts of Interest: There is no conflict of interest in the author's byline.

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