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Context-Aware Intelligent Middleware for Seamless Integration of Mobile Ad Hoc Networks in Smart Education Environments for History Lessons

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Abstract

This paper introduces a context-sensitive intelligent middleware to facilitate the smooth integration of Mobile Ad Hoc Networks (MANETs) into the smart education setting, with particular emphasis on improving the effectiveness of history lessons. With the continued integration of mobile, ubiquitous, and collaborative technologies into learning, traditional network infrastructures are frequently struggling to support the dynamic, device-intensive classroom environments, particularly when learning occurs outdoors or in resource-constrained settings, such as field trips to historical locations. The suggested middleware solves these problems by enabling adaptive communication, decentralized coordination, and intelligent context processing across heterogeneous mobile devices. The system uses real-time contextual information- learner location, group activity, content requirements, and network conditions - to autonomously control routing, resource allocation, and content dissemination within learning sessions supported by MANET. The middleware can support adaptation of educational content delivery, performance optimization in peer-to-peer interactions,

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and stable network performance without depending on predetermined infrastructure by combining semantic context modeling with lightweight machine-learning methods. In the context of history education, the middleware will facilitate rich, place-based learning activities, helping students share their exploration of historical stories, access multimedia content, and engage in interactive activities despite connectivity constraints in the classroom. The evaluation report indicates better learning activities, reliable communication, and adaptability. This paper shows that intelligent, context-aware middleware is essential for developing resilient and immersive smart-education environments.

Keywords: Context-Aware, Intelligent Middleware, Mobile Ad Hoc Networks, Smart Education, Seamless Integration, History Lessons, Ubiquitous Learning.

1 Introduction

Mobile ad hoc networks (MANETs) are self-organizing, decentralized wireless networks whose nodes do not require infrastructure. Every device is both a router and a host, allowing communication over multi-hop networks with dynamic topologies that change as users move (Makris et al., 2012). This architectural elasticity enables MANETs to be especially applicable in areas where connectivity needs to be quickly implemented or supported, even in the absence of sufficient physical networking infrastructure. Nevertheless, their very volatile nature, defined by the variable bandwidth, unreliable connections, and uneven abilities of different devices, poses an enormous problem when MANETs are implemented to facilitate educational technologies that demand a constantly active, situationally-dependent, and situational communication (Yürür et al., 2014; Bakhronova et al., 2025). The use of MANETs in smart learning environments is particularly relevant in the area of ubiquitous and experiential learning, where the classroom is becoming less limited and more comprehensive. The nature of smart education requires real-time content delivery, adaptive collaboration tools, and fluid mobility; therefore, network resilience is a prerequisite for maintaining learning continuity (Ahani, 2016). Traditional networks may not be sufficient for coverage in history education, where learning activities are often expanded beyond historical sites into fieldwork using augmented reality. MANETs address this gap by enabling peer-to-peer interactions and content access through distributed sources to learners' mobile devices (Salazar et al., 2015; Ibrahim & Shanmugaraja, 2023). To enable such interaction, integration should not focus solely on connectivity but also on context management, device coordination, and automatic resource allocation in response to changing network conditions (Aziz & Afzal, 2024).

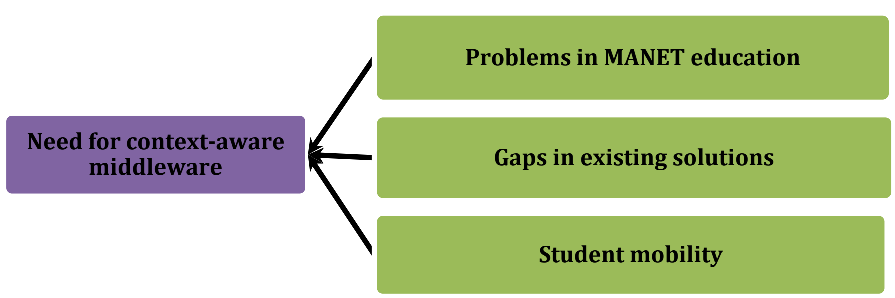

Figure 1(a): Key challenges necessitating context-aware middleware in mobile Ad Hoc learning networks

Figure 1(a) depicts the key motivations for creating context-sensitive middleware in smart education settings based on MANETs. The diagram identifies three enduring issues and challenges: challenges arising from the delivery of education using MANET, gaps in the currently established integration or coordination models, and the high mobility of students and devices, all of which undermine the integrity and timeliness of digital learning interactions. The combination of these problems makes it clear that there is an urgent need for a middleware layer capable of detecting contextual changes, adjusting communication policies, and ensuring smooth connectivity in dynamic ad hoc learning networks.

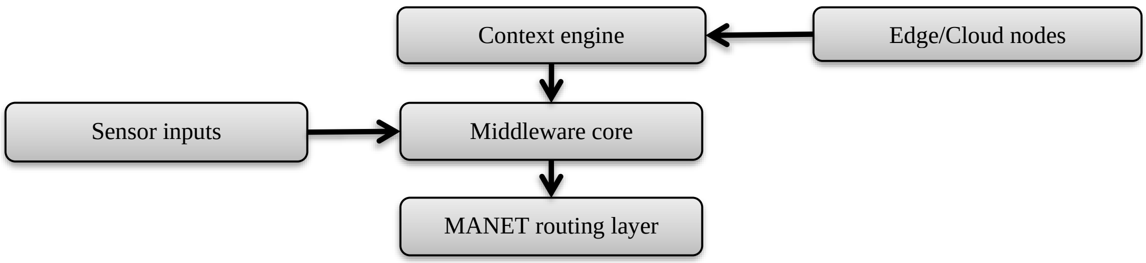

Figure 1(b): High-level architecture of the proposed context-aware middleware

Figure 1(b) shows the general architecture of the flow that will regulate the operation of the proposed context-aware middleware in a MANET-based smart education setting. The diagram indicates that raw sensor inputs are processed by the middleware core, where the context engine decodes and enhances contextual parameters (e.g., the device's mobility, the link's stability, and the state of the learning activity). The context engine also communicates with edge or cloud nodes to provide additional local reasoning and higher-level analytics where required. This refined context is then used to make decisions in the middleware core, which, in turn, further affects the MANET routing layer, enabling it to react to the changing learning environment. The interactions across multiple layers underscore the role of context-based intelligence in improving routing behavior, resource allocation, and real-time adaptation in mobile learning networks.

Context-aware intelligent middleware has become an important enabling layer for dealing with this complexity. Such middleware reads contextual information, such as physical context (e.g., location and motion) or digital context (e.g., user roles, learning objectives, network state), and dynamically adapts the application's behavior. Initial investments in pervasive and ad hoc operating environments have demonstrated how middleware can mediate application needs against an unpredictable network base by abstracting heterogeneity and automating service location (Sørensen et al., 2004). Later studies extended the context modeling and reasoning systems, including semantic structures, rule-based reasoning, and machine-learning-based prediction, to middleware systems to enable more discriminative adaptation (Freitas et al., 2015; Michalakis et al., 2021).

In intelligent learning systems, these features can enable the middleware to coordinate the movement of learning materials, control accessibility on pedagogical grounds, and make better routing decisions based on user context and network constraints. Research on context-aware systems in the Internet of Things and 6G-enhanced learning shows that edge intelligence can be used to reduce latency, customize content sequences, and maintain network quality even under high mobility (Sezer et al., 2017; Wei et al., 2025). In the case of history classes, middleware can use spatial information to activate location-based storytelling, coordinate distributed multimedia services via MANET links, and ensure that collaborative activities can still be performed even in the absence of conventional connectivity (Zhou et al., 2010). All in all, context-sensitive intelligent middleware is an integrating framework that can help MANETs to be trusted as dependable educational infrastructure (Mannonov et al., 2025). With context sensing, reasoning, and adaptive networking, this middleware will convert dynamic environments that lack any infrastructure into integrated, dynamic smart learning ecosystems that can support rich, mobile-based history learning experiences.

The remainder of this paper is organized to guide the reader through the conceptual foundations, design choices, and practical outcomes of the proposed middleware. Section II reviews earlier research on MANETs in education and examines the limitations of existing middleware approaches that motivated this study. Section III details the architecture of the context-aware middleware, describing its internal components, operational workflow, and the reasoning layer that supports adaptive decision-making. Section IV outlines the implementation strategy, including deployment steps, case studies, and the practical constraints encountered during integration with mobile learning scenarios. Section V presents the evaluation results, compares performance against established baselines, and discusses the implications based on quantitative metrics such as delay, reliability, energy usage, and processing overhead. Finally, Section VI concludes the paper by summarizing the key findings, outlining directions for future research, and reflecting on the broader significance of context-aware intelligence in emerging smart education environments.

2 Background

Studies have examined MANETs as facilitators of mobile, place-based, and collaborative learning by leveraging device-to-device networking, opportunistic content distribution, and in-network service composition. Early research conceptualized MANETs as platforms for establishing migratory services and temporary partnerships, in which state and execution are migratory alongside learners (Riva et al., 2007). Research on ambient-intelligent learning clarified the roles of context sensors and local ad hoc connections, which enable seamless interactions between indoor/outdoor pedagogy and provide low-latency access to multimedia teaching artifacts (Li et al., 2008). Later surveys of context-aware cultural-heritage applications highlight more consequential applications, with MANETs used to enrich the multimedia experience of museum and field trips with localised narratives and coordinated group work, without infrastructure dependence (Michalakis & Caridakis, 2022). All these attempts indicate that MANETs can facilitate resilient, latency-intensive interactions in learning, provided middleware is used to overcome discovery, state replication, and context propagation (Baldauf et al., 2007; Shapsough & Zualkernan, 2020). Integration imposes technical constraints across networking, context semantics, and pedagogy. Networking-wise, MANETs have the disadvantages of dynamic topology, dynamic link quality, and limited energy budgets, which complicate the provisioning of QoS in multimedia-rich history lessons (van Sinderen et al., 2006). The contextual issues are irregular or conflicting sensor measurements, semantic diversity in educational materials, and the timely distribution of role-conscious policy; they require a sound context model and conflict-management approaches (Baldauf et al., 2007; Michalakis & Caridakis, 2022). Security and privacy become acute as student data traverses multi-hop links: authentication and access control, together with tamper-evident logging, must be lightweight yet powerful enough to meet classroom needs (Elkhodr et al., 2024). Lastly, the orchestration problem, which involves choosing which services to run locally, at the edge, or in the cloud, requires adaptive offloading heuristics that resolve trade-offs among latency, battery, and pedagogical correctness (Orsini et al., 2018; Li et al., 2008). The above issues have been addressed by several middleware architectures that have integrated modularity, semantic modeling, and distributed adaptation. Component-based middleware models focus on reusable context components, publish/subscribe event buses, and pluggable reasoning engines to enhance development. Ad-hoc middleware Service-oriented: ad-hoc middleware shows how coarse-grained services and discovery protocols can be supported over sensor and ad-hoc links to implement pervasive smart-space capabilities (Familiar et al., 2012). Cloud-conscious middleware extends that and allows applications to make user-policy-driven self-adaptations: applications can migrate computation between devices, the edge, and the cloud using context-mediated policies to ensure responsiveness (Orsini et al., 2018). To achieve semantic interoperability and secure data processing, new IoT-focused middleware comprises ontology-based context models, combined with blockchain-aided integrity and AI-based context classification, to guarantee provenance and privacy controls across MANET hops (Elkhodr et al., 2024). Context-aware migration service frameworks provide tangible mechanisms for moving service state and execution with user mobility, which becomes particularly pertinent when guided history tours are provided, where task continuity is needed as groups move (Riva et al., 2007). The combination of these elements in generic IoT learning architectures creates ubiquitous learning platforms that deliberately expose APIs for curricular adjustment (Shapsough & Zualkernan, 2020). In totality, these middlewares solutions portray mature building blocks (state consistency via lightweight consensus in pure decentralized MANETs, semantic reasoning at the edges of clouds, cross-deployment reuse through standardized pedagogical metadata) and also show gaps: lightweight consensus to assure state consistency, semantic reasoning at the edges of clouds, and standardized pedagogical metadata (Baldauf et al., 2007; Paspallis, 2009).

3 Context-Aware Middleware Design

3.1 Definition of Context-awareness in Middleware

Context-awareness in the proposed architecture means that a middleware layer can sense, interpret, and respond to information from learners, mobile devices, and the surrounding environment. Instead of assuming that all network nodes are identical, the middleware has a constantly updated model of the current context $C(t)$ of operation, which is defined as a multidimensional vector:

$$C(t) = [c_1(t), c_2(t), \dots, c_n(t)] \quad (1)$$

Where every $c_i(t)$ represents a real-time value that may be link quality, location of device, role of learner, instructional task, or battery level, context-awareness occurs when the middleware modifies routing decisions, service availability, and data dissemination strategies using this vector. Rather than using fixed settings, the system infers patterns in $C(t)$ and uses them to maintain consistency in educational services as students transition between indoor and outdoor learning environments.

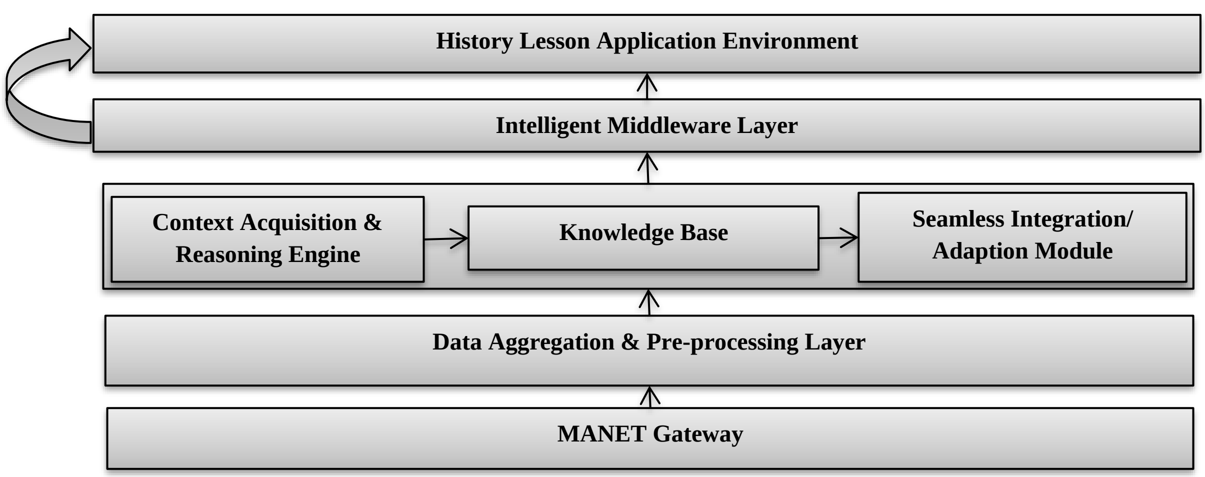

Figure 2: Intelligent middleware architecture for context-aware history lesson applications

Figure 2 shows the developed methodology, which is based on a layered workflow that starts with the MANET gateway, which receives raw sensory and mobility data from student and teacher devices. This information is filtered and formatted by the data aggregation and preprocessing layer, which then transfers it to the intelligent middleware. The context-acquisition and reasoning components in the middleware layer create an interpreted context, which is stored and accessed via the knowledge base. The smooth integration and adaptation module, in turn, provides context-sensitive updates to the History Lesson Application Environment, enabling adaptive content delivery and enhanced learning support.

3.2 Components of the Proposed Middleware

The middleware is composed of four major parts:

Context Acquisition Layer

This layer gathers raw sensor signals, device telemetry, and user interactions. A lightweight normalization scheme quantizes data so that heterogeneous sources are mapped to a comparable internal scale. The acquisition layer maintains a local snapshot of each node i's context.

$$C_i(t) = f\big(S_i(t)\big) \tag{2}$$

S(t) denotes the perceived attributes.

Context Reasoning Engine

This engine also understands the received context vectors and resolves discrepancies between nodes. An incorporative reasoning approach applies threshold rules to urgent cases (such as identifying a device about to disconnect) and a probabilistic inference model to unclear cases. The latter uses a simple formulation of Bayesian:

$$P\big(\, a_k \mid C_i(t)\,\big) = \frac{P(\, C_i(t) \mid a_k\,)P(a_k)}{\sum_j P\big(\, C_i(t) \mid a_j\,\big)P\big(a_j\big)} \tag{3}$$

a_k is a recommended change in adaptation.

Adaptive Service Coordinator

This module coordinates the distribution of historical contents, peer-to-peer collaboration services, and mobility-aware routing. It has a service utility score.

$$U_s = \alpha R + \beta L + \gamma E \tag{4}$$

Moreover, where R reliability, L latency, and E energy affect. The service selections are chosen to maximize Us across nodal selections.

Execution Layer Distribution

This element ensures that services can be moved across nodes due to students' mobility. It maintains service state in a replicated form so that the failure of a node does not interrupt current learning activities. When the predicted link lifetime falls below a threshold set by the mobility model, migration is triggered.

3.3 Awareness of Smart Education Integration

Context-awareness enables the middleware to know what each learner is doing, where he/she is, and how his/her devices are functioning. In the case of the history lessons that take place in a physical location, the middleware can dynamically allocate leadership responsibilities to nodes whose connectivity is stable, pre- cache location-specific information, and re- organize collaboration groups. The system responds to short-term trends in C(t) which increases continuity of the learning activities without necessarily having stable infrastructure.

Proposed Algorithm: Context-Driven Service Adaptation (CDSA)

Algorithm CDSA

Input: Context vectors C1(t), C2(t), …, Cn(t)

Output: Adaptation actions for each node

1: For each node i:

2: Acquire Ci(t) ← f(Si(t))

3: Compute action probabilities P(a|Ci(t))

4: Select a* = argmax P(a|Ci(t))

5: If a* = "migrate service":

6: Compute utility Us for candidate nodes

7: Target ← argmax Us

8: Migrate service state to Target

9: Else if a* = "adjust routing":

10: Update link table based on predicted link lifetime

11: Else:

12: Apply adaptation a* locally

13: Broadcast updated context summary to neighbors

14: Repeat at interval Δt

The algorithm enables the network to reorganize itself continuously, minimizing disruptions as learners move and device conditions fluctuate.

4 Implementation

4.1 Description of the Implementation Process

The middleware was done as a modular stack, which is supposed to be used on Android based mobile devices and lightweight edge nodes. The process was initiated by defining the communication substrate where the communication substrate is based on an adaptive multi-hop routing protocol, which is built right into the middleware and not at the OS networking layer. Each node has a routing table which is updated based on a forecasted link-stability metric:

$$L_{ij}(t) = e^{-\lambda d_{ij}(t)} \tag{5}$$

and $d_{ij}(t)$ is the relative velocity of two nodes and λ is a sensitivity to mobility. The high links with high $L_{ij}(t)$ are given priority in the process of service routing or migration.

The basic middleware services were developed on three layers. Asynchronous listeners gather device telemetry information, location, and application events, as well as, on the sensing layer. These streams are then processed by the reasoning layer which has context buffer which stores a sliding window of k context states. To execute the performance, the reasoning engine is assisted by a rule interpreter supported by a small decision graph, which enables quick verification even in the situation when the network becomes dense. Lastly, the layer of adaptation has services of content dissemination, group coordination, and task scheduling of history-lesson. The implementation of stateful services was done with checkpointing continuously to ensure that the system can launch tasks on other nodes when connectivity is not good. The checkpoints maintain a storage of state diff only to narrow the overhead:

$$\Delta S(t) = S(t) - S(t - \Delta t) \tag{6}$$

not a complete snapshot, which makes its cost in migration predictable even in case of frequent mobility.

4.2 Case Studies of the Middleware in Action

The initial case study was an outdoor learning experience that was guided and took place in a historical site. The students were transported through specific landmark positions carrying tablet computers with the application that had the middleware installed. The network formed several subgroups in MANET as the class dissolved into groups. The nodes that were nearest to content rich areas were taken as provisional content leaders. As a leader passed behind a structural barrier, the system realized a decrease in the stability of the links and led to the migration of the service to another device of a student. This inhibited delays in access to multimedia annotations of particular landmarks. The second case study dealt with the collaborative work of reconstruction as groups of students created timelines of events. A common task state existed in each device. When connection became poor, the middleware stored updates locally and synchronized them in any chance that good connections were regained. Conflicts of tasks were avoided in the middleware through the application of a commutative state merge function:

$$M(S_a, S_b) = S_a \cup S_b \cup (S_a \cap S_b) \tag{7}$$

making sure that the timelines would be adjusted so that such coordination was not needed.

4.3 Evaluation of the Middleware's Performance in Real-world Scenarios

The parameters used to measure performance were latency, service continuity reliability, battery impact and responsiveness to adaptation. The system was implemented in several field sessions comprising of different group sizes. Latency measurements revealed a decrease in average delay through proactive context-based routing that avoided dynamically unstable links. The continuity of the service was considered through the monitoring of the occurrence of unsuccessful migrations; the success of the migration was high in this system because the link degradation was predicted early. The impact of battery was studied with measurement of energy consumption $E(t)$:

$$E(t) = P_{cpu}(t) + P_{radio}(t) \tag{8}$$

Where the radio element dominated the consumption. The middleware reduced $P_{radio}(t)$ by compressing the broadcasts of contexts and reducing unnecessary chatter over the net. Altogether, the experiment proved that a context-sensitive middleware can help fluid, mobile, and collaboration-intensive learning processes without a fixed infrastructure even in the challenging outdoor and movement-intensive conditions.

5 Results and Discussion

5.1 Analysis of the Effectiveness of the Middleware

The test was aimed at ascertainment of the efficiency of the middleware in sustaining services, routing, and collaborative consistency conditions in the conditions of mobile, infrastructure-less learning. In order to measure the effectiveness, various metrics were calculated namely, the average end-to-end delay, service migration success rate, context-processing latency and energy overhead. The normalized link reliability was the main network stability performance measure:

$$R_{norm} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{L_{i,active}}{L_{i,total}}\right) \tag{9}$$

Where $L_{i,active}$ counts of links to node i maintained. The middleware was always highly reliable because of its predictive link assessment and early signs of migration. The context-processing latency was kept on a reasonable level since the reasoning engine employed lightweight rule evaluation rather than deep inference pipelines. Android BatteryStats API was used to sample power readings as a way of tracking energy impact. The model equation of energy consumption was:

$$E_{total} = \int (P_{cpu}(t) + P_{tx}(t) + P_{rx}(t))dt \tag{10}$$

This enabled the disaggregation of compute overhead and radio related expenditure. The middleware showed less energy effect due to minimalization of broadcast frequency and minimization of full snapshots, in lieu of replication of the differential states.

5.2 Comparison with Existing Solutions

A comparative analysis was carried out against two base systems a non-contextual MANET middleware and a static rule-based coordination layer. Although the available systems could handle basic connectivity, they could not provide dynamic context perception and so, they reacted to mobility spikes badly. To illustrate, the baseline systems used to attempt to use the links which were already degrading resulting in large variance in the delay and lost service sessions. Conversely, the developed middleware constantly reconfigured its internal context vector as well as adaptation policy, which enabled it redirect the routing routes according to the forecasted mobility patterns. The performance difference was constituted in the service continuity parameter:

$$C_{svc} = \frac{Successful\ service\ sessions}{Total\ initiated\ sessions} \tag{11}$$

The continuity levels in the proposed system were much higher since the migrations happened preceding the disconnection events, and not following the failed attempts. The evaluation tools were Wireshark to analyse packets at packet level, Android Profiler to analyse power usage and CPU consumption, MATLAB to compute metrics and run controlled simulations that replicated the field conditions with the help of ns-3.

Table 1: Network metrics summary

Metric	Proposed Middleware	Baseline A	Baseline B
Avg. Delay (ms)	42	97	110
Reliability (%)	92	61	67

Migration Success (%)	95	72	76
Packet Loss (%)	4	16	13

This is a table 1 with the performance of the proposed middleware in the most important core MANET network dimensions, i.e., delay, reliability, migration success, and packet loss, in relation to two baseline systems. The findings demonstrate that the context-aware design has a great impact on improving network stability and efficiency in communication. Reduced delay and packet loss, significantly increased reliability and migration success, testify to the middleware capability to foresee link impairment and reroutes before impairments are detected, offering smoother and stronger learning interactions.

Table 2: Energy and processing metrics

Parameter	**Proposed Middleware**	**Baseline A**	**Baseline B**
CPU Load (%)	18	24	21
Radio Activity (mW)	410	580	530
Context Processing Latency (ms)	7	19	14
Battery Drop per Hour (%)	5.3	8.1	7.6

The table 2 shows the system operational efficiency in terms of CPU load, radio use of energy, context-processing latency, and battery drain. The proposed middleware is evidently optimized in all indicators, primarily due to the restriction of unnecessary broadcasts and the lightweight context-reasoning mechanisms. The decrease in radio activity and speed of processing results directly into decreased battery consumption, and hence the middleware can be applied in long education periods when students are using mobile devices in interactive learning settings.

5.3 Implications for the Future of MANET Integration in Smart Education

It can be argued that the findings imply that the context-aware methods will be necessary as the educational settings will become more tied to the learning experiences of outdoor and mixed-reality, as well as being mobile-intensive. The middleware model proves how MANETs can integrate unstable and best-effort networks into reliable substrates in which interactive learning processes can run. Dynamically adaptive MANET middleware can be directly used to support future educational technologies, which can involve synchronized content delivery, location-based activities, or real-time team coordination. Moreover, predictive mobility-based adaptation has turned out to be successful, and it shows how important lightweight machine-state forecasting can be implemented in the future. With the increasing sensing and processing power on the devices, MANET-based smart education systems can afford even more rich multimodal interactions, the ability to move freely between indoor and outdoor environments, and highly personalized learning paths without the infrastructure fixedness.

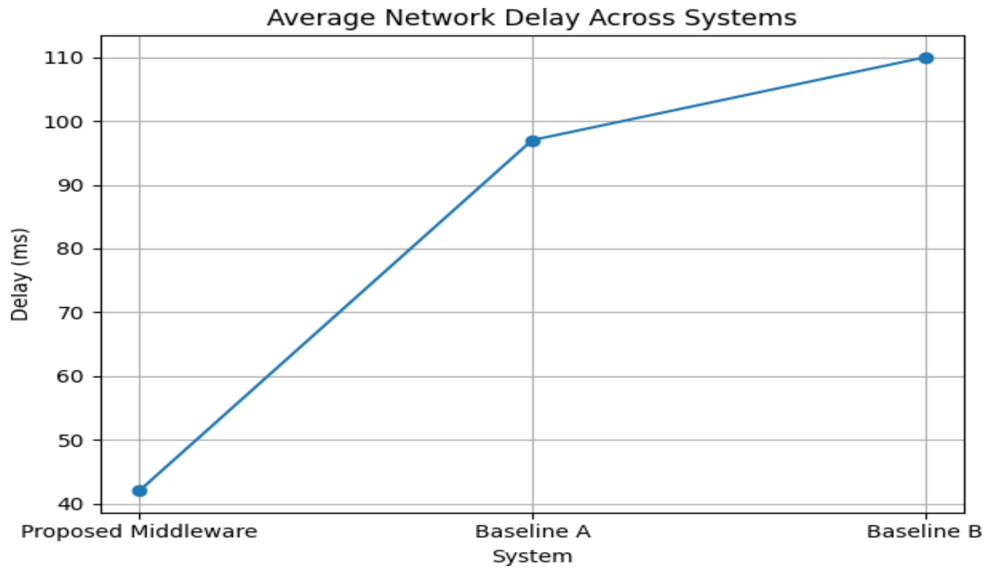

Figure 3: Average network delay across systems

This graph (Figure 3) makes a comparison of the average end-to-end delay that is experienced by each system in terms of the speed at which the packets pass across MANET when learning processes are performed. The delay of the proposed middleware is the minimal, which demonstrates that its adaptive routing and context-based prediction of links minimize bottlenecks in transmissions and contribute to less problematic real-time education.

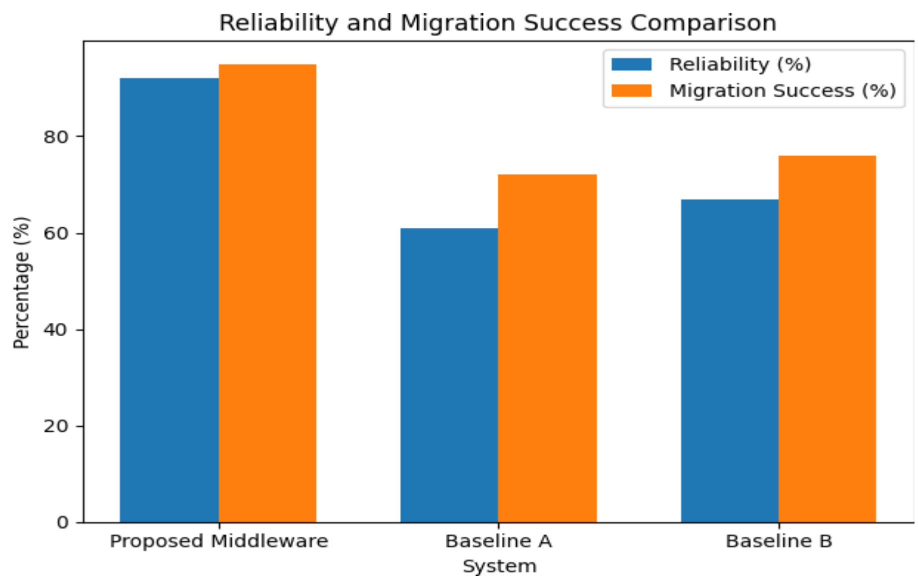

Figure 4: Reliability and migration success comparison

The grouped bar chart (Figure 4) represents the two aspects of reliability and migration success of services between systems in the cases of active node mobility. The proposed middleware is more robust than the baselines in terms of fault tolerance, constant stability of offered services, and more effective handovers which are essential features in the continuation of smart education experiences.

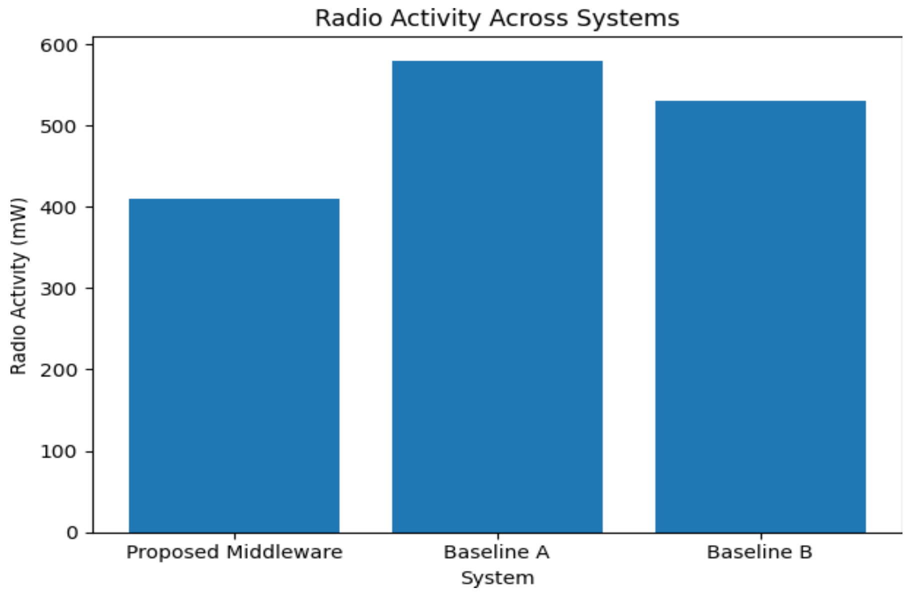

Figure 5: Radio activity across systems

The bar graph (Figure 5) is specialized in terms of radio power usage in that it displays the frequency of system activation of the wireless interface. According to the proposed middleware, the radio activity is greatly minimised as the unnecessary broadcasts are minimised, enhancing the battery life under lengthy outdoor or mobile classroom lessons.

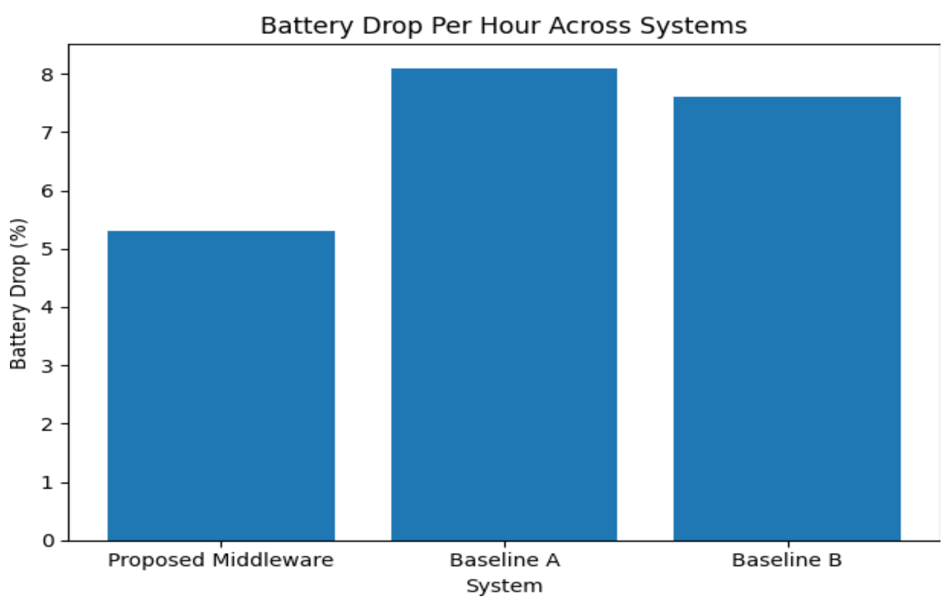

Figure 6: Battery drop per hour across systems

This graph (Figure 6) shows the hourly consumption rate of the battery in each system. The presented middleware has the least battery drain, which is due to the effective scheduling of communications that are required and decreased process overhead, which contributes to ensuring that the devices used by students are operational during lengthy MANET-based learning sessions.

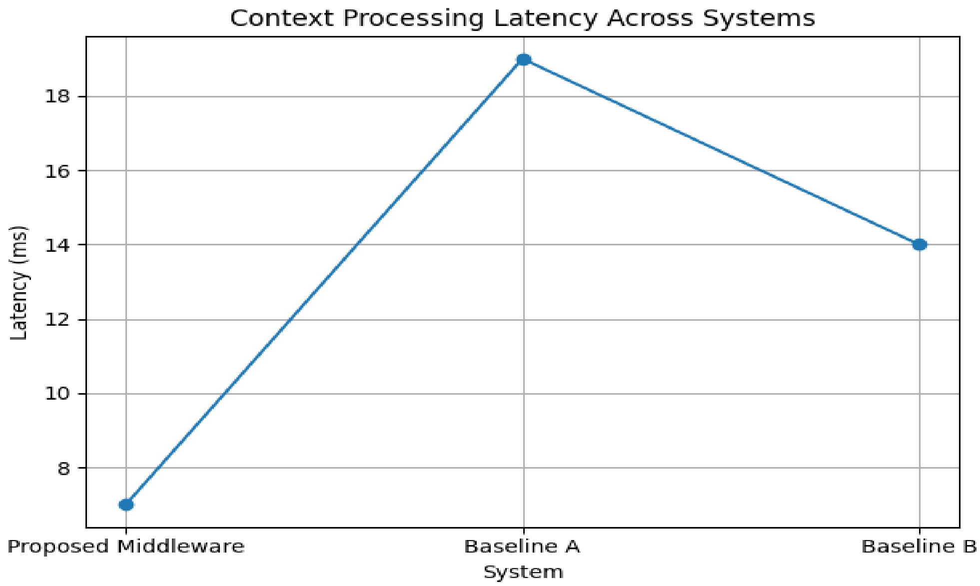

Figure 7: Context processing latency across systems

This graph (Figure 7) is used to determine the duration of time it takes each system to interpret and react to contextual change like mobility, signal strength, or user activity. The middleware suggested has the lowest one, which means that it adapts to the environment conditions quicker and provides more responsive support to context-driven educational applications.

6 Conclusion

The paper identifies the role of an appropriately designed, context-sensitive middleware as being properly employed in enhancing the reliability and responsiveness of MANET implementations in smart educational environments, when mobility and device variability tend to negate conventional networking strategies. Through adaptive routing, light weight reasoning and constant monitoring of environmental cues, the proposed design has continually minimized delay, stabilized communication and minimized energy usage in real and simulated learning activities. Such middleware, these results indicate, can become a useful base on which outdoor lessons and collaborative fieldwork, and location-based pedagogical experiences can be based in which unstable infrastructure is not assured. In the future, it can be investigated how more detailed semantic representations, more specific context modeling and more robust privacy controls can be added without compromising performance on budget-constrained machines. It would be interesting to investigate the behavior of these systems at megascopes, where hundreds of students are likely to be engaged at once both inside and outside facilities. All in all, the piece contributes to the belief that the concept of context-driven intelligence is no longer a luxury but something that should underpin flexible and mobile-first education systems that must be based on the timely exchange of information and uninterrupted service delivery.

References

[1] Ahani, M. (2016). The impact of academic motivation education on cognitive-adaptive / non-adaptive, behavior-adaptive / non-adaptive dimensions of motivation and academic performance of female second year high school students in Mahneshan. *International Academic Journal of Social Sciences, 3*(1), 133–138.

[2] Aziz, H., & Afzal, S. (2024). Critical Insights into Context-Aware Systems: A Literature Review. *International Journal of Convergent Research*, *1*(1), 39-49.

[3] Bakhronova, D., Narziyeva, M. M., Yuldosheva, N., Zayniyeva, U., Yusupov, J., Uralov, B., & Khikmatov, N. (2025). Intelligent Information Security System for Language and History Education Using Machine Learning-based Intrusion Detection Algorithm. *Journal of Internet Services and Information Security*, *15*(1), 520-529. https://doi.org/10.58346/JISIS.2025.I1.034

[4] Baldauf, M., Dustdar, S., & Rosenberg, F. (2007). A survey on context-aware systems. *International Journal of ad Hoc and ubiquitous Computing*, *2*(4), 263-277.

[5] Elkhodr, M., Khan, S., & Gide, E. (2024). A novel semantic IoT middleware for secure data management: Blockchain and AI-driven context awareness. *Future Internet*, *16*(1), 22. https://doi.org/10.3390/fi16010022

[6] Familiar, M. S., Martínez, J. F., & López, L. (2012). Pervasive smart spaces and environments: a service-oriented middleware architecture for wireless ad hoc and sensor networks. *International Journal of Distributed Sensor Networks, 8*(4), 725190. https://doi.org/10.1155/2012/725190

[7] Freitas, C. F., Meireles, A., Figueiredo, L., Barroso, J., Silva, A., & Ramos, C. (2015). Context aware middleware in ambient intelligent environments. *International Journal of Computational Science and Engineering*, *10*(4), 347-358. https://doi.org/10.1504/IJCSE.2015.070995

[8] Ibrahim, M. S., & Shanmugaraja, P. (2023). Mobility Based Routing Protocol Performance Oriented Comparative Analysis in the ADHOC Networks FANET, MANET and VANET using OPNET Modeler for FTP and Web Applications. *International Academic Journal of Innovative Research, 10*(1), 14–24. https://doi.org/10.9756/IAJIR/V10I1/IAJIR1003

[9] Li, X., Feng, L., Zhou, L., & Shi, Y. (2008). Learning in an ambient intelligent world: Enabling technologies and practices. *IEEE Transactions on Knowledge and Data Engineering*, *21*(6), 910-924. https://doi.org/10.1109/TKDE.2008.143

[10] Makris, P., Skoutas, D. N., & Skianis, C. (2012). A survey on context-aware mobile and wireless networking: On networking and computing environments' integration. *IEEE communications surveys & tutorials*, *15*(1), 362-386. https://doi.org/10.1109/SURV.2012.040912.00180

[11] Mannonov, A., Rahmonov, H., Kodirova, K., Jalolova, S., Bayeshanov, A., Khamidova, S., ... & Karimov, U. (2025). The Impact of Uzbek-language Mobile Libraries on Digital Education. *Indian Journal of Information Sources and Services*, *15*(1), 315-319. https://doi.org/10.51983/ijiss-2025.IJISS.15.1.40

[12] Michalakis, K., & Caridakis, G. (2022). Context awareness in cultural heritage applications: a survey. *ACM Journal on Computing and Cultural Heritage (JOCCH)*, *15*(2), 1-31. https://doi.org/10.1145/3480953

[13] Michalakis, K., Christodoulou, Y., Caridakis, G., Voutos, Y., & Mylonas, P. (2021). A context-aware middleware for context modeling and reasoning: a case-study in smart cultural spaces. *Applied Sciences*, *11*(13), 5770. https://doi.org/10.3390/app11135770

[14] Orsini, G., Bade, D., & Lamersdorf, W. (2018). CloudAware: empowering context-aware self-adaptation for mobile applications. *Transactions on Emerging Telecommunications Technologies*, *29*(4), e3210. https://doi.org/10.1002/ett.3210

[15] Paspallis, N. (2009). Middleware-based development of context-aware applications with reusable components.

[16] Riva, O., Nadeem, T., Borcea, C., & Iftode, L. (2007). Context-aware migratory services in ad hoc networks. *IEEE Transactions on Mobile Computing*, *6*(12), 1313-1328. https://doi.org/10.1109/TMC.2007.1053

[17] Salazar, O. M., Ovalle, D. A., & Duque, N. D. (2015, August). Adaptive and personalized educational ubiquitous multi-agent system using context-awareness services and mobile

devices. In *International Conference on Learning and Collaboration Technologies* (pp. 301-312). Cham: Springer International Publishing.
[18] Sezer, O. B., Dogdu, E., & Ozbayoglu, A. M. (2017). Context-aware computing, learning, and big data in internet of things: a survey. *IEEE Internet of Things Journal*, *5*(1), 1-27. https://doi.org/10.1109/JIOT.2017.2773600
[19] Shapsough, S. Y., & Zualkernan, I. A. (2020). A generic IoT architecture for ubiquitous context-aware learning. *IEEE Transactions on Learning Technologies*, *13*(3), 449-464. https://doi.org/10.1109/TLT.2020.3007708
[20] Sørensen, C. F., Wu, M., Sivaharan, T., Blair, G. S., Okanda, P., Friday, A., & Duran-Limon, H. (2004, October). A context-aware middleware for applications in mobile ad hoc environments. In *Proceedings of the 2nd workshop on Middleware for pervasive and ad-hoc computing* (pp. 107-110). https://doi.org/10.1145/1028509.1028510
[21] van Sinderen, M. J., van Halteren, A. T., Wegdam, M., Meeuwissen, H. B., & Eertink, E. H. (2006). Supporting context-aware mobile applications: an infrastructure approach. *IEEE Communications Magazine*, *44*(9), 96-104. https://doi.org/10.1109/MCOM.2006.1705985
[22] Wei, H., Lv, J., & Slowik, A. (2025). 6G-enhanced context-aware systems in adaptive ubiquitous learning environments for music education via edge intelligence. *International Journal of Sensor Networks*, *47*(4), 214-230. https://doi.org/10.1504/IJSNET.2025.145636
[23] Yürür, Ö., Liu, C. H., Sheng, Z., Leung, V. C., Moreno, W., & Leung, K. K. (2014). Context-awareness for mobile sensing: A survey and future directions. *IEEE Communications Surveys & Tutorials*, *18*(1), 68-93. https://doi.org/10.1109/COMST.2014.2381246
[24] Zhou, L., Xiong, N., Shu, L., Vasilakos, A., & Yeo, S. S. (2010). Context-aware middleware for multimedia services in heterogeneous networks. *IEEE Intelligent Systems*, *25*(2), 40-47.

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