

ARCHITECTURAL MODELING AND PERFORMANCE ANALYSIS OF EVENT-DRIVEN REAL-TIME MOBILE SYSTEMS

АРХІТЕКТУРНЕ МОДЕЛЮВАННЯ ТА АНАЛІЗ ПРОДУКТИВНОСТІ ПОДІЄВО-ОРІЄНТОВАНИХ МОБІЛЬНИХ СИСТЕМ РЕАЛЬНОГО ЧАСУ

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Abstract. Purpose. Development of a formal methodology for architectural modeling and performance analysis of event-driven real-time mobile systems, addressing bounded response times, energy minimization, and predictable behavior under resource constraints and dynamic network conditions.

Method. Integration of algebraic modeling, graph-theoretical analysis, and WCET estimation. System formalized as a tuple $\langle E, H, C, T, R \rangle$ representing events, handlers, mappings, temporal constraints, and execution locations. WCRT analysis establishes temporal guarantees: $WCRT(e_i) = \{WCET(h_j) + \Delta_{comm}(h_j) + \Delta_{queue}\}$. AdaptiveEventOffloading algorithm implements multi-criteria optimization for dynamic execution placement.

Results. A comparative analysis of four architectural strategies was conducted: local processing, cloud offloading, edge computing, and adaptive hybrid distribution. Local processing provides the highest determinism but increases energy consumption; cloud offloading reduces device energy but introduces latency variability; edge computing achieves intermediate trade-offs; adaptive hybrid strategies achieve balanced multi-dimensional performance. The WCRT-based analytical evaluation provides provable upper bounds on response time at the design stage without profiling.

Scientific novelty. The study integrates algebraic system specification, WCRT analysis, and graph-based dependency modeling into a unified architectural evaluation framework. An explicit multi-dimensional trade-off model is developed between latency, energy, and determinism within device–edge–cloud hybrid systems. Adaptive execution placement is formalized as a constrained multi-criteria optimization problem. The work proposes a structural shift from implementation-level profiling to architectural-level predictive modeling.

Practical importance. The methodology enables systematic design of event-driven mobile real-time systems through early-stage architectural decisions and supports temporal prediction without full implementation. Application domains include autonomous navigation, augmented reality, intelligent transportation, and telemedicine.

Key words: event-driven architecture; real-time systems; mobile computing; worst-case response time; energy-aware scheduling; edge computing; latency optimization; architectural modeling.

Анотація. Мета. Розробка формальної методології для архітектурного моделювання та аналізу продуктивності подієво-орієнтованих мобільних систем реального часу, що враховує обмежений час відгуку, мінімізацію енергії та передбачувану поведінку за умов обмежених ресурсів та динамічних мереж.

Методика. Інтеграція алгебраїчного моделювання, графо-теоретичного аналізу та оцінки WCET. Система формалізована як кортеж $\langle E, H, C, T, R \rangle$ що представляє події, обробники, відображення, часові обмеження та місця виконання. Аналіз WCRT встановлює часові гарантії: $WCRT(e_i) = \{WCET(h_j) + \Delta_{comm}(h_j) + \Delta_{queue}\}$. Алгоритм AdaptiveEventOffloading реалізує багатокритеріальну оптимізацію для динамічного розміщення виконання.

Результати. Було проведено порівняльний аналіз чотирьох архітектурних стратегій: локальна обробка, розвантаження хмари, периферійні обчислення та адаптивний гібридний розподіл. Локальна обробка забезпечує найвищий детермінізм зі збільшеним споживанням енергії; розвантаження хмари зменшує енергоспоживання пристроїв, але вводить дисперсію затримки; периферійні обчислення досягають проміжних характеристик; адаптивні гібридні стратегії забезпечують збалансовану продуктивність. Аналітична оцінка на основі WCRT забезпечує доведені верхні межі часу відгуку на етапі проектування без профілювання.

Наукова новизна. Досягнуто інтеграції алгебраїчної специфікації системи, аналізу WCRT та моделювання залежностей на основі графів в єдину архітектурну систему оцінки. Розроблено явну багатовимірну систему компромісів між затримкою, енергією та детермінізмом у гібридних системах пристрій-периферія-хмара.

Адаптивне розміщення виконання було формалізовано як проблему обмеженої багатокритеріальної оптимізації. Запропоновано структурний перехід від профілювання на рівні реалізації до прогнозного моделювання на рівні архітектури.

Практична значимість. Методологія забезпечує систематичне проектування подієво-орієнтованих мобільних систем реального часу через архітектурні рішення на ранній стадії та підтримує часове прогнозування без повної реалізації. Прикладні домени: автономна навігація, доповнена реальність, інтелектуальний транспорт, телемедицина.

Ключові слова: подієво-орієнтована архітектура; системи реального часу; найгірший час відгуку; мобільні обчислення; периферійні обчислення; енерго-орієнтоване планування; оптимізація затримки; архітектурне моделювання.

PROBLEM STATEMENT

Mobile real-time systems operating in critical domains (autonomous navigation, augmented reality, intelligent transportation, telemedicine) must simultaneously guarantee bounded response times, minimize energy consumption, and ensure predictable system behavior. Traditional architectural approaches exhibit inherent limitations. Purely local execution leads to increased energy consumption, while cloud offloading introduces network-induced latency variability that compromises temporal predictability. Edge computing introduces additional coordination complexity due to multiple conflicting optimization objectives.

Despite extensive research efforts, a unified and formally grounded methodology for systematic architectural modeling and performance analysis remains insufficiently addressed in the literature, particularly with respect to rigorous analysis of energy–latency–determinism trade-offs in hybrid multi-tier architectures.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Existing research on performance optimization in hybrid cloud–edge real-time systems can be grouped into several major directions.

The first direction focuses on load distribution and energy-aware optimization between cloud and edge infrastructures [1, 6, 19]. These works emphasize energy efficiency and resource allocation but typically address limited performance dimensions in isolation.

The second direction investigates formal methods for timing analysis and real-time verification, including WCET/WCRT modeling and parametric analysis [3, 4, 11, 18]. While these approaches provide rigorous timing guarantees, they often lack explicit integration of energy and adaptive offloading strategies.

The third direction explores model-driven and architectural frameworks for embedded and reactive systems [7, 8, 15, 16]. These studies enhance structural modeling and code generation capabilities but do not fully capture multi-dimensional trade-offs in hybrid multi-tier environments.

Finally, recent works apply AI-based optimization and neural control techniques to dynamic systems [5, 14]. Although promising, such approaches rarely provide formally verifiable guarantees required for safety-critical domains.

Despite substantial contributions across these areas, existing studies remain fragmented and do not provide a unified formal methodology integrating timing determinism, energy modeling, and adaptive architectural decision-making within a single framework.

SEPARATION OF PREVIOUSLY UNRESOLVED PARTS OF THE GENERAL PROBLEM

Despite substantial progress in individual aspects, integration into a unified architectural modeling framework remains fundamentally incomplete. Existing works typically optimize a single performance dimension while treating others merely as constraints rather than co-equal analytical variables. Formal real-time models rarely incorporate explicit energy modeling or dynamic workload allocation strategies. Moreover, model-driven frameworks lack the expressive capability to represent runtime adaptation mechanisms that adjust execution strategies based on battery level, network quality, and workload variability.

RESEARCH OBJECTIVE

The objective of this research is to develop a unified formal methodology for architectural modeling and performance analysis of event-driven real-time mobile systems. The proposed approach integrates algebraic system specification, analytical timing evaluation, and systematic comparison of hybrid execution strategies within device–edge–cloud environments. The methodology supports evidence-based architectural decision-making by explicitly modeling trade-offs between temporal predictability, energy efficiency, and system determinism.

METHODS, OBJECTS

AND SUBJECTS OF RESEARCH

The object of research is event-driven mobile real-time systems operating on resource-constrained platforms.

The subject of research is the formal architectural modeling and analytical evaluation of temporal behavior, energy efficiency, and load distribution strategies in hybrid execution environments.

The research methodology integrates formal algebraic modeling, graph-theoretical analysis of dependency structures, worst-case execution-time estimation, and comparative analytical evaluation of execution strategies across architectural tiers.

MAIN MATERIAL

To enable architectural-level formal analysis, a structured algebraic representation of the system is

introduced. The system is formally represented as a tuple $S = \langle E, H, C, T, R \rangle$, where E is the set of event types, H is the set of event handlers, $C: E \rightarrow 2^H$ maps events to handlers, $T: H \rightarrow \mathbb{R}^+ \cup \infty$ assigns temporal constraints, and $R: H \rightarrow L \times \mathbb{N}$ determines execution location and resource requirements. This formal representation structures architectural decision-making and serves as the analytical foundation for subsequent performance evaluation [1, p. 1; 2, p. 259].

Event-driven systems are characterized by asynchronous event arrival triggering computational reactions. The fundamental challenge is ensuring bounded response time despite uncertainty in arrival patterns [3, p. 41]. Hybrid systems combining time-triggered and event-triggered paradigms enable improved resource utilization while preserving temporal predictability within constrained mobile environments [4, p. 1].

Figure 1 presents the conceptual architecture of hybrid event-driven real-time mobile systems integrating local processing, edge computing, and cloud resources.

The architecture consists of three tiers with adaptive coordinator for event routing decisions. Intelligent task distribution requires monitoring device state, network conditions, and load [6, p. 63].

For handler h_i , define worst-case execution time $WCET(h_i)$ as the maximum time required under worst-case conditions. The formal approach [7, p. 2] provides compositional semantics for temporal properties:

$$WCRT(e_i) = \{WCET(h_i) + \Delta_{comm}(h_i) + \Delta_{queue}\}$$

where $WCRT(e_i)$ denotes worst-case response time, $WCET(h_i)$ denotes handler execution time, $\Delta_{comm}(h_i)$ is communication delay, and Δ_{queue} is queuing delay. This

formulation enables derivation of explicit upper bounds on system response time under constrained resource and dynamic communication conditions. In contrast to empirical profiling approaches, the presented WCRT model provides predictive analytical guarantees at the architectural design stage, allowing quantitative validation of temporal feasibility before implementation.

Model-driven approaches [8, p. 48] enable automated component generation. The MQTT protocol performance analyzed in [9, p. 21] demonstrates variable latency depending on message size and broker load.

Figure 2 depicts an event dependency graph with temporal stages for representative use cases.

Events propagate through stages (t_1 - t_5) with dependencies determining the critical path. WCET analysis methods [10, p. 3] provide bounded prediction through static analysis and profiling. Parametric WCET [11, p. 2] analysis refines upper bounds as a function of input-dependent parameters. Biographical modeling [12, p. 5] supports formal verification of structural and behavioral properties.

The multi-criteria decision logic for adaptive event distribution:

Algorithm: AdaptiveEventOffloading

Input: event e , battery level B , network latency L , cpu load C

Output: location $\in \{\text{LOCAL}, \text{EDGE}, \text{CLOUD}\}$

- 1: $wcet_local \leftarrow \text{EstimateWCET}(e, \text{LOCAL})$
- 2: $wcet_edge \leftarrow \text{EstimateWCET}(e, \text{EDGE}) + \text{NetworkDelay}(L)$
- 3: if IsCritical(e) then
- 4: if $wcet_local \leq \text{Deadline}(e)$ then return LOCAL
- 5: else if $wcet_edge \leq \text{Deadline}(e)$ then return EDGE
- 6: else return LOCAL

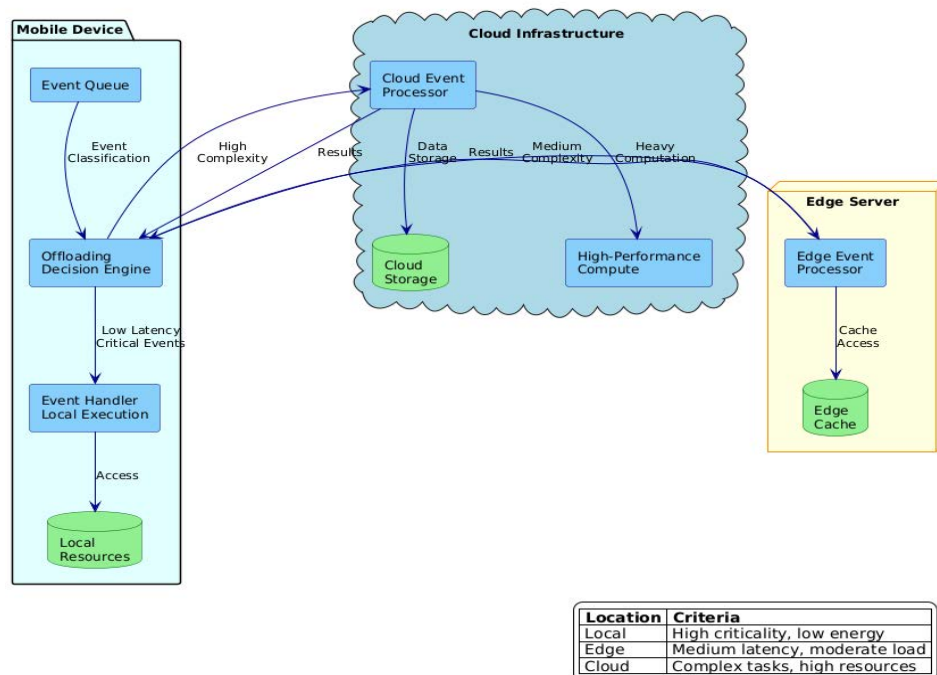


Fig. 1. Hybrid event-driven real-time mobile system architecture with a three-tier execution model

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7: else
8: utility_local  $\leftarrow 1/(\alpha \cdot \text{wcet\_local} +$ 
 $\beta \cdot \text{Energy}(e, \text{LOCAL}, B))$ 
9: utility_edge  $\leftarrow 1/(\alpha \cdot \text{wcet\_edge} +$ 
 $\beta \cdot \text{Energy}(e, \text{EDGE}, B))$ 
10: return  $\text{argmax}\{\text{utility\_local}, \text{utility\_edge}\}$ 

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The weights α and β ($\alpha, \beta > 0$) reflect the relative importance of latency and energy efficiency in the decision process. In practical scenarios, these coefficients may be tuned according to application-specific requirements or quality-of-service policies.

This algorithm implements multi-criteria optimization [13, p. 3]. AI techniques' role in design optimization is analyzed by Casini [14, p. 295]. Formal verification methods [15, p. 2] enable compositional reasoning. MATERIAL framework [16, p. 1] bridges specification and code. Optimization technique selection [14, p. 296] shows MILP provides optimal solutions for small-scale problems. Inter-core timing analysis [17, p. 2] addresses multicore interference. Static analysis specialization [18, p. 492] reduces WCET. Resource-aware allocation [19, p. 2] minimizes latency while respecting QoS.

Theoretical trade-offs between architectural strategies are presented through qualitative comparison based on literature [1; 6; 13].

Figure 3 presents conceptual latency comparison across strategies.

Adaptive hybrid approaches achieve the lowest latency by dynamically selecting the optimal execution location depending on event criticality and device context.

Hybrid approaches achieve intermediate latency between local and remote processing [1, p. 2].

Figure 4 depicts conceptual energy consumption patterns.

Local processing exhibits highest sustained consumption; intelligent offloading reduces device energy [1; 2].

Figure 5 presents a deadline miss rate comparison.

Local execution provides highest determinism; cloud introduces variance; adaptive methods achieve better compliance [3, p. 42; 10, p. 5].

Cloud offloading shows the highest miss rate; local execution shows a moderate miss rate; adaptive methods achieve the lowest miss rate [3, 10].

Table 1 systematizes the theoretical characteristics of architectural approaches.

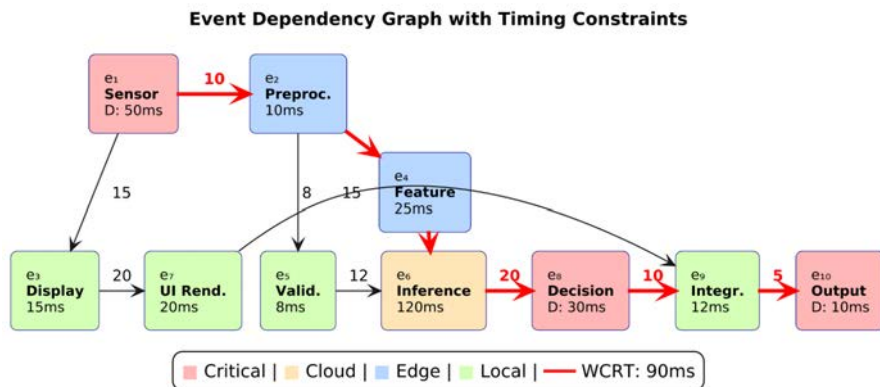


Fig. 2. Event dependency graph with critical path and temporal constraints for real-time processing

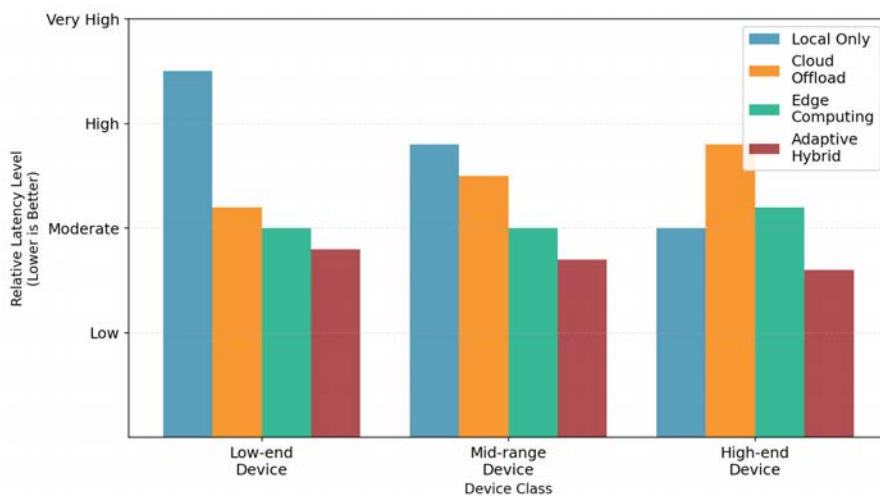


Fig. 3. Conceptual comparison of event processing latency across architectural approaches

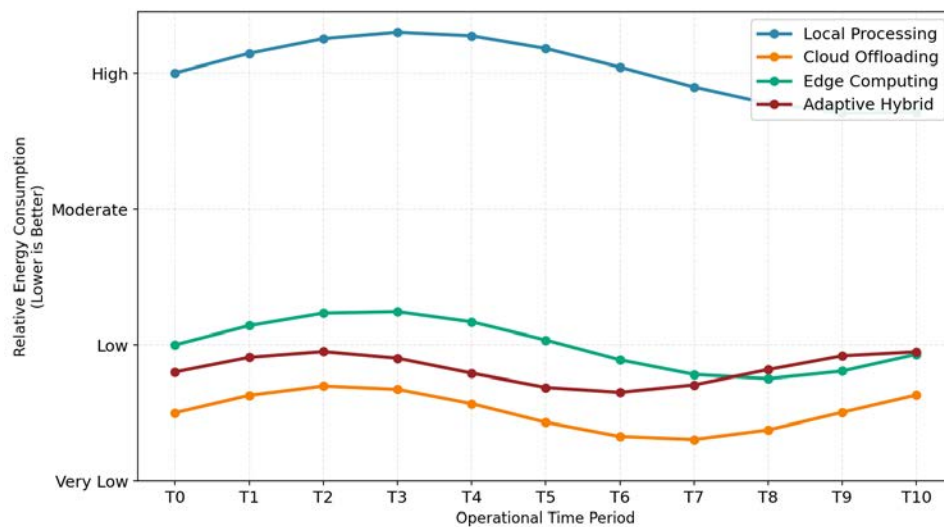


Fig. 4. Conceptual energy consumption profiles for different execution strategies

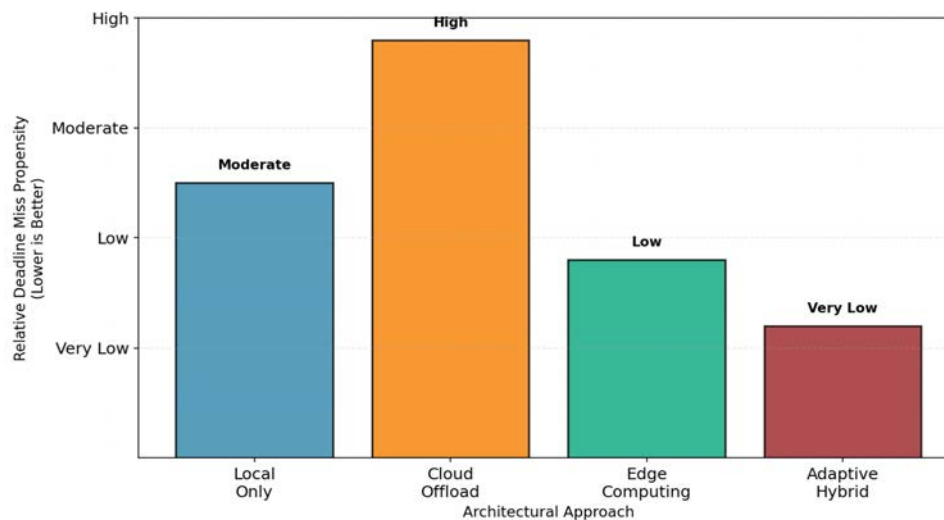


Fig. 5. Conceptual deadline miss rates under varying system load conditions

Table 1. Theoretical comparison of event processing architectures

Approach	Latency	Energy	Determinism	Resilience
Local Only	Variable	High	High	High
Cloud Offload	Variable	Low	Low	Low
Edge	Moderate	Moderate	Moderate	Moderate
Adaptive Hybrid	Context-dependent	Low	Moderate-High	High

No single architectural strategy optimally satisfies all performance criteria simultaneously [1]. Energy–latency trade-offs remain fundamental for battery-constrained devices [2]. Temporal determinism favors local execution in safety-critical scenarios [4].

DISCUSSION OF THE RESULTS

The developed formal model $S = \langle E, H, C, T, R \rangle$ establishes a unified analytical framework for architectural specification of event-driven real-time mobile systems. By explicitly modeling dependencies, temporal constraints,

and execution allocation policies, the approach enables systematic reasoning about performance trade-offs.

WCRT-based analytical evaluation provides provable upper bounds on response time, incorporating handler execution cost, communication latency, and queuing effects. Comparative analysis demonstrates that adaptive hybrid strategies achieve a more balanced compromise across latency, energy efficiency, determinism, and resilience than purely local or purely offloading approaches.

The proposed AdaptiveEventOffloading algorithm operationalizes multi-criteria optimization within runtime decision-making, dynamically selecting execution location based on deadline feasibility and weighted performance utility.

CONCLUSIONS

The presented study establishes a unified formal framework for architectural modeling and performance analysis of event-driven real-time mobile systems under hybrid execution strategies. The integration of algebraic

system specification, event-dependency modeling, and WCRT-based temporal analysis enables predictive architectural-level evaluation without implementation-level profiling. Comparative theoretical analysis confirms that adaptive hybrid strategies provide improved multi-dimensional balance across latency, energy efficiency, determinism, and resilience. Future work should focus on empirical validation under realistic workloads and extension toward probabilistic timing guarantees for soft real-time systems.

REFERENCES

- [1] Kwon, G., & Bahn, H. (2025). Quantifying the effectiveness of cloud and edge offloading: An optimization study on energy efficiency of mobile real-time systems. In *International Conference on Artificial Intelligence in Information and Communication, ICAIIC 2025*, Fukuoka, Japan, February 18-21 (pp. 427-432). <https://doi.org/10.1109/ICAIIIC64266.2025.10920771>
- [2] Pothineni, S. H. (2025). Battery-efficient mobile systems: Design patterns and performance trade-offs. *Journal of Artificial Intelligence General Science (JAIGS)*, 8(1), 258-263. <https://doi.org/10.60087/jaigs.v8i1.388>
- [3] Günzel, M., von der Brüggen, G., & Chen, J.-J. (2024). Tighter Worst-Case Response Time Bounds for Jitter-Based Self-Suspension Analysis. In R. Pellizzoni (Ed.), *36th Euromicro Conference on Real-Time Systems (ECRTS 2024)*, Leibniz International Proceedings in Informatics (LIPIcs), Vol. 298, pp. 4:1–4:24. Schloss Dagstuhl – Leibniz-Zentrum für Informatik. <https://doi.org/10.4230/LIPIcs.ECRTS.2024.4>
- [4] Noroozi, M., & Fidler, M. (2024). Age- and deviation-of-information of hybrid time- and event-triggered systems: What matters more, determinism or resource conservation? *Performance Evaluation*, 164, Article 102412. <https://doi.org/10.1016/j.peva.2024.102412>
- [5] Jiang, B., Karimi, H. R., Wu, Z., & Zhang, X. (2024). Neural quadratic sliding mode control of interconnected Markov jump systems through dynamic event-triggered observers. *Information Sciences*, 669, Article 120609. <https://doi.org/10.1016/j.ins.2024.120609>
- [6] Yu, X., Zhou, S., & Wei, B. (2024). Dependent Task Offloading and Resource Allocation via Deep Reinforcement Learning for Extended Reality in Mobile Edge Networks. *Electronics*, 13(13), Article 2528. <https://doi.org/10.3390/electronics13132528>
- [7] Albalwe, M., Archibald, B., & Sevegnani, M. (2025). Modelling real-time systems with bigraphs (Version 1). *arXiv*. <https://doi.org/10.48550/ARXIV.2505.13449>
- [8] Awan, M. M., Anwar, M. W., Butt, W. H., & Azam, F. (2025). A blended modeling framework for real-time design and verification of safety-critical embedded systems. *PLoS ONE*, 20(12), Article e0337604. <https://doi.org/10.1371/journal.pone.0337604>
- [9] Gentile, A. F., Macri, D., Carni, D. L., Greco, E., & Lamonaca, F. (2024). A Performance Analysis of Security Protocols for Distributed Measurement Systems Based on Internet of Things with Constrained Hardware and Open Source Infrastructures. *Sensors*, 24(9), Article 2781. <https://doi.org/10.3390/s24092781>
- [10] Schoeberl, M., Jellum, E., Lin, S., Jerad, C., Maroun, E. J., Lohstroh, M., & Lee, E. A. (2025). Worst-case performance for real-time systems. *Research Directions: Cyber-Physical Systems*, 3, Article e3. <https://doi.org/10.1017/cbp.2025.1>
- [11] Grebant, S., Ballabriga, C., Forget, J., & Lipari, G. (2024). Parametric WCET as a function of procedure arguments: Analysis and applications. *Journal of Systems Architecture*, 148, Article 103086. <https://doi.org/10.1016/j.sysarc.2024.103086>
- [12] Archibald, B., Sevegnani, M., & Xu, M. (2025). Modelling and verifying BDI agents under uncertainty. *Science of Computer Programming*, 242, Article 103254. <https://doi.org/10.1016/j.scico.2024.103254>
- [13] Li, Y., & Fujita, S. (2024). A synergistic Elixir-EDA-MQTT framework for advanced smart transportation systems. *Future Internet*, 16(3), Article 81. <https://doi.org/10.3390/fi16030081>
- [14] Casini, D. (2025). To MILP or not to MILP? On AI techniques for the design and optimization of real-time systems. *Real-Time Systems*, 61(2), 294-299. <https://doi.org/10.1007/s11241-025-09440-0>
- [15] Adelt, J., Gebker, J., & Herber, P. (2024). Reusable formal models for concurrency and communication in custom real-time operating systems. *International Journal on Software Tools for Technology Transfer*, 26(2), 229-245. <https://doi.org/10.1007/s10009-024-00743-4>
- [16] Becker, M., & Casini, D. (2024). The MATERIAL framework: Modeling and Automatic code Generation of Edge Real-Time Applications under the QNX RTOS. *Journal of Systems Architecture*, 154, Article 103219. <https://doi.org/10.1016/j.sysarc.2024.103219>
- [17] Palomo, X., & Molina, C. (2024). ITER: an ITERative approach for inter-core timing analysis in statically scheduled cyclic executive systems on COTS multicore platforms for CRTES. *The Journal of Supercomputing*, 80(13), 19719-19770. <https://doi.org/10.1007/s11227-024-06208-4>
- [18] Entrup, G., Kässens, A., Fiedler, B., & Lohmann, D. (2024). Applied static analysis and specialization of cross-core syscalls for multi-core AUTOSAR OS. *Real-Time Systems*, 60(3), 491-533. <https://doi.org/10.1007/s11241-024-09429-1>
- [19] Song, I., Tam, P., Math, S., & Kim, S. (2024). Offloading Decision and Resource Allocation in Mobile Edge Computing for Cost and Latency Efficiencies in Real-Time IoT. *Electronics*, 13(7), Article 1218. <https://doi.org/10.3390/electronics13071218>

СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ

- [1] Kwon, G., & Bahn, H. (2025). Quantifying the effectiveness of cloud and edge offloading: An optimization study on energy efficiency of mobile real-time systems. In *International Conference on Artificial Intelligence in Information and Communication, ICAIIC 2025*, Fukuoka, Japan, February 18-21 (pp. 427-432). <https://doi.org/10.1109/ICAIIIC64266.2025.10920771>
- [2] Pothineni, S. H. (2025). Battery-efficient mobile systems: Design patterns and performance trade-offs. *Journal of Artificial Intelligence General Science (JAIGS)*, 8(1), 258-263. <https://doi.org/10.60087/jaigs.v8i1.388>
- [3] Günzel, M., von der Brüggen, G., & Chen, J.-J. (2024). Tighter Worst-Case Response Time Bounds for Jitter-Based Self-Suspension Analysis. In R. Pellizzoni (Ed.), *36th Euromicro Conference on Real-Time Systems (ECRTS 2024)*, Leibniz International Proceedings in Informatics (LIPIcs), Vol. 298, pp. 4:1–4:24. Schloss Dagstuhl – Leibniz-Zentrum für Informatik. <https://doi.org/10.4230/LIPIcs.ECRTS.2024.4>
- [4] Noroozi, M., & Fidler, M. (2024). Age- and deviation-of-information of hybrid time- and event-triggered systems: What matters more, determinism or resource conservation? *Performance Evaluation*, 164, Article 102412. <https://doi.org/10.1016/j.peva.2024.102412>
- [5] Jiang, B., Karimi, H. R., Wu, Z., & Zhang, X. (2024). Neural quadratic sliding mode control of interconnected Markov jump systems through dynamic event-triggered observers. *Information Sciences*, 669, Article 120609. <https://doi.org/10.1016/j.ins.2024.120609>
- [6] Yu, X., Zhou, S., & Wei, B. (2024). Dependent Task Offloading and Resource Allocation via Deep Reinforcement Learning for Extended Reality in Mobile Edge Networks. *Electronics*, 13(13), Article 2528. <https://doi.org/10.3390/electronics13132528>
- [7] Albalwe, M., Archibald, B., & Sevegnani, M. (2025). Modelling real-time systems with bigraphs (Version 1). *arXiv*. <https://doi.org/10.48550/ARXIV.2505.13449>
- [8] Awan, M. M., Anwar, M. W., Butt, W. H., & Azam, F. (2025). A blended modeling framework for real-time design and verification of safety-critical embedded systems. *PLoS ONE*, 20(12), Article e0337604. <https://doi.org/10.1371/journal.pone.0337604>
- [9] Gentile, A. F., Macri, D., Carnì, D. L., Greco, E., & Lamonaca, F. (2024). A Performance Analysis of Security Protocols for Distributed Measurement Systems Based on Internet of Things with Constrained Hardware and Open Source Infrastructures. *Sensors*, 24(9), Article 2781. <https://doi.org/10.3390/s24092781>
- [10] Schoeberl, M., Jellum, E., Lin, S., Jerad, C., Maroun, E. J., Lohstroh, M., & Lee, E. A. (2025). Worst-case performance for real-time systems. *Research Directions: Cyber-Physical Systems*, 3, Article e3. <https://doi.org/10.1017/cbp.2025.1>
- [11] Grebant, S., Ballabriga, C., Forget, J., & Lipari, G. (2024). Parametric WCET as a function of procedure arguments: Analysis and applications. *Journal of Systems Architecture*, 148, Article 103086. <https://doi.org/10.1016/j.sysarc.2024.103086>
- [12] Archibald, B., Sevegnani, M., & Xu, M. (2025). Modelling and verifying BDI agents under uncertainty. *Science of Computer Programming*, 242, Article 103254. <https://doi.org/10.1016/j.scico.2024.103254>
- [13] Li, Y., & Fujita, S. (2024). A synergistic Elixir-EDA-MQTT framework for advanced smart transportation systems. *Future Internet*, 16(3), Article 81. <https://doi.org/10.3390/fi16030081>
- [14] Casini, D. (2025). To MILP or not to MILP? On AI techniques for the design and optimization of real-time systems. *Real-Time Systems*, 61(2), 294-299. <https://doi.org/10.1007/s11241-025-09440-0>
- [15] Adelt, J., Gebker, J., & Herber, P. (2024). Reusable formal models for concurrency and communication in custom real-time operating systems. *International Journal on Software Tools for Technology Transfer*, 26(2), 229-245. <https://doi.org/10.1007/s10009-024-00743-4>
- [16] Becker, M., & Casini, D. (2024). The MATERIAL framework: Modeling and Automatic code Generation of Edge Real-Time Applications under the QNX RTOS. *Journal of Systems Architecture*, 154, Article 103219. <https://doi.org/10.1016/j.sysarc.2024.103219>
- [17] Palomo, X., & Molina, C. (2024). ITER: an ITERative approach for inter-core timing analysis in statically scheduled cyclic executive systems on COTS multicore platforms for CRTES. *The Journal of Supercomputing*, 80(13), 19719-19770. <https://doi.org/10.1007/s11227-024-06208-4>
- [18] Entrup, G., Kässens, A., Fiedler, B., & Lohmann, D. (2024). Applied static analysis and specialization of cross-core syscalls for multi-core AUTOSAR OS. *Real-Time Systems*, 60(3), 491-533. <https://doi.org/10.1007/s11241-024-09429-1>
- [19] Song, I., Tam, P., Math, S., & Kim, S. (2024). Offloading Decision and Resource Allocation in Mobile Edge Computing for Cost and Latency Efficiencies in Real-Time IoT. *Electronics*, 13(7), Article 1218. <https://doi.org/10.3390/electronics13071218>

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