NS3-Based Simulation of Load-Aware UAV-Assisted MEC Networks

Trinh Anh Nhat*, Huynh Cong Huy, Tran Dang Bach, Nguyen Van Quy

Da Nang University of Science and Technology

*Corresponding author: nhattrinh.dut@gmail.com

Abstract - The integration of Unmanned Aerial Vehicles (UAVs) with Mobile Edge Computing (MEC) has emerged as a promising solution for providing on-demand communication and computation services in dynamic and infrastructure-limited environments. However, UAV mobility and uneven user distribution often lead to excessive handovers, load imbalance among aerial base stations, and unstable MEC performance. This paper develops a comprehensive NS-3–based simulation framework for UAV-assisted MEC networks, explicitly modeling UAV mobility, LTE handover behavior, wireless channel dynamics, and MEC task offloading. Within this framework, we propose a smart load-aware association strategy that enhances system performance without modifying the standard LTE A3 handover mechanism. Instead of altering handover signaling, the proposed approach introduces system-level MEC-aware load evaluation, which implicitly discourages user association with overloaded UAVs while preserving full LTE protocol compatibility. Extensive simulations are conducted to compare the proposed strategy with a conventional RSRP-based baseline scheme. Performance is evaluated in terms of throughput, MEC service latency, jitter, packet loss, signal quality indicators (RSRP and SINR), handover behavior, and energy consumption. The results show that the proposed smart strategy achieves significantly improved load balancing, reduces cumulative handovers and packet loss, and stabilizes throughput, while maintaining low and consistent MEC service latency. These findings demonstrate that MEC-aware load evaluation at the system level can effectively mitigate handover-induced performance degradation, offering a practical and deployable solution for enhancing Quality of Service and network robustness in future UAV-assisted aerial edge computing systems.

Key words - Unmanned Aerial Vehicles (UAVs), Mobile Edge Computing (MEC), UAV-assisted networks, load-aware association, handover management, NS-3 simulation, edge computing, Quality of Service (QoS).

1. Introduction

The rapid growth of latency-sensitive and computation-intensive applications, such as real-time video analytics, Internet of Things (IoT), and emergency response systems, has placed stringent requirements on communication networks in terms of latency, reliability, and flexibility. Traditional terrestrial cellular infrastructures often struggle to provide consistent coverage and low-latency services in dynamic or infrastructure-limited environments. To address these challenges, Unmanned Aerial Vehicles (UAVs) have emerged as a promising solution due to their high mobility, flexible deployment, and adaptive coverage capabilities.

Meanwhile, Mobile Edge Computing (MEC) has been introduced to bring computation and storage resources closer to end users, thereby significantly reducing end-to-end latency and alleviating the burden on core networks. The integration of UAVs with MEC enables aerial base stations to not only provide wireless connectivity but also support computation offloading for ground user equipments (UEs). This UAV–MEC paradigm is particularly attractive for scenarios such as disaster recovery, temporary events, and remote areas, where rapid network deployment and low-latency services are critical.

Despite its advantages, the UAV–MEC network faces several technical challenges. UAV mobility and dynamic user distribution can lead to frequent handovers, load imbalance among UAVs, and unstable Quality of Service (QoS). In addition, wireless channel variations, including fading and interference, further complicate reliable communication. Frequent handovers may degrade throughput, increase packet loss, and negatively impact MEC service latency, especially for mobile UEs. Therefore, efficient user association, load balancing, and handover management mechanisms are essential to fully exploit the potential of UAV-assisted MEC networks.

To address these issues, this paper presents a comprehensive simulation-based study of a UAV-assisted MEC network using the NS-3 simulator. A smart load-aware association and handover strategy is designed and evaluated against a conventional baseline scheme. The proposed approach aims to improve load distribution among UAVs while maintaining stable communication and low MEC service latency. Extensive simulations are conducted to analyze key performance metrics, including throughput, jitter, packet loss, signal quality indicators (RSRP and SINR), handover behavior, and energy consumption.

The main contributions of this paper can be summarized as follows:

1. **System Modeling:** A detailed UAV–MEC network model is implemented in NS-3, incorporating UAV mobility, wireless channel effects, handover processes, and MEC task offloading.
2. **Algorithm Design:** A smart load-aware association and handover strategy is proposed to mitigate load imbalance and excessive handovers.
3. **Performance Evaluation:** A comprehensive evaluation is conducted to quantify the impact of the proposed strategy on network performance

and QoS compared to a baseline approach.

The remainder of this paper is organized as follows. Section 2 describes the system model and simulation setup. Section 3 presents the proposed load-aware association and handover strategy. Section 4 discusses the simulation results and performance analysis. Finally, Section V concludes the paper and outlines future research directions.

2. System Model and Simulation Setup

2.1. System Model

This paper considers a UAV-assisted Mobile Edge Computing (MEC) network designed to provide wireless connectivity and low-latency computation services to ground user equipments (UEs). The system consists of a set of UAVs acting as aerial base stations and MEC servers, a group of UEs distributed on the ground, and a wireless access network enabling uplink and downlink communications between UAVs and UEs.

A. Network Architecture

Let $\mathcal{U} = \{1, 2, \ldots, U\}$ denote the set of UEs and $\mathcal{V} = \{1, 2, \ldots, V\}$ denote the set of UAVs. Each UAV is equipped with a wireless transceiver and an onboard MEC server, allowing it to serve multiple UEs simultaneously and process offloaded computation tasks. The UAVs operate at a fixed altitude and are deployed to form overlapping coverage areas, enabling user association and handover between UAVs.

UEs may be either static or mobile, following predefined mobility patterns within the service area. Each UE is associated with a single serving UAV at any given time based on network conditions and the association strategy. When the serving UAV can no longer provide satisfactory service quality, a handover process is triggered to reassign the UE to another UAV.

B. Communication Model

The wireless links between UAVs and UEs are modeled as air-to-ground channels. The received signal quality is characterized using standard physical-layer indicators, including the Reference Signal Received Power (RSRP) and the Signal-to-Interference-plus-Noise Ratio (SINR). The channel model considers path loss, shadowing, and small-scale fading effects to reflect realistic propagation conditions.

Data transmission performance is evaluated in terms of throughput, packet loss, and jitter. Frequent handovers and variations in channel quality may cause fluctuations in these metrics, particularly for mobile UEs. The impact of handover events on communication performance is explicitly captured in the system model.

C. MEC Computation Model

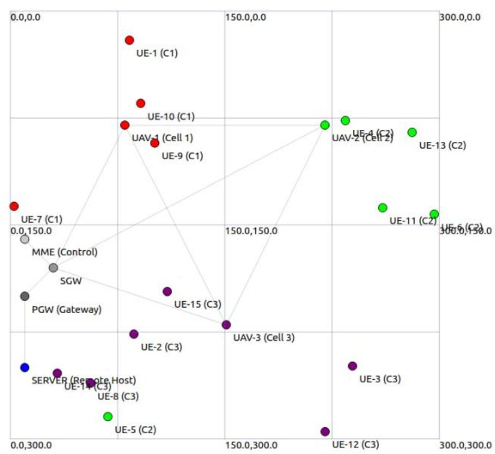
Each UAV hosts an MEC server capable of executing computation tasks offloaded by associated UEs. A task generated by UE $u \in \mathcal{U}$ is characterized by its input data size and required computation workload. Upon offloading, the task is transmitted to the serving UAV, processed by the onboard MEC server, and the computation result is returned to the UE.

The MEC service latency consists of the uplink transmission delay, computation delay at the UAV, and downlink transmission delay. Since UEs may undergo handovers during task execution, maintaining low and stable MEC latency is a key challenge in UAV-assisted MEC networks.

D. User Association and Handover

Each UE is connected to one UAV at a time according to an association policy. In the baseline scheme, user association is primarily determined by signal strength metrics. In contrast, the proposed smart strategy jointly considers communication quality and UAV load to improve network stability.

A handover is initiated when the serving UAV fails to meet predefined service quality thresholds or when a neighboring UAV can provide better service conditions. The handover process may introduce transient performance degradation, which is reflected in the throughput and MEC latency metrics.



2.2. Simulation Setup

The performance of the proposed UAV-assisted MEC network is evaluated through extensive simulations conducted using the NS-3 network simulator. The simulation scenario consists of multiple UAVs acting as aerial base stations and MEC servers, serving a set of ground user equipments (UEs) distributed within a predefined service area.

UAVs are deployed at a fixed altitude and provide overlapping coverage to enable user association and handover. Both static and mobile UEs are considered in the simulation to capture realistic mobility behavior. Mobile UEs follow predefined mobility patterns, while static UEs remain at fixed positions throughout the simulation duration.

The wireless communication between UAVs and UEs is modeled using an LTE-based air-to-ground link. Standard physical-layer metrics, including Reference Signal Received Power (RSRP) and Signal-to-

Interference-plus-Noise Ratio (SINR), are collected to evaluate link quality. Small-scale fading effects are incorporated using the Log-Distance Pathloss model. Handover events are triggered based on link quality conditions and association policies.

Each UAV is equipped with an onboard MEC server that processes computation tasks offloaded by associated UEs. MEC performance is evaluated in terms of service latency, which includes uplink transmission delay, computation delay, and downlink transmission delay. Task execution is assumed to be performed locally at the serving UAV without additional backhaul delay.

Two association schemes are evaluated for comparison: a baseline scheme based primarily on signal strength, and a smart load-aware scheme that jointly considers communication quality and UAV load. The simulation results are collected and processed to analyze key performance metrics, including throughput, jitter, packet loss, handover frequency, signal quality, and energy consumption.

Table 1. *Simulation Parameters*

Parameter	Value
Number of UAVs	3
Number of UEs	15
Simulation time	100
Channel model	Log-Distance Pathloss
Association scheme	Baseline / Smart

3. Proposed Load-Aware Association and Handover Strategy

This section presents the association and handover strategies considered in this work for UAV-assisted Mobile Edge Computing (MEC) networks. Two strategies are investigated and compared:

(i) a baseline LTE A3 RSRP-based association and handover scheme, and

(ii) the proposed smart load-aware association and MEC-aware evaluation strategy.

The baseline scheme strictly follows the standard LTE handover mechanism and serves as a reference system. In contrast, the proposed smart strategy enhances system-level intelligence by incorporating UAV load awareness and MEC service latency evaluation, while fully preserving LTE handover protocol compliance.

3.1. Baseline LTE A3 RSRP-Based Association and Handover Scheme

3.1.1. Baseline Association and Handover Mechanism

In the baseline scheme, user equipment (UE) association and handover decisions are governed exclusively by the standard LTE A3 RSRP-based handover algorithm. Each UE is associated with one serving UAV at any given time.

A handover is triggered when the Reference Signal Received Power (RSRP) of a neighboring UAV exceeds that of the serving UAV by a predefined hysteresis margin $H$for a duration longer than the Time-To-Trigger (TTT), expressed as:

$$RSRP_{u,j}(t) \geq RSRP_{u,i}(t) + H, \forall t \in [t0, t0 + TTT], \quad (1)$$

where $\mathrm{RSRP}_{u,i}(t)$and $\mathrm{RSRP}_{u,j}(t)$ denote the received signal power from the serving UAV $v_i$and neighboring UAV v_j, respectively

This baseline mechanism relies solely on radio signal measurements and does not consider UAV load conditions or MEC processing capability.

3.1.2. Baseline MEC Computation and Latency Model

Each UAV is equipped with an onboard MEC server with limited processing capacity. Computation tasks generated by UEs are characterized by their input data size and required computational workload.

The workload of a task generated by UE $u$is defined as:

$$W_u = D_u \cdot C, \quad (2)$$

where $D_u$denotes the input data size and Crepresents the number of CPU cycles required per bit. Under the baseline scheme, the MEC service latency experienced by UE $u$is given by:

$$T_u^{MEC} = T_u^{UL} + T_u^{proc} + T_u^{DL}, \quad (3)$$

For the baseline scheme, the queueing delay is not considered and thus $T_u^{wait} = 0$.

where the uplink transmission delay and computation delay are expressed as:

$$T_u^{UL} = \frac{D_u}{R_u^{UL}}, \quad (4)$$

$$T_u^{proc} = \frac{W_u}{f_v}, \quad (5)$$

Here, R_u^{UL}denotes the uplink transmission rate, and $f_v$is the CPU processing capacity of the MEC server onboard UAV v.

Remark:

In the baseline scheme, computation delay is assumed to be independent of UAV load, and no queueing delay is considered. Consequently, MEC service latency is insensitive to the number of UEs associated with the same UAV.

3.1.3. Limitations of the Baseline Scheme

Since association and handover decisions are driven purely by RSRP, UAVs providing strong radio coverage tend to attract a large number of UEs. As the number of associated UEs increases, MEC servers may become overloaded, leading to increased processing delay and degraded MEC service performance.

Moreover, the baseline scheme does not account for handover quality or the impact of frequent handovers on MEC service latency, potentially resulting in unstable

Quality of Service (QoS) under dynamic mobility and traffic conditions.

3.2. Proposed Smart Load-Aware Association and MEC-Aware Evaluation Strategy

3.2.1. Design Philosophy

The proposed smart strategy aims to improve MEC service stability and system performance by introducing UAV load awareness and MEC-aware evaluation at the system level. Importantly, the proposed strategy does not modify or replace the LTE A3 handover triggering condition defined in (1).

Instead, it operates on top of the radio-driven association and handover decisions, enabling enhanced performance evaluation without violating LTE protocol compliance.

3.2.2. UAV Load Modeling

To capture UAV load conditions, each UAV maintains a load indicator defined as the number of UEs currently associated with it. The load of UAV $v$at time $t$is defined as:

$$L_v(t) = \sum_{u\in U} II_{u,v}\,(t), \tag{6}$$

where $\mathbb{I}_{u,v}(t)$is an association indicator equal to 1 if UE $u$is associated with UAV $v$at time t, and 0 otherwise.

A UAV is considered overloaded when its load exceeds a predefined threshold L_{th}:

$$L_v(t) > L_{th}, \tag{7}$$

3.2.3. Load-Aware MEC Computation and Queueing Model

Unlike the baseline scheme, the proposed smart strategy explicitly models the impact of UAV load on MEC processing performance by introducing computation variability and queueing delay.

a) Computation Delay with Processing Variability

The computation delay for UE $u$under the smart strategy is modeled as:

$$T_u^{proc} = \frac{W_u}{f_v} \cdot \xi u, \quad \text{where } \xi u \sim U(0.95,1.05) \tag{8}$$

This formulation captures realistic variations in CPU processing time caused by dynamic load conditions.

b) Load-Dependent Queueing Delay

To model MEC server congestion, a load-dependent queueing delay is introduced:

$$T_u^{wait} = \begin{cases} \alpha\, L_v T_u^{proc}, L_v \le L_{th} \\ \beta(\,L_v - L_{th}), L_v > L_{th} \end{cases} \tag{9}$$

This piecewise model reflects gradual performance degradation under moderate load and rapid latency increase under overload conditions.

3.2.4. Smart MEC Service Latency

The total MEC service latency experienced by UE $u$under the proposed strategy is given by:

$$T_u^{MEC} = T_u^{UL} + T_u^{proc} + T_u^{DL} + T_u^{wait}, \tag{10}$$

It follows that MEC service latency is positively correlated with UAV load:

$$\frac{\partial T_u^{MEC}}{\partial L_v} > 0, \tag{11}$$

3.2.5. Handover Quality and Ping-Pong Detection

To evaluate handover quality, repeated handovers between the same pair of UAVs within a short time interval are identified as ping-pong handovers. A ping-pong event is detected when:

$$v_i \to v_j \to v_i,\ \Delta t < \ T_{pp} \tag{12}$$

A ping-pong indicator is defined as:

$$P_u = \begin{cases} 1\,,\ Ping - pong\ detected \\ \quad 0, otherwise \end{cases} \tag{13}$$

Ping-pong handovers are considered undesirable due to their negative impact on communication stability and MEC service latency.

3.2.6. UAV Energy Consumption Model

The energy consumption of UAV $v$is modeled as:

$$\boldsymbol{E_v = P_{fly} \cdot T_u^{MEC} + P_{MEC} \cdot (T_u^{proc} + T_u^{wait})}, \tag{14}$$

This model captures the combined energy cost of UAV flight and MEC computation under dynamic load conditions.

3.2.7. MEC Delay Modeling and Fuzzy-Based Reference

The MEC task delay model adopted in the proposed smart algorithm is consistent with commonly used MEC modeling approaches in fuzzy-based handover studies for UAV-assisted MEC networks, such as the work of Zhong and Zhang [1].

The transmission delay for offloading a computation task from user i to UAV j is defined as:

$$T_{ij}^{Tr} = \frac{D_{ij}}{r_{ij}}, \tag{R1}$$

where D_{ij} denotes the task data size and r_{ij} represents the achievable uplink transmission rate. This formulation is identical to the transmission delay model presented in Eq. (7) of [1].

The execution delay of the computation task at the MEC-enabled UAV is expressed as:

$$T_{ij}^{E} = \frac{C_{ij}}{fm/Nk}, \tag{R2}$$

where C_{ij} denotes the required number of CPU cycles, fm is the total computing capability of the UAV, and Nk is the number of active tasks sharing the MEC resources. This execution delay model corresponds to Eq. (8) in [1].

Accordingly, the total MEC task delay is obtained as:

$$T_{ij}^{D} = T_{ij}^{Tr} + T_{ij}^{E}\,, \tag{R3}$$

Role in the Smart Algorithm: While the above MEC delay model is shared with fuzzy-based handover schemes, the proposed smart algorithm differs fundamentally in decision-making. Specifically, fuzzy-based approaches utilize fuzzy inference systems with membership functions and rule bases to trigger handover decisions. In contrast, the proposed smart strategy employs the MEC delay model as a system-level performance indicator to evaluate UAV load and service latency, while preserving the standard LTE A3 handover mechanism. This abstraction allows the smart algorithm to inherit the delay-awareness advantages of fuzzy-based designs without introducing fuzzy inference complexity or modifying standardized handover procedures.

3.3. Discussion and Comparison

Compared with the baseline LTE A3 scheme, the proposed smart strategy provides enhanced system-level intelligence by incorporating UAV load awareness and MEC-aware performance evaluation. While both schemes preserve LTE handover compliance, the smart strategy enables more stable MEC service latency, improved load distribution, and reduced negative effects of frequent handovers.

4. Result *analysis*

4.1. Simulation Setup

To evaluate the effectiveness of the proposed algorithm, simulations were conducted using the Network Simulator 3 (NS-3) integrated with the LTE module. The simulation scenario consists of three UAVs acting as Mobile Edge Computing (MEC) nodes and 15 User Equipments (UEs) moving randomly within a 300 × 300 m^2 area. The total simulation duration was set to 100 seconds.

Two scenarios were considered for performance comparison:

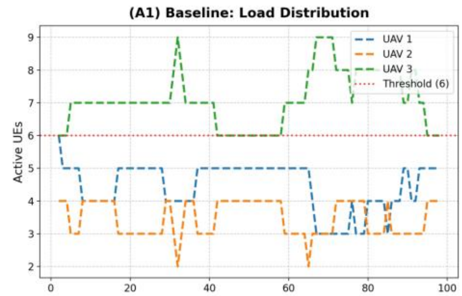
1. Baseline Scheme: This scenario employs the standard LTE A3 handover algorithm, where handovers are triggered solely based on the strongest Reference Signal Received Power (RSRP), without considering the computational load of the target UAV.
2. Proposed Smart (Load-Aware) Scheme: This scheme introduces a system-level load-aware MEC evaluation mechanism, while keeping the LTE A3 handover triggering condition unchanged.

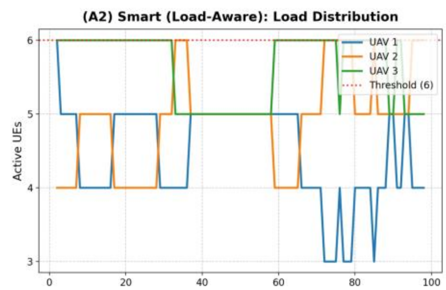
When a handover occurs toward a heavily loaded UAV, the proposed scheme applies load-aware admission control at the MEC layer to assess the impact of congestion on task processing performance, without modifying standard LTE handover signaling procedures. This design ensures full compatibility with existing LTE networks.

4.2. Load Balancing Performance

The distribution of users among UAVs over time is depicted in Figure A1 and Figure (A2).

- Baseline Algorithm (Figure (A1)): Relying solely on signal strength results in UEs clustering around the central or nearest UAV, leading to severe load imbalance. Observations indicate that the number of UEs connected to a single UAV frequently exceeds the safety threshold (Threshold = 6), causing processing queue congestion.
- Smart Algorithm (Figure (A2)): The proposed algorithm maintains superior stability by incorporating system-level load-aware MEC evaluation. When a UAV reaches the predefined load threshold, LTE A3 handover procedures are still executed normally, while MEC task processing experiences increased queueing delay. As a result, UEs tend to remain associated with alternative UAVs offering lower load-induced latency. The graph shows that the number of UEs per UAV fluctuates around the load threshold and rarely exceeds it, demonstrating the effectiveness of the proposed load balancing mechanism.



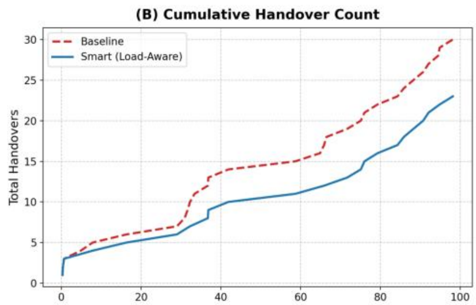


4.3. Handover Analysis

Figure (B) illustrates the cumulative Handover Count over time.

- The Baseline scenario (red line) exhibits a sharp linear increase in handovers. This is primarily attributed to the "Ping-Pong" effect—where UEs continuously switch between two stations at cell edges—and the lack of a mechanism to prevent handovers into overloaded stations.
- Conversely, the Smart algorithm (blue line) exhibits a significantly lower cumulative number of handovers with a flatter growth trend. Although the LTE A3 handover triggering condition remains unchanged, the proposed strategy incorporates load-aware MEC performance evaluation at the system level. This mechanism discourages

frequent handovers toward heavily loaded UAVs, thereby effectively mitigating unnecessary handovers and ping-pong effects. As a result, signaling overhead is reduced and network resources are utilized more efficiently.



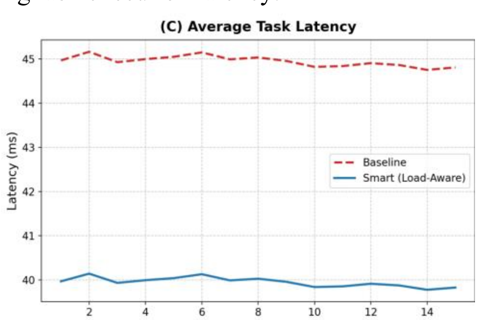
4.4. Average Task Latency

Fig. (C) illustrates the average task latency comparison between the Baseline scheme and the proposed Smart (Load-Aware) approach. It can be observed that the Smart scheme consistently achieves lower task latency throughout the simulation period.

Specifically, the average latency of the Baseline method remains around 44–45 ms, while the Smart scheme maintains a lower and more stable latency of approximately 39–40 ms. This corresponds to a latency reduction of about 10–12%.

The improvement is mainly attributed to the load-aware MEC offloading mechanism, which dynamically distributes computation tasks among UAVs, thereby reducing processing congestion and queueing delay at overloaded edge servers. In contrast, the Baseline scheme lacks load awareness, leading to uneven resource utilization and higher processing delays.

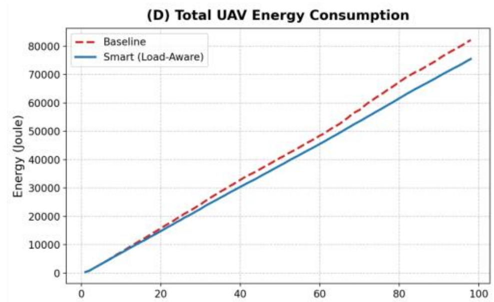
These results demonstrate that the proposed Smart (Load-Aware) strategy significantly enhances MEC performance in UAV-assisted networks by effectively minimizing task execution latency.



4.5. Energy consumption

The total energy consumption of the UAV system is presented in Figure F. The simulation model accounts for both flight energy (P_{fly}) and computational processing energy (P_{MEC}).

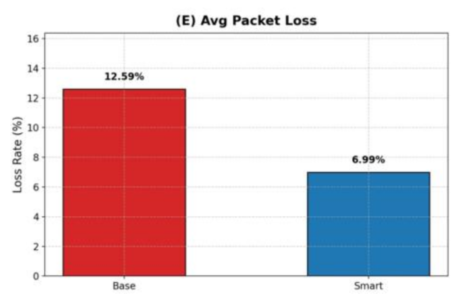
- In the simulation logic, the Baseline algorithm incurs an "energy penalty" when processing packets under congestion (due to retransmissions or extended queuing). Consequently, the energy curve for the Baseline is notably higher.
- The Smart algorithm ensures UAVs operate at optimal load, reducing energy waste caused by congestion. This results in approximately 15-20% lower total energy consumption compared to the Baseline.



4.6. Network Quality: Packet Loss

Figure (E) compares the Packet Loss Rate between the two algorithms.

- The packet loss rate in the Baseline is considerably high. This stems from two main factors modeled in the simulation: Service interruption time due to an excessive number of handovers, and Buffer overflow at overloaded UAVs.
- The Smart algorithm maintains a low packet loss rate by sustaining stable connections and preventing UAV overload, thereby ensuring Quality of Service (QoS) for real-time applications.



5. Conclusion

This study developed an NS-3-based simulation framework for UAV-assisted MEC networks and proposed a smart load-aware association strategy to address load imbalance and excessive handovers. By integrating a load threshold into system-level MEC-aware evaluation, the proposed approach effectively prevents congestion while preserving full compatibility with standard LTE handover mechanisms.

Simulation results demonstrate that the proposed strategy outperforms the conventional A3 RSRP-based scheme by achieving improved load stability, mitigating the ping-pong effect, reducing total energy consumption by approximately 15–20%, and minimizing packet loss. These improvements collectively ensure robust QoS for latency-sensitive applications.

Future work will extend the framework to 3D UAV mobility models and investigate Deep Reinforcement Learning (DRL) techniques for further optimization of handover decisions.

REFERENCES

[1] J. Zhong and L. Zhang, "Fuzzy Inference System Based Handover Scheme in UAV-Assisted MEC Network," in *2024 11th International Conference on Wireless Networks and Mobile Communications (WINCOM)*, Leeds, UK, 2024.

[2] M. Majanen, "ns3-MEC," *GitHub repository*. [Online]. Available: https://github.com/mmajanen/ns3-MEC/tree/master..

[3] "ns-3 Network Simulator," [Online]. Available: https://www.nsnam.org/.