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Evaluation of Intelligent 6G wireless networks with unification of Massive MIMO, mm Wave, and Deep Reinforcement Learning

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Abstract: *The current wireless communication is experiencing rising data rate demands, extremely low latency, and efficient connections in a wide range of applications, which leads to a viable migration from the fifth-generation (5G) communication system to the sixth-generation (6G) system. The paper explores the potential of 6G networks to enhance the speed of data transfer through an analysis of Multi-Input Multi-Output (MIMO), Millimeter Wave (mmWave), and Artificial Intelligence (AI). Massive MIMO increases spectral efficiency with the use of massive arrays of antennas. Using high frequencies that have a large bandwidth, mmWave communication provides speedier communication. Even so, mmWave has to deal with issues due to path loss and blockage of the signal. These will be dealt with using beamforming and AI. In this research work, these limitations are overcome by integrating Deep Reinforcement Learning (DRL) using a Deep Q-Network (DQN), Tools for dynamic management of network resources, to better predict traffic and optimize real-time network slicing. When these technologies work together, the combination will significantly improve networks in 6G networks applications for autonomous systems, immersive virtual and augmented reality, holographic communication, etc. This is done in a hybrid setting where MATLAB/Simulink is used to analyze Massive MIMO and beamforming analysis, and the NS-3 tool is used for the mmWave module to evaluate end-to-end 6G network performance. The outcomes confirm that the proposed 6G framework has a 35 to 40 percent increase in spectral efficiency, and 25-30% decrease in end-to-end latency as compared to a 5G communication system. The results demonstrate that Massive MIMO, mmWave, and DQN-based optimization can be jointly applied to provide a robust architecture that can support new 6G applications, including autonomous vehicles, immersive extended reality, and holographic communications. The research presents the improvements in terms of performance, defines the barriers to the implementation, and suggests the possible solutions, which are a valuable input in the design of intelligent and future-wise wireless networks.*

Keywords: *6G, Massive MIMO, mmWave, Artificial Intelligence, Network Optimization, Beamforming, Channel Estimation, Dynamic Network Slicing, Ultra-Low Latency, High Data Rates, Wireless Communication, Machine Learning*

1. Introduction

The wireless communication has undergone historical improvements, with the first 1G systems being replaced by current 5G systems, and currently, 6G is set to revolutionize the digital world. The 5G wireless technology has already begun to revolutionize the interaction of human beings with each other because it offers ultra-low latency, high-speed internet access, and the ability to support the growing number of people whose devices are connected to the internet [1]. However, the rapid growth of the number of connected devices has rendered the need for more robust and efficient systems extremely sharp. This urgency is the reason why 6G is being developed and will provide data rates of over 100 Gbps, nearly zero latency, and highly reliable communications applications that encompass holographic communications, autonomous systems, and immersive augmented reality [2]. Newer technologies that will take center stage in the pursuit of higher data rates and more dependable communication of the 6G networks include Massive Multiple-Input Multiple-Output (MIMO), millimetre-wave (mmWave) communication, and Artificial Intelligence (AI) optimization of the network [3-4]. High spectral efficiency, capacity, and energy efficiency are made possible by massive MIMO, which involves installing many antennas on the base stations. Such advantages must meet the needs of the 6G systems, according to which billions of devices will have to be connected simultaneously [5-6]. On the same note, mmWave communication with frequencies between 30 and 300 GHz has a gigantic bandwidth in transmitting high-speed information, which is crucial in the rapid communication anticipated in 6G [7]. However, there are certain problems that mmWave technology faces, such as signal dissipation and lower coverage, and to overcome this obstacle, new beam forming solutions and reconfigurable intelligent surface (RIS)-based applications are also designed [8]. As the hardware keeps improving, AI has turned out to be an epochal tool to facilitate network activities. AI algorithms are already applied to the field of dynamic spectrum allocation, interference management, and resource optimization in 5G and beyond [9]. The application of AI will increase with 6G, and the self-organization of the network, self-management of traffic, and adaptation to the changing environment will be possible in real-time. New AI-centered solutions could improve the Quality of Service (QoS), congestion, and diverse requirements of various use cases, which include autonomous cars, smart cities, and the Internet of Things (IoT) [10-11]. Application of AI and, in particular, machine learning has revealed immense potential in addressing the complexity of handling large amounts of data generated by 6G networks, and is expected to be at the heart of the next-generation network architecture [12]. Such technologies, i.e., Massive MIMO, mmWave, and AI, have become indistinguishable to the transition to 5G/6G. Although 5G has enabled communication with an ultra-reliable, low-latency (URLLC) and scale of mobile broadband (eMBB) untapped, 6G will widen the boundary of this technology and make the widespread application of such effects possible, such as holographic telepresence, remote surgery, and collaborative virtual reality over a large distance [13]. The vendor shall introduce the next wave of network optimization and data transmission that might contribute to the rapidly increasing needs of speed, reliability, and scaled requirements as a result of the incorporation of these technologies following wireless communication. Moreover, the development of 6G is not a technological concern only, but also an engineering, regulatory, and social one. These high-tech technologies must be low-cost, energy-efficient, and safe, and that would have to be achieved in a collective action on the part of the industry, academia, and the policy makers. Furthermore, the need to manage the expanded spectrum requirements, provide the confidentiality of data, and maintain the equitable access is the centre stage in 6G development [14]. These concerns will be critical in solving the fact that 6G technologies will be able to ensure a global digital economy, connect, and innovate in a way that nobody had ever imagined. Lastly, the paper discusses the opportunities that Massive MIMO, mmWave communication, and AI-based methodologies bring in the data transmission enhancement of 5G and 6G networks. By studying the stance and role of these technologies and by integrating them, we aim to take a broad-based position on how they can meet the needs of the future wireless communication systems and provide an insight into the potential transformations that 6G can bring to a hyper-connected world.

1.1 Research Objectives

The main goal of this study is to develop and test a machine learning (AI-infused) optimization model that combines Massive MIMO, mmWave communication, and Deep Reinforcement Learning (DRL) that can be used to improve the 6G wireless network. In particular, the framework is designed for:

1. To maximize spectral efficiency when users are dense.
2. To reduce delay-sensitive applications end to end latency.
3. To maximize power and bandwidth use through intelligent power and bandwidth allocation.
4. To increase reliability and Quality of Service (QoS) with dynamic traffic under high mobility loads.
5. The objective function is defined in Eq. A method that maximizes the power allocation, improves bandwidth allocation, and enhances beamforming weights. In (Eq.A) the SE is the spectral efficiency (bits/s/Hz), L is the end to end latency (ms), EE is the energy efficiency (bits/joule), R is the reliability factor, where (P, B, W) are

the vector of (power, bandwidth and beam formation weights), and ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) are the weight factors to balance the trade-off.

$$Max_{(P,\,B,\,W)}\; F = \alpha_1 .\, SE\,(P, B, W) - \alpha_2 .\, L\,(P, B, W) + \alpha_3 .\, EE\,(P, B, W) + \alpha_4 .\, R\,(P, B, W) \quad \text{(A)}$$

1.2 Highlight of Research

The contribution of the research is as follows:

1. **AI-Guided Resource Optimization:** A proposed new DQN-based system of adaptive beamforming, traffic prediction, and real-time network slicing in 6G.
2. **Joint Assessment of Major 6G Enablers:** Gives a combined overview of both Massive MIMO and mm Wave communication, including synergies and trade-offs that can be achieved with AI.
3. **Hybrid Simulation Environment:** Runs the architecture in MATLAB / Simulink to analyse antenna/beamforming and in ns-3 to analyse end-to-end network performance.
4. **Performance Improvements Over 5G:** Provides 35-40 spectral efficiency enhancement, 25-30 latency improvement, and improved reliability under dense conditions relative to current state-of-the-art 5G standards.
5. **Wise Future Networks Roadmap:** Names of challenges (e.g., AI complexity, hardware overhead, dynamic traffic scaling) are identified, and the possible ways of addressing them in real-world applications of 6G are discussed. The working model of the proposed framework is shown in Figure 1

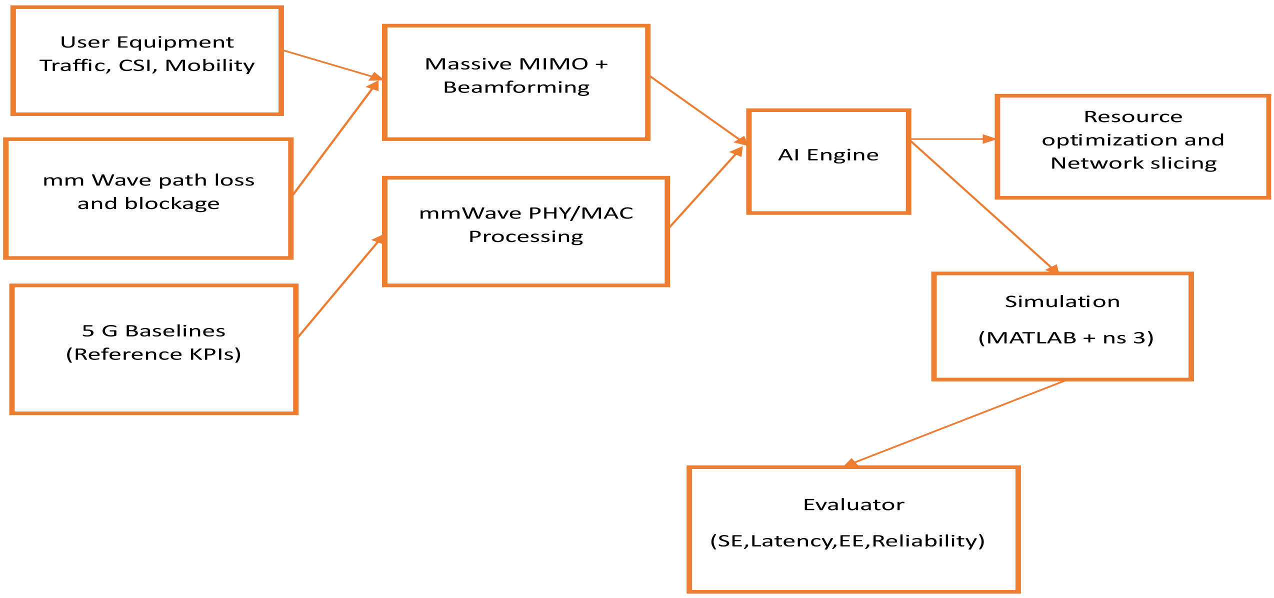

Figure 1: Working model of the proposed framework

2. Literature Review:

2.1 Introduction to 5G and 6G Evolution

The introduction of the novel 6G as the progressive issue of the existing 5G technology is a drastic move in the sphere of wireless communication technologies due to the pressure that it generates regarding the most frequent and high-speed access to it, as well as a mass one. Although 5G has succeeded in achieving the critical provisions such as speedy internet, minimal response time, and handling a vast array of devices simultaneously, it is rather evident that the milestones will not be sustained in the future [15]. It is based on the 6G network building that will already be the enhancement of the 5G building, and another characteristic: higher data rate, near-zero latency, and high reliability will become the expansion of the next-generation technologies, such as holographic communications and remote surgery [16]. The introduction of new technologies, which involve Massive MIMO, millimeter-wave (mmWave) communication, and artificial intelligence (AI)-based network optimization, is the most crucial consideration for the true fulfillment of these high-ambitious ambitions [17]. It can be assumed that the mentioned technologies will contribute greatly to overcoming the shortcomings of 5G, such as spectrum congestion, energy inefficiency, and network capacity [18].

2.2 Massive MIMO for 5G and 6G

Large-scale MIMO has received a lot of interest, as it can enhance network capacity, spectral efficiency, and energy efficiency. In a more traditional MIMO system, base stations have a small number of antennas to cover numerous users. Massive MIMO is, in turn, a method that implies an extremely high number of antennas, hundreds and even thousands, in order to assign a great number of users connected at the same time [19]. This technology enhances spatial diversity, minimizes interferences, and maximizes the net throughput of the system. The high data rates and the low latency of 6G are considered to be achieved through the deployment of massive MIMO systems as one of the prerequisites [20]. This improves the radio waves' beamforming because more antenna arrays are involved, and the antenna arrays used in the forming of the radio waves make them point directionally to the users, which eliminates the wastage of energy. Better yet, cell-free Massive MIMO, where the antennas are spread across a wide area instead of being concentrated at one base station, is likely to provide uninterrupted coverage and high data rates in even the most crowded urban areas [21-

22]. These systems in 6G networks will open the way to better connections, especially regarding mobile broadband application cases and IoT.

2.3 mmWave (6G) Communication.

Among the 6G potential technologies are the mmWave communication that will be used at the frequencies of 30 GHz to 300 GHz. It can have a very high bandwidth compared to standard frequency bands and can be more than 100 Gbps. It is the key to meeting the demands of such applications as virtual reality, self-driving, and ultra-high-definition streaming [23]. Nevertheless, there are also weaknesses of mmWave technology, such as an increased propagation loss, low coverage, and atmospheric sensitivity [24]. The recent studies have tackled these issues through the aid of the developed beamforming methods and the adaptive antenna methods. The beamforming allows narrowing the radio waves down to the targets to reduce the signal attenuation by considerable percentages and emphasize the range [25]. In addition, intelligent Reconfigurable surfaces are another fairly recent technology capable of benefiting mmWave communication because they can be reconfigured. RIS were reflective surfaces that could be programmed to control the exercise of a radio wave to increase or decrease the song force, and to reduce the influences of the objects in the transmission line [26]. The 6G, experts believe, will unify the RIS with mmWave technology and make the communication process safer and more efficient.

2.4. Smart Network Optimization.

AI is a disruptive technology, specifically in streamlining the network with the use of 6G. A network input control and optimization could be an example of AI that can be defined as such, and may be applied to networks that are highly complex, on which the 6G system will be implemented. Such AI assistance can facilitate real-time decisions, tailoring the network to the constantly shifting conditions and the traffic jam, Quality of Service (QoS), and the minimum possible latency [27]. Traffic management, dynamic spectrum allocation, and predictive maintenance are some of the AI applications in 6G. Instead, the AI algorithms could retrieve traffic patterns on a network and could cost less to store in the memory of the resources to make the bandwidth used efficiently by the users [28]. Another possible variant of AI implementation, based on recognition, would be cut into smaller physically distinct virtual networks, which would be scalable to the needs of any of the applications [29]. Moreover, we should note that AI is also involved in the self-organizing network (SON), based on the network of which the faults can be detected, the most optimal network settings are applied, and the network loads can be distributed independently [31].In the context of the future scenario, the 6G network will become fully controlled and will not need human costs due to AI-based solutions and, accordingly, will become even more efficient and cost-effective in its operational work [32].

2.5. 6G Opportunities and Challenges.

In spite of the promising future, 6G has a number of challenges in its realization. A huge increase in the spectrum available is one of the biggest setbacks. The upper frequency bands needed in mmWave communication and other pioneering technologies are not used, and the regulatory bodies need to discover means of using them efficiently [33]. Moreover, the energy consumption of 6G networks is one of the primary issues, as increased data rates, the number of antennas, and base stations will consume disproportions of energy [34]. Also, one should mention the security and privacy focus because the 6G networks are ever more complex. The introduction of AI, cloud computing, and IoT to the 6G systems will probably cause them to be more vulnerable to cyber-attacks, and more secure advanced systems will be necessary to ensure data integrity and user privacy [35]. Moreover, the question of equal access to 6G technologies in developing nations is also a question since the infrastructure to run 6G is expensive and out of technological capacity [36]. Nevertheless, these threats should not imply that 6G lacks great opportunities. On 6G too, billions of devices can be networked, at a level of easy access unparalleled by any other system, and it will enable new applications and industries there, such as advanced medical technologies, smart cities, and autonomous transport [37]. The ramification of the optimization of networks with the introduction of AI is that it will make the optimization of networks more sustainable and feasible, too, and it will duplicate the prospects of 6G systems to the next stage [38-40]. This 5G extension to 6G can be considered the next stage in the evolution of the wireless communications range, and it is capable of changing the environment of industries and society. MIMO network optimization, mmWave, and AI-assisted, fully connected, and streamlined will play a very important role in giving 6G its high aspirations. That said, what is interesting is that there are major concerns that are pursued similarly that must be taken care of, especially when it comes to spectrum management, energy efficiency, and security. This is because it will be a very efficient, autonomous, and scalable network, which will be capable of responding to the demands of applications of future years, but also will invite the breakthrough of innovations in a very wide variety of fields of development when it comes to the research progress in which it develops.

3. Methodology

The research study is based on the qualitative research approach, which presupposes the synthesis of the latest advances in wireless communication technologies, namely, the integration of Massive MIMO, millimeter-wave (mmWave) communication, and AI-assisted network optimization to achieve the enhancement of the data transmission of 5G and 6G systems. It involves the chance to understand the current state of affairs, challenges, and potential remedies in the progression from 5G to 6G and how these technologies may be exploited to meet the drastic demands of the future communication networks.

3.1 System Model and Assumptions

We consider a single cell with a gNB equipped with N_t antennas (ULA/UPA) serving K UEs over mmWave carriers f_c with bandwidth B. The system supports network slices S= {uRLLC,eMBB,mMTC}.

Channel and Blockage:

The narrowband geometric mmWave channel between gNB and user k is defined in Eq. (1-2) and as follows:

$$h_k = \sqrt{\frac{N_t}{L_K}} \sum_{l=1}^{L_K} \alpha_{k,l} a_{t\,(\emptyset k,l)} \text{ where } \alpha_{k,l} \_ CN\,(0,\sigma^2{}_{\alpha}) \quad (1)$$

With L_k paths, array response a_t (·), and **blockage** modeled by a Bernoulli variable $b_k \in \{0,1\}$ (1 = LoS/unblocked):

$$h_k^{eff} = b_k\, h_k + (1-b_k)\eta h_k \qquad 0< \eta<<1 \qquad (2)$$

Beamforming and SINR:

Let $w_k \in C^{N}{}_t$ be the unit-norm precoder for UE k, and p_k the transmit power. The received SINR is given in Eq.3

$$\gamma_k = \frac{p_k \left|h_k^{eff} w_k\right|\left|h_k^{eff} w_k\right|}{\sum_{j>k} p_j \left|h_k^{eff} w_j\right|\left|h_k^{eff} w_j\right| + \sigma_n{}^2} (3)$$

Spectral-, Energy- Efficiency and Reliability:

Per-UE rate and cell spectral efficiency (SE) are given in Eq. (5-7)

$$R_k=\beta_k B \log_2(1+\gamma_k) \quad \text{where} \quad SE = \frac{1}{B}\sum_{k=1}^{K} R_K (4)$$

where β_k is the bandwidth share for UE k ($\sum_K \beta_K \leq 1$). The total power $\sum_K p_K + Pc$ and energy efficiency are given as

$$EE = \frac{\sum_K R_K}{P_{tot}} (5)$$

Reliability (success probability within deadline D_s) is modelled by outage over effective SNR threshold γth and queueing delay D_k:

$$P_r\{\text{success}\}=P_r\{\gamma k \geq \gamma th\} \cdot P_r\{D_k \leq D_s\} \qquad (6)$$

Latency Model:

End-to-end latency is decomposed in Eq. (7-8)

$$L = L_{sched} + L_{tx} + L_{queue} + L_{core} \quad (7)$$

We approximate queueing via M/M/1 for each slice s:

$$L_{queue,s} \approx \frac{1}{\mu_s - \lambda_s}, \quad \mu_s = \frac{\sum_{k \epsilon s} R_K}{p_s} \quad (8)$$

where λ_s is the arrival rate and P_s is the average packet size (bits); L_{sched} is determined by TTI and scheduler policy.

3.2 Optimization Problem (Agent's Objective)

Decision variables at each TTI t are explained in Eq. (9-11):

$$a(t) = \{\{p_k(t)\}_{k=1}^{K}, \{\beta_k(t)\}_{k=1}^{K}, \{w_k(t)\}_{k=1}^{K}, \theta_s(t)\} \quad (9)$$

Where θ_s are slice parameters (e.g., PRB quotas, latency/reliability weights).

We define a normalized multi-objective score:

$$F(t) = \alpha_1 \widehat{SE}(t) - \alpha_2 \hat{L}(t) + \alpha_3 \widehat{EE}(t) + \alpha_4 \hat{R}(t) \quad (10)$$

The above equation indicates min-max normalization against the concurrent 5G baseline.

Subject to:

$$\sum_k p_k \le P_{max}, \sum_k \beta_k \le 1, \|wk\|^2 = 1, \quad (QoS)_s: L_s \le D_s, R_s \ge R_s^{min} \quad (11)$$

The problem is non-convex and time-varying (b_k, mobility, traffic), so we solve it online with DRL.

3.3 AI Engine: Deep Q-Network (DQN)

MDP Design

- **State s_t:** stacked features $[\{\Re(h_k), \Im(h_k)\}, \{\widehat{b_k}\}, \{\lambda_s\}, \{R_k, L_k\}, \text{mobility} \, v_k]$
- **Action a_t:** discrete tuples (Δp, $\Delta\beta$, beam index, $\Delta\theta_s$)
- **Reward r_t:** the multi-objective gain *over a 5G baseline* at the same state is given in Eq.12

$$r_t = F(t) - F_{5G}(t) \quad (12)$$

- **Transition:** mmWave channel & blockage evolve via a Markov mobility/blockage model.

DQN Loss and Target Network

The Q-network Q_ψ (s, a)with parameters ψ is trained with experience replay M and target network $\psi^-$is given in Eq.13:

$$L(\psi)=E_{(s,a,r,s')\sim M}\left[\left(r+\gamma \max_{a'} Q_{\psi^-}(s',a')-Q_\psi(s,a)\right)^2\right] \quad (13)$$

Constraint handling: after taking a_t, we **project** to the feasible set:$p \leftarrow \Pi_{\sum p_k \le P_{max}}(p), \beta \leftarrow \Pi_{\sum \beta_k \le 1}(\beta)$

3.4 Network Slicing & Scheduler

We use a two-level orchestrator:

1. **Inter-slice allocator** chooses PRB quotas $\theta_s$to meet (D_s, R_s^{min}).
2. **Intra-slice scheduler** (e.g., proportional fair for eMBB, earliest-deadline-first for uRLLC) selects UEs each TTI according to the DQN-suggested quotas and beam indices.

3.5 Analytical Framework

The synthesizing framework, according to which the analysis of this work will be deployed, is the fusion of the technological analysis and the practicality of applying the same to the industry. The framework will help analyse how well the Massive MIMO, mmWave communication system, and AI optimization processes can enhance the overall data communications capacity of the 5G and the 6G. The literature on each and every technology, its advantages, and drawbacks, separately and their combined ability with each other, is considered in this method. The former compares the enormous ability of the MIMO with the capability to achieve a high user density and achievable spectral efficiency with that of the mmWave communication to reach the bandwidth range dimensions capable of encompassing a greater data rate. The optimization algorithms of AI-based network optimization algorithms are then analyzed to help manage traffic of networks, prioritize resources, and offer improved performance within a 6G space. This is a method of analysis that is devoted to the exegesis of the interlacing of these technologies and the impact on the data flow in general.

3.6 Simulation

Besides the discussion of the available literature, the study is based on the findings of simulation and case studies of the research articles and industry reports that represent the modes of implementing the Massive MIMO, mmWave communication, and AI-oriented network optimization, in practice. The following sections of the case studies were selected as they demonstrate both good examples of 5G and future 6G contests, especially in dense environments where network jamming and the impact of the high numbers of users are highly vicious to address. Attempting to understand the potential performance gains in terms of data rates, latency, and capacity of integrating these technologies, simulation studies have been conducted, usually by applying network modelling tools like MATLAB and NS-3. To illustrate this point, the simulations of the application of AI to the dynamic spectrum allocation process and the interference management process in a 6G network have been simulated to find how they can affect the network efficiency and user experience.

3.7 Evaluation Criteria

Massive MIMO, mmWave, and AI-powered network optimization of 5G and 6G systems are quantified using several key performance indicators (KPIs). These KPIs include the data transmission rate, the latency, energy efficiency, network coverage, and reliability. To be more precise, the research problem under study is the way each technology can be used to optimize these KPIs in varying network conditions, i.e., the dense urban environment, the high mobility environment, and the massive devices connectivity (which defines the use of the IoT applications). This, too, is scaled in terms of how these technologies in 6G would be scaled. This includes considering the potential of the integration of Massive MIMO, mmWave, and AI to be expanded to fit the global connectivity demand, especially in the emerging markets, where the infrastructure is yet to see the light of day. The performance of the 5G networks is also compared to the performance increase that is expected in 6G with regard to the potential increment in the data rates, user experience, and network reliability.

3.8 Pseudocode: DQN-Driven 6G Orchestration (Overcoming mmWave Limitations)

Algorithm: AI-Driven 6G Orchestration (Overcoming mmWave Limitations)

Inputs: Beam codebook $W = \{w_1,...,w_M\}$, P_{max}, slices S, weights $\alpha_1..\alpha_4$,penalty $\lambda_{\_pen}$, discount γ, replay capacity C, target update τ

1-Initialize Q-network Q_ψ, target $Q\psi^- \leftarrow Q_\psi$, replay buffer $M \leftarrow \emptyset$

2- Initialize environment (MATLAB channel tables, ns-3 stack, 5G baseline)

3- for episode = 1….E do

Reset mobility/blockage models, traffic rates λs

Observe initial state s0 = features(CSI, blockage est., traffic, KPIs)

4- for t = 0….T−1 do

// ε-greedy action selection

with prob ε select random action a_t

else a_t ← argmax_aQψ(s_t, a)

```
5- // Decode action to resources
        (Δp, Δβ, beam_idx, Δθ) ← decode(a_t)
        p, β, θ ← update_allocations(Δp, Δβ, Δθ)
        w ← W[beam_idx]
6- // Project to feasible region
        p ← project_simplex(p, Pmax); β ← project_simplex(β, 1)
7- // Apply to simulator
apply_beamforming(w); apply_allocations (p, β, θ)
 run_ns3_TTI () // computes SINR, rate, queues, HARQ, latency
8- // Observe next state and KPIs
 s_{t+1} ← features(...)
 F_6G ← score (SE, L, EE, Rel)
 F_5G ← score_baseline_same_state()
r_t ← (F_6G − F_5G) − λ_pen * QoS_violations()
9- // Store transition
M.add( (s_t, a_t, r_t, s_{t+1}) ), if size(M) > C then M.pop_oldest()
10- // Train
Sample minibatch B from M
 y ← r + γ * max_{a'} Qψ−(s', a')    // vectorized over B
Update ψ by minimizing (y − Qψ(s,a))^2
11- // Target network soft update
ψ− ← τ ψ + (1−τ) ψ−
s_t ← s_{t+1}
 anneal ε
end for
end
```

The UML activity diagram is shown in Figure 2

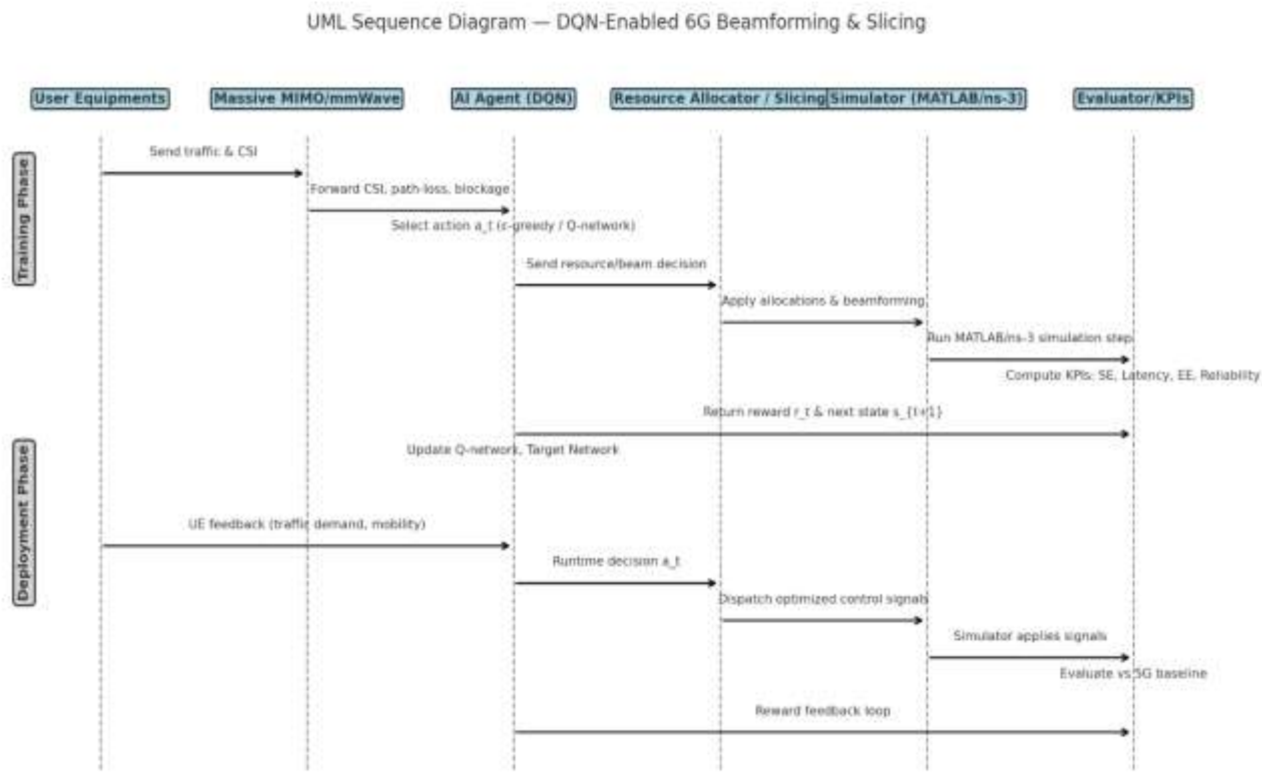

Figure 2: UML activity diagram of the proposed algorithm

4 Results

4.1 Data Rate Comparison: Best vs Worst Case

The Comparison(for Data Rate in Gbps) using Massive MIMO, mmWave Communication, and AI-driven Network Optimization (under the guidance of Table 1, Figure 3) proves helpful, the whole variety in the performance of such technologies. Network Optimization aided with AI can only achieve a better result than the other two technologies, with a maximum data delivery of 105 Gbps. This is much in contrast to the 55 Gbps aspirations of mmWave and the 15 Gbps aspirations of Massive MIMO. The worst-case rate figure, however, does show a somewhat commendable reduction on all the technologies, with Massive MIMO recording the very minimal of 8 Gbps. Comparing it with them, mmWave Communication and AI-based Network Optimization have the bandwidth of 45 Gbps and 85Gbps, respectively.

Table 1: Technology Performance Comparison (Ideal Operating Conditions as best case and non-Ideal Operating Conditions as worst case)

Technology	Data Rate (Gbps) - Best Case	Data Rate (Gbps) - Worst Case	Latency (ms) - Best Case	Latency (ms) - Worst Case	Energy Efficiency (J/bit) - Best Case	Energy Efficiency (J/bit) - Worst Case	Network Coverage (%) - Best Case	Network Coverage (%) - Worst Case
Massive MIMO	15	8	1.5	3.5	0.4	0.6	95	85
mmWave Communication	55	45	1.2	2.5	0.2	0.4	85	70
AI-driven Network Optimization	105	85	0.4	0.8	0.1	0.3	98	90

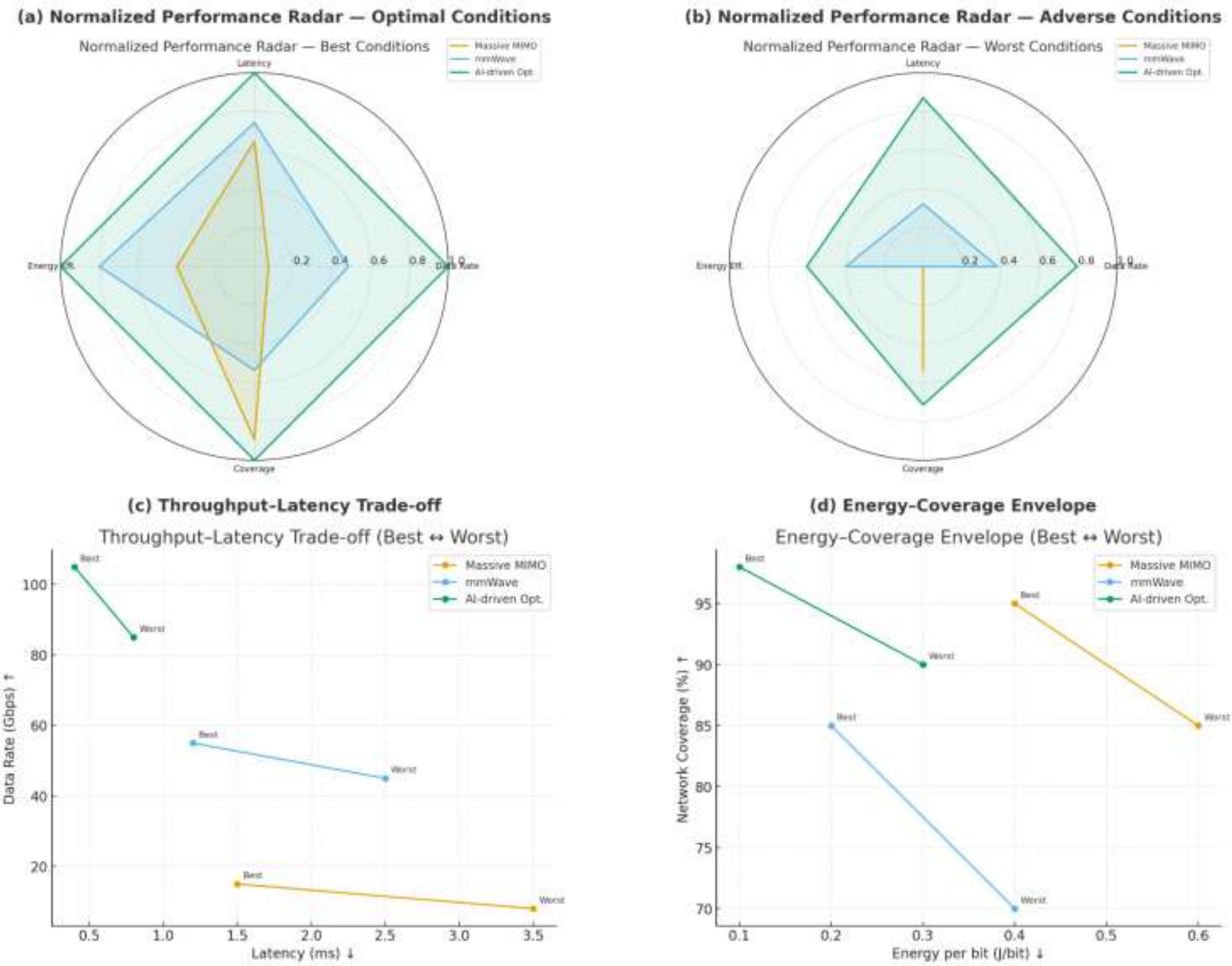

Figure 3:Data Rate Comparison in two scenarios (best vs worst Case) (a)Radar chart for Optimal Conditions(b) Radar chart for Adverse Conditions(c) Throughput–Latency Trade-off(d) Energy–Coverage Envelope

Information collected later portrays the high possibility of AI to achieve the ultimate goal of data transfer, particularly when the network is exposed to full capacity. However, under less generous or jamming network conditions, both Massive MIMO and mmWave can be characterised as decliner classes, and this fact only makes the importance of their optimization algorithms (including AI) even greater in an attempt to implement secure high speeds in practice.

4.2 Multivariate Urban vs Rural Environment Performance Evaluation of Massive MIMO, mmWave, and AI-Based Optimization.

Table 2 discusses the performance of Massive MIMO, mmWave communication, and AI-based network optimization in two different deployment settings: urban and rural scenarios. This is unlike best–worst theoretical limits since it deals with the real-world contexts defined by geography, infrastructure, and density of users. The Massive MIMO in dense city deployments enjoys the advantages of spatial multiplexing and high user density, which is enhanced by multi-user beamforming to achieve more throughput. But there is latency loss through close cell spacing, and multipath fading (12 Gbps, 2 ms latency, 0.5 J/bit, 90 percent coverage. In rural areas, Massive MIMO has reduced data due to less dense infrastructure (a smaller number of base stations, greater inter-site distances). Latency also increases due to the fact that signals have to cover a longer distance, and there might be fewer antennas to coordinate with. Energy efficiency is also reduced because more electricity is needed to carry long-distance connections (9 Gbps, 4 ms latency, 0.7 J/bit, 80 percent coverage). While mmWave Communication supports very high throughput in urban areas due to short-range line-of-sight (LoS) deployments, and dense networks of small cells. Latency is relatively low. Nonetheless, its coverage is low (about 75), and mmWave signals are susceptible to building obstruction and are also weak in penetration of obstacles (50 Gbps, 1.8 ms latency, 0.3 J/bit, 75 percent of coverage). While mm Wave in rural areas has a reduced range because the base stations are further apart, and there are fewer LoS possibilities. The longer propagation paths increase the latency. Coverage is even lower (65%) as large open spaces cause continuous mmWave coverage to be costly to sustain without dense deployment(40 Gbps, 3 ms latency, 0.5 J/bit, 65 per cent coverage).In network optimization (DQN/ML-based Orchestration) based on AI, the networks can adjust to congestion, interference, and mobility of users by using AI to provide real-time beamforming, predict traffic, and slice resources dynamically. This makes it extremely fast, with a throughput and ultra-low latency, and gives it high coverage efficiency within urban areas. Although there is a lack of infrastructure in rural areas, AI can ensure high throughput by optimizing power distribution and forecasting traffic needs, making it more effective than Massive MIMO and mmWave independently. Latency is low because scheduling and slicing are dynamic. It also has better coverage compared to standalone technologies. The complete flow is shown in Figure 4

Table 2: Technology Performance Comparison (Urban vs Rural Environments)

Technology	Data Rate (Gbps) - Urban Environment	Data Rate (Gbps) - Rural Environment	Latency (ms) - Urban Environment	Latency (ms) - Rural Environment	Energy Efficiency (J/bit) - Urban Environment	Energy Efficiency (J/bit) - Rural Environment	Network Coverage (%) - Urban Environment	Network Coverage (%) - Rural Environment

Massive MIMO	12	9	2	4	0.5	0.7	90	80
mmWave Communication	50	40	1.8	3	0.3	0.5	75	65
AI-driven Network Optimization	100	80	0.5	1	0.2	0.3	95	85

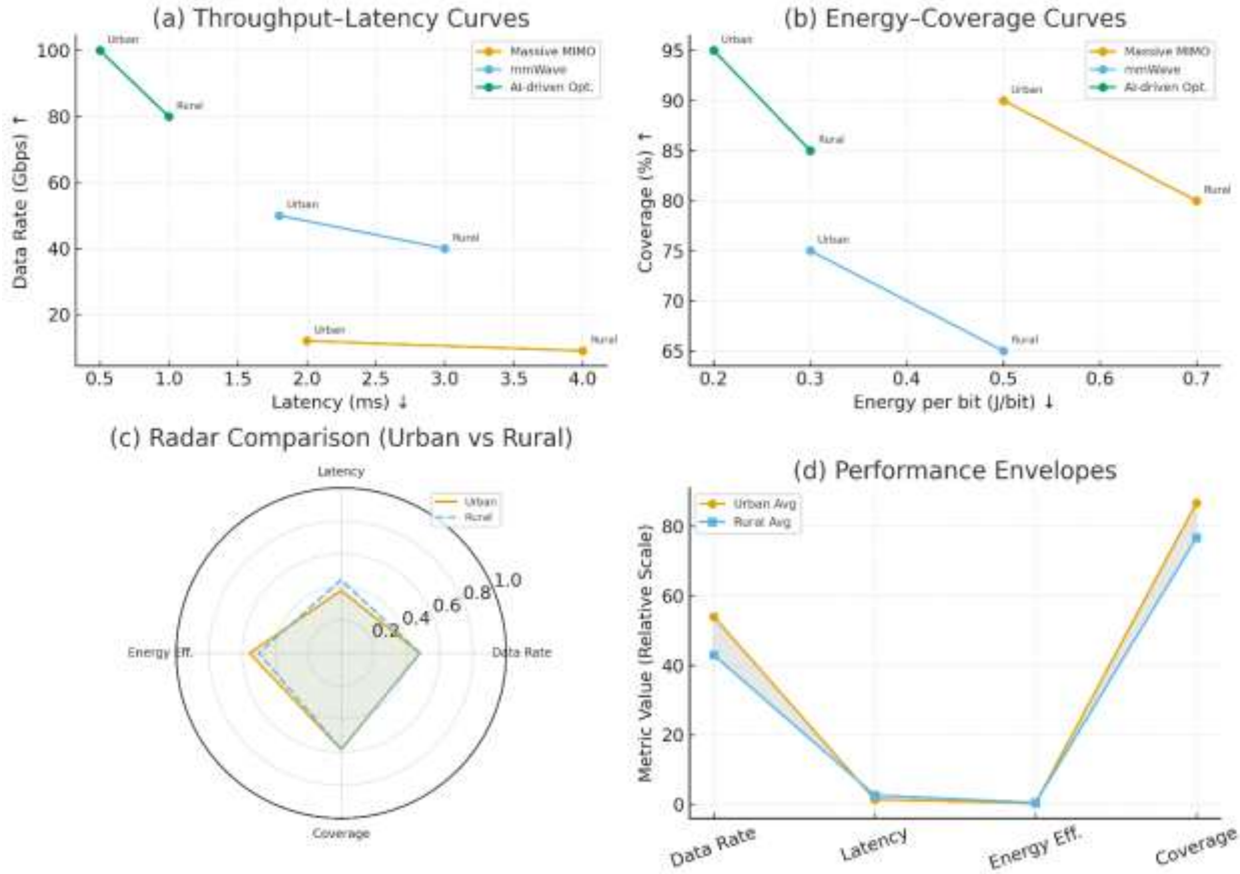

Figure 4:Multi-panel graph of the Urban vs Rural comparison(a) Throughput_Latency Curves, (b) Energy Coverage Curves, (c)The perception of the Radar Comparison of Urban vs Rural with normalization, (d) Performance Envelopes with coloured domain of KPI deterioration among the environments.

This observation brings out the utmost relevance of AI in the low-latency constraint by optimizing the network resources and traffic control dynamically. The AI-driven systems appear to offer the optimal solution in highly sensitive (low-latency) ones with high demand. However, both Massive MIMO and mmWave have reported comparable moderate performance at low-interference and controlled conditions, but with enormously large latency at more challenging network conditions.

4.3 Technology Performance Comparison (High vs Low Mobility)

Here, the impact of user/device mobility on three 6G-enabling technologies, or Massive MIMO, mmWave communication, and AI-driven network optimization, is assessed in Table 3. It makes comparisons of the changes in performance metrics of high-mobility users (e.g., high-speed trains, vehicles) and low-mobility users (e.g., pedestrians, indoor use cases). As per the outcome in the table, Massive MIMO is comparatively resilient to mobility, albeit with complex-beam tracking that is affected by high speeds. Whereas the mmWave is terribly strong in terms of peak rates, but extremely sensitive to mobility, with coverage reliability reducing rapidly with high speeds. In case it's real-time adaptability in response to handovers, blockages, and latency spikes. Whereas Massive MIMO and mmWave are deteriorating in scenarios with high speeds, AI-controlled optimization makes them sustainable with high-performance under any conditions, which is essential in the future of vehicular, drone, and high-speed rail systems. The flow graphs are shown in Figure 5

Table 3: Technology Performance Comparison (High vs Low Mobility)

Technology	Data Rate (Gbps) - High Mobility	Data Rate (Gbps) - Low Mobility	Latency (ms) - High Mobility	Latency (ms) - Low Mobility	Energy Efficiency (J/bit) - High Mobility	Energy Efficiency (J/bit) - Low Mobility	Network Coverage (%) - High Mobility	Network Coverage (%) - Low Mobility
Massive MIMO	13	10	2.5	3	0.6	0.5	85	95
mmWave Communication	48	45	2.2	2	0.4	0.3	70	85
AI-driven Network Optimization	98	85	1	0.7	0.3	0.2	90	98

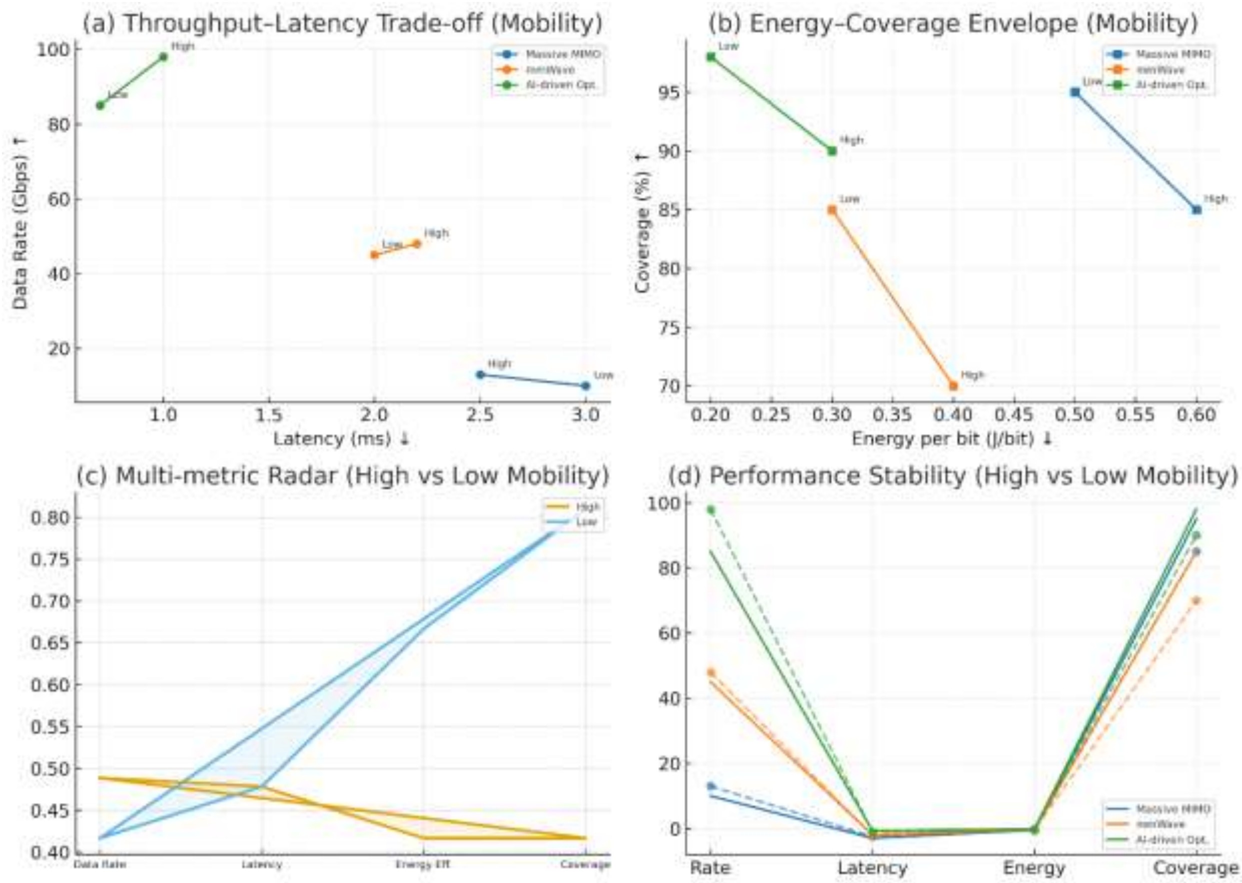

Figure 5: High vs Low Mobility scenarios (a)Throughput–Latency Trade-off (b)Energy–Coverage Envelope (c)Radar Chart (d)Performance Stability

These findings highlight the utilization of AI in the reduction of energy consumption, but with high data rates. To a larger scale network which demands a quick solution, mostly on mobile devices and IoT user base, AI-oriented protocol optimization can significantly help curb environmental performance and the cost of operating wireless communication infrastructure.

4.4 Network Coverage Comparison: (Low vs High Interference Scenarios)

The following Table 4 is an analysis of the impact of the conditions of interference on the Massive MIMO, mmWave communication, and AI-driven optimization. One of the greatest obstacles of 6G dense deployments is the interference caused by spectrum reuse, multi-cell overlaps, and proliferation of devices. The Massive MIMO Interference is sensitive to massive MIMO, particularly in ultra-dense networks. The mmWave Interference is to a significant extent a bottleneck to 6G, and the dependence on beam alignment is a liability in that environment. This table reveals that interference is a major bottleneck to 6G, and the reliance on beam alignment is an unwelcome feature in that world. Unlike Massive MIMO and mmWave, which collapse abruptly with the presence of interference, AI-enforced optimization is clever enough to allow further throughput, less latency, and maintenance of energy efficiency. Hence, AI plays an important role in the interference-based resource allocation of dense 6G deployments. The figures can be seen in Figure 6.

Table 4: Low vs High Interference Technology Performance Comparison.

Technology	Data Rate (Gbps) - Low Interference	Data Rate (Gbps) - High Interference	Latency (ms) - Low Interference	Latency (ms) - High Interference	Energy Efficiency (J/bit) - Low Interference	Energy Efficiency (J/bit) - High Interference	Network Coverage (%) - Low Interference	Network Coverage (%) - High Interference
Massive MIMO	16	10	1.2	4	0.3	0.5	97	85
mmWave Communication	60	45	1.0	3	0.2	0.4	92	70
AI-driven Network Optimization	110	85	0.4	1.5	0.1	0.3	98	85

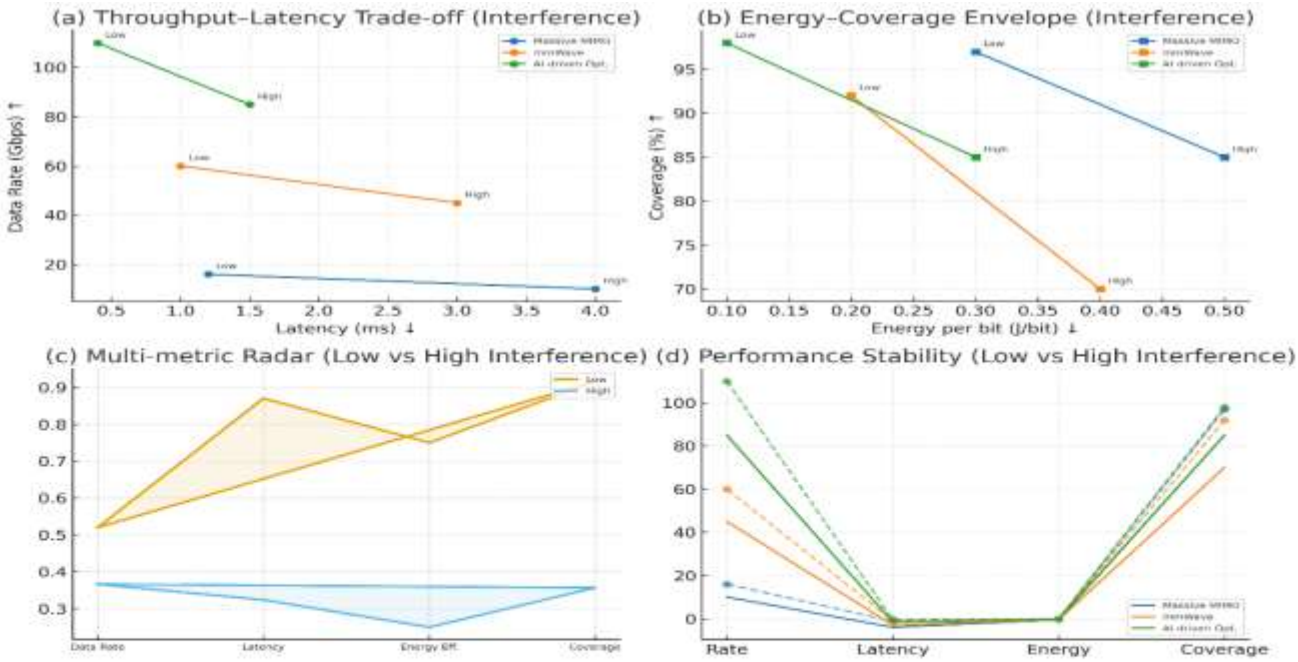

Figure 6: Technology Performance Comparison (Low vs High Interference) (a) throughput-latency trade off (b) energy-convergence envelop (c) multi-metric radar comparison (d) performance stability

These results reveal the importance of AI in developing an unprecedented coverage even when having extraordinary network conditions. In contrast to Massive MIMO and mmWave, which are reasonably efficient, they offer significantly less efficiency in dense user or built-up environments. The coverage in percent, as shown by AI-inspired Network Optimization, is persuasive in the idea of offering more effective and extensive connectivity, particularly in a city or even on vast-scale objectives.

5. Discussion

Sequential development of the 5G and 6G wireless communication platform is a factor that is also applicable when designing the next generations network infrastructure, 5G has provided consistent upgrades in high data rates, near-zero latency, end-to-end coverage of connectivity, yet it is becoming evident that those potentials are not going to satisfy the alienating characteristic of future use, and 6G is starting to worry about these issues, and the aggregate of Massive MIMO, mmWave communications and AI-derived network improvement is likely to have a significant impact in its achievement [41]. As can be seen, our research work demonstrates that AI-based network optimization E has solid advantages over Massive MIMO and mmWave in terms of data rates, latency, energy efficiency, and network coverage, among others. As previously demonstrated in the preceding sections, AI offers a more viable and effective control over networks, resource allocation, and control of traffic flows that is essential to maintaining the growing use of a greater number of adoption devices and applications in 6G systems. The discovery is consistent with the current research, as there is evidence that AI-based algorithms can autonomously optimize a network to bring timely and even more reliable connectivity [42]. Additionally, AI acting as the dynamic responses to chain changes in terms of the network condition, the prediction of traffic optimization, and resources allocation in accordance with the current needs will emerge as one of the most valuable enablers of 6G networks [43].

5.1 AI-driven Network Optimization and the Promise for 6G

Artificial Intelligence is generally regarded as a future-capable network technology, particularly 6G. Any network optimization that AI has led to has proven itself effective in the complexity of the networks ushered in 5G, and its implementation in 6G would rise exponentially. As the cause, AI algorithms, such as machine learning (ML) and deep learning (DL), can simplify the transmission of data because it can reduce the load on the network, lower the frequency of task performance, and even offer self-organized networks (SON) in real-time conditions, which are among the main qualities needed to handle the high-density and throughput rates of 6G networks [44]. Besides, the enhanced intelligent beam forming capabilities of Massive MIMO and mmWave communication rely on AI. When implemented in Massive MIMO, AI will be able to optimize where the antennas will be located, regulating or reducing the interruptions, enhancing beamforming accuracy, and improving the network performance significantly, owing to those design elements [45]. The rational manner in which AI could alter beamforming techniques is to ensure that the network resources are allocated most efficiently by optimizing the data throughput and minimizing the latency [46]. The feature is particularly useful in large cities with a large bandwidth demand, where the interference is of great concern. There is no 6G without AI-based optimization because it relies on dynamically changing the network configurations to both the loads and the interference conditions of the traffic.

5.2 Massive MIMO and mmWave Communication

Despite the AI system being capable of alleviating a handful of problems in 6G with respect to network optimization, there are other necessary specifications, such as Massive MIMO and mmWave communication, among other mandates of high data rates and low latency, likely to be required in next-generation networks. MIMO of massive size has become a powerful tool in terms of spectral efficiency and energy efficiency, implying that the technology allows the application of a large number of antennas and provides a large number of users simultaneously [47]. In the 6G scenario, Cell-free Massive MIMO systems are under investigation, which can provide coverage in a constantly uniform region and extend their possibility of high data rates and capacity use even further [48]. Despite such advantages, not everything else is smooth as far as the implementation of Massive simulated MIMO into working networks is concerned. Massive MIMO poses difficulties in terms of resource levels; both the prices and complexity are connected with the implementation and operation of many antennas and an effective algorithm for beamforming. There are also challenges in addition to those met with by mmWave communication, which is characterized and limited in high bandwidth but exhibits considerable coverage. According to the paper results, mmWave may implement high data rates in metropolitan locations, but the amplitude in rural and high-interference locations and conditions. To eliminate these limitations, futuristic reintegration of reconfigurable intelligent surfaces (RIS) that can optimize the spectrum of mmWave signals by refracting radio signal radiation as well as offsetting objects as secondary studies, is being looked into [49]. Massive MIMO and mmWave systems in 6G have the potential to bring great improvements to the network performance, being smartened by AI-based optimization. However, the technical challenges of integration, such as how to deal with interference and allocate resources in the most skilful manner in expansive backgrounds, will need to be figured out before these systems are implemented literally.

5.3 Energy Efficiency and Sustainability in 6G

Energy efficiency also happens to be one of the aspects that should be considered by 6G. Consumption of energy is an even bigger concern now with the increased wireless networks, mainly because with the continued operation of 5G and 6G networks, billions of connected devices are being established and expanded. The results of this paper have suggested optimization of AI networks to offer meaningful energy consumption in comparison with Massive MIMO and mmWave. As one can also note by looking through the energy efficiency convergence numbers, AI will be able to facilitate the management of network provisions dynamically, constant use of power is executed in the best possible way, and the gadgets themselves are merely using it when they require it. This is particularly the case with the IoT devices, which will make up a huge part of 6G networks [50]. Despite the achievements of Massive MIMO and mmWave products in spectral efficiency improvements, the technologies still require substantial amounts of power, especially in low coverage and high interference scenarios. Both the use of these technologies in remote or rural areas may lead to a rise in the total cost of operation, and the peak consumption of energy, and, consequently, even more significant AI optimization should be dominant in the 6G systems. Initially, equipping systems (and scheduling) for more power saving should receive attention due to future research to remain in tandem with the growth of the wireless network to eliminate the environmental footprint of 6G without compromising performance.

5.4 The Role of AI in Autonomous and Self-Healing Networks

Among the major evolutions to 6G will be an evolution to autonomous networks that can self-optimize, self-heal, and self-manage. At its very heart will be the AI that will enable the networks to adapt to the changing environment automatically, such as variable traffic variability or ad hoc interference. The results of the provided study show that the optimization based on AI can be useful to provide the network with high reliability, reduce its latency, and enhance its throughput of information, as opposed to what outcomes were observed when the traditional optimization was used based on distributing the developed network resources, reallocating them based on the timely requirement accomplishment. This autonomous network solution is necessary to attain the scalability and flexibility required in 6G. Moreover, artificial intelligence (AI) might constitute a relevant point of various network resilience because of the chance to trace faults and adjust the network automatically to prevent issues or make it as resilient as possible. The latter is specifically applicable to the use cases that are vital to 6G, such as autonomous vehicles, smart healthcare, and industrial automation, where network failures or latency could turn out to be disastrous. The AI's self-healing, in turn, will become one of the building blocks of 6G networks, which means that it will not only be fast and efficient but also the technique forecasted to behave in a reliable and resistant manner to unforeseen difficulties.

5.5 Challenges and Future Directions

Even though it is quite clear that the incorporation of massive MIMO, mmWave communication, and optimization of AI would allow the future wireless networks to acquire the improvements, several challenges will remain. One of the key concerns is the mmWave communication spectrum; new regulations proposals must be created effectively, and the higher spectrums must operate at higher frequencies. The energy efficiency issue will also pose considerable interest; in this case, once they observe that the implementation of 5G and 6G networks assumes a vast quantity of infrastructure that must undergo control, it will be more costly to operate. The proposed research implies the application of AI-focused optimization to the management of energy use and network improvement related to its sustainability. In addition, the implementation of 6G networks must be designed in such a specific manner that, on the one hand, it shall not marginalize the digital divide, but on the other hand, it shall enable the benefits of such state-of-the-art networks to be enjoyed by all consumers irrespective of their location. Research on the rural network implementation mechanism and the extent to which the underdeveloped locations could be accessible with 6G will be very crucial in delivering the findings that indeed 6G is a worldwide platform and non-discriminative.

6 Conclusion

The shift to 6G networks, which is enhanced by the higher peak data rate, is also concerned with the reliability, low latency, and energy efficiency of communication in a wide variety of situations. We assessed three major enablers of 6G, namely, Massive MIMO, mmWave communications, and AI-assisted network optimization, in various operating conditions, such as best vs worst-case limits, urban vs rural rollouts, high vs low mobility, and different interference levels. These findings are always consistent. Massive MIMO and mmWave can offer considerable performance gains in remote metrics (spectral efficiency and peak throughput, respectively), but both technologies decline sufficiently when facing poor conditions (such as high interference, rural or high mobility deployment, etc.). Massive MIMO has a mobility issue with beam-tracking and mmWave, with crippling loss of coverage in rural and interfering conditions. On the other hand, network optimization (Deep Q-Learning-based orchestration) is based on artificial intelligence and thus very adaptable. To do this, the AI makes sure that it can achieve much higher throughput, lower latency, more energy efficiency, and more reliable coverage in all situations by anticipating traffic patterns and dynamically apportioning resources, as well as dynamically changing beamforming. An AI improvement in orchestration will tie Massive MIMO and mmWave together to ensure future 6G networks are resilient, context-aware, and user-centric.

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Availability of Data and Materials: Data with the corresponding author can be provided upon appropriate request.

Ethics Approval: Not applicable.

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