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Hybrid Deep and Reinforcement Learning for Adaptive Bandwidth Prediction in Iraq Network

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Abstract

Multimedia traffic and other real-time streaming services continue grow exponentially have promoted the accurate, low-latency bandwidth prediction across heterogeneous networks to be more urgent. For dynamic wireless networks including Iraq multi-ISP infrastructure with millisecond-scale fluctuation in throughput, latency and jitter around a mean value, the traditional probing or heuristic models alone cannot offer accurate estimates for adaptive bitrate (ABR) control.

This dissertation presents a comprehensive and Machine-learning-Based Bandwidth Prediction Framework that leverages measurement-based analytics, ensemble learning, temporal models and reinforcement-learning (RL) to achieve QoE-aware multimedia adaptation in the wild. The architecture combines windows and Android data acquisition clients that are instrumented to gather real-time metrics-RTT, jitter, packet loss, throughput and hop delay-using active probes (ping, traceroute, speedtest-cli) as well as passive context logging; a Supabase RESTful backend for real-time cloud synchronization of user measurement tables; and an automated preprocessing pipeline which normalizes, denoises and aligns temporal features prior to learning. More than 60k synchronized samples were collected from Zain, AsiaCell and EarthLink ISPs providing the first publicly available Iraq-centric bandwidth measurement dataset for machine learning.

Performance comparison was conducted on local Iraqi and external AlphaRTC datasets between the proposed (HyBoB-RL) and Microsoft BoB baseline. The average MAE reduction is found to be ≈ 25

% and the QoE gain of 12 – 15% under normal testing conditions, with inference latency <10 ms and model size below 5 MB—proving the real-time deployability on end devices. Under stress testing of induced congestion, HyBoB-RL maintained QoE to within ±5 % of baseline levels, indicating resilience and self-adaptive gate regulation. All the modules, i.e., data collectors, ML / GRU models, RL controller and evaluation scripts are offered as open-source apps that offers reproducibility for bandwidth prediction research.

The combination of ensemble learning, temporal quantile modeling and reinforcement control provides a practical, scalable and QoE-optimized framework for adaptive multimedia streaming in terms of heterogeneous and limited bandwidth network.

Chapter One

Introduction

Chapter 1: Introduction

1.1 Background and Motivation

Great interest in multimedia quality delivery has emerged recently with the rapid evolution of video-on-demand, a cloud gaming and interactive conferencing. These services often depend on varying network bandwidth at short timescales, particularly in Iraq's multi-ISP environment where congestion, wireless interference, and routing asymmetries are prevalent. Adaptive streaming protocols, such as HTTP Live Streaming (HLS) and MPEG-DASH—attempt to mitigate these effects by dynamically adjusting the video bitrate according to estimated available bandwidth [1][2]. However, traditional heuristic or model-based estimators (e.g., Exponential Weighted Moving Average (EWMA) or harmonic-mean filters) often fail under non-stationary conditions caused by mobility, wireless fading, and cross-traffic[3].

Measurement-based bandwidth estimation techniques traditionally compute available capacity by probing packet-pair dispersion, yet they suffer from inaccuracies when multiple bottlenecks or interrupt-coalescing phenomena exist . Recent progress in machine learning (ML) and deep reinforcement learning (DRL) has transformed this field [4][5]. Data-driven models can learn nonlinear mappings between measurable features—such as throughput, round-trip time (RTT), jitter, and loss—and the true available bandwidth. Moreover, reinforcement-learning controllers dynamically optimize bitrate selection to maximize the Quality of Experience (QoE) by balancing rebuffering, visual smoothness, and bitrate utility .

In Iraq, where broadband and mobile networks display extreme spatiotemporal variability (Zain 4G/AsiaCell 5G vs. Earthlink fiber), accurate real-time bandwidth prediction is indispensable for smooth playback. This dissertation introduces a Machine-Learning-Based Bandwidth Prediction Framework that fuses measurement-based analytics with hybrid ML + RL intelligence—termed the Hybrid Blend-of-Blends with Reinforcement Learning (HyBoB-RL) system.

1.2 Related Works

Early research on available bandwidth estimation focused primarily on model-based and measurement-driven methods. Below is a detailed presentation of the most important scientific research related to and supporting the thesis, which confirms the scientific and experimental advantages that were undertaken according to those clear and pioneering foundations in making the work continuous and maintaining a level of trust without bias towards one side over another.

- In 2018 Yang & Dong [6], employed machine learning to categorize video streams across inferred QoE levels based on throughput, delay, and rebuffering. Their supervised model achieved around 95% accuracy on predicting user perceived quality categories. This statistical relationship between network_QoS and subjective QoE emphasizes the necessity of perceptual modeling. Our approach incorporates this idea by using QoS–QoE mappings directly to generate reward functions for guiding RL control.
- In 2019 Khangure & Fidler [7], proposed one of the first machine-learning-based measurement frameworks for bandwidth estimation,

applying Random Forest regression to infer available bandwidth from delay and packet-dispersion measurements. Their study showed that ML estimators outperform traditional analytical models in heterogeneous networks with bursty cross-traffic, highlighting the potential of supervised learning for complex Internet conditions. The model achieved high accuracy even under noisy measurements, suggesting that non-linear feature interactions (e.g., RTT, jitter, packet loss) can be effectively captured through regression ensembles. This foundational work motivated the transition toward data-driven and hybrid learning approaches for adaptive video streaming.

- In 2019 Zhao et al [8]. proposed T-GCN, an integrated Hybrid Graph Convolutional + GRU network for traffic forecasting. Originally developed for urban transportation, the structure of its deep learning model naturally captures spatiotemporal correlations among nodes and time stamps. The model achieved a better prediction accuracy than the existing models on real traffic datasets, and proved the effectiveness of joint structural and temporal learning. This was motivation behind the temporal GRU predictor in HyBoB-RL include sequential bandwidth dependencies.
- In 2020 Lekharu & Moulii [9], they constructed a hybrid CNN–LSTM network for predicting the optimal video bitrates in adaptive streaming. The architecture learned spatiotemporal features of throughput and buffer time-series in order to predict future bandwidth fluctuations. The findings revealed a decrease of 18% in rebuffering and an increase in bitrate stability compared with rule-based ABR algorithms. This work

showed deep temporal learning to enhance network awareness, offering direct reasons for our GRU quantile predictor.

- In 2022 Eo et al [10] presented OpenNetLab, an open testbed for RL-based congestion control and adaptive streaming. The platform is used to replay network traces and compare different algorithms under same conditions. Its modular nature as an environment, agent, and observation API allows benchmarking congestion-control in a controlled manner. OpenNetLab has served as a backbone for large RL-based streaming experiments since and BoB, Pandia, and this work are funded by this facility. We extend this work by incorporating live Supabase-synchronized datasets to simulate realistic learning contexts.
- In 2022 Bentaleb & Akcay [11], they introduced BoB (Blend-of-Blends), a hybrid framework that combines heuristic estimation with reinforcement learning (RL) for bandwidth prediction in real-time communications. The system begins with GCC-like moving average filters and transitions to a PPO- based RL policy that dynamically adjusts bitrate decisions based on congestion feedback. With the AlphaRTC/MMSys 2021 dataset, BoB reduced latency and provided smoother bitrate adaptation compared to traditional methods. Its two-stage architecture with rule-based start-up and learning-driven control motivated the hybrid fusion theory presented later in this dissertation. Even for latter frameworks, such as the proposed HyBoB-RL system, BoB is still a baseline that it can extend with quantile awareness and QoE-driven optimization.

- In 2022 Isabona & lmoize [12], they implemented an optimized forest ensemble composition with Gradient Boosting and Random Forest. By exploiting the complex nonlinear relationships between features, the model generalized well across diverse wireless conditions. It achieved 25% improvement in average accuracy and improved robustness to noisy measurements. The proposed ensemble design motivated the ML-MBE module in our HyBoB-RL.
- In 2022 Wang & Agarwal [13], they presented a multi agent MARL based approach to optimize total QoE by multiple clients acting collaboratively. Each agent learns a policy with shared critic, and the shared critic balances fairness, stability and network utilization. With this proposed system, it was able to have ~20% higher QoE and reduced stalls from congestion in multi-user cases. Such multi-agent collaboration is a potential extension point for the future deployment of the distributed HyBoB-RL.
- In 2023 Huang & Zhang [14], they proposed an RL based model with human feedback to optimize adaptive streaming decisions. Through integrating the instances of subjective users ratings into the RL reward function, their system can give better perceptual quality and more smooth playback. MOS showed improvements of up to 12–15% over QoE-driven RL baselines. This perspective is consistent with our dissertation's QoE-aware reinforcement mechanism, which focuses on human-centric evaluations.

- In 2024 Tan [15], The study called Accurate Bandwidth Prediction suggested an offline reinforcement learning method in the context of adaptive streaming. It employed past Microsoft Teams trajectories to train RL agents that forecast future bandwidth and select bitrates with limited QoE loss. In contrast to the full-online RL approach, this offline first design helped us alleviate instability and overfitting by training on pre-collected network traces. In experiments predictive accuracy and smooth adaptation were observed with both Wi-Fi and 5G. This work serves as a direct basis for the offline pre-training strategy introduced in our HyBoB-RL pipeline to initialize safe RL. This work explicitly motivates the offline pretraining procedure, which we incorporate into our HyBoB-RL pipeline as a way to safely initialize RL.
- In 2024 Li & Vikberg [16], they introduced the Pandia framework contributed a DRL testbed for adaptive bitrate control on the open-source AlphaRTC. It made reinforcement learning agents such as PPO, DDPG, A2C modularized, and you could do plug-and-play experiments in a controlled setting. Pandia confirmed that multi-agent RL-based systems could schedule multiple ongoing sessions to achieve fairness and resource utilization. This work influenced to the research methodology by giving a concrete evaluation environment for RL (Reinforcement Learning) based congestion control. Pandia was primarily concerned with simulated cases, contrary to HyBoB-RL that applies the idea to measurements collected from the Iraqi ISPs.

- In 2024 Khairy [17]. This competition established a dataset and metric for testing the bandwidth prediction algorithms based on real trace adopted Microsoft Teams' and AlphaRTC traces. It included generic and realistic mobility patterns, as well as describing a set of common evaluation procedures for both emulated and real-world network scenarios with respect to QoE centred metric. The challenge promoted quantile regression techniques and reward learning based testing into a unified platform for ML and RL to study in this area. Our method is benchmarked on this dataset as external validation set to match up with state-of-the-art comparative baselines.
- In 2024 Zhang & Zhuo [18], they introduced AraLive that presented a reward-adaptive bitrate controller using RL, in which QoE terms were dynamically re-weighted according to live streaming environments. It exhibited better long-term QoE stability and lower stall frequency than fixed-reward agents. The experiment revealed that reward adaptation facilitates generalization to new content and networks. This principle was ever applied directly in reward calibrations of HyBoB-RL for QoE considering (i.e., weights adjustment according to playback behavior).
- In 2024 Raman & Turkkan [19]. drew original LL-GABR, a deep reinforcement learning model account for QoE and energy consumption in live streaming. By the collaboration of bitrate and energy control agents it reached savings of ~10% cost while maintaining a good user experience. The multi-objective optimization technique demonstrates that RL can address conflicting performance

measures in real-time systems. Our HyBoB-RL architecture also achieves the trade-off of accuracy and smoothness under QoE constraints, with a further extension to real-world deployment.

- In 2024 Lee & Bae [20], the COCKTAIL methodology for chunk replacement with reinforcement learning was developed to improve adaptive video streaming. It performed smart chunk replacing during playback, and updated its future bitrate selections to improve QoE. The performance results illustrated ≈17% enhancement in QoE with respect to the classical ABR algorithms. This principle of guided learning is implemented in-spirit by our reinforcement model, which relies on reward shaping to mitigate oscillations.
- In 2024 Woo & Hong **[**21**]**, GRU-based short-term bandwidth prediction for ABR selection and integrated buffer occupancy control. The GRU model forecasted short-term throughput, which was then used by the ABR to avoid overly aggressive bitrate shifts. Experimental results showed a decrease in the rebuffering and an increase of the smoothness of playback. Their hybrid method justifies our use of GRU quantile model for short-term predictions in the HyBoB-RL framework.
- In 2025 Mowgli **[**22**]** introduced a passive learning approach where, based on historical streaming logs instead of probing, one can infer the optimal transmission rates. The model is trained on a large-scale real-world video call dataset to alleviate rebuffering and latency. It achieved a 20–30% reduction in the rate of playback freezes when compared to Google Congestion Control (GCC) which highlights the utility of log-based learning for dynamic adaptation. This passive approach

demonstrates how real user logs could replace synthetic training environments -- a notion reinforced by our use of live Iraqi measurement data.

Table (1.1): Summary of Related Works

No.	Reference / Year	Core Idea or Contribution	Dataset / Experimental Setting	Relevance to This Dissertation (HyBoB-RL)	Key Results / Performance	Limitations
1	[6] Yang et al.2018	employed machine learning to categorize video streams across inferred QoE levels	real network scenarios	statistical relationship between network_QoS and subjective QoE emphasizes	Achieved ≈90–95% classification accuracy for QoE levels	Requires subjective user feedback collection, which may not be scalable in practical systems.
2	[7] (Khangura et al.,2019)	Introduced ML-based measurement-driven bandwidth estimation using Random Forest on probe-pair statistics.	Real-network traces with delay/jitter metrics.	Foundational supervised approach inspiring the ML-MBE baseline.	RF reduced estimation error vs analytical models (≈15–25% improvement)	Offline policies may not fully adapt to real-time network changes.
3	[8] (Zhao et al., 2019)	Graph convolution + GRU for spatiotemporal traffic prediction.	Real traffic and mobility data.	Theoretical foundation for our temporal GRU quantile predictor.	Outperformed ARIMA/LSTM with improved prediction accuracy (~10–20%)	Primarily simulation-based; lacks real ISP measurements.
4	[9] (Lekharu et al., 2020)	Deep CNN-LSTM predictor mapping network metrics to bitrate decisions.	Simulated adaptive video sessions.	Motivates temporal learning (precursor to our GRU module).	Reduced rebuffering (~15–20%) and improved bitrate stability	Dataset represents controlled scenarios rather than real-world variability.

No.	Reference / Year	Core Idea or Contribution	Dataset / Experimental Setting	Relevance to This Dissertation (HyBoB-RL)	Key Results / Performance	Limitations
5	[10] (Eo et al., 2022)	Open platform for RL-based congestion control and trace replay.	Global network testbed (AlphaRTC).	Architectural foundation for our RL evaluation pipeline.	Enabled reproducible RL evaluation; improved fairness across agents	Reward tuning complexity and training instability may arise in real networks.
6	[11] (Bentaleb et al., 2022)	Hybrid heuristic + RL predictor; switches from EWMA to PPO policy for bandwidth control.	AlphaRTC / MMSys 2021 traces.	Direct baseline; origin of "Blend-of-Blends" concept adopted in HyBoB-RL.	Improved QoE by ≈20–23% and reduced delay variance	Focuses on energy trade-offs rather than prediction accuracy.
7	[12] (Isabona et al., 2022)	Combined XGBoost, RF, GB for QoE-aware adaptive learning.	Heterogeneous wireless traces.	Basis of our ML-MBE ensemble layer for regression accuracy.	Achieved ≈20–25% accuracy improvement over single models	Requires complex segment management and may increase client overhead.
8	[13] (Wang et al., 2022)	Cooperative multi-agent RL bitrate control for multi-user QoE.	Simulation and real stream tests.	Suggests future distributed HyBoB-RL extension for multi-client coordination.	Increased QoE (~20%) and reduced stalls (~30%) in multi-user setup	Focuses on short-term prediction only and lacks hybrid ML–RL integration.
9	[14] (Huang et al., 2023)	RL with subjective human feedback to align training with perceptual QoE.	Live multimedia datasets.	Reinforces human-centric QoE metrics in our reward function.	Improved MOS by ≈12–15% compared to baseline RL	Dependent on large historical logs and may struggle with unseen network conditions.
10	[15]	Offline RL model	Microsoft	Provides offline	Stable policy learning with	Requires subjective user

No.	Reference / Year	Core Idea or Contribution	Dataset / Experimental Setting	Relevance to This Dissertation (HyBoB-RL)	Key Results / Performance	Limitations
	(Tan et al., 2024)	trained on Teams-style data for adaptive bitrate control.	RTC Challenge dataset.	RL methodology and evaluation protocol used here.	reduced variance and improved QoE (~10–15%)	feedback collection, which may not be scalable in practical systems.
11	[16] (Lie et al., 2024)	Open-source DRL testbed integrating PPO/A2C agents for ABR research.	AlphaRTC emulated environment.	Supplies modular RL testbed concept mirrored in our experiments.	Demonstrated consistent RL performance improvements vs GCC baseline	Offline policies may not fully adapt to real-time network changes.
12	[17] (Khairy et al., 2024)	Defines large-scale benchmark traces and quantile-based metrics for bandwidth estimation.	Microsoft Teams / AlphaRTC testbed.	Serves as external validation dataset for HyBoB-RL.	Standardized evaluation (MAE, QoE, quantile loss)	Primarily simulation-based; lacks real ISP measurements.
13	[18] (Zhang et al., 2024)	RL framework with automatic reward adaptation for live video streaming.	YouTube-style live data.	Inspires our adaptive QoE-weighted reward formulation.	Improved QoE stability and reduced reward oscillation (~10–15%)	Dataset represents controlled scenarios rather than real-world variability.
14	[19] (Raman et al., 2024)	Energy-efficient RL approach balancing QoE and power consumption.	Simulated live-streaming traces.	Demonstrates multi-objective optimization for future extensions.	Reduced energy consumption (~10%) without QoE loss	Reward tuning complexity and training instability may arise in real networks.
15	[20] (Lee et al., 2024)	Guided learning and chunk replacement for QoE optimization.	Testbed video sessions.	Provides reward-shaping concept for our RL controller.	QoE improvement ≈15–17% vs baseline ABR	Focuses on energy trade-offs rather than prediction accuracy.
16	[21]	(a) GRU-based	Real	Validate the GRU	Reduced rebuffering and	Requires complex segment

No.	Reference / Year	Core Idea or Contribution	Dataset / Experimental Setting	Relevance to This Dissertation (HyBoB-RL)	Key Results / Performance	Limitations
	(Woo et al., 2024)	bandwidth forecast combined with buffer control; (b) ML QoE classification linking QoS to perceived quality.	streaming testbeds and QoE labeled datasets.	forecast module and QoS–QoE mapping used for reward design.	improved smoothness (~10–15%)	management and may increase client overhead.
17	[22] (Agarwal et al., 2025)	Passive-learning rate-control using historical RTC logs (no active probing).	Real video call logs + emulation.	Supports our data-driven, log-based measurement approach.	Increased bitrate (~15–20%) and reduced freezes (~25–30%) vs GCC	Focuses on short-term prediction only and lacks hybrid ML–RL integration.

Collectively, these seventeen studies mark the evolution from measurement-based learning toward hybrid deep and reinforcement-learning approaches emphasizing QoE (see Table 1.1). While early models established the value of ML for network estimation, recent works have converged on adaptive, perceptual, and multi-agent frameworks. The proposed HyBoB-RL system integrates these paradigms combining ensemble regression, GRU temporal modeling, and actor–critic reinforcement learning—to deliver real-time, QoE-optimized bandwidth prediction across heterogeneous Iraqi and global networks.

1.3 Problem Statement

Despite extensive research, short-term bandwidth prediction remains challenging due to several interconnected resons:

1. A wireless and congested networks exhibit high-frequency variability from user mobility, fading, and bursty cross-traffic, which rapidly alters link capacity.
2. A non-linear interactions among delay, jitter, and throughput complicate modeling because classical estimators assume linear and stationary behavior.
3. A heuristic filters such as EWMA or harmonic averaging do not generalize well outside of controlled testbeds and result in large errors when exposed to real-world Iraqi ISP conditions where paths, routing and interference are constantly changing.
4. A quality of experiment sensitivity enhances the impact of even small prediction errors—over-estimation leads to playback stalls and under estimation wastes bandwidth and degrades perceptual quality.
5. Finally, because of resource constraints on end-user devices, light-weight models are required, that can do inference in sub-10 ms without requiring access to the cloud.

These challenges also underscore the necessity for combining insights of traditional, human-interpretable models with the flexibility of machine learning and the decision optimality of reinforcement learning in a hybrid measurement-driven fashion. This integration allows for QoE-aware and real-time accurate

bandwidth prediction as per the needs of heterogeneous and highly dynamic network conditions.

1.4 Research Aim and Objectives

The main aim of this dissertation is to develop, implement and validate an integrated hybrid framework using reinforcement learning (RL) and machine learning (ML) techniques for accurate, measurement-based bandwidth prediction and QoE-sensitive bitrate adaptation. The designed system is aiming for a real time prediction accuracy, adaptive control responsiveness, and resource utilization to be efficient against the variety of conditions over mobile and wired networks in Iraq to have high quality multimedia streaming through Internet among diverse environments. The objective of dissertation can be categorized as :

1. Get a synchronous record of Iraq's bandwidth usage on customers' computers and mobile phones via the Supabase cloud.
2. Design a measurement-based ML estimator (ML-MBE) employing ensemble regressors and quantile inference.
3. Integrate a GRU temporal predictor for short-term sequence modeling.
4. Fuse the outputs through a Hybrid Blend-of-Blends (BoB) gate controlled by an actor–critic RL module.
5. Optimize bitrate decisions using QoE-driven rewards that penalize rebuffering and oscillations.
6. Validate performance against external datasets (e.g., Microsoft BoB Challenge / AlphaRTC).
7. Demonstrate real-time deployability with low computational overhead.

1.5 Research Questions

A set of specific research questions which define the direction of analysis and experimentation for the proposed hybrid framework, are formulated in this research. The questions focus on the predicting ability, trade-off between responsiveness and stability and the QoE improving across heterogeneous real-world networks. Together, they serve as the building blocks for construction of the HyBoB-RL system.

1. How accurately can ensemble-based ML models predict near-term available bandwidth from measurement features?
2. What hybrid design (heuristic + ML + RL) achieves the best balance between responsiveness and stability?
3. How does quantile-aware prediction improve bitrate safety and QoE?
4. Which network features most strongly influence predictive accuracy under Iraqi conditions?
5. Can lightweight on-device inference (< 10 ms) sustain acceptable QoE for mobile users?

1.6 Scope Dessirtation

This dissertation provides a defined experimental and analytical barrier to allow for focused research and reproducible results. The note emphasizes the prediction time frame, range and scaling of data sets, as well as evaluation criteria relevant to the goals of the study. It describes the environments for which the HyBoB-RL framework is developed and evaluated in.

- Focus on short-term (1–4 s) bandwidth prediction for HTTP adaptive video streaming.
- Coverage of Iraqi (ISP, device) and external (Microsoft BoB) datasets.
- Evaluation through both predictive metrics (MAE, RMSE, R^2) and perceptual QoE indicators.

1.7 Limitations Dissertation

Although the study contributes insightful views on adaptive streaming of heterogeneous media, there are still some limitations. The constraints include external, scene realism and lab testing coverage. These bounds serve to illustrate the scope and possible generalizations of the proposed framework in future research.

- Geographical bias limited to central Iraq.
- Simulated playback traces rather than live commercial streams.
- External datasets represent controlled rather than real end-user variability.

1.8 Dissertation Contributions

In this dissertation, we provide a number of technical and computational contributions such that measurement-based analytics is combined with smart learning models. Every contribution is a key milestone—from online data collecting and ML model constructing, to the RL-control mechanism and performance evaluation. Their combined derivation forms the full pipeline of the proposed HyBoB-RL framework for adaptive multimedia streaming.

1. Data Acquisition**:** Developed Python-based PC and Android monitoring scripts using ping, traceroute, and speedtest-cli, integrated with a Supabase REST API for real-time Iraq dataset collection and cloud synchronization.
2. ML-MBE Module**:** Implemented ensemble regression models (Random Forest, Gradient Boosting, XGBoost) with quantile prediction using scikit-learn and xgboost, forming the core of the measurement-based estimator.
3. Temporal Model**:** Programmed a GRU-based quantile predictor in TensorFlow and PyTorch to learn short-term sequence dynamics from temporal bandwidth traces.
4. Hybrid Fusion: Coded **a** Blend-of-Blends (BoB) gate with actor–critic reinforcement learning control, updating blending parameters (α, θ, L, H) through adaptive feedback.
5. QoE Feedback: Designed a Python reward syndissertation module combining bitrate, rebuffering, and smoothness metrics into a unified QoE function.
6. Evaluation: Created cross-ISP benchmarking scripts to compare Hybrid BoB-RL performance (ΔQoE, ΔMAE, ΔR^2) against the BoB baseline.
7. Efficiency**:** Optimized code for <10 ms inference latency and <5 MB model size for on-device execution.
8. Open Research Artifact**:** Published all source code, datasets, and automation notebooks for reproducibility and future research extension.

1.9 Dissertation Organization

The organization of this dissertation is intended to provide the research progression in a meaningful sequence from motivation to experimental verification. The theoretical basis, system design and the empirical results to the new framework are presented with each chapter in continuation of one another. The contents of chapters designated to the specific purpose of the dissertation are summarized below.

- Chapter 1: Motivation, objectives, and related works.
- Chapter 2: Detailed literature review on measurement-based estimation, ML ensembles, and RL adaptation.
- Chapter 3: System Design and Methodology — the HyBoB-RL framework architecture .
- Chapter 4: Experimental Evaluation — datasets, metrics, and QoE analysis .
- Chapter 5: Conclusions and Future Works.

ملخص

مع استمرار النمو المتسارع لحركة بيانات الوسائط المتعددة وخدمات البث المباشر الأخرى، باتت الحاجة ملحة إلى التنبؤ الدقيق بعرض النطاق الترددي المنخفض عبر الشبكات غير المتجانسة. في الشبكات اللاسلكية الديناميكية، بما في ذلك البنية التحتية العراقية متعددة مزودي خدمة الإنترنت، والتي تشهد تقلبات في الإنتاجية وزمن الاستجابة والارتعاش على مستوى أجزاء من الثانية حول قيمة متوسطة، لا تستطيع نماذج الاستكشاف أو الاستدلال التقليدية وحدها تقديم تقديرات دقيقة للتحكم التكيفي في معدل البت (ABR).

تقدم هذه الأطروحة إطار عمل شاملًا للتنبؤ بعرض النطاق الترددي قائمًا على التعلم الآلي، يستفيد من التحليلات القائمة على القياس، والتعلم الجماعي، والنماذج الزمنية، والتعلم المعزز لتحقيق تكيف الوسائط المتعددة مع مراعاة جودة تجربة المستخدم (QoE) في بيئات التشغيل الحقيقية. يجمع هذا النظام المعماري بين عملاء جمع البيانات لأنظمة ويندوز وأندرويد، والمُجهّزين لجمع مقاييس آنية - زمن الاستجابة، والارتعاش، وفقدان الحزم، ومعدل النقل، وتأخير القفزة - باستخدام أدوات فحص نشطة (مثل ping وtraceroute وspeedtest-cli) بالإضافة إلى تسجيل السياق السلبي؛ وواجهة خلفية Supabase RESTful لمزامنة جداول قياسات المستخدم في الوقت الفعلي مع السحابة؛ ومسار معالجة مسبقة مؤتمت يعمل على تطبيع البيانات، وإزالة التشويش، ومواءمة الخصائص الزمنية قبل عملية التعلم. وقد جُمع أكثر من 60 ألف عينة متزامنة من مزودي خدمة الإنترنت زين، وآسيا سيل، وإيرث لينك، مما يوفر أول مجموعة بيانات متاحة للجمهور لقياس عرض النطاق الترددي تركز على العراق لأغراض التعلم الآلي.

أُجريت مقارنة أداء على مجموعات بيانات AlphaRTC محلية عراقية وخارجية بين النظام المقترح (HyBoB-RL) ونظام Microsoft BoB الأساسي. يُلاحظ انخفاض متوسط الخطأ المطلق (MAE) بنسبة 25% تقريبًا، وتحسن جودة تجربة المستخدم (QoE) بنسبة 12-15% في ظل ظروف الاختبار العادية، مع زمن استجابة للاستدلال أقل من 10 مللي ثانية وحجم نموذج أقل من 5 ميجابايت، مما يُثبت إمكانية النشر الفوري على الأجهزة الطرفية. وفي ظل اختبارات الضغط الناتجة عن الازدحام المُستحث، حافظت خوارزمية HyBoB-RL على جودة تجربة المستخدم ضمن نطاق ±5% من المستويات الأساسية، مما يدل على مرونتها وقدرتها على تنظيم البوابات ذاتيًا. جميع الوحدات، أي مُجمّعات البيانات، ونماذج

التعلم الآلي/وحدات التكرار البوابية (ML/GRU)، ووحدة تحكم التعلم المعزز (RL)، وبرامج التقييم، مُتاحة كتطبيقات مفتوحة المصدر، مما يُتيح إمكانية إعادة إنتاج النتائج لأبحاث التنبؤ بعرض النطاق الترددي.

يُوفر الجمع بين التعلم الجماعي، ونمذجة الكميات الزمنية، والتحكم المعزز، إطار عمل عمليًا وقابلًا للتطوير ومُحسّنًا لجودة تجربة المستخدم، لبث الوسائط المتعددة التكيفي في الشبكات غير المتجانسة ذات النطاق الترددي المحدود.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة ديالى
كلية العلوم
قسم علوم الحاسبات

التعلم العميق والتعلم المعزز الهجين للتنبؤ التكيفي بعرض النطاق الترددي في شبكة العراق

اطروحة مقدمة
الى كلية العلوم في جامعة ديالى وهي جزء من متطلبات نيل
شهادة الدكتوراه في علوم الحاسبات

من قبل
احمد مجيد كريم

بإشراف
أ.م.د منتظر خميس مصطفى
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