CSCI 572: Computer Networks (Fall 2023)

Proposal: Smart Bandwidth Allocation: Using Machine Learning for Home Networks

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1 Introduction

Overview

As home networks grow more complex with an increasing number of devices requiring bandwidth simultaneously, there arises a pressing need to manage and optimize bandwidth allocation efficiently. This project aims to harness the power of machine learning to predict bandwidth requirements and dynamically allocate resources based on the behavior patterns and usage trends of family members.

Assumptions

User Behavior Consistency: Family members' behavior in content consumption is somewhat consistent over time, allowing for predictive patterns to be discerned.
Data Quality: The data collected from devices is accurate, timely, and free from corruption or tampering.
Network Stability: The home network is stable and reliable, with minimal unexpected downtimes or disruptions.
Device Homogeneity: All devices in the network can communicate seamlessly with the local server or middleware without compatibility issues.
Privacy and Security: Family members are aware of and consent to the data collection. The system's internal security measures are sufficient to prevent unauthorized access.
ML Model Assumptions: Features chosen for the ML model are relevant and have a direct impact on predicting network usage.
Adaptability: The system can adapt to the addition of new devices or family members without significant reconfigurations.
Network Limitations: There is a consistent and predictable upper limit to the home network's bandwidth.

Application Requirement

Data Collection: Monitor real-time network traffic, device usage rates, and active times to understand bandwidth demand.
ML Model Integration: Incorporate ML model to predict bandwidth requirements based on historical and real-time data. Ensure periodic model updates with fresh data.
Bandwidth Management: Dynamically allocate bandwidth to devices based on predicted demand, ensuring optimal distribution.
Adaptability: Respond in real-time to any unexpected surges in bandwidth requirement, adapting allocations as necessary. Continuous feedback-driven improvement.
Notifications: User and admin alerts about bandwidth usage, potential high-usage periods, and suggestions for optimal usage times.

Goals

Analyzes: Captures real-time data on device activities, time of usage, and specific bandwidth-heavy tasks, correlating them with specific family members' habits.
Predicts: Utilizes machine learning algorithms to anticipate when high bandwidth periods are likely based on family behavior, thus enabling pre-emptive allocation.
Optimizes: Dynamically allocates bandwidth based on predicted needs, ensuring high-priority tasks have necessary bandwidth, reducing lag and ensuring efficient network performance.
Adapts: As family behavior evolves, the system learns from new data and feedback. It refines its predictions and bandwidth allocation strategies to better serve the evolving needs of the family, preventing bottlenecks before they can happen.

Non-Goals

Deep Learning Integration: The project does not aim to integrate complex deep learning models, as the focus is on lightweight machine learning algorithms suitable for home networks.
Specific Content Prediction: The primary objective is bandwidth allocation, not predicting the specific content that users might access.
Infrastructure Overhaul: The project does not intend to replace or drastically modify existing home network infrastructure but rather aims to enhance its performance.
Addressing Wide Area Networks: The project is centered on home networks, so challenges specific to wide area networks or large-scale infrastructures are not addressed.
Complex Algorithm Development: The goal is to use existing, proven machine learning techniques rather than developing entirely new algorithms from scratch.

2 Related work

After browsing through some resources and filtered article that publish after 2019. Have noticed that there are some research had conducted under similar concept.

Hatem's[1], Wang's[2], and this proposal, focus on optimization. Hatem's article emphasizes optimizing bandwidth in NG-EPONs, Wang's is about optimizing video stream analytic at the edge, and this solution revolves around optimizing bandwidth allocation in home networks. All of these try to use the leverage of machine learning to predict and optimize.

The three concepts aim to reduce unnecessary overhead and latency in their respective domains. Hatem seeks to decrease the control overhead in NG-EPONs, Wang's approach tries to cut down on latency by employing edge computing, and this solution targets seamless content delivery in home networks.

For the differences of each concept and solution, the solution I proposed is particularly tailored for home network environments. Unlike the intensive deep learning approach of Hatem or the algorithmic complexity presented by Wang, the proposal approach is cognizant of the fact that home networks may not have the computational resources comparable to dedicated optical networks or edge servers. Thus, this solution is designed to be less computationally intensive, ensuring it's feasible and effective for residential settings.

Which aim to do this without imposing heavy computational burdens that could potentially slow down the network or require additional, often expensive, hardware upgrades.The approach is intended to be integrated directly into existing home network systems. By harnessing machine learning in a manner that isn't overly resource-intensive, the proposal solution offers an efficient, practical way to improve bandwidth allocation in everyday residential networks.

3 Approach

Sketch

The project starts by grasping the family's online habits, from streaming videos to browsing websites. Concurrently, an understanding of the family's network setup is formed, identifying all the devices and their average bandwidth consumption. Logging tools are then integrated into these devices to facilitate the tracking of network usage patterns and bandwidth requirements.

A focused approach to data collection is adopted, monitoring the bandwidth consumption patterns across devices during different times of the day. The goal is to identify peak usage times, devices that consume more bandwidth, and services or applications that demand significant network resources. This granular data provides insights into the network's pulse and how resources are typically distributed.

After a detailed analysis, the data is cleansed, standardized, and any anomalies are addressed. Using this curated dataset, machine learning models are developed to predict bandwidth requirements based on user behavior patterns. The optimal model would aim to forecast network demand, allowing for preemptive bandwidth allocation.

Leveraging the NS-3 simulator, various bandwidth allocation strategies, driven by the trained machine learning model, are tested. This simulated environment provides insights into how the system would react to different devices trying to access resources concurrently, ensuring efficient bandwidth distribution without causing network congestion.

Post-simulation, the system undergoes testing in the home network. The emphasis is on observing how effectively the system allocates bandwidth, ensuring each device gets its required resources without hampering the experience of other devices. Feedback from family members about their online experience, especially during peak usage times, is gathered to measure the system's real-world impact.

4 Evaluation Plan

Setting clear, straightforward objectives. While the primary aim is faster content delivery, other goals might include user satisfaction and reduced buffering. Before rolling out the allocation system, collect feedback from family members about their current content viewing experience. This will serve as a benchmark to understand the improvements post-implementation.

Subjective opinion of user is the key of this project. The project build up on the user experience and satisfaction. Which collecting user feedback is crucial too. User survey after the deployment. Is the content loading faster? Is network there when you need it? Gain feedback from the survey and may adjust the model parameter accordingly.

Whats more log the data and monitor evaluate the changes of bandwidth under different time schedule and different contents stream. Evaluate the accuracy of the allocation.

5 Milestones

Setup & Preliminaries Oct 22: Project Onboarding, Network Assessment, Data Collection Setup

Data Accumulation & Initial Analysis Oct 29: Collect Historical Data, Online Database, Preliminary Analysis

Model Design & Training Nov 5: Data Preprocessing, Model Selection, Model Training

Model Validation & Integration Nov 12: Model Testing, Optimization, System Integration

Prototype Testing & Feedback Nov 19: Deploy Test Version, Monitor Performance, Feedback

Refinement Nov 26: Iterative Improvement, Final Deployment

References

[1] J. A. Hatem, A. R. Dhaini, and S. Elbassuoni. Deep learning-based dynamic bandwidth allocation for future optical access networks. *IEEE Access*, 7:97307–97318, 2019.

[2] Can Wang, Sheng Zhang, Yu Chen, Zhuzhong Qian, Jie Wu, and Mingjun Xiao. Joint configuration adaptation and bandwidth allocation for edge-based real-time video analytics. pages 257–266, 2020.