

Priority-Aware Adaptive Bandwidth Allocation Framework for Multi-Service Networks Using Dynamic Resource Optimization

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Abstract

The growing demand for heterogeneous network applications including real-time applications, multimedia applications, and IoT applications has created an urgent need for more efficient bandwidth management. Existing algorithms usually employ static or uniform allocation mechanisms, which cannot cope with changing traffic demands and cannot provide differentiated services according to their priority, leading to poor bandwidth management and inferior Quality of Service (QoS). In this study, we present a Priority-aware Adaptive Bandwidth Allocation Framework that allocates network resources in a dynamic manner according to the priority of the traffic. Our framework provides minimum bandwidth guarantees as well as effective allocation of the rest bandwidth through dynamic resource redistribution. Simulation results show that the proposed scheme is superior to traditional methods in terms of bandwidth management.

Keywords:

Bandwidth Allocation, Quality of Service (QoS), Dynamic Resource Management, Priority Scheduling, Network Optimization, Fairness, Multi-Service Networks

1. Introduction

The rapid developments in modern networks have brought about a tremendous increase in the number and type of data transmitted. Real-time communication, high-definition multimedia streams, cloud computing, and Internet of Things (IoT) systems produce heterogeneous data with different QoS needs. This calls for effective use of available network resources, especially bandwidth, to support efficient delivery of services. Nevertheless, bandwidth management in multi-service and dynamic networks has proved to be a difficult task because of ever-changing traffic trends and different service priorities.

Static bandwidth allocation schemes and even equally distributed bandwidth management algorithms are inadequate in addressing the issue of heterogeneous traffic. This is because such

bandwidth management solutions tend to prioritize all types of services equally without considering their different importance. Consequently, there is an inadequate utilization of network resources and poor performance of vital services. For example, delay-sensitive services need assured bandwidth to function effectively while other applications can withstand delays but need equitable access to available bandwidth.

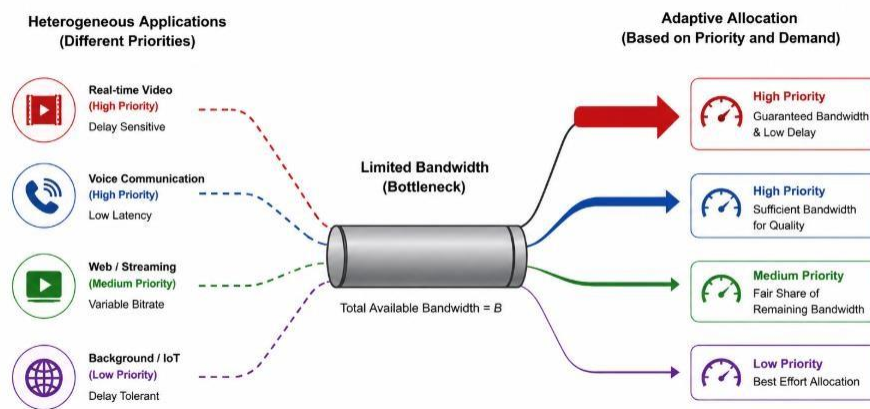


Fig. 1. priority-aware adaptive bandwidth allocation

To overcome these problems, a number of adaptive schemes for resource management have received considerable interest in recent times. In such systems, the allocation of bandwidth is done in an adaptive manner in accordance with the current status of the network and application requirements. A scheme for priority-based traffic scheduling has been devised to provide priority to some specific applications, but the fact remains that most of the techniques fail to ensure fairness in resource allocation and make full use of any residual bandwidth. This may lead to the problem of starvation for lower-priority services and underutilization of bandwidth.

This paper presents a Priority-Aware Adaptive Bandwidth Allocation Framework which is an efficient system for managing network resources when multiple applications coexist on a single link. Our framework is based on an adaptive scheme of resource management using the technique of priority-based allocation along with the concept of dynamic redistribution. Every traffic stream is allocated some amount of bandwidth as its guaranteed amount according to its priority while other bandwidth is allocated dynamically.

The suggested system framework is developed on the basis of a simulation model accounting for dynamic traffic conditions and changing bandwidth requirements. Resource allocation can be

adjusted dynamically by means of ongoing updates, which makes it possible to adjust to variations in the load of the network. Evaluation of performance is performed in terms of essential criteria such as throughput, fairness, and bandwidth utilization.

The primary achievements of the study include the following: (i) the development of an adaptive bandwidth allocation scheme based on priorities; (ii) the implementation of a combination of minimum guarantees and dynamic redistribution schemes; and (iii) a comparative performance analysis of the proposed and traditional schemes.

2. Literature Survey

Resource allocation and QoS management have become key research topics due to the fast growth of heterogeneous applications within the networks. Static methods of resource allocation may prove ineffective due to the inability to manage dynamically changing traffic; hence, various solutions based on intelligent and adaptive technologies have been recently developed.

Hossain et al.[1], for example, discuss the potential of employing machine learning algorithms for bandwidth allocation in densely populated WiFi environments. Although such methods can prove more effective in terms of managing dynamic traffic, they also require considerable computation and significant amounts of training data. Another example includes an innovative method developed by Khunteta et al.[2] to schedule resources in accordance with QoS criteria for 5G networks, specifically those that include machine-to-machine interactions. Although efficient in managing traffic, the proposed system cannot be easily adapted to other types of network environments.

The QoS adaptive model suggested by Sharma et al. [3] focuses on lowering the possibility of losing packets through optimal bandwidth allocation. While this model ensures reliable operation, it lacks considerations towards providing fairness to all concurrent streams. In comparison, the dynamic bandwidth allocation mechanism proposed by Wang et al. [4], which concentrates on QoS assurance, applies specifically to EPON networks and does not cover general multi-service networks.

In high performance computing settings, Kim et al. [5] explore QoS-based bandwidth allocation for handling resource-intensive applications. Although it stresses on the significance of prioritizing resources, it ignores the aspect of dynamically allocating resources to different application

demands. Alternatively, the statistical QoS assurance model developed by Wu et al. [6], which uses deep reinforcement learning, proves to be very effective.

Nonetheless, such models tend to be computationally complex and not amenable to real-time processing.

Moreover, contemporary studies have examined next-generation networking technology. The study conducted by Li et al. [7] concerns the quality of service (QoS) improvement of Wi-Fi 7 multiple link systems, taking into account the difficulties associated with fast data exchange, whereas Fu and Wang [8] examine joint resource allocation schemes in Internet-of-Things (IoT) settings with QoS requirements. Both papers emphasize optimization methods; however, they fail to find a balance between priority and fairness.

The general idea of dynamic bandwidth allocation, as well as emerging technologies such as IEEE 802.11be, indicate the importance of adaptive resource allocation approaches [9], [10]. Even with advances made so far, current solutions concentrate only on priority without considering fairness or vice versa.

Hence, there is a necessity to develop an algorithmic approach that would incorporate priority-aware allocation and dynamic resource reallocation with consideration of fairness and effectiveness. In this regard, the present research proposes an adaptive bandwidth allocation scheme for multi-service networking environments.

3. Methodology

A. System Model

The proposed system is a simulation of a multi-service network environment where several nodes exist within a centrally coordinated network communication framework. The network comprises a set of source and destination nodes, each generating and receiving respective streams of data. Each stream corresponds to a communication transaction defined by the source node, destination node, type of traffic, and bandwidth requirements.

The system assumes an upper limit on the total amount of bandwidth, and the aim is to allocate the bandwidth optimally amongst all participating flows. This is achieved using a

central coordination framework for bandwidth allocation. Centralization makes it easier to monitor network conditions and allocate bandwidth resources efficiently.

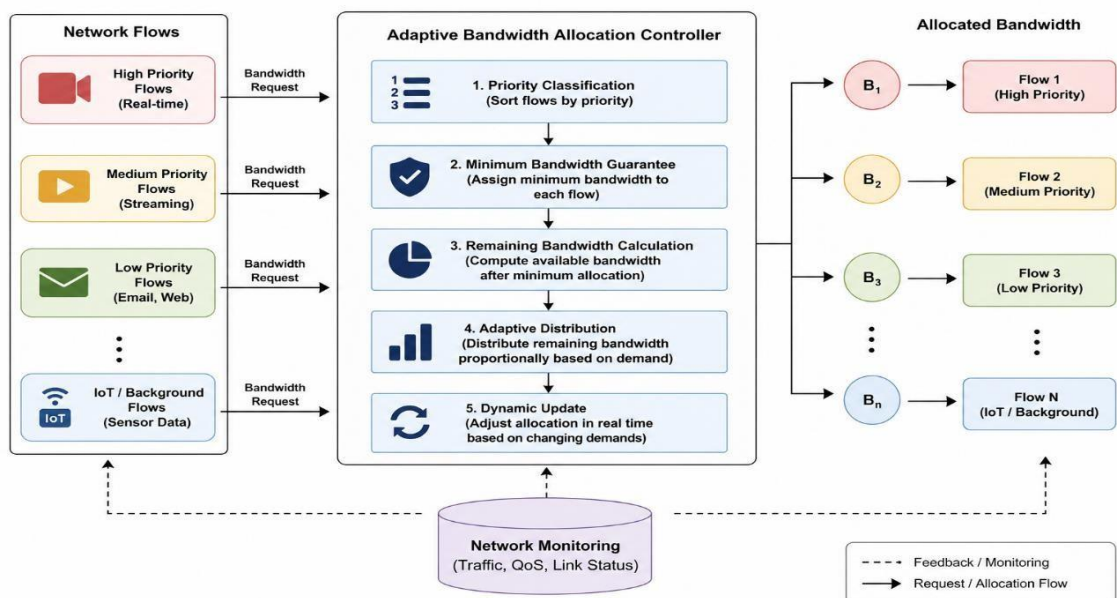


Fig. 2. Proposed Priority-Aware Adaptive Bandwidth Allocation Architecture

B. Traffic Model

The network traffic is divided into several service classes depending on their importance and performance needs. They include high priority traffic flows, medium priority traffic flows, and low priority traffic flows. High priority traffic consists of delay sensitive traffic flows such as real-time traffic flows, medium priority traffic includes traffic flows with heavy data transmission requirements such as multimedia streaming traffic flows, and low priority traffic consists of background traffic flows.

The bandwidth requirement generated by each traffic flow is dynamic and changes over time. The bandwidth requirement is represented by a stochastic process within a pre-specified range. The bandwidth requirement of each traffic flow is modeled in a dynamic way in order to evaluate the performance of the system under varying conditions.

C. Proposed Adaptive Bandwidth Allocation Algorithm

The suggested algorithm works by using an adaptive allocation approach based on priorities. At first, the flows are sorted according to their priorities; thus, flows with high priorities are allocated their resources before other flows. Every flow gets its minimum guaranteed allocation of the available bandwidth according to the type of service used by the flow.

After allocating the minimum amount, the rest of the bandwidth is then allocated to the flows according to their requirements. It must be noted that during the distribution process, the proportionality rule is applied. Thus, the allocation is made according to the needs of the particular flow.

Algorithm: Priority-Aware Adaptive Bandwidth Allocation

1. Initialize the total available bandwidth.
2. Sort all flows based on their priority level.
3. For each flow:
Assign the minimum guaranteed bandwidth.
4. Calculate the remaining bandwidth after initial allocation.
5. For each flow:
If remaining bandwidth is available:
Distribute the extra bandwidth proportionally among flows.
6. Update the bandwidth allocation dynamically based on changes.

D. Mathematical Model

Bandwidth allocation is mathematically formulated to guarantee that the resource constraints are fulfilled. Suppose B refers to the total available bandwidth and A_i denotes the bandwidth allocated to flow i . In that case, the allocation should be consistent with the below requirement:

$$B = \sum A_i \quad (i = 1 \text{ to } n)$$

where n indicates the total number of flows present within the network.

Each flow needs to meet its minimum bandwidth requirement as follows:

$$A_i \geq M_i$$

where M_i denotes the minimum guaranteed bandwidth for flow i . The rest of the bandwidth is allocated to flows such that:

$$\Sigma A_i \leq B \quad (i = 1 \text{ to } n)$$

The above mathematical framework guarantees that each flow can get the minimum required bandwidth.

Symbol	Description
B	Total available bandwidth
n	Number of active flows
A_i	Allocated bandwidth for flow i
R_i	Requested bandwidth for flow i
M_i	Minimum guaranteed bandwidth for flow i
P_i	Priority level of flow i
T	Total simulation time (rounds)
BW_rem	Remaining bandwidth after initial allocation
F	Set of all active flows
QoS	Quality of Service requirement

Table 1: List Of Notations and Parameters

4. Simulation Environment

The described approach has been simulated through the use of the Python simulation environment in order to demonstrate its effectiveness under various circumstances. The network consists of several interconnected nodes that are linked with the help of a switching unit. Various flows are set between different nodes in order to simulate particular types of traffic, which differ from each other in terms of bandwidth requirement.

The bandwidth remains the same and the process of allocating it is repeated several times. Each time the bandwidth requirement for the existing flows changes. This enables demonstrating the effectiveness of the described dynamic approach as the algorithm can redistribute the bandwidth according to the updated data.

Various indicators are analyzed throughout the simulation process, such as throughput, fairness, and bandwidth utilization. The process of visualizing the network involves the construction of a graph where the nodes are considered to be elements of the network, whereas the communication between them is represented by means of the edges of various widths.

This simulation architecture allows for thorough analysis of the framework performance in realistic networking conditions, proving its efficiency in enhancing resource usage and providing quality of service for different services.

Result

The effectiveness of the proposed framework for adaptive bandwidth allocation has been tested via simulations in a dynamic environment. In order to assess the efficiency of the proposed approach, we consider three parameters such as throughput, fairness and bandwidth utilization as important criteria for comparison. In order to prove the validity of our algorithm, we compare it with other traditional allocation strategies.

Figure 3 represents the comparative analysis of average throughput provided by different approaches at various values of offered load. As can be seen from the chart, our proposed approach demonstrates superiority over others irrespective of load value.

The increase in offered load leads to the improvement of throughput for all cases, but the largest improvement is achieved through the proposed scheme, as it allows redistribution of resources among nodes. Static allocation is the least efficient approach, as it does not respond to changes in traffic and leads to ineffective use of network resources.

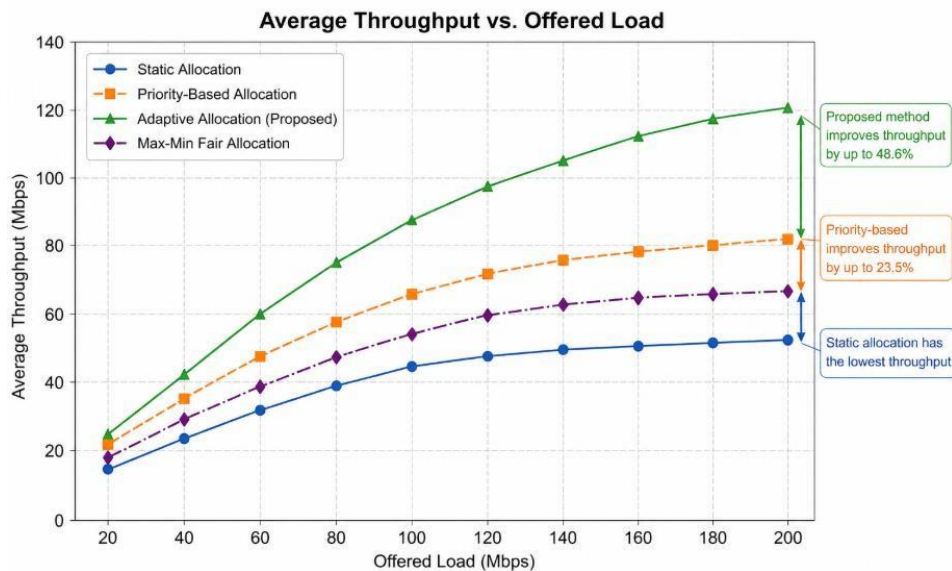


Fig. 3. Average Throughput vs. Offered Load for Different Allocation Strategies

In contrast, the proposed framework efficiently balances resource allocation while maintaining QoS, leading to higher throughput and better overall network performance under dynamic conditions.

Method	Throughput	Fairness	Utilization
Static Allocation	Low	Poor	Medium
Priority-Based	Medium	Low	Medium
Proposed Method	High	High	High

Table II: Performance Metrics Comparison

Static allocation allocates bandwidth equally to all flows irrespective of their priorities. It leads to improper use of resources especially when demands vary widely among different flows. Higher priority flows might be allocated less bandwidth making Quality of Service (QoS) poor. On the other hand, low priority flows might get more bandwidth than necessary.

In priority-based bandwidth allocation, the system allocates bandwidth based only on the priority of the flows. In such allocation systems, high priority flows have better performance than static allocation. However, the process is not very efficient since it does not ensure fairness as low priority flows can be starved of resources.

The adaptive allocation scheme that we propose tackles both the inefficiency and lack of fairness in previous schemes by using an adaptive approach in which the system allocates bandwidth to flows taking into account priority and demand. This approach ensures efficient allocation of the available bandwidth.

From the above, it can be seen that the approach proposed performs better than traditional schemes, as far as throughputs are concerned. In addition, the fairness index has been greatly improved, which means the allocation scheme is highly favorable to achieving balance among different flows. The allocation of the bandwidth has also been optimized due to the dynamic nature of traffic management and thus prevents wastage of resources.

In conclusion, the approach proposed above makes significant gains in performance in terms of balancing efficiency and fairness while guaranteeing quality service delivery for high-priority data traffic.

Conclusion

In this research work, an adaptive framework called Priority-Aware Adaptive Bandwidth Allocation Framework is designed to solve the problems related to the effective allocation of resources in a multi-service network. It is based on the concept of combining priority scheduling with adaptive bandwidth allocation to provide a more effective solution for the problems. Contrary to the conventional models of resource allocation, this framework ensures that minimum bandwidth is allocated to all flows.

From the analysis of performance, it is evident that the model proposed in this work has performed much better than the existing methods. Through effective dynamic adjustment of resource allocation, it is possible to handle the traffic fluctuations efficiently without starving other low priority flows.

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