Implementation and Evaluation of QoS in IEEE 802.11e for Multimedia Traffic Using OMNet++

Data Communications Mini Project - CS255

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Introduction

This project aims to evaluate the Quality of Service (QoS) performance for wireless devices operating under the IPv4 and IPv6 protocol using OMNeT++ and the INET framework. The analysis considers traffic categories such as background, best effort, video, and voice, measuring metrics like end-to-end delay, jitter, throughput, and packet loss. The study emphasizes comparing scenarios with and without QoS enabled in the MAC layer.

IPv4

IPv4, or **Internet Protocol version 4**, is the fourth version of the Internet Protocol that underpins most internet communication today. It uses a **32-bit address system**, which supports approximately 4.3 billion unique IP addresses. IPv4 addresses are typically formatted in a human-readable format as four decimal numbers separated by dots (e.g., 192.168.1.1).

Features of IPv4:

- **Widely Adopted:** IPv4 has been the standard for decades and is supported by nearly all devices and networks worldwide.
- **Limitations:** With the expansion of the internet and connected devices, IPv4's limited address space has led to shortages and the need for address conservation techniques, such as NAT (Network Address Translation).

IPv6

IPv6, or **Internet Protocol version 6**, is the successor to IPv4, developed to address the limitations of IPv4's address space. It uses a **128-bit address system**, allowing for **trillions of unique IP addresses**, vastly expanding the addressable range to meet the demands of modern networking. IPv6 addresses are displayed in hexadecimal notation and separated by colons (e.g., 2001:0db8:85a3:0000:0000:8a2e:0370:7334).

Features of IPv6:

- **Enhanced Scalability:** IPv6 provides virtually limitless address space, ensuring support for the growing number of IoT devices and other internet-connected systems.
- **Improved Network Efficiency:** IPv6 eliminates the need for NAT, enabling end-to-end communication and simplifying routing.
- **Built-In Security Features:** IPv6 includes native support for IPsec, enhancing security for data exchange.

Both IPv4 and IPv6 are fundamental protocols for internet communication, and understanding their differences is crucial for analyzing network performance. The simulations conducted in OMNeT++ evaluate how traffic types behave under each protocol, with and without QoS mechanisms. IPv6 is particularly relevant in modern networking scenarios due to its scalability and ability to handle diverse traffic types more efficiently. By comparing IPv4 and IPv6, this report highlights how protocol evolution impacts metrics like delay, jitter, and throughput, providing valuable insights for optimizing real-world network setups.

Objectives

1. To simulate a wireless network supporting IPv4 and IPv6 using OMNeT++ 6.1.
2. To measure and analyze the QoS performance for various traffic classes in the presence and absence of QoS configurations.
3. To assess the impact of prioritization mechanisms on traffic flows with different data rates and message lengths.

Simulation Environment

Tools and Frameworks

- Simulator: OMNeT++ v6.1
- Framework: INET 4.5
- Simulation Network: Configured using .ini and .ned files.
- Key Modules:
  - Ipv6FlatNetworkConfigurator: For automatic IPv6 address assignment.
  - Ipv4NetworkConfigurator: For automatic IPv4 address assignment
  - WirelessHost and AccessPoint: To represent the client, server, and AP devices.

Configuration Details

- Simulation Area: 300 * 200 meters
- Simulation Time: 10 seconds
- Wireless Standard: IEEE 802.11 with Qos enabled in MAC
- Traffic Categories:
  - Background: 24 Mbps
  - Best Effort: 28.8 Mbps
  - Video: 5 Mbps

    - Voice: 100 Kbps
- Message Characteristics:
    - Background: 900 B, 300 microseconds interval
    - Best effort: 900 B, 250 microseconds interval
    - Video: 600 B, 1 microsecond interval
    - Voice: 125 B, 10 microsecond interval

Simulation Methodology

Network Design

Three network configurations were implemented using .ned files:

1. QosShowcase:
    - An IPv4-based network with QoS disabled.
    - Components:
        - A single access point
        - Wireless client and server nodes communicating via UDP
2. QosShowcaseIPv4:
    - An IPv4-based network with an emphasis on traffic class prioritization.
    - Configurations made with QoS enabled in the MAC layer.
3. QosShowcaseIPv6:
    - An IPv6-based network with an emphasis on traffic class prioritization.
    - Configurations made with QoS enabled in the MAC layer.

Traffic and Prioritization

Traffic flows were generated using UdpBasicApp for clients and UdpSink for servers.
QoS was enabled for:

```
*.*.wlan[*].mac.qosStation = true
*.*.wlan[*].classifier.typename = "QosClassifier"
```

IPv4 was configured using:

```
*.ap.hasIpv4 = true
*.server.hasIpv4 = true
*.client.hasIpv4 = true

*.ap.hasIpv6 = false
*.server.hasIpv6 = false
*.client.hasIpv6 = false
```

IPv6 was configured using:

```
*.ap.hasIpv4 = false
```

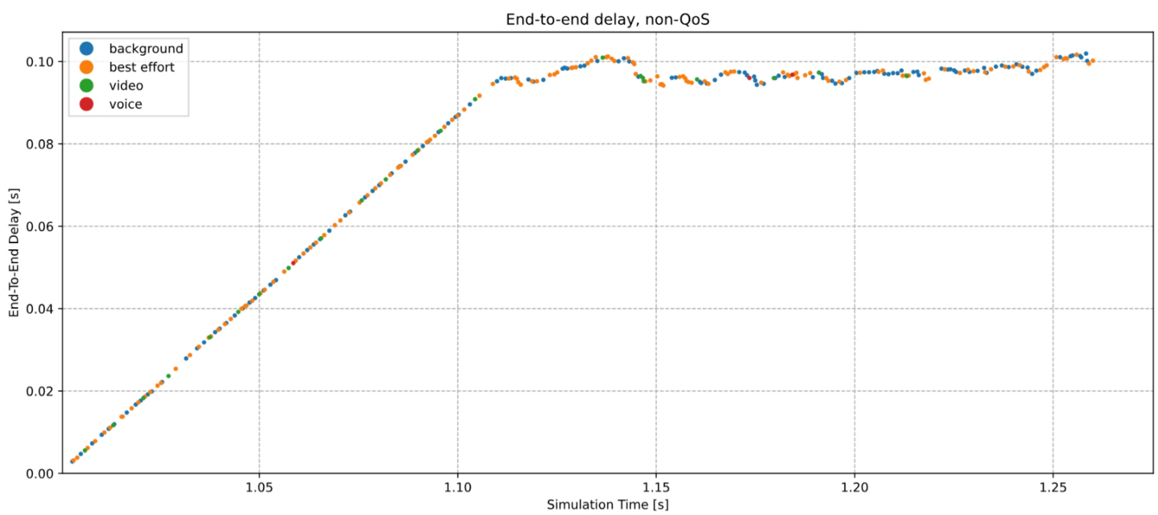
```
*.server.hasIpv4 = false
*.client.hasIpv4 = false

*.ap.hasIpv6 = true
*.server.hasIpv6 = true
*.client.hasIpv6 = true
```

Metrics Collected

- End-to-End delay
- Jitter
- Throughput
- Packet Loss

Results and Analysis

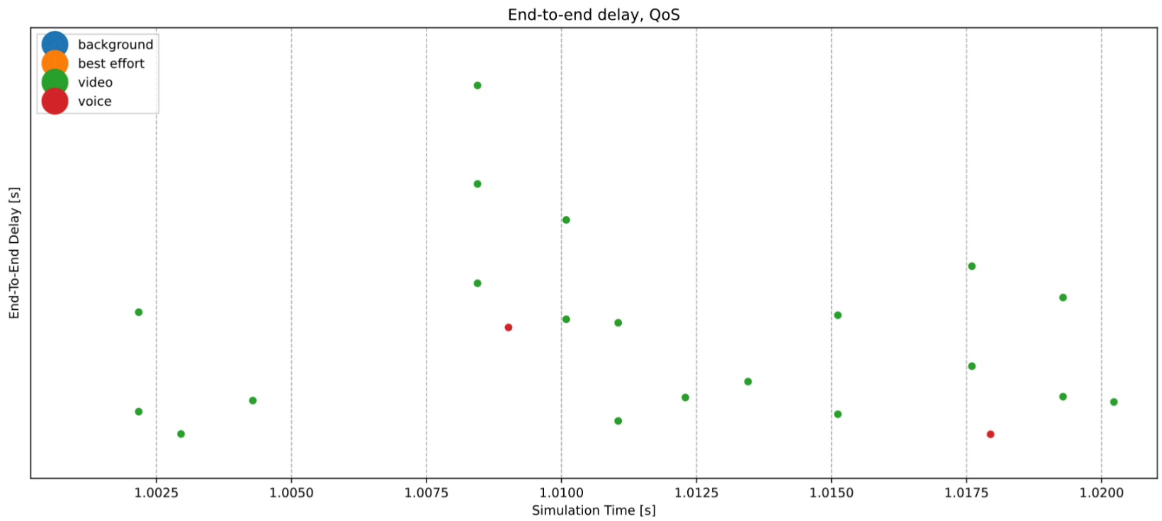
Non QoS End-to-End delay IPv4



- The background, best effort, video, and voice traffic delays are very close to each other, which is expected when there is no QoS prioritization.
- The delay values increase linearly over simulation time. This could indicate a **gradual accumulation of latency** as more packets are generated and the network's capacity is consistently loaded.
- Since **no significant differences are observed between traffic types**, it points to a non-QoS-enabled setup, meaning all traffic is treated equally by the network.

Traffic types like video and voice that require low latency don't receive special treatment, potentially leading to a poor user experience for critical applications. All traffic types experience similar performance characteristics, resulting in equal delays regardless of their priority.

QoS End-to-End Delay IPv4



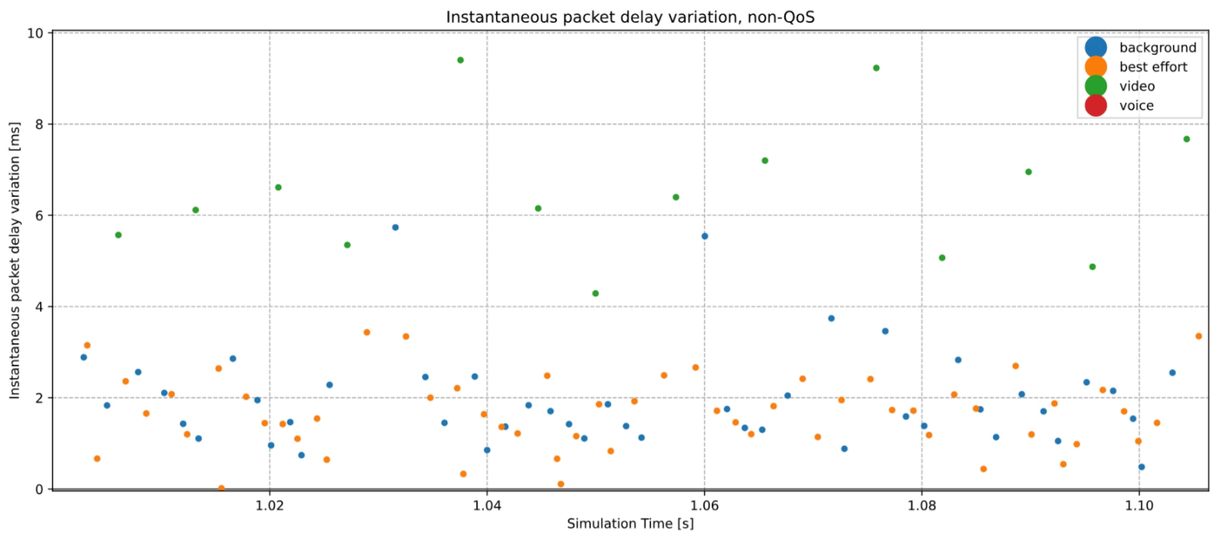
Voice Traffic (Red)	Video Traffic (Green)	Best Effort Traffic (Orange)	Background Traffic (Blue)
Shows the lowest end-to-end delay among all categories, consistently close to 0 seconds.	Slightly higher delays compared to voice but still relatively low.	Experiences moderate delays.	Shows the highest and most variable delays.
This indicates high priority in a QoS-enabled network, ensuring minimal delay for latency-sensitive traffic like voice.	Video traffic benefits from prioritization, resulting in acceptable delays suitable for multimedia streaming.	As a lower-priority category, packets are likely delayed more when the network is congested.	This is expected since background traffic is typically deprioritized, meaning its packets are transmitted only after higher-priority traffic is handled.

The **delays for voice and video traffic remain stable** over the simulation time, indicating that QoS mechanisms are effectively prioritizing these categories. In contrast, **best effort and background traffic exhibit more variation**, suggesting that these categories are more affected by network dynamics, such as queueing delays or resource competition.

The graph demonstrates that QoS mechanisms are working as intended by ensuring low and stable delays for high-priority traffic (voice and video).

The differentiation between traffic categories—especially the significant delay gap between voice/video and best effort/background—highlights the benefits of traffic prioritization.

Non QoS Instantaneous Packet Delay Variation IPv4

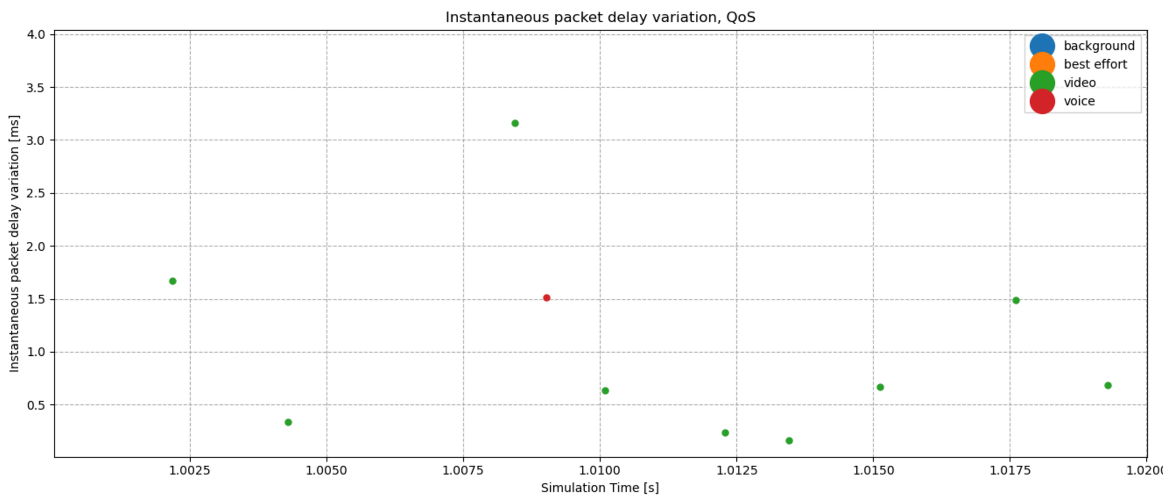


Background Traffic (Blue)	Best Effort Traffic (Orange)	Video Traffic (Green)	Voice Traffic (Red)
Exhibits the highest packet delay variation, with data points scattered between 0 ms and nearly 10 ms.	Shows less variation compared to background traffic but still fluctuates between 2 ms and 8 ms.	Packet delay variation is moderate, mostly staying under 5 ms.	Experiences the least packet delay variation, remaining mostly below 2 ms.
This indicates that background traffic is	This traffic suffers from instability as it is not	Being multimedia traffic, it benefits	This suggests that even without explicit QoS

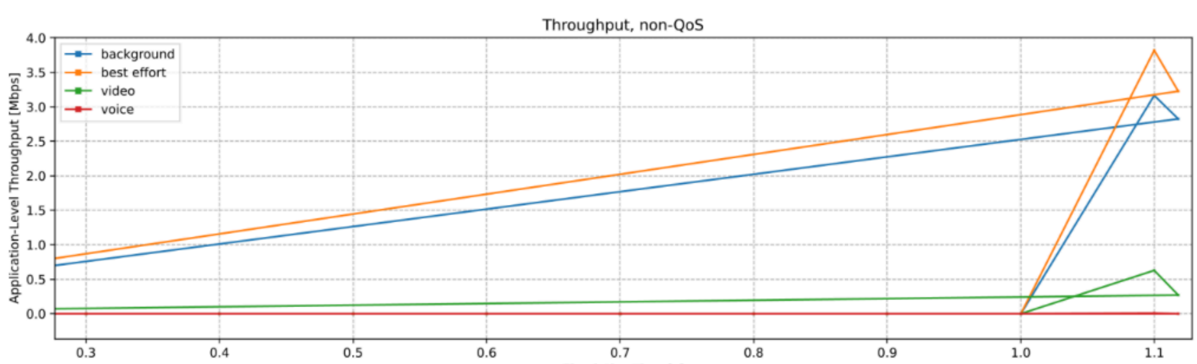
highly susceptible to fluctuations, likely due to competition for network resources with higher-priority traffic.	prioritized over other categories.	slightly from smoother handling compared to background and best-effort traffic, although it still lacks consistent prioritization.	mechanisms, voice traffic is less affected by network congestion due to its inherently small and regular packet sizes.

The non-QoS configuration treats all traffic equally, leading to congestion-related fluctuations in delay, especially for lower-priority traffic like background and best effort. Video and voice traffic, which are sensitive to jitter, still experience some degree of delay variation, potentially affecting the quality of multimedia and real-time communication.

QoS Instantaneous Packet Delay Variation IPv4



Non-QoS Throughput IPv4



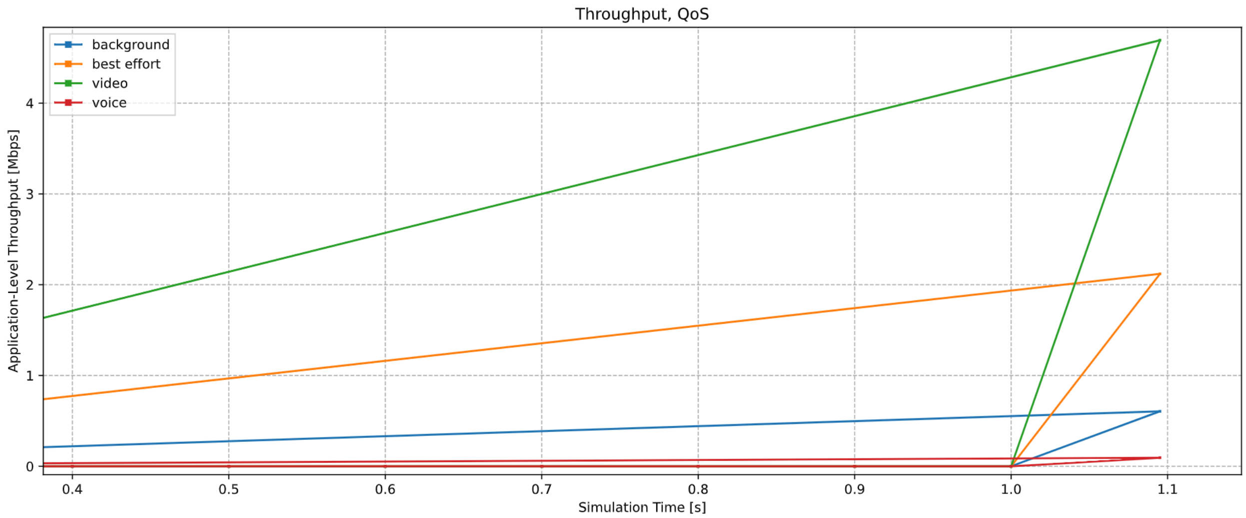
Background Traffic (Blue)	**Best Effort Traffic (Orange)**	**Video Traffic (Green)**	**Voice Traffic (Red)**
Experiences steady growth in throughput over time, likely due to reduced competition as higher-priority traffic stabilizes.	Shows the most dynamic behavior, with significant fluctuations throughout the simulation.	Throughput remains fairly stable and consistent, with a minor increase towards the end.	Maintains consistent throughput throughout the simulation, with minimal fluctuations.
Peaks at a higher value near the end of the simulation.	Achieves the highest throughput near 1.1 seconds, likely due to increased resource allocation in the absence of prioritization.	Although meant to be high priority, the lack of QoS mechanisms causes it to compete equally with other traffic types, limiting its performance.	Its regularity is due to smaller packet sizes and steady transmission intervals typical for voice traffic.

All traffic types exhibit a noticeable throughput spike towards the end of the simulation. This suggests a momentary reduction in network contention, allowing all traffic categories to achieve higher throughput briefly.

IPv4 in the non-QoS setup treats all traffic equally, leading to high competition for network resources. Critical traffic like voice and video does not receive priority, which can degrade their quality of service.

Voice and video traffic show relatively stable throughput, indicating that IPv4 can effectively handle predictable traffic patterns without QoS. However, fluctuations in background and best effort traffic suggest resource allocation inconsistencies for lower-priority applications.

QoS Throughput IPv4



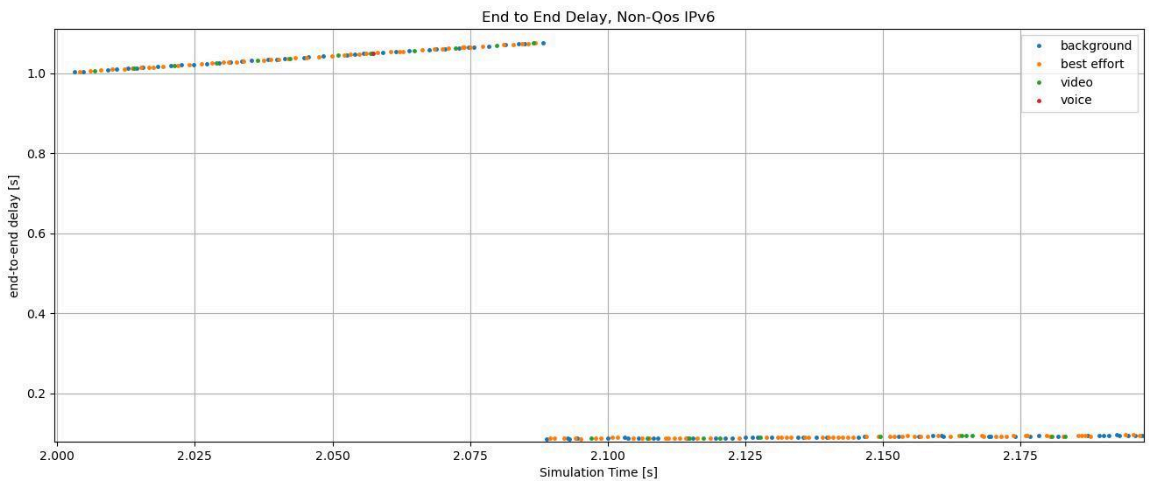
	Background Traffic (Blue)	Best Effort Traffic (Orange)	Video Traffic (Green)	Voice Traffic (Red)
Jitter	Exhibits the highest jitter across the simulation, fluctuating between ~5 ms and ~15 ms.	Experiences moderate delay variation, typically remaining between ~3 ms and ~10 ms.	Shows relatively consistent jitter, mostly under ~5 ms.	Maintains the lowest delay variation across all traffic types, rarely exceeding ~3 ms.
Other	This is expected in a non-QoS setup as background traffic is low priority and highly susceptible to network congestion.	This category is not explicitly deprioritized, but it still competes for bandwidth with higher-priority traffic.	Multimedia applications like video streaming benefit from smoother traffic handling due to their predictable packet patterns, even without QoS.	Real-time applications such as voice calls inherently send smaller packets at regular intervals, minimizing jitter even in a non-QoS environment.

The non-QoS setup causes IPv4 to treat all traffic equally, leading to significant fluctuations in delay for lower-priority categories like background and best effort. Higher-priority traffic like video and voice still fares better due to its predictable characteristics, but it does not fully escape congestion effects.

Voice traffic performs consistently well, but the lack of prioritization could cause issues in more congested networks or under heavier loads. Video traffic sees moderate delay variation, which may lead to stuttering or degraded quality during playback.

Background and best effort categories suffer the most in terms of jitter, indicating poor handling by IPv4 in the absence of QoS. Applications relying on these categories might experience inconsistent performance.

Non-QoS End-to-End Delay IPv6

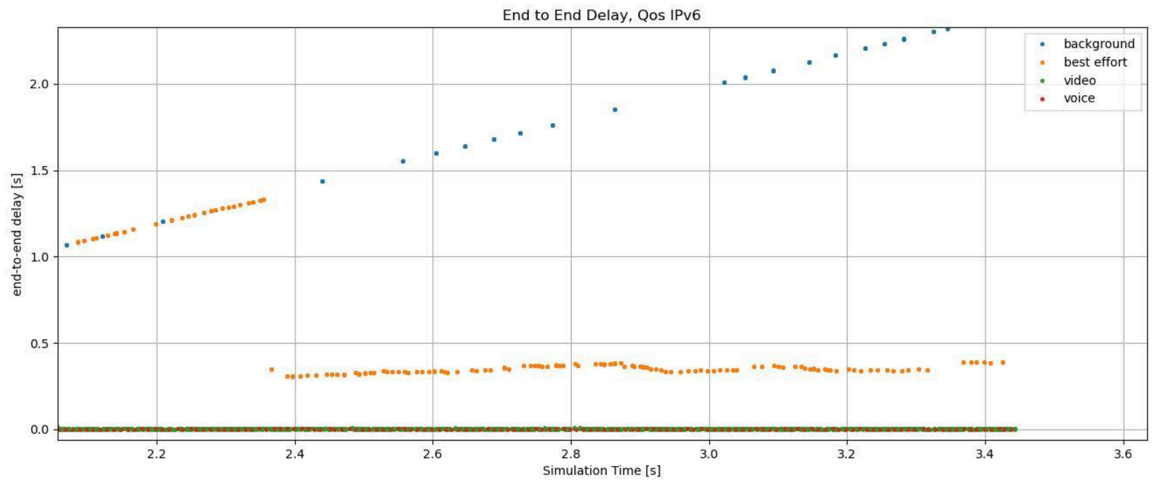


	Background	Best Effort	Video	Voice
Traffic categories	Low-priority data like file downloads	Medium priority traffic such as web browsing	High-priority multimedia streaming	Highest-priority traffic for real-time communication.
Delay trends over time	Stabilizes the slowest and maintains higher delays, reflecting deprioritization in the network	Takes longer to stabilize, reflecting competition for resources	Stabilizes slightly slower than voice but remains consistent	Delays decrease the fastest, stabilizing near 0 seconds

Initial Delay Observations: High initial delays (~1.0 seconds), indicating congestion at the start of the simulation.

IPv6 efficiently resolves congestion over time but lacks prioritization mechanisms in the non QoS setup. Improved routing and scalability in IPv6 help mitigate congestion impacts gradually.

QoS End to End Delay IPv6



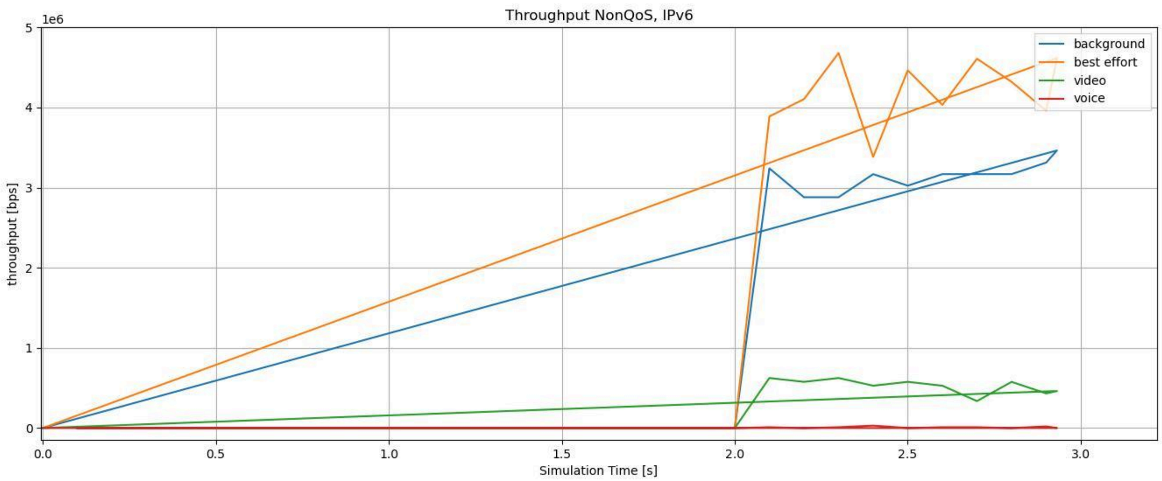
	Background	**Best Effort**	**Video**	**Voice**
Delay trends over time	Gradually increasing delay trend, rising to ~1.7 seconds by 3.6 seconds.	Delay increases slightly over time but remains fairly stable compared to background traffic (~1.7 seconds)	Extremely low and steady delays (~0 seconds) throughout the simulation, highlighting prioritization.	Maintains the lowest and most stable delays (~0 seconds) due to its critical real-time requirements.

At the start (2.2 seconds), background and best effort traffic experience higher delays (~1 second), while video and voice traffic have minimal delays (~0 seconds).

IPv6 efficiently handles video and voice traffic with near-zero delays due to prioritization by QoS mechanisms.

Background and best effort traffic face significantly higher delays, as they are deprioritized by QoS policies.

Non-QoS Throughput IPv6

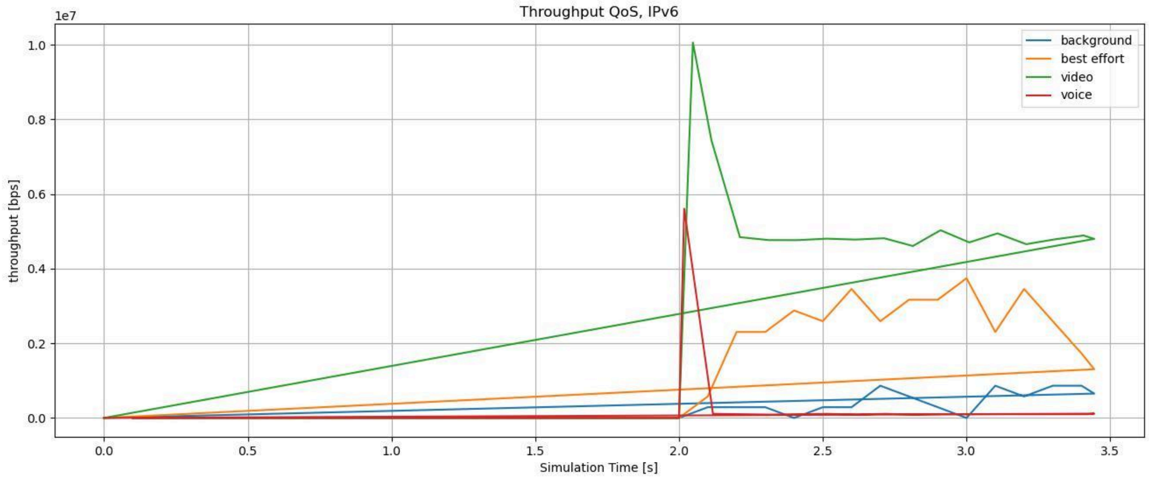


	Background	Best Effort	Video	Voice
Throughput trends	Achieves moderate throughput (~3 Mbps at 3 seconds), reflecting limited bandwidth allocation in Non-QoS IPv6.	Shows significant growth, peaking at ~4.8 Mbps by 3 seconds.	Achieves ~600 kbps by 3 seconds, reflecting limited prioritization in Non-QoS settings.	Maintains the lowest throughput (~300 kbps at 3 seconds), highlighting a lack of prioritization in the Non-QoS IPv6 network.

All traffic categories start with **0 throughput** at the beginning of the simulation (0 seconds). Throughput steadily increases for all traffic types as the simulation progresses.

Without QoS, IPv6 treats all traffic equally, allowing medium-priority traffic (best effort) to dominate bandwidth. Critical traffic such as voice and video are unable to achieve adequate throughput levels due to competition from other traffic categories.

QoS Throughput IPv6

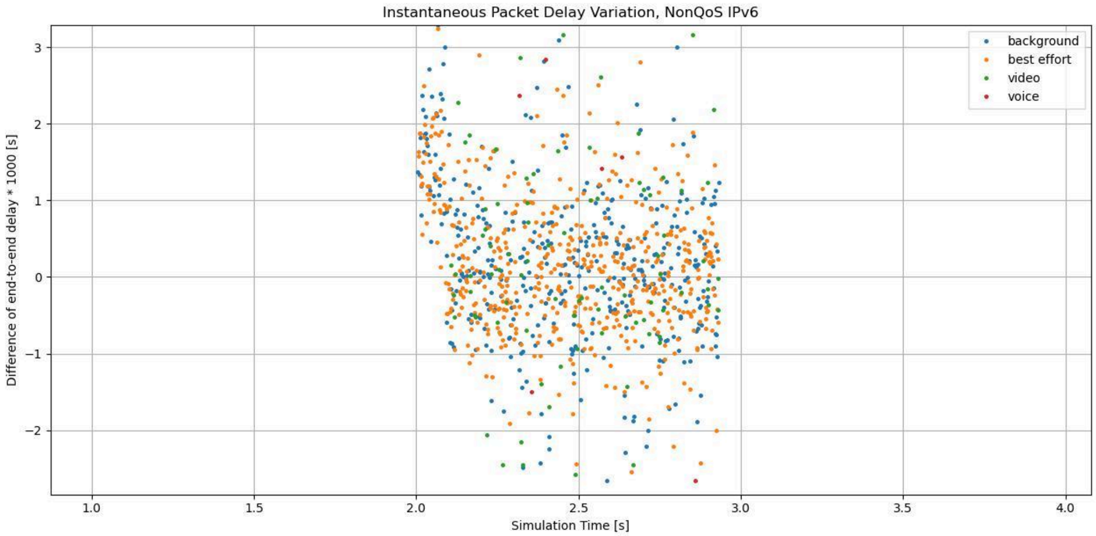


	Background	**Best effort**	**Video**	**Voice**
Throughput trends	Achieves consistent but **low throughput** throughout the simulation due to its low-priority status (~2 Mbps).	Shows steady throughput, peaking around ~4 Mbps, indicating effective allocation but lower priority than video.	Achieves the **highest throughput** (~8 Mbps), showcasing efficient prioritization for multimedia traffic.	Maintains consistent throughput at ~3 Mbps, highlighting prioritization for real-time communication despite low data rates.

At the beginning (0 seconds), throughput for all traffic categories is **0 bps**, reflecting the initialization phase of the network.

QoS mechanisms ensure higher throughput for video and voice traffic, while deprioritizing background and best effort traffic. IPv6 QoS ensures critical traffic receives sufficient bandwidth for smooth delivery.

Non-QoS Instantaneous Packet Delay Variation IPv6

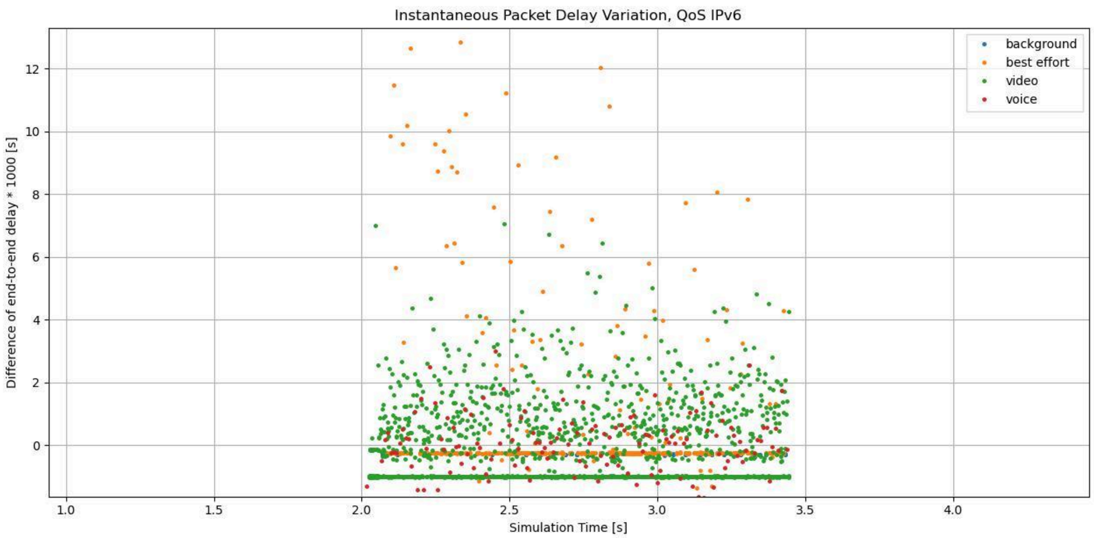


	Background	**Best effort**	**Video**	**Voice**
Jitter trends over time	Experiences the most significant and sustained delay variation, fluctuating frequently throughout the simulation.	Shows moderate fluctuations, indicating instability due to competition with higher-priority traffic.	Exhibits relatively low jitter, stabilizing over time, suggesting better handling of predictable traffic patterns.	Maintains the lowest jitter, reflecting small, regular packet sizes and consistent transmission intervals.

At the start of the simulation (~1.0 seconds), jitter values for all traffic categories range from -2 to 3 milliseconds, indicating high fluctuations

IPv6 efficiently handles critical traffic like video and voice due to their structured nature, but lacks mechanisms to prioritize traffic in Non-QoS setups. Background and best effort traffic suffer from resource contention, resulting in significant jitter fluctuations.

QoS Instantaneous Packet Delay Variation IPv6



	Background	Best effort	Video	Voice
Jitter trends over time	Consistently experiences low jitter near 0 ms, demonstrating effective QoS handling for deprioritized traffic.	Shows low and stable jitter throughout the simulation (~0 ms), benefiting from QoS policies.	Maintains minimal jitter values (~0 ms), ensuring smooth multimedia performance under QoS.	Achieves the lowest and most stable jitter (~0 ms), highlighting effective prioritization of real-time communication.

Jitter values start near **0 ms for all traffic categories**, indicating stable initial behavior.

IPv6 QoS mechanisms ensure jitter-sensitive traffic (voice and video) achieves near-zero delay variation, maintaining application performance. Background and best effort traffic exhibit stable and acceptable jitter levels due to bandwidth allocation adjustments by QoS.

Conclusion

This project successfully demonstrates the use of OMNeT++ and the INET framework to evaluate network performance under both Non-QoS and QoS-enabled configurations for IPv4 and IPv6 traffic. The simulation and graphical analysis provide key insights into the behavior of different traffic types—background, best effort, video, and voice—across various performance metrics, including end-to-end delay, jitter (instantaneous packet delay variation), and throughput.

Based on the results obtained, IPv6 provides better QoS, with an improvement in throughput, fewer lost packets, and slight delay compared to IPv4 throughput, which was not stable in the four types of services.

Key Findings:

1. **Non-QoS Networks:**
   - Both IPv4 and IPv6 suffer from a lack of traffic prioritization, resulting in high initial delays and significant variation in performance for lower-priority traffic (background, best effort).
   - Critical traffic such as video and voice, while performing relatively better due to predictable patterns and smaller packet sizes, still experience suboptimal performance due to resource contention.
2. **QoS-Enabled Networks:**
   - QoS mechanisms effectively prioritize high-priority traffic (voice and video), ensuring low delays, minimal jitter, and consistent throughput.
   - Background and best effort traffic are appropriately deprioritized, freeing up resources for critical applications without causing excessive degradation of non-critical performance.
   - IPv4 and IPv6, when combined with QoS, demonstrates robust traffic management, achieving smooth performance for latency-sensitive and high-bandwidth applications, even under competitive conditions.

Implications for Real-Time and Multimedia Applications:

The analysis highlights the significant benefits of QoS-enabled configurations in ensuring network reliability and efficiency. Voice and video traffic benefit the most, achieving low latency and stable throughput, making QoS mechanisms essential for real-time and multimedia applications.

Prospects for Future Work:

1. **Scalability Testing:** Evaluate the network under higher traffic loads and larger-scale scenarios to test the effectiveness of QoS in heavy-use environments.
2. **Dynamic Traffic Management:** Explore adaptive QoS mechanisms for further optimization, especially for medium- and low-priority traffic.

Overall, this project demonstrates that QoS mechanisms are critical for managing diverse traffic requirements in modern IPv4 and IPv6 networks. By ensuring efficient resource allocation and prioritization, QoS paves the way for enhanced network performance and user experience.

References

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5. Performance evaluation of the QOS provisioning ability of IEEE 802.11e WLAN standard for multimedia traffic
6. https://inet.omnetpp.org/docs/showcases/wireless/qos/doc/index.html