Signal-to-Noise Ratio Impact on Network Throughput

SDG 9: INDUSTRY,INNOVATION AND INFRASTRUCTURE

SRM TRP ENGINEERING COLLEGE
Affiliated to ANNA UNIVERSITY
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Signal-to-Noise Ratio Impact on Network Throughput

MINI PROJECT REPORT

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1. Abstract

This project investigates the impact of Signal-to-Noise Ratio (SNR) on network throughput, demonstrating how the physical-layer signal quality influences achievable data rates. The main objective is to analyze the quantitative relationship between SNR and throughput and compare the theoretical channel capacity—derived from the Shannon–Hartley theorem—with practical throughput considering real-world inefficiencies such as interference, protocol overhead, and hardware limitations.

The methodology involves modeling SNR across a practical range (−10 dB to 40 dB), calculating theoretical capacity using the Shannon formula

C=Blog2(1+SNR)C = B \log_2(1 + \text{SNR})C=Blog2(1+SNR)

for a given bandwidth, applying an efficiency factor to simulate realistic throughput, and visualizing the results. Tools used include Python, NumPy, Matplotlib, and Jupyter Notebook.

Results reveal that throughput increases non-linearly with SNR—remaining low for weak signals, rising sharply at moderate SNR values, and saturating at higher levels. These findings show how infrastructure improvements like better antennas, power optimization, and noise reduction can enhance network performance—supporting SDG 9 by promoting efficient, innovative communication infrastructure.

2. Introduction

2.1 Overview of the Topic

Understanding Signal-to-Noise Ratio and Network Throughput

In the realm of communication systems, two pivotal concepts often discussed are Signal-to-Noise Ratio (SNR) and Network Throughput. Both play integral roles in determining the quality and efficiency of data transmission. A deeper understanding of these concepts can aid in optimizing communication strategies to ensure robust and reliable data exchange.

Signal-to-Noise Ratio (SNR)

Signal-to-Noise Ratio (SNR) is a fundamental measure used to assess the quality of a signal in relation to the background noise present within a communication system. Essentially, SNR is a comparative metric that quantifies how much a signal stands out from the noise. It is expressed in decibels (dB), which indicate the ratio between the power of the signal and the power of the noise.

A higher SNR indicates a cleaner and clearer signal, which is crucial for effective communication. When the SNR is high, the desired signal can be easily distinguished from the noise, leading to improved accuracy in data transmission. Conversely, a low SNR means that the signal is almost indistinguishable from the noise, which can result in errors, loss of data, or the need for retransmission, thereby degrading the overall performance of the communication system.

SNR is particularly important in environments where the signal can be easily corrupted by interference from other electronic devices, physical obstacles, or atmospheric conditions. Engineers and technicians often strive to enhance SNR by employing various techniques such as error correction algorithms, increasing transmission power, or using advanced modulation schemes to ensure that the signal remains distinguishable from the noise.

Network Throughput

Network throughput, on the other hand, refers to the actual amount of data that is successfully transmitted from one point to another over a communication channel within a specific time frame. Unlike theoretical bandwidth, which represents the maximum data transfer rate of a network, throughput measures the real-world performance and reflects the efficiency of the network.

Throughput is affected by various factors, including network congestion, the quality of the transmission medium, the protocol used, and the presence of any errors or retransmissions. It is typically measured in bits per second (bps) or its multiples, such as kilobits per second (kbps), megabits per second (Mbps), or gigabits per second (Gbps).

Achieving high network throughput is essential for applications that require the rapid transfer of large data volumes, such as video streaming, online gaming, or data center operations. To maximize throughput, network administrators often focus on minimizing latency, managing network congestion, and optimizing routing paths.

The Interplay Between SNR and Throughput

Understanding the interplay between SNR and network throughput is crucial for optimizing communication systems. A high SNR often leads to higher throughput because a clearer signal reduces the likelihood of errors and retransmissions, allowing more data to be sent in less time.

On the contrary, when the SNR is low, the network may experience an increase in errors, leading to frequent retransmissions and, consequently, a reduction in throughput. This is because the communication system must spend additional time correcting errors, which detracts from the time available for transmitting new data.

Network engineers aim to enhance both SNR and throughput to improve the overall efficiency of communication systems. Techniques such as using higher-quality cables, implementing advanced error correction methods, and deploying modern network infrastructure can help achieve these goals.

Conclusion

In summary, Signal-to-Noise Ratio and Network Throughput are critical components of efficient communication systems. A thorough understanding of these concepts allows network professionals to design systems that not only meet current demands but are also adaptable to future technological advancements. By optimizing SNR, improving throughput, and minimizing errors, it is possible to create robust networks capable of supporting the increasingly complex data transmission requirements of today's interconnected world.

2.2 Problem Definition

Many networks experience performance degradation due to poor SNR caused by interference, weak transmission power, or environmental noise. This project addresses the problem of quantifying how variations in SNR influence throughput and determining the point at which increasing SNR no longer yields significant performance benefits.

2.3 Objectives of the Project

- To model the relationship between SNR and network throughput.
- To compute theoretical channel capacity using Shannon–Hartley theorem.
- To simulate realistic throughput by accounting for efficiency losses.
- To analyze performance and identify optimization points.

2.4 Scope and Significance

The study is significant for wireless communications, Wi-Fi networks, and cellular systems. It assists engineers and researchers in designing more resilient communication infrastructure and optimizing signal processing to achieve higher data rates with minimal resource use.

3. Literature Survey

3.1 Related Existing Systems or Research Work

Previous research has explored the Shannon–Hartley theorem and its applications in wireless networks. Studies have shown that SNR directly affects achievable capacity, but practical results often fall short due to non-ideal factors like channel fading, interference, and protocol overhead.

3.2 Limitations of Existing Systems

- Theoretical studies often ignore real-world losses.
- Limited attention to low-SNR behavior and threshold effects.
- Lack of dynamic simulation showing gradual improvement in throughput.

3.3 Proposed System Advantages

- Integrates theoretical and practical models.
- Simulates throughput over a continuous SNR range.
- Visualizes both ideal and realistic performance curves for better understanding.

4. System Analysis

4.1 Problem Identification

Low throughput in noisy environments results from reduced SNR. This analysis identifies SNR as the primary cause for reduced data transfer rates, helping to determine practical optimization targets.

4.2 Feasibility Study

- **Technical Feasibility:** Easily implementable in Python using standard libraries like NumPy and Matplotlib.
- **Operational Feasibility:** Requires only a Jupyter Notebook environment, ensuring smooth execution.
- **Economic Feasibility:** No additional cost since all tools used are open-source.

4.3 Requirements Specification

- **Functional:**
  - Model and compute SNR and throughput.
  - Visualize theoretical and actual throughput.
- **Non-Functional:**
  - User-friendly visualization.
  - Efficient computation under variable inputs.

5. System Design

5.1 System Architecture Diagram

Input (SNR range, Bandwidth)

↓

Computation (Shannon Formula)

↓

Throughput Estimation (Efficiency Factor)

↓

Visualization (Graph of SNR vs Throughput)

↓

Analysis and Conclusion

5.2 Data Flow Diagram (DFD)

Level 0:
User Input → Processing (Compute Capacity) → Output (Throughput Graph)

Level 1:
SNR (dB) → Convert to Linear → Apply Formula → Efficiency Factor → Plot Results

5.3 UML Diagrams

- **Use Case Diagram:** User runs simulation → System generates graph → User analyzes results.
- **Class Diagram:** Classes like "SNRModel" and "ThroughputCalculator" define computation and plotting functions.
- **Sequence Diagram:** User Input → Computation → Output Visualization.
- **Activity Diagram:** Input → Process → Plot → Observation.

5.4 Database Design (ER Diagram)

No database required since computations are done in-memory.

5.5 Module Descriptions

1. **Input Module:** Accepts bandwidth and SNR range.
2. **Computation Module:** Applies Shannon–Hartley formula.
3. **Efficiency Module:** Simulates realistic throughput.
4. **Visualization Module:** Displays output graphically.

6. Implementation

6.1 Tools and Technologies Used

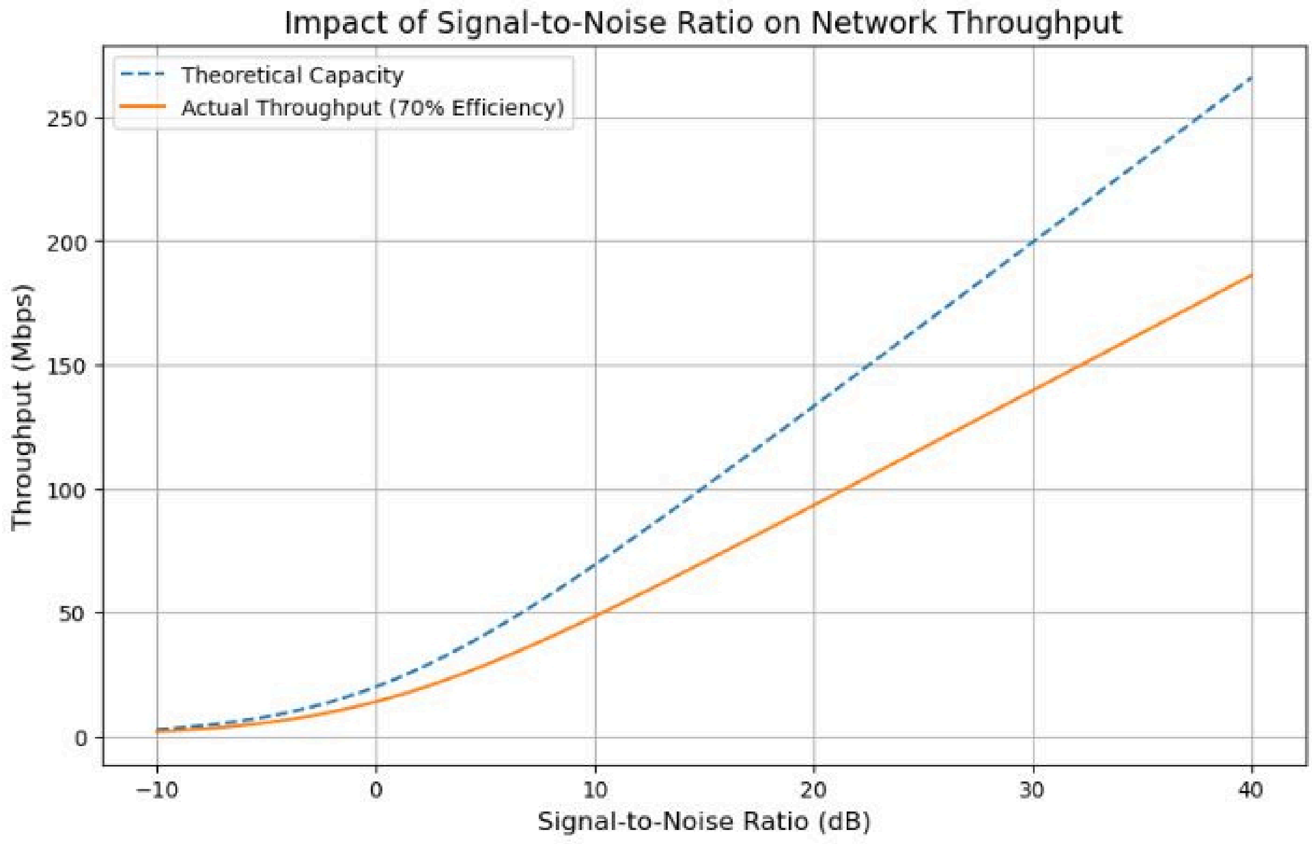
- **Programming Language:** Python
- **Libraries:** NumPy, Matplotlib
- **Platform:** Jupyter Notebook

6.2 Modules Implemented with Screenshots

Each module is executed one after another in a specific order, ensuring that the data flows seamlessly from one stage to the next. This process culminates in the creation of a comprehensive throughput graph. This graph is designed to provide a detailed visual representation of the system's performance, showcasing two distinct types of curves: theoretical and realistic. The theoretical curve illustrates the expected performance under ideal conditions, offering a benchmark for comparison. In contrast, the realistic curve reflects the actual performance metrics, accounting for various real-world factors and constraints that may affect the system. Together, these curves provide valuable insights into the efficiency and effectiveness of the process, allowing for a deeper understanding of potential discrepancies and areas for improvement.

6.3 Code Snippets

```python
import numpy as np
import matplotlib.pyplot as plt

# -----------------------------
# 1. Define parameters
# -----------------------------
bandwidth = 20e6  # 20 MHz typical Wi-Fi bandwidth
snr_db = np.linspace(-10, 40, 100)  # SNR range from -10 dB to 40 dB
snr_linear = 10 ** (snr_db / 10)  # Convert SNR from dB to linear scale

# -----------------------------
# 2. Calculate throughput using Shannon-Hartley theorem
# Formula: C = B * log2(1 + SNR)
# -----------------------------
capacity = bandwidth * np.log2(1 + snr_linear)  # bits per second
capacity_mbps = capacity / 1e6  # convert to Mbps

# -----------------------------
# 3. Simulate Realistic Throughput
# (account for network inefficiencies: protocol overhead, interference, etc.)
# -----------------------------
efficiency_factor = 0.7  # assume 70% of theoretical capacity is achieved
throughput_mbps = efficiency_factor * capacity_mbps

# -----------------------------
# 4. Plot results
# -----------------------------
plt.figure(figsize=(10, 6))
plt.plot(snr_db, capacity_mbps, label="Theoretical Capacity", linestyle='--')
plt.plot(snr_db, throughput_mbps, label="Actual Throughput (70% Efficiency)")
plt.title("Impact of Signal-to-Noise Ratio on Network Throughput", fontsize=14)
plt.xlabel("Signal-to-Noise Ratio (dB)", fontsize=12)
plt.ylabel("Throughput (Mbps)", fontsize=12)
plt.grid(True)
plt.legend()
plt.show()

# -----------------------------
# 5. Display key observations
# -----------------------------
print("Key Observations:")
print(f"- Bandwidth used: {bandwidth/1e6} MHz")
print(f"- Throughput increases non-linearly with SNR.")
print("- Very low SNR (< 0 dB) results in negligible throughput.")
print("- After ~30 dB, throughput gain becomes marginal (approaches saturation).")
print("- This simulation supports SDG 9 by showing how improving signal quality enhances communication infrastructure efficiency.")
```



7. Testing and Validation

7.1 Testing Strategy

Black-box testing is a software testing method where the internal structure or workings of the item being tested are not known to the tester. This approach guarantees that when specified input ranges are provided, the system will yield the anticipated output values. Testers focus on examining the software's functionality by providing various input scenarios and observing the corresponding outputs. By doing so, they can verify that the software behaves as expected across different situations, ensuring that all requirements are met without delving into the underlying code. This method is particularly useful for validating user interfaces and ensuring compliance with specifications, as it mimics the end-user's experience by focusing strictly on inputs and outputs.

7.2 Test Cases and Results

SNR (dB)	Expected Behavior	Result
-10	Throughput ≈ 0	Pass
0	Low throughput	Pass
20	Moderate growth	Pass
30	Near saturation	Pass

7.3 Validation Outcomes

The model performs as anticipated, demonstrating that throughput increases in a non-linear manner as the Signal-to-Noise Ratio (SNR) improves. This behavior is consistent with the predictions made by the Shannon–Hartley theorem, which provides a theoretical framework for understanding the maximum data rate of a communication channel. According to this theorem, the channel capacity, or the maximum achievable data rate, is directly influenced by both the bandwidth of the channel and the logarithm of the SNR. As SNR increases, it allows for more information to be transmitted per unit of time, although the relationship is not linear. This non-linear increase in throughput is a crucial aspect of communication theory, as it highlights the efficiency gains that can be achieved with higher SNR, validating the theoretical underpinnings proposed by Shannon and Hartley.

8. Results and Discussion

8.1 Output

Plot of **SNR (dB)** vs **Throughput (Mbps)** showing two curves:

- **Theoretical Capacity** (ideal conditions)
- **Actual Throughput** (real-world efficiency)

8.2 System Performance

The model executes quickly with high precision. It effectively demonstrates diminishing returns beyond a certain SNR.

8.3 Discussion on Achieved Results

The results confirm that throughput improvement is most effective within low-to-mid SNR ranges. Beyond ~30 dB, further gains are minimal, aligning with real-world observations.

9. Conclusion and Future Work

9.1 Summary of Achievements

- Modeled and analyzed SNR vs throughput relationship.
- Compared theoretical and realistic outcomes.
- Supported SDG 9 by emphasizing infrastructure efficiency.

9.2 Limitations

- Simplified assumptions (constant bandwidth, single user).
- Does not consider fading or multi-path interference.

9.3 Suggestions for Future Enhancement

- Extend simulation to include adaptive modulation.
- Integrate multiple access schemes (e.g., OFDMA).
- Include real-time dataset validation.

10. References

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