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Title

Analysis and Performance Optimization
of Network Congestion in
Microwave Networks

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Dedication

I dedicate this modest work to:

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All my teachers who accompanied me throughout my educational journey, from primary school to university.

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Dedication

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List of Abbreviations

2G: Second Generation

3G: Third Generation

4G LTE: Fourth Generation Long-Term Evolution

5G: Fifth Generation

IoT: Internet of Things

DWDM: Dense Wavelength Division Multiplexing

SFP: Small Form-factor Pluggable

FDMA: Frequency Division Multiple Access

TDMA: Time Division Multiple Access

QoS: Quality of Service

NMS: Network Management Systems

NCE: Network Cloud Engine

Web LCT: Web Local Craft Terminal

KPIs: Key Performance Indicators

FE: Fast Ethernet

GE: Gigabit Ethernet



General Introduction



The continuous evolution of mobile communication networks has significantly transformed modern telecommunications by enabling high-speed connectivity, real-time communication, and large-scale data exchange. The rapid growth in the number of mobile users, combined with the increasing demand for bandwidth-intensive applications such as video streaming, cloud computing, and online services, has generated a substantial increase in network traffic. As a result, transmission infrastructures have become a critical component in ensuring efficient and reliable communication within mobile networks.

To support this growing demand, telecommunication operators deploy various transmission technologies, including microwave radio systems and optical fiber networks. Microwave transmission, particularly in K band and E band frequencies, provides flexible and cost-effective backhaul solutions for connecting base stations and transport nodes. Optical fiber systems based on Dense Wavelength Division Multiplexing (DWDM) technology offer very high transmission capacity and reliability for aggregation and core network transport. Despite these technological advancements, transmission networks remain exposed to congestion phenomena caused by traffic growth, limited capacity, environmental conditions, and inefficient resource allocation.

In this context, network monitoring and congestion analysis have become essential tasks for maintaining Quality of Service (QoS) and ensuring network stability. Modern management platforms such as Network Cloud Engine (NCE) and local management interfaces such as Web LCT enable operators to supervise network performance, analyze traffic behavior, and identify potential congestion situations. The combination of centralized and local monitoring approaches provides accurate visibility into network conditions and facilitates efficient troubleshooting and optimization processes.

The continuous increase in mobile data traffic represents a major challenge for modern telecommunication networks, particularly at the transmission level. In mobile backhaul infrastructures, congestion frequently occurs when traffic demand exceeds the effective capacity of transmission resources. This phenomenon leads to performance degradation characterized by increased latency, packet loss, reduced throughput, and deterioration of service quality.

Microwave transmission links are especially vulnerable to congestion because of their limited spectrum resources and sensitivity to environmental factors such as rain attenuation and

interference. In addition, Fast Ethernet (FE) interfaces with limited bandwidth capacity may create bottlenecks in high-traffic environments, while even Gigabit Ethernet (GE) interfaces can experience overload under heavy traffic conditions. Optical fiber networks, although offering significantly higher capacity, may also suffer from congestion due to traffic aggregation, oversubscription, or inefficient network dimensioning.

Within the Mobilis network infrastructure, congestion issues directly impact network reliability and user experience. Consequently, identifying the causes of congestion, analyzing network performance indicators, and understanding the behavior of transmission links are essential for improving network efficiency and ensuring service continuity.

This study is based on both theoretical analysis and practical investigation of congestion phenomena in mobile transmission networks. The first part of the work focuses on the theoretical foundations of mobile communication systems, transmission technologies, transmission link capacities, and congestion mechanisms in microwave and optical networks.

The second part addresses network monitoring and congestion analysis using management tools and performance indicators. Particular attention is given to centralized management platforms such as NCE and local diagnostic interfaces such as Web LCT, which provide visibility into network behavior and facilitate troubleshooting operations.

The practical investigation is based on the analysis of congestion situations within the Mobilis network infrastructure. Different transmission segments, including microwave links, Ethernet interfaces, and optical fiber systems, are examined using Key Performance Indicators (KPIs) such as link utilization, throughput, delay, and packet loss. The collected data is then used to identify congestion sources and evaluate network performance under varying traffic conditions.

Finally, optimization approaches and corrective actions are proposed in order to improve transmission efficiency, reduce congestion risks, and enhance overall network .



Chapter I
Mobile Networks and Transmission
Systems



I.1 Introduction

Mobile communication networks have undergone continuous development in order to meet the increasing demand for high data rates, low latency, and reliable connectivity. The rapid expansion of mobile services, coupled with the widespread use of smart devices and data-intensive applications, has resulted in a significant growth of traffic within mobile networks. This evolution has placed considerable pressure on transmission infrastructures, which are responsible for transporting large volumes of data between different network segments. In modern mobile networks, the transmission network plays a fundamental role in ensuring efficient communication between access nodes, aggregation points, and core network elements. Any limitation in transmission capacity or reliability directly impacts network performance and user experience. As traffic demand continues to grow, congestion has become a critical issue, particularly in mobile backhaul and transport networks. Different transmission technologies are employed to support mobile network traffic, each characterized by specific capabilities and limitations. Microwave transmission, operating in various frequency bands such as K band and E band, offers flexible and cost-effective backhaul solutions but remains sensitive to environmental conditions and capacity variations. Optical fiber transmission, especially through Dense Wavelength Division Multiplexing (DWDM), provides very high capacity and reliability, yet may still experience congestion due to traffic aggregation and network dimensioning constraints. A detailed understanding of transmission media, their capacity characteristics, and congestion mechanisms is therefore essential for analyzing performance limitations in mobile networks. This theoretical background provides the necessary foundation for addressing congestion problems and developing effective optimization strategies in microwave transmission systems [1].

I.2 General overview of mobile networks

Mobile communication networks constitute a fundamental pillar of modern telecommunication infrastructures, enabling seamless connectivity between users regardless of their geographical location or mobility conditions. These networks support the transmission of voice, data, and multimedia services and have become essential for both personal communication and socio-economic development. The rapid expansion of mobile services has been driven by the exponential growth in the number of users, the widespread adoption of smartphones, and the increasing demand for high-speed data applications such as video streaming, cloud computing, online gaming, and real-time interactive services. The development of mobile networks has followed a generational evolution, with each generation

introducing significant technological improvements to address emerging user requirements and traffic demands. Second-generation (2G) systems were primarily designed to provide reliable voice communication, with limited support for data services. The introduction of third-generation (3G) networks marked a transition toward packet-switched communication, allowing users to access basic internet services and multimedia applications. A major breakthrough occurred with the deployment of fourth-generation (4G/LTE) systems, which adopted an all-IP architecture and significantly enhanced data rates, spectral efficiency, and latency performance. More recently, fifth-generation (5G) networks have been developed to meet stringent requirements such as ultra-high data throughput, massive device connectivity, and extremely low latency, supporting advanced use cases including the Internet of Things (IoT), autonomous systems, and mission-critical communications.

From an architectural perspective, a mobile communication network is generally structured into three main segments: the access network, the core network, and the transmission (or transport) network. The access network, also referred to as the radio access network, provides the wireless interface between user equipment and base stations, ensuring radio coverage and initial data transmission. The core network is responsible for essential control and management functions, including user authentication, mobility management, session control, and service delivery. The transmission network interconnects all network elements by transporting traffic between base stations, aggregation points, and core network nodes, forming the backbone that ensures end-to-end communication. The transmission network plays a decisive role in the overall performance and reliability of mobile systems. As mobile traffic continues to grow due to increasing data consumption and service diversification, the transmission network must guarantee sufficient capacity, high availability, and low latency to maintain acceptable quality of service. Any limitation or degradation within the transmission network can directly impact user experience, leading to service interruptions, increased delays, and reduced data throughput. Consequently, the transmission network has become one of the most critical components of modern mobile architectures and is particularly vulnerable to congestion phenomena, especially in dense urban environments where traffic demand is highly concentrated.

In contemporary mobile networks, the transmission segment relies on a combination of wireless and wired technologies to ensure flexible and efficient connectivity. Microwave radio links and optical fiber systems are among the most widely deployed transmission media, each

offering specific advantages in terms of capacity, deployment cost, scalability, and reliability. However, despite continuous technological advancements, the mismatch between rapidly increasing traffic demand and available transmission capacity remains a major challenge. This imbalance often leads to congestion situations that degrade network performance and require advanced troubleshooting and optimization strategies [2].

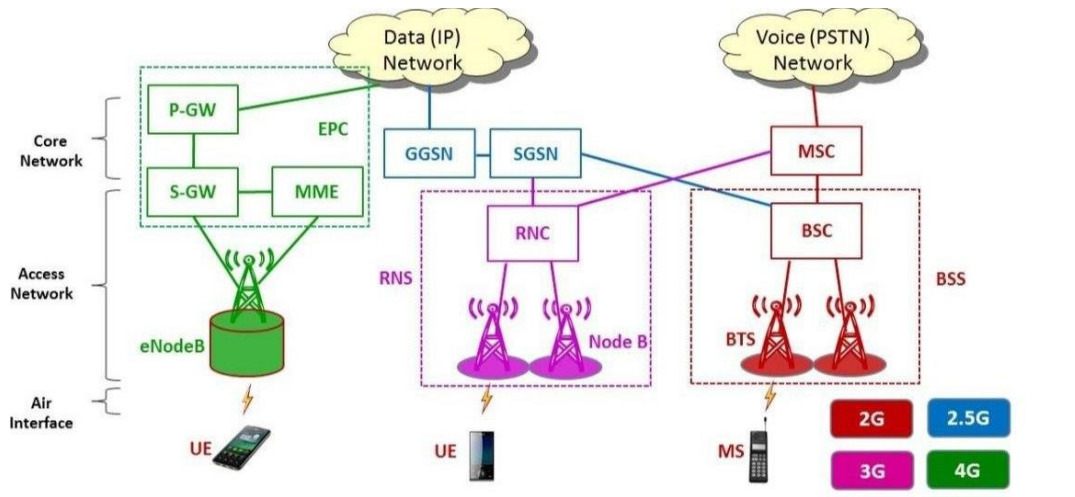


Figure I.1: Architecture of 2G, 3G, and 4G mobile networks

I.3 Transmission media

Transmission media play a fundamental role in mobile communication networks, as they ensure the transport of information between the radio access network, aggregation nodes, and the core network. With the continuous growth of mobile data traffic and the increasing demand for high-capacity services, transmission networks are required to provide sufficient bandwidth, low latency, and high reliability. In this context, the choice of transmission technology directly affects network performance and congestion behavior. Among the different transmission solutions, microwave radio systems and optical fiber technologies are the most widely deployed in mobile backhaul and transport networks [3].

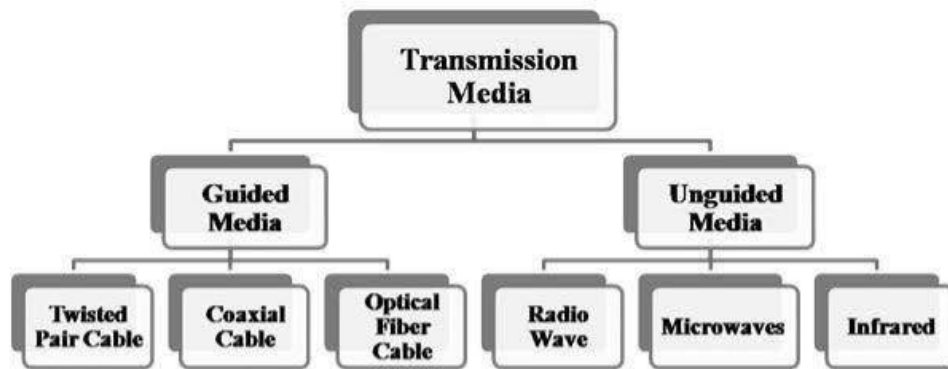


Figure I.2: Classification of transmission media

I.3.1 Microwave transmission

Microwave transmission is extensively used in mobile backhaul networks due to its flexibility, rapid deployment, and lower cost compared to wired solutions. Microwave links rely on line-of-sight propagation and use electromagnetic waves to transmit information between fixed network nodes. These systems are particularly suitable in environments where optical fiber installation is difficult or economically inefficient.

In mobile networks, microwave links are commonly used to connect base stations to aggregation sites and to provide transport capacity in urban, suburban, and rural areas. However, the performance of microwave transmission depends on several factors, including operating frequency, channel bandwidth, modulation techniques, and propagation conditions. These factors have a direct impact on link capacity and congestion risk [4].

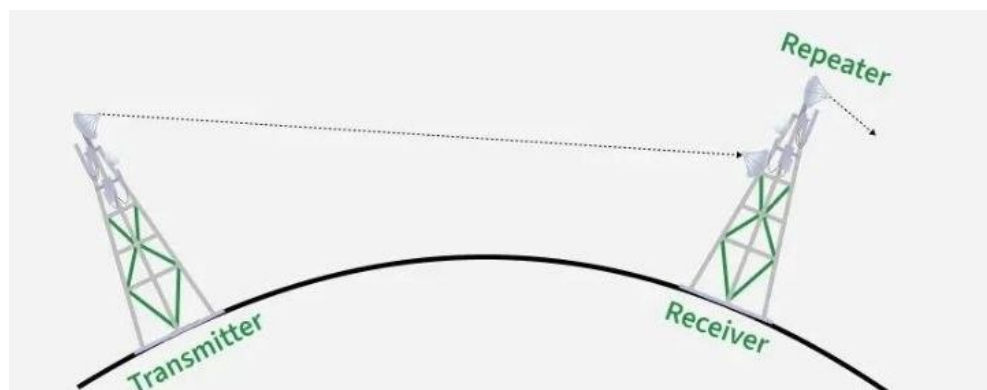


Figure I.3: Line-of-Sight Microwave Backhaul Link in Wireless Networks

I.3.1.1 K Band microwave transmission

K band microwave systems generally operate in the frequency range between 18 GHz and 27 GHz. This band is widely used in mobile backhaul networks because it offers a good compromise between transmission range, achievable capacity, and link availability. Depending on the channel bandwidth and modulation scheme, K band links are capable of supporting medium to high data rates suitable for many mobile network applications.

Under normal propagation conditions, K band links provide stable and reliable transmission. Adaptive modulation and coding techniques allow the system to dynamically adjust transmission parameters according to channel quality. When radio conditions are favorable, higher-order modulation schemes can be employed to maximize throughput.

However, K band transmission is moderately affected by atmospheric conditions, particularly rain attenuation. During periods of heavy rainfall, signal degradation may occur, leading to a reduction in signal quality. In such situations, the system switches to more robust modulation schemes with lower spectral efficiency, resulting in a decrease in effective link capacity. When traffic demand remains high during these periods, congestion may occur, causing increased latency and reduced quality of service. For this reason, K band links are often considered critical points in congestion analysis, especially in dense urban environments [5].

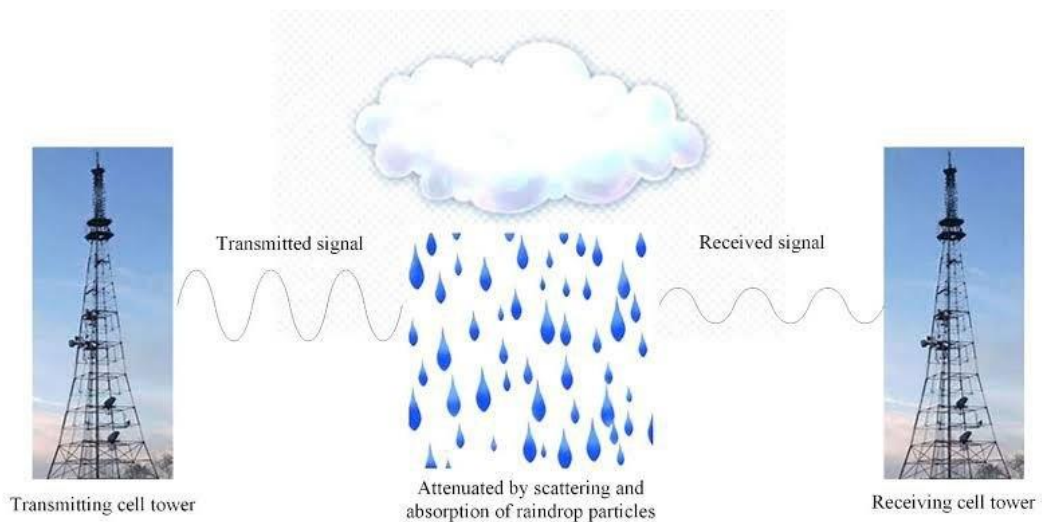


Figure I.4: Rain Attenuation of K-band Signal

I.3.1.2 E Band microwave transmission

E band microwave transmission operates in higher frequency ranges, specifically 71–76 GHz and 81–86 GHz. These frequency bands have been introduced to support the growing demand for very high transmission capacity in modern mobile networks. The availability of wide channel bandwidths enables E band links to achieve multi-gigabit per second data rates.

E band systems are particularly suitable for short-distance, high-capacity backhaul links, such as those used in dense urban areas and small-cell deployments. However, the use of high frequencies also makes E band transmission more sensitive to environmental factors, including rain attenuation and atmospheric absorption. As a result, E band links typically have shorter transmission ranges and require precise planning and accurate antenna alignment.

Despite these limitations, E band links are increasingly deployed in combination with lower-frequency microwave bands. In such configurations, E band links act as capacity enhancement solutions, allowing operators to offload traffic from congested K band links and improve overall network performance.

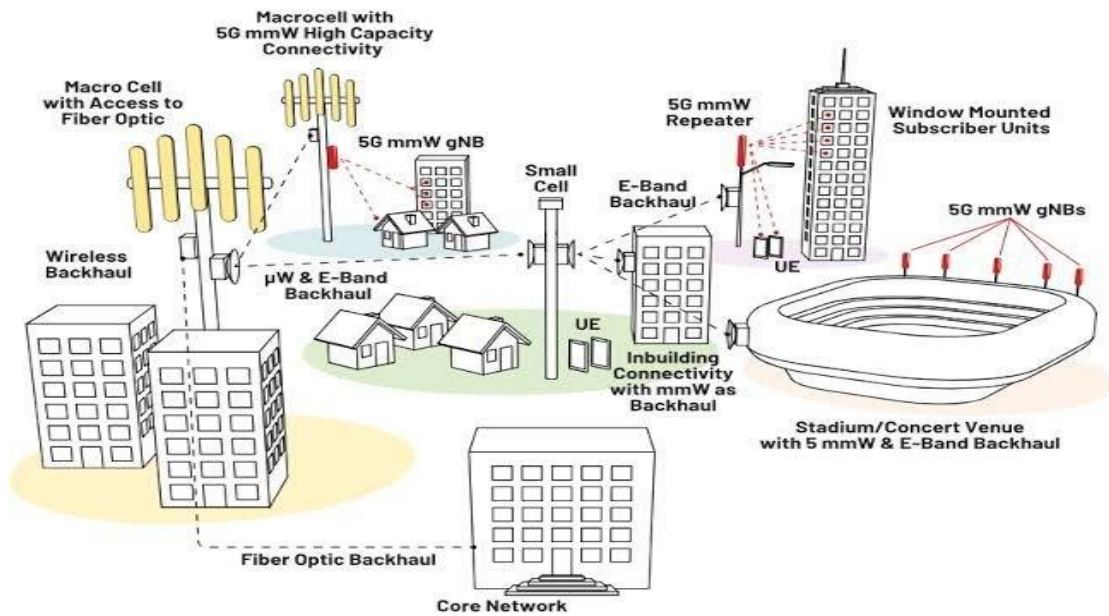


Figure I.5: Millimeter-Wave and E-Band Backhaul in 5G

I.3.1.3 Comparison between K band and E band

From a congestion perspective, K band and E band microwave systems offer complementary characteristics. K band links provide wider coverage and higher availability,

while E band links deliver very high capacity over shorter distances. The combined use of both bands enables network operators to balance capacity, availability, and resilience, thereby reducing congestion risks in mobile backhaul networks [6].

I.3.2 Optical fiber transmission

Optical fiber transmission is considered the highest-capacity and most reliable transmission medium in modern telecommunication networks. Optical fibers offer very large bandwidth, low signal attenuation, and strong immunity to electromagnetic interference. These characteristics make optical fiber systems essential for aggregation and core network segments.

Dense Wavelength Division Multiplexing (DWDM) is an optical transmission technology that significantly increases fiber capacity by allowing multiple optical signals to be transmitted simultaneously over a single fiber using different wavelengths. Each wavelength acts as an independent communication channel, enabling efficient utilization of the optical spectrum.

DWDM systems consist of optical transmitters and receivers, multiplexers, demultiplexers, and intermediate switching elements such as optical add-drop multiplexers. These components provide scalability and flexibility, allowing network capacity to be increased according to traffic growth.

Although DWDM offers extremely high transmission capacity, congestion may still occur due to traffic aggregation, inefficient wavelength allocation, or inadequate network dimensioning. Therefore, proper planning and traffic engineering are required to ensure optimal use of DWDM resources and to avoid congestion in optical transport networks [7].

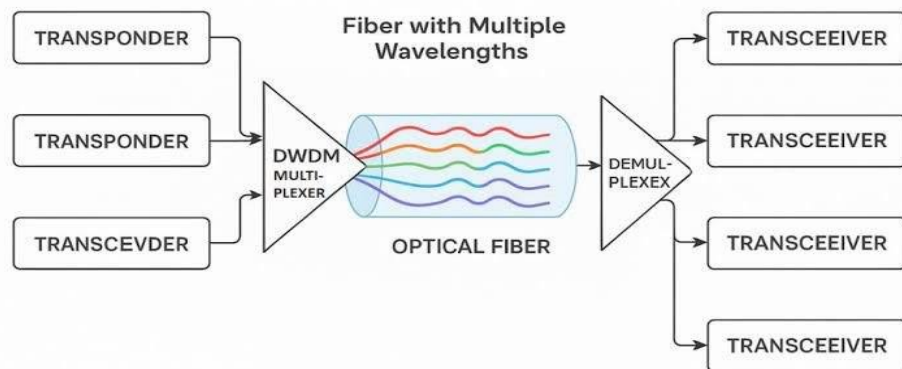


Figure I.6: Architecture of a DWDM optical transmission system

I.3.3 Transmission interfaces and connectivity media

I.3.3.1 SFP Modules

Small Form-factor Pluggable (SFP) modules are compact transceivers used in telecommunication and transmission networks to connect network equipment with optical or electrical media. They are widely integrated into switches, routers, and transmission systems due to their small size, flexibility, and hot-swappable capability, which facilitate maintenance and network upgrades.

SFP modules support different communication technologies, including Fast Ethernet and Gigabit Ethernet, while ensuring reliable and efficient data transmission. According to the transmission medium used, SFP modules are mainly divided into Single-Mode and Multi-Mode types.

Single-Mode SFP modules are designed for long-distance communication using single-mode optical fibers. They provide low attenuation and stable transmission performance, making them suitable for backbone and metropolitan networks. In contrast, Multi-Mode SFP modules are generally employed for short-distance communication, particularly in local area networks and data centers, where lower deployment cost and simplified installation are required.

The use of SFP technology contributes to improving transmission efficiency, communication reliability, and network scalability in modern telecommunication infrastructures [8].

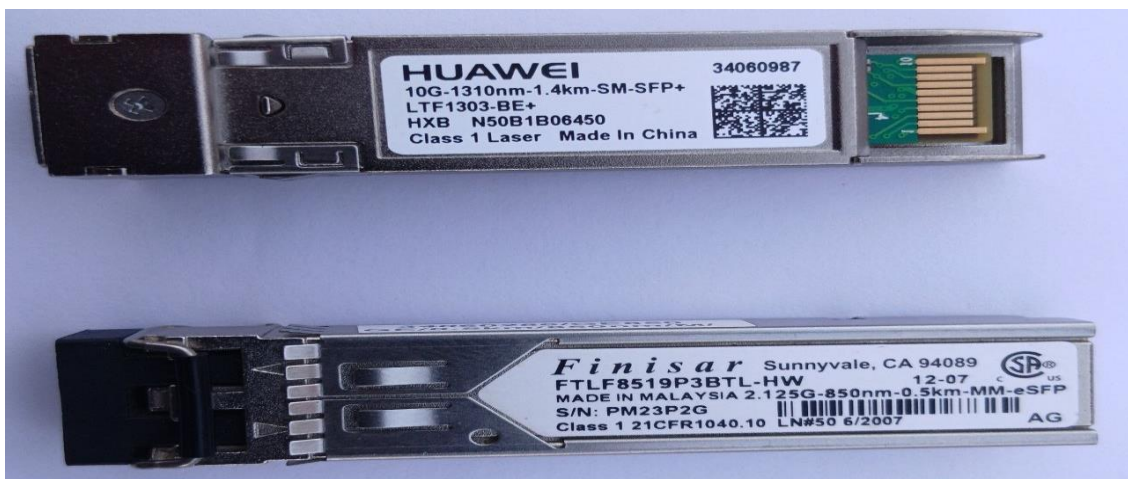


Figure I.7: Single-Mode and Multi-Mode SFP transceivers used in optical transmission networks

I.3.3.2 RJ45 Ethernet cable

The RJ45 cable is a widely used transmission medium in Ethernet networks. It consists of twisted copper pairs terminated with an RJ45 connector and is mainly employed to establish electrical connections between network devices such as routers, switches, and computers.

RJ45 cables are commonly used in Fast Ethernet and Gigabit Ethernet technologies due to their simplicity, low cost, and ease of installation. Depending on the cable category, they can support different transmission speeds and bandwidth capacities. In addition, the twisted-pair structure helps reduce electromagnetic interference and improves signal quality during data transmission.

Despite the development of optical communication technologies, RJ45 cables remain essential in local and access networks because of their reliability and widespread compatibility with Ethernet infrastructures [9].



Figure I.8: RJ45 Ethernet cable

I.4 Capacity of transmission links in mobile networks

The capacity of a transmission link represents a key parameter in the design and operation of mobile communication networks. It defines the maximum amount of information that can be transmitted over a communication channel within a given time interval under specific technical and environmental conditions. In mobile networks, transmission link capacity directly influences quality of service, network reliability, and the occurrence of congestion phenomena.

Transmission capacity is determined by several fundamental factors, including the available bandwidth, the applied modulation scheme, the coding rate, and the quality of the transmission channel. In wireless transmission systems, capacity is also influenced by propagation conditions, interference, and environmental effects. In optical transmission systems, capacity mainly depends on wavelength availability, channel spacing, and optical signal quality.

In the context of mobile networks, accurate capacity dimensioning is essential. Transmission links must be designed not only to support current traffic demands but also to accommodate future growth resulting from increasing numbers of users, higher data rates, and new services. Insufficient capacity provisioning often leads to congestion, which negatively affects network performance and user experience [10].

I.4.1 Capacity considerations in microwave transmission links

Microwave transmission links are widely used in mobile backhaul networks, but their capacity is inherently constrained by spectrum availability and propagation conditions. The achievable data rate of a microwave link depends on the allocated channel bandwidth and the selected modulation and coding scheme. Higher-order modulation schemes allow increased throughput but require favorable radio conditions to maintain acceptable error performance.

Adaptive modulation and coding techniques are commonly employed in modern microwave systems to dynamically adjust transmission parameters according to channel quality. Under good propagation conditions, the system operates with high spectral efficiency, maximizing link capacity. However, when channel conditions degrade due to rain attenuation or interference, the system reduces modulation order and coding rate to preserve link availability.

This adaptive behavior results in variable link capacity over time. During periods of degraded propagation, the effective capacity of a microwave link may decrease significantly. If traffic demand remains constant or increases during these periods, congestion may occur. This situation is particularly critical in dense urban networks where traffic variability is high and microwave links operate close to their maximum capacity [11].

I.4.2 Capacity of microwave transmission links

K band microwave links provide moderate to high capacity and are suitable for medium-range backhaul connections. Their capacity performance is generally stable under normal weather conditions, but it can be reduced during adverse environmental conditions. As

a result, K band links are often dimensioned with additional margin to ensure acceptable performance during worst-case scenarios.

E band microwave links, on the other hand, offer very high capacity due to the availability of wide channel bandwidths. These links are capable of supporting multi-gigabit per second data rates, making them highly suitable for high-traffic areas and short-distance connections. However, E band capacity is more sensitive to propagation impairments, which limits transmission range and requires careful network planning.

The complementary use of K band and E band links allows operators to optimize capacity distribution within the network. K band links provide coverage and resilience, while E band links deliver high-capacity support where traffic demand is concentrated. This hybrid approach contributes to improved capacity management and congestion mitigation [12].

I.4.3 Capacity in optical transmission links using DWDM

Optical transmission links based on DWDM technology offer significantly higher capacity compared to microwave systems. By transmitting multiple wavelengths over a single optical fiber, DWDM systems enable efficient utilization of the optical spectrum and provide scalability according to traffic growth.

Each wavelength in a DWDM system represents an independent transmission channel capable of carrying high data rates. The total capacity of an optical fiber link is therefore determined by the number of wavelengths and the data rate supported on each wavelength. Advanced optical modulation techniques further enhance capacity and spectral efficiency.

Despite their high capacity, DWDM-based transmission links are not immune to congestion. Traffic aggregation from multiple access and backhaul nodes can lead to capacity bottlenecks if wavelength resources are insufficient or poorly allocated. In addition, uneven traffic distribution and inadequate network dimensioning may result in localized congestion, particularly at aggregation and switching points [13].

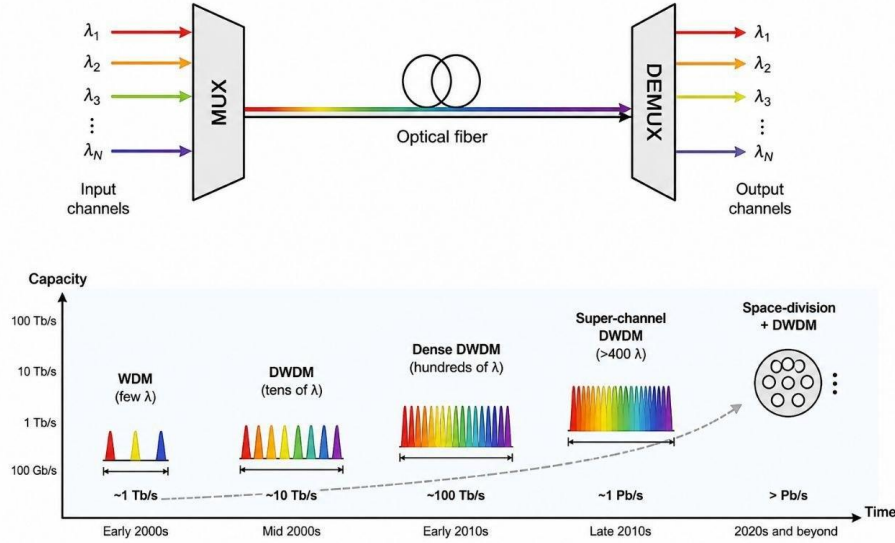


Figure I.9: Evolution of DWDM Capacity Using Spatial Division Techniques

I.5 Relationship between capacity and congestion

Congestion in transmission networks occurs when the offered traffic exceeds the available link capacity for a sustained period of time. In mobile networks, this situation is often the result of rapid traffic growth, insufficient capacity planning, or temporary capacity degradation caused by environmental factors.

Microwave links are particularly vulnerable to congestion due to their variable capacity behavior. During periods of reduced capacity, even well-dimensioned links may experience congestion if traffic demand remains high. Optical links, while offering higher capacity, may also experience congestion if traffic aggregation is not properly managed.

Therefore, effective capacity planning and continuous monitoring are essential to prevent congestion and ensure acceptable quality of service. Understanding the relationship between transmission capacity and congestion phenomena provides a necessary foundation for the troubleshooting and optimization strategies discussed in subsequent chapters [14].

I.6 Congestion

Congestion in communication networks refers to a state where the demand for network resources exceeds the available capacity, resulting in performance degradation. This

phenomenon occurs when multiple users or services attempt to transmit data simultaneously over limited network resources, leading to increased delays, packet loss, and reduced throughput.

In mobile networks, congestion has become a critical issue due to the continuous growth in traffic demand, driven by the widespread use of smartphones and bandwidth-intensive applications. The impact of congestion is particularly significant in real-time services such as voice over IP and video streaming, where latency and packet loss directly affect user experience.

From a technical perspective, congestion may occur at different levels of the network, including the radio access network, the transmission network, and the core network. Each domain has its own characteristics and constraints, which influence how congestion appears and how it can be mitigated.

Effective congestion management requires a combination of capacity planning, traffic engineering, and adaptive resource allocation mechanisms to ensure that network performance remains within acceptable limits under varying traffic conditions [15].

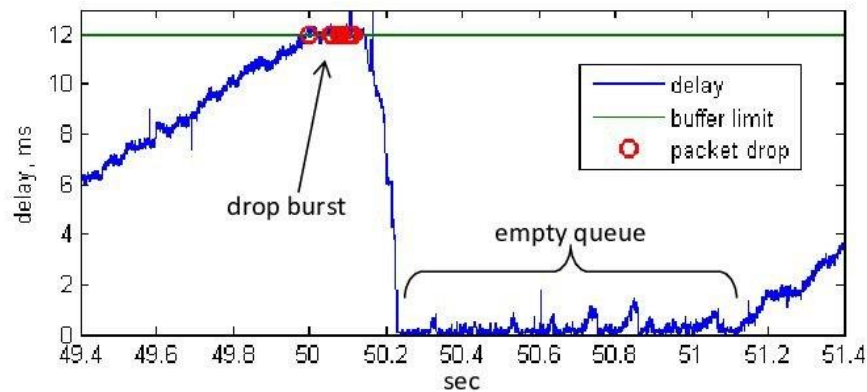


Figure I.10: Congestion-Induced Delay and Packet Loss

I.6.1 Congestion in radio domain (GSM Networks)

In the radio domain, congestion primarily occurs at the air interface between mobile users and base stations. In GSM networks, this type of congestion is typically associated with the limited availability of radio resources, such as time slots and frequency channels.

GSM systems rely on a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), where each user is allocated a specific

frequency channel and time slot. Since the number of available channels is limited, congestion arises when the number of active users exceeds the available radio resources.

One of the most common indicators of congestion in GSM networks is the blocking probability, which represents the likelihood that a new call cannot be established due to insufficient resources. High blocking rates indicate that the network is unable to handle the offered traffic, leading to poor quality of service.

Additionally, congestion may affect ongoing calls through increased call drops, degraded voice quality, and reduced data performance. This situation is particularly critical in densely populated urban areas, where traffic demand fluctuates significantly during peak hours.

To mitigate congestion in the radio domain, operators implement various techniques such as frequency reuse optimization, cell splitting, sectorization, and dynamic channel allocation. These solutions aim to improve the utilization of available radio resources and increase overall network capacity [16].

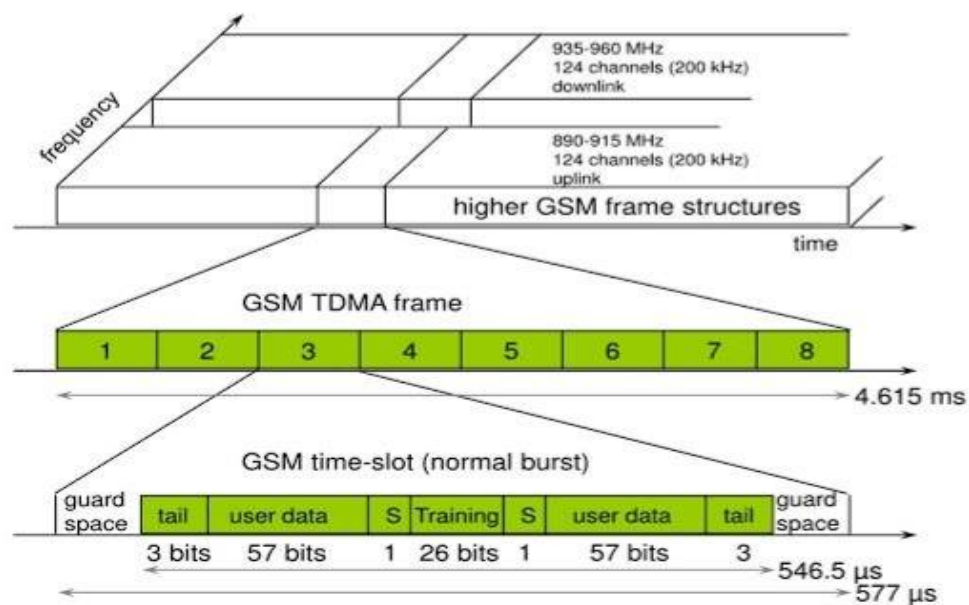


Figure I.11: GSM Radio Resource Structure Based on TDMA/FDMA

I.6.2 Congestion in transmission media

Congestion represents one of the most critical challenges in mobile transmission networks, as it directly affects network performance, service quality, and user experience. In

transmission media, congestion occurs when the volume of traffic offered to a link exceeds its effective capacity over a certain period of time. This situation leads to performance degradation, including increased latency, packet loss, and reduced throughput.

In mobile networks, congestion is not limited to a specific transmission technology. Both wireless and optical transmission media are exposed to congestion phenomena, although the underlying causes and manifestations may differ. Understanding congestion behavior in microwave and optical fiber links is therefore essential for effective network design, troubleshooting, and optimization [17].

I.6.3 Congestion in microwave transmission links

Microwave transmission links are inherently vulnerable to congestion due to their limited spectrum resources and sensitivity to environmental conditions. In mobile backhaul networks, microwave links often operate close to their maximum capacity, particularly in dense urban environments where traffic demand is high and continuously increasing.

One of the primary causes of congestion in microwave links is rapid traffic growth. The introduction of data-intensive services, such as video streaming and cloud-based applications, significantly increases the traffic load on backhaul links. When traffic demand grows faster than transmission capacity upgrades, congestion becomes inevitable.

Another important factor contributing to congestion is the variability of microwave link capacity. As discussed previously, microwave systems employ adaptive modulation and coding techniques to maintain link availability under varying propagation conditions. During adverse weather conditions, such as heavy rainfall, the system reduces modulation efficiency to preserve signal quality. This adaptive behavior leads to a temporary reduction in link capacity.

If traffic demand remains high during periods of reduced capacity, the microwave link may become congested. This situation is particularly critical during peak hours, when user activity is at its highest. Congestion in microwave links manifests through increased packet delay, higher packet loss rates, and degraded quality of service for end users.

Interference and spectrum limitations can also contribute to congestion in microwave transmission. In densely deployed networks, frequency reuse and interference from neighboring links may reduce effective link capacity. Additionally, regulatory constraints on channel bandwidth limit the maximum achievable throughput, further increasing congestion risks.

Effective congestion management in microwave networks requires a combination of proper capacity planning, intelligent traffic distribution, and continuous performance monitoring. The use of multiple frequency bands, such as the combined deployment of K band and E band links, allows operators to distribute traffic more efficiently and mitigate congestion during high-demand periods [18].

I.6.4 Congestion in optical fiber transmission links

Optical fiber transmission links, particularly those based on DWDM technology, offer significantly higher capacity compared to microwave systems. However, despite their superior capacity, optical networks are not immune to congestion phenomena.

Congestion in optical fiber links typically occurs at aggregation points, where traffic from multiple access and backhaul nodes converges. When the aggregated traffic exceeds the available wavelength capacity or switching resources, congestion may arise. This situation is often caused by insufficient wavelength provisioning or inefficient traffic distribution across available channels.

Another cause of congestion in optical networks is inadequate network dimensioning. If the optical transport network is designed based on outdated traffic assumptions, rapid growth in mobile data traffic may lead to capacity bottlenecks. In such cases, congestion may appear even though the physical fiber infrastructure is capable of supporting higher capacity.

Operational factors may also contribute to congestion in DWDM networks. Poor wavelength management, uneven traffic distribution, and limited flexibility in optical switching can reduce effective capacity utilization. As a result, some wavelengths may become congested while others remain underutilized.

Congestion in optical fiber links affects network performance in a different manner compared to microwave systems. While optical links are generally more stable, congestion may still lead to increased latency, buffering delays, and reduced service quality, particularly for latency-sensitive applications.

To mitigate congestion in optical networks, operators employ traffic engineering techniques, dynamic wavelength allocation, and proactive capacity expansion strategies. Proper planning and continuous monitoring are essential to ensure that optical resources are efficiently utilized and that congestion risks are minimized.

I.6.5 Comparative view of congestion in microwave and optical media

From a comparative perspective, congestion in microwave and optical transmission media exhibits distinct characteristics. Microwave congestion is often dynamic and strongly influenced by environmental conditions and spectrum limitations. Optical congestion, on the other hand, is primarily related to traffic aggregation and network dimensioning.

In mobile networks, microwave and optical transmission media are frequently used in a complementary manner. Microwave links provide flexible and cost-effective backhaul solutions, while optical fiber networks offer high-capacity transport for aggregated traffic. The interaction between these technologies plays a crucial role in overall congestion behavior.

A comprehensive understanding of congestion mechanisms across different transmission media is essential for developing effective troubleshooting and optimization strategies. This understanding forms a key foundation for the analysis presented in the subsequent chapters of this thesis, which focus on congestion issues in microwave transmission networks [19].

I.7 Conclusion

An overview of mobile communication networks and their transmission infrastructures has been presented, with particular attention given to congestion phenomena. The role of the transmission network has been highlighted as a key factor in ensuring efficient data transport between access and core network components, especially in the context of rapidly increasing mobile traffic.

Microwave transmission technologies operating in the K band and E band were examined in terms of propagation characteristics, capacity behavior, and susceptibility to environmental effects. While K band links offer a balanced solution in terms of coverage and availability, their capacity may be reduced under adverse weather conditions, leading to congestion during high-traffic periods. E band links provide very high capacity over short distances and are well suited for dense urban environments, particularly when combined with lower-frequency microwave links to enhance overall network performance.

Optical fiber transmission using DWDM technology was also analyzed as a high-capacity transport solution for aggregation and core networks. Despite its superior capacity and stability, congestion may still arise due to traffic concentration, inefficient wavelength allocation, or insufficient network dimensioning. This demonstrates that congestion is not

solely dependent on the transmission technology, but also on planning and traffic management strategies.

The concepts and analyses presented establish a solid theoretical basis for understanding congestion behavior in transmission networks. This foundation is essential for the identification, analysis, and optimization of congestion issues in microwave transmission systems, which represent the main focus of the subsequent work [20].

I.8 References

- [1] A. Goldsmith, *Wireless Communications*, Cambridge University Press, 2005.
- [2] J. Schiller, *Mobile Communications*, 2nd ed., Pearson Education, 2012.
- [3] G. Keiser, *Optical Fiber Communications*, 4th ed., McGraw-Hill, 2011.
- [4] D. M. Pozar, *Microwave Engineering*, 4th ed., Wiley, 2012.
- [5] ITU-R, *Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems*, Recommendation ITU-R P.530, 2005.
- [6] ITU-R, *Attenuation by Atmospheric Gases and Related Effects*, Recommendation ITU-R P.676, 2015.
- [7] W. Stallings, *Data and Computer Communications*, 10th ed., Pearson Education, 2013.
- [8] C. S. R. Murthy and M. Gurusamy, *WDM Optical Networks: Concepts, Design, and Algorithms*, Prentice Hall PTR, 2002.
- [9] B. A. Forouzan, *Data Communications and Networking*, 5th ed., McGraw-Hill Education, 2013.
- [10] G. Miao, J. Zander, K. W. Sung, and B. Slimane, *Fundamentals of Mobile Data Networks*, Cambridge University Press, 2016.
- [11] J. T. J. Penttinen, *Microwave Transmission Networks: Planning, Design, and Deployment*, John Wiley & Sons, 2015.
- [12] T. S. Rappaport, R. W. Heath Jr., R. C. Daniels, and J. N. Murdock, *Millimeter Wave Wireless Communications*, Prentice Hall, 2014.
- [13] R. Ramaswami, K. N. Sivarajan, and G. H. Sasaki, *Optical Networks: A Practical Perspective*, 3rd ed., Morgan Kaufmann, 2009.

- [14] D. Bertsekas and R. Gallager, *Data Networks*, 2nd ed., Prentice Hall, 1992.
- [15] J. F. Kurose and K. W. Ross, *Computer Networking: A Top-Down Approach*, 8th ed., Pearson, 2021.
- [16] J. Zander and S. Kim, *Radio Resource Management for Wireless Networks*, Artech House, 2001.
- [17] W. Stallings, *High-Speed Networks and Internets: Performance and Quality of Service*, 2nd ed., Pearson, 2002.
- [18] R. S. Elliott, *Digital Microwave Communication: Engineering Point-to-Point Microwave Systems*, Wiley-IEEE Press, 2007.
- [19] I. P. Kaminow, T. Li, and A. E. Willner, *Optical Fiber Telecommunications Volume VIB: Systems and Networks*, Academic Press, 2013.
- [20] A. S. Tanenbaum and D. J. Wetherall, *Computer Networks*, 5th ed., Pearson, 2011.



Chapter II

Network Monitoring and Congestion Analysis



II.1 Introduction

As introduced in Chapter 1, microwave communication systems constitute a fundamental component of mobile backhaul networks. However, ensuring their efficiency requires not only reliable transmission technologies but also advanced mechanisms for network supervision and performance evaluation.

Modern telecommunication networks are characterized by heterogeneous architectures integrating microwave links, Ethernet interfaces, and optical fiber systems. The increasing demand for high data rates and real-time services has significantly intensified the load on these infrastructures, making congestion a critical issue that directly affects Quality of Service (QoS).

To address these challenges, operators rely on network management frameworks that provide visibility over network behavior and enable proactive performance control. These frameworks are generally based on centralized management systems complemented by local configuration interfaces.

This chapter focuses on two essential aspects: the role of network management interfaces, particularly centralized and local tools, and the analysis of congestion phenomena in different segments of the Mobilis network. This theoretical foundation is necessary for the practical optimization study presented in Chapter 3 [1].

II.2 Interface NCE and Web LCT

II.2.1 Network management framework telecommunication network

Telecommunication networks are managed through a layered architecture that separates operational functions into distinct planes: the data plane, control plane, and management plane. The management plane is responsible for supervising network elements, collecting performance metrics, and ensuring proper system operation [2].

According to standard telecommunication models, network management involves several key functions, including fault management, performance management, configuration management, and security management. These functions are essential to maintain service continuity and optimize resource utilization.

In practical deployments, these functionalities are implemented through Network Management Systems (NMS), which provide centralized monitoring and control capabilities across the network [3].

II.2.2 NCE (Network Cloud Engine)

The Network Cloud Engine (NCE), widely adopted in modern telecommunication infrastructures, represents an advanced centralized management platform designed to support intelligent network operations.

From a functional perspective, NCE integrates features aligned with classical NMS principles while incorporating automation and data analytics capabilities. It enables operators to monitor network performance through Key Performance Indicators (KPIs) such as:

- Throughput
- Link utilization
- Packet loss rate
- Latency

These indicators provide quantitative insights into network behavior and allow the identification of abnormal conditions, including congestion.

NCE operates by collecting data from distributed network elements and aggregating it into a unified management interface. This centralized approach allows:

- Continuous monitoring of network elements.
- Detection and reporting of alarms.
- Analysis of traffic patterns and utilization levels.
- Centralized configuration and optimization.

In addition, modern implementations inspired by vendor solutions (such as Huawei management systems) emphasize intelligent monitoring, where data analytics is used to anticipate potential congestion before it impacts service quality [4].

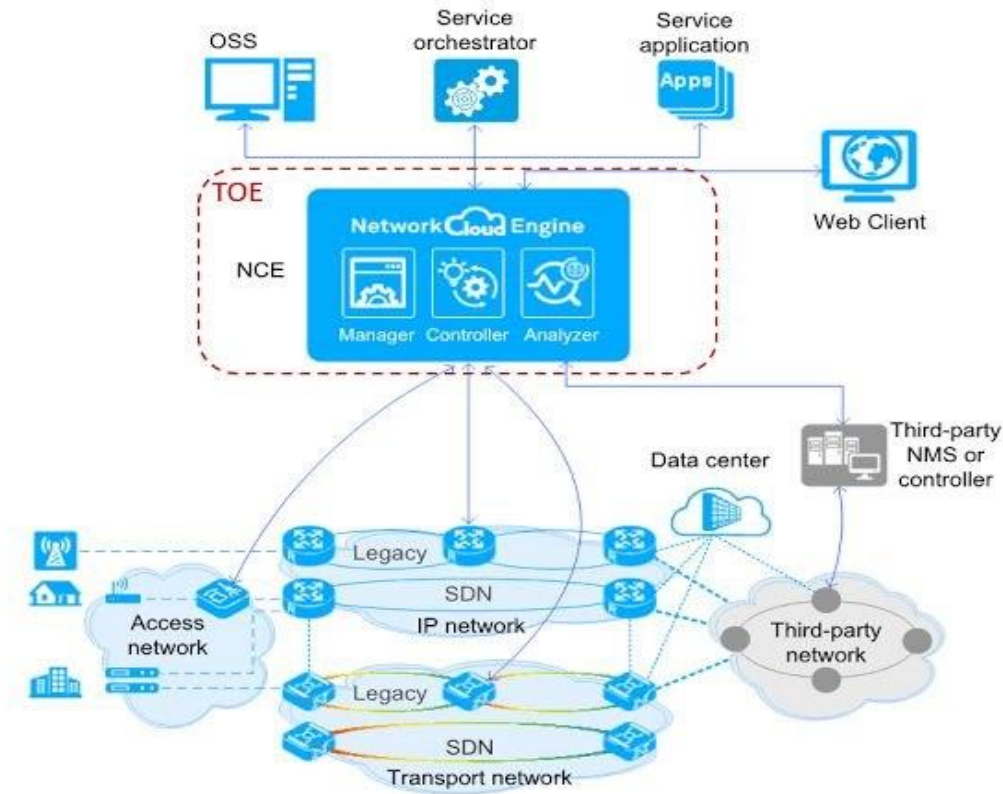


Figure II.1: Architecture of Network Cloud Engine (NCE)

II.2.3 Web LCT (Local Craft Terminal)

While centralized platforms provide a global overview, detailed analysis at the device level requires local access interfaces such as Web LCT.

Web LCT enables direct interaction with network equipment, allowing engineers to retrieve fine-grained technical information that may not be fully accessible through centralized systems.

At this level, monitoring focuses on physical and link-layer parameters, including:

- Monitoring link quality and signal parameters.
- Checking port utilization and error statistics.
- Accessing configuration settings of the equipment.
- Performing maintenance and diagnostic operations.

This detailed visibility is essential for understanding the root causes of performance degradation. For example, high utilization observed at the centralized level can be further

analyzed locally to determine whether it is caused by traffic overload, configuration issues, or transmission impairments.

Thus, Web LCT complements centralized management by providing a microscopic view of network behavior [5].

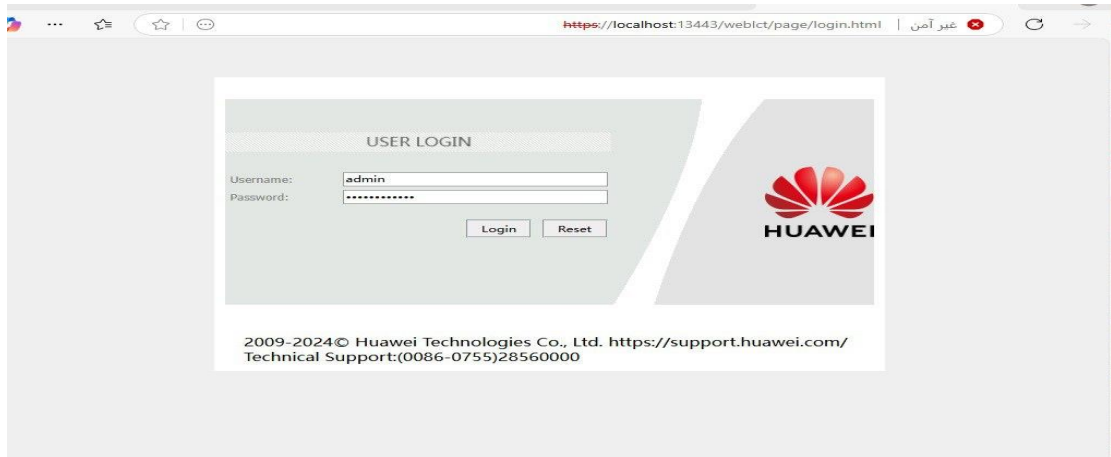


Figure II.2: Home page (WebLCT)

II.2.4 Complementarity between NCE and Web LCT

The efficiency of network management relies on the combined use of centralized and local tools.

NCE provides:

- A macroscopic view of the network
- Long-term performance analysis
- Early detection of congestion trends

Web LCT provides:

- A microscopic view at the device level
- Detailed technical diagnostics
- Immediate troubleshooting capabilities

This dual approach aligns with best practices in telecommunication network management, where global monitoring is supported by local analysis to ensure accurate problem identification [6].

II.3 Congestion problem in mobilis network (extended analysis)

II.3.1 Theoretical background of network congestion

Congestion is one of the most critical challenges in modern telecommunication networks, particularly with the continuous growth of data traffic and digital services. It occurs when the volume of incoming data exceeds the available capacity of network resources, whether at the level of links or network devices.

From a teletraffic engineering perspective, congestion results from an imbalance between the packet arrival rate and the service rate. When the arrival rate exceeds the service capacity, packets begin to accumulate in buffers, leading to:

- Increased latency
- Packet loss
- Degradation of overall throughput

Academic studies in networking emphasize that congestion is not only related to the theoretical capacity of the network but also to how efficiently resources are managed. Therefore, identifying congestion sources across different network segments is essential for performance optimization [7].

II.3.2 Congestion in microwave links

Microwave links are widely used in mobile networks, particularly for backhaul connectivity between base stations and the core network. Their flexibility and cost-effectiveness make them a preferred solution; however, they are inherently limited in capacity.

II.3.2.1 Causes of microwave congestion

- Limited bandwidth

Compared to optical fiber systems, microwave links offer relatively limited transmission capacity, which depends on channel bandwidth and modulation schemes.

- Growth in data traffic

The increasing use of high-bandwidth applications, such as video streaming and real-time services, significantly increases traffic demand.

➤ Environmental factors

According to industry practices (e.g., vendor guidelines such as Huawei), microwave link performance can be affected by weather conditions, which may reduce effective capacity and increase congestion probability.

➤ Improper network planning

Poor traffic distribution or connecting multiple base stations to a single link may lead to overload conditions.

II.3.2.2 Congestion indicators (KPIs)

Based on network management practices:

- High link utilization (typically above 80–90%)
- Increased transmission delay
- Reduced effective throughput
- Frame or packet loss

Research shows that microwave links often represent bottlenecks in mobile backhaul networks due to their limited capacity. As a result, congestion typically appears first at this level when traffic demand increases [8].

II.3.3 Congestion in fast ethernet (FE) ports

Fast Ethernet (FE) ports, with a capacity of 100 Mbps, are still present in some network infrastructures, especially in legacy deployments. However, their limited capacity makes them prone to congestion in modern high-demand environments.

II.3.3.1 Causes of congestion in FE ports

➤ Limited capacity (100 Mbps)

This bandwidth is often insufficient to handle current traffic volumes.

➤ Traffic aggregation

When multiple data flows converge on a single port, the total traffic may exceed its capacity.

➤ Speed mismatch with higher interfaces

When FE interfaces are connected to higher-speed links (e.g., GE), bottlenecks may occur due to capacity differences.

II.3.3.2 Technical indicators

- Port utilization reaching maximum levels (near 100%)
- Buffer overflow
- Packet drops
- Degradation of service quality

Literature in networking indicates that low-capacity interfaces within high-traffic environments are a major source of congestion. Therefore, the presence of FE ports in certain segments of the network can significantly contribute to performance degradation.

II.3.4 Congestion in gigabit ethernet (GE) ports

Gigabit Ethernet (GE) ports provide higher capacity (1 Gbps) compared to FE and are widely used in modern networks. Nevertheless, they can still experience congestion under heavy traffic conditions.

II.3.4.1 Causes of congestion in GE ports

- High traffic demand

Even a 1 Gbps capacity may become insufficient in high-density environments or under peak traffic conditions.

- Aggregation role

GE ports are often used as aggregation points, which increases the risk of overload.

- Load imbalance

Uneven traffic distribution across ports can lead to congestion on specific interfaces.

II.3.4.2 Indicators

- Persistent high utilization
- Increased transmission delay
- Packet loss during peak periods
- Overall performance degradation

Studies suggest that congestion in GE ports is generally not due to technological limitations but rather to traffic growth and inefficient network design. Proper load balancing and capacity planning are therefore essential [9][10].

II.3.5 Congestion in optical fiber network

Optical fiber systems form the backbone of modern telecommunication networks due to their extremely high transmission capacity. However, congestion can still occur under certain conditions.

II.3.5.1 Causes in optical congestion

➤ **Oversubscription**

This occurs when the total traffic demand exceeds the available bandwidth.

➤ **Network bottlenecks**

Certain links may have lower capacity, leading to localized congestion.

➤ **Suboptimal network design**

Poor traffic routing or imbalance in network architecture may result in uneven load distribution.

II.3.5.2 Indicators

➤ **Sudden increase in delay**

➤ **Performance degradation despite high capacity**

➤ **Instability in service quality**

Research indicates that optical fiber itself is rarely the direct cause of congestion. Instead, congestion is typically related to traffic management and network design issues. Therefore, optimization strategies focus more on traffic engineering than on increasing physical capacity [11][12].

II.4 Conclusion

This chapter has presented a comprehensive overview of network management principles and congestion phenomena within modern telecommunication systems. Emphasis was placed on the role of management interfaces, particularly centralized platforms such as NCE and local tools such as Web LCT, in ensuring efficient monitoring and control of network performance.

The analysis highlighted that effective network supervision relies on the combination of global visibility and detailed device-level investigation. Centralized systems provide a macroscopic understanding of network behavior, while local interfaces enable precise diagnosis of performance issues.

Furthermore, this chapter examined congestion problems across different segments of the Mobilis network infrastructure. It was shown that congestion is not limited to a single component but may arise at multiple levels, including microwave links, Ethernet interfaces (FE and GE), and optical fiber systems. Each of these elements presents specific constraints and challenges related to capacity, traffic distribution, and network design.

From a theoretical perspective, congestion was identified as a direct consequence of the imbalance between traffic demand and available resources. The analysis also demonstrated that performance degradation is closely linked to key indicators such as utilization, delay, and packet loss.

Overall, the findings of this chapter provide a solid analytical foundation for understanding congestion behavior in telecommunication networks. This understanding is essential for the next stage of the study, which focuses on the practical investigation of congestion in the Mobilis network and the implementation of appropriate optimization strategies.

II.5 References

- [1] Andreas F. Molisch, *Wireless Communications*, 2nd edition. Hoboken, NJ: Wiley-IEEE Press, 2011.
- [2] Internet Engineering Task Force, “RFC 7426: Software-Defined Networking (SDN): Layers and Architecture Terminology,” Jan. 2015.
- [3] International Telecommunication Union Telecommunication Standardization Sector, *Principles for a Telecommunications Management Network (TMN)*, 2000.
- [4] Huawei Technologies Co., Ltd., Network Cloud Engine (NCE): Product Documentation and Solution Overview, Huawei, 2020.
- [5] Huawei Technologies Co., Ltd., *Web LCT User Guide for Microwave Transmission Equipment*, Huawei, 2019.
- [6] ISO, *Information Processing Systems — Open Systems Interconnection — Basic Reference Model — Part 4: Management Framework*, International Organization for Standardization, 1989.
- [7] L. Kleinrock, *Queueing Systems, Volume 1: Theory*, Wiley-Interscience, 1975.
- [8] ITU-R, *Recommendation ITU-R P.530: Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems*, International Telecommunication Union (ITU), Geneva, Switzerland.
- [9] IEEE Standards Association, *IEEE Standard for Ethernet (IEEE 802.3)*, IEEE, latest edition.
- [10] J. F. Kurose and K. W. Ross, *Computer Networking: A Top-Down Approach*, 7th ed., Pearson, 2017.
- [11] R. Ramaswami, K. N. Sivarajan, and G. H. Sasaki, *Optical Networks: A Practical Perspective*, 3rd ed., Morgan Kaufmann, 2010.

- [12] International Telecommunication Union Telecommunication Standardization Sector (ITU-T), *G-Series Recommendations for Optical Transport Networks*, ITU, Geneva, Switzerland.

Chapter III

***Practical Study: Network
Congestion and Troubleshooting***

III.1 Introduction

Network congestion is a major issue in modern telecommunication systems, particularly in mobile networks. It occurs when the demand for traffic exceeds the available network capacity, leading to performance degradation such as increased latency, packet loss, and reduced throughput. In general, this phenomenon can affect all communication services and has a direct impact on the end-user experience. In mobile networks, congestion is often more critical due to the continuous growth of data traffic generated by smartphones, online applications, and multimedia services. This increasing demand places significant pressure on network resources, especially in the radio access domain and transport links. From an architectural perspective, congestion can occur at different levels of the mobile network. It may affect the Radio Access Network (RAN), where frequency and channel resources are limited, as well as the transport network, particularly microwave links used to connect remote sites. Each of these segments plays a key role in overall network performance. More specifically, microwave links represent a critical part of the transmission network. They ensure connectivity between radio sites and the core network, especially in areas where fiber infrastructure is not available. However, these links can also become a bottleneck when capacity is insufficient or poorly dimensioned, directly impacting service quality. In this context, this practical study focuses on the analysis of congestion issues, with particular emphasis on microwave links, in order to identify the main causes and propose appropriate solutions to improve overall network performance.

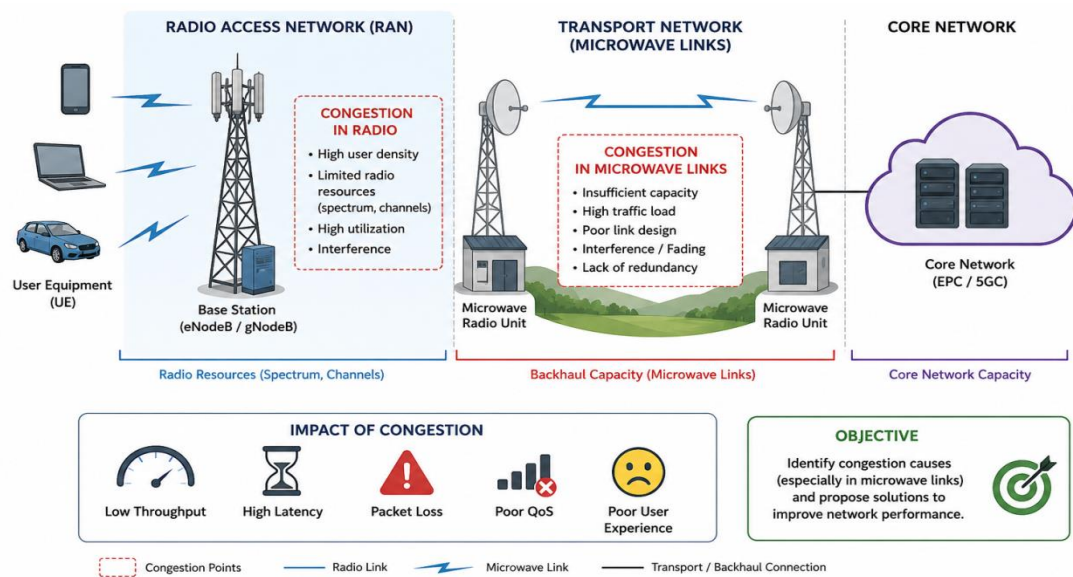


Figure III.1: Illustration of Congestion in Mobile Networks (RAN and Microwave Links) [1]

III.2 What does congestion mean in mobile networks?

Network congestion in mobile networks refers to a condition where the demand for network resources exceeds the available capacity, leading to performance degradation such as increased latency, packet loss, reduced throughput, and call blocking. It can occur at different layers of the mobile architecture, including the radio access network (RAN), transport network (e.g., microwave or fiber backhaul), and core network. In cellular systems such as LTE and 5G, congestion is typically caused by high user density, sudden traffic peaks, insufficient spectrum or backhaul capacity, or suboptimal network dimensioning. When congestion occurs, network elements become overloaded, which forces scheduling delays and resource contention among users, ultimately affecting Quality of Service (QoS) and Quality of Experience (QoE). Operators mitigate congestion using techniques such as admission control, traffic offloading, carrier aggregation, and dynamic resource allocation [2][3].

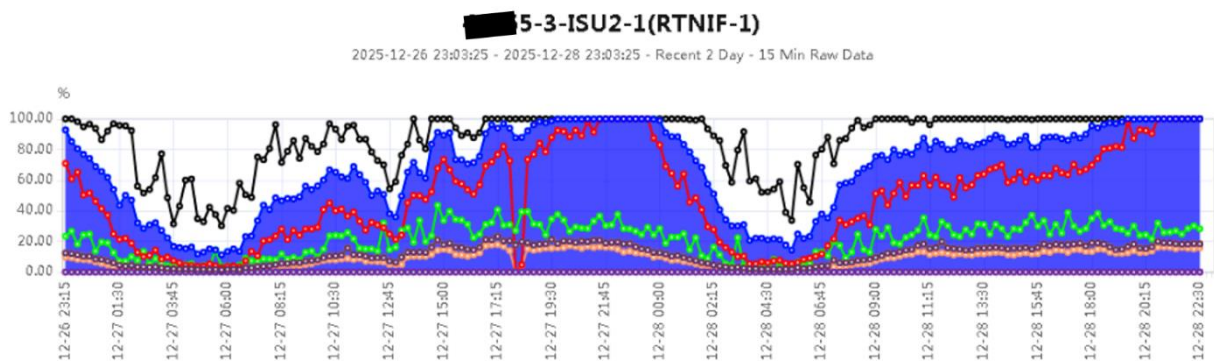


Figure III.2: Illustration of Congestion Based on Bandwidth Utilization

III.3 Analysis and Troubleshooting of Congestion in Mobile Microwave

The continuous growth of mobile data traffic, driven by broadband services, video streaming, and IoT applications, has significantly increased the pressure on mobile network infrastructures. In modern cellular systems, the microwave backhaul network plays a critical role in connecting radio access networks (RAN) to the core network. Any congestion within this layer can severely degrade end-user experience by increasing latency, packet loss, and reducing throughput.

Network congestion occurs when the demand for network resources exceeds available capacity. In mobile networks, this phenomenon can occur at different layers, mainly within the radio access network and the transmission/backhaul network [4].

III.3.1 Congestion in the Radio Access Network (RAN)

Congestion in the RAN occurs when radio resources are insufficient to serve active users in a cell. This is typically due to high traffic demand, limited spectrum availability, or inefficient radio planning. Key causes include :

- High user density in a specific cell area
- Limited spectrum allocation
- Poor radio coverage or interference
- Inefficient load balancing between neighboring cells
- Common KPIs affected:
 - Physical Resource Block (PRB) utilization
 - User throughput degradation
 - Call setup success rate reduction
 - Increased drop call rate

RAN congestion directly impacts Quality of Service (QoS), especially in urban and high-density environments [5].

III.3.2 Congestion in the Transmission Network

Transmission congestion occurs in the microwave network segment, which connects base stations to the core network. Unlike RAN congestion, transmission congestion is related to transport capacity limitations rather than radio resources.

Main causes include:

- Insufficient backhaul capacity
- Oversubscription of transport links
- Inefficient traffic engineering
- Bottlenecks in aggregation nodes

Impacts include:

- Increased latency
- Packet loss and retransmissions
- Throughput limitation regardless of radio conditions

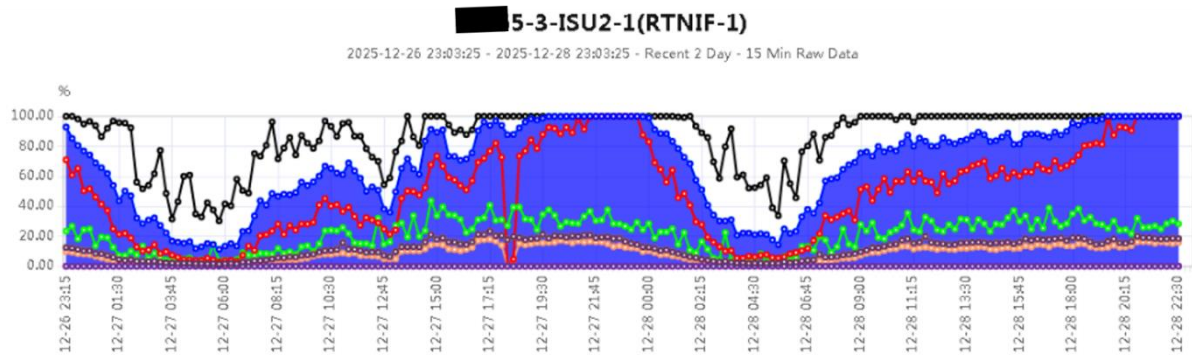


Figure III.3: Illustration of Congestion in the Microwave Network (Bandwidth Utilization)

III.4 Congestion in Microwave Networks

Microwave links are widely used in mobile networks as a flexible and cost-effective backhaul solution. However, they are also prone to congestion, especially under high traffic loads.

Microwave congestion typically arises from:

- Limited channel bandwidth (e.g., 7/14/28 MHz channels)
- Modulation constraints under adverse weather conditions
- Saturation of Ethernet interfaces (FE/GE limitations)
- Traffic imbalance across network hops
- High aggregation of traffic at hub sites

Unlike fiber-based backhaul, microwave links are more sensitive to environmental conditions such as rain fade and interference, which may further reduce effective capacity.

Key Microwave KPIs:

- Link throughput (Mbps/Gbps)
- Ethernet utilization rate (%)
- Packet loss ratio
- Modulation scheme stability (QPSK, QAM levels)
- Availability and link downtime

Congestion in microwave networks often manifests as persistent high utilization (>85–90%) combined with throughput degradation and increased latency [6][7].

III.5 Troubleshooting and Resolution of Real Congestion Cases

Effective troubleshooting requires a structured methodology combining KPI analysis, alarm monitoring, and traffic evaluation.

III.5.1 Congestion in the Radio Access Network (RAN)

Step 1: Radio KPI Analysis

Even though congestion may originate in the backhaul, radio KPIs are essential for initial diagnosis:

- PRB utilization above threshold indicates traffic stress
- Reduced user throughput despite good signal quality
- Increased scheduling delays

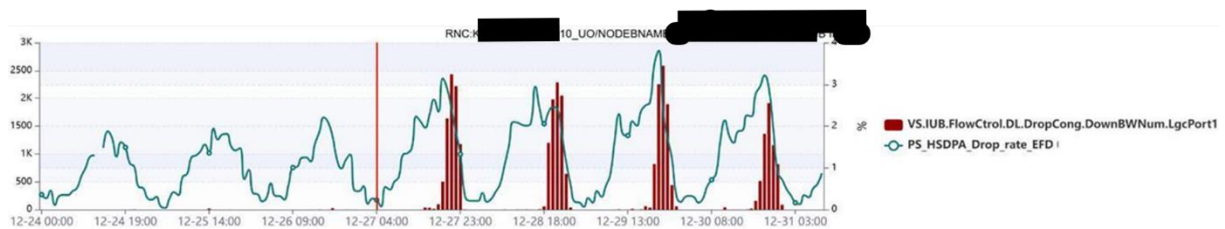


Figure III.4: Example of Key Performance Indicators (KPIs) in the Radio Network

Step 2: Traffic and Alarm Analysis

- Traffic extraction from network management systems
- Identification of congestion-related alarms (link overload, buffer overflow)
- Correlation between traffic peaks and performance degradation

This phase helps determine whether congestion originates from RAN or transmission layers.

III.5.2 Resolution of Congestion Cases

Case 1: Fast Ethernet (FE) to Gigabit Ethernet (GE) Bottleneck

A common issue occurs when legacy FE interfaces (100 Mbps) become saturated due to increasing traffic demand.

Symptoms :

- Interface utilization near 100%
- Packet drops at transport level
- High latency during peak hours

Solution:

- Migration from FE to GE interfaces
- Reconfiguration of VLAN and traffic mapping
- Capacity upgrade at aggregation nodes

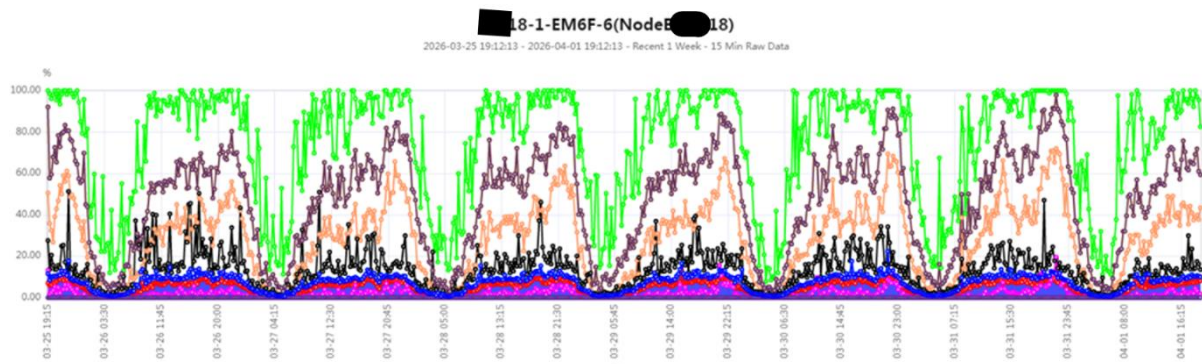


Figure III.5: Illustration of FE Interface Congestion (Bandwidth Utilization)

Case 2: Congested Microwave Link

In some scenarios, a specific microwave hop becomes a bottleneck due to uneven traffic distribution.

Symptoms:

- One link showing significantly higher utilization than others
- Packet loss on overloaded hop
- Degraded end-to-end throughput

Solution:

- Traffic rebalancing or rerouting (rehoming)
- Load redistribution across neighboring links
- Capacity upgrade or additional carrier deployment

Case 3: Hardware Upgrade

When traffic growth exceeds network design limits, hardware expansion becomes necessary.

Actions include:

- Upgrade of microwave radios
- Addition of higher-capacity RF modules
- Expansion of antenna systems or channel bandwidth

Hardware upgrades directly increase transport capacity and reduce congestion risks.

Case 4: Software Optimization

Software-level improvements can also mitigate congestion without physical changes.

Actions include:

- QoS policy optimization
- Traffic prioritization tuning
- Load balancing algorithm improvements
- Firmware or network software upgrades

These optimizations improve resource utilization efficiency and reduce unnecessary congestion[7].

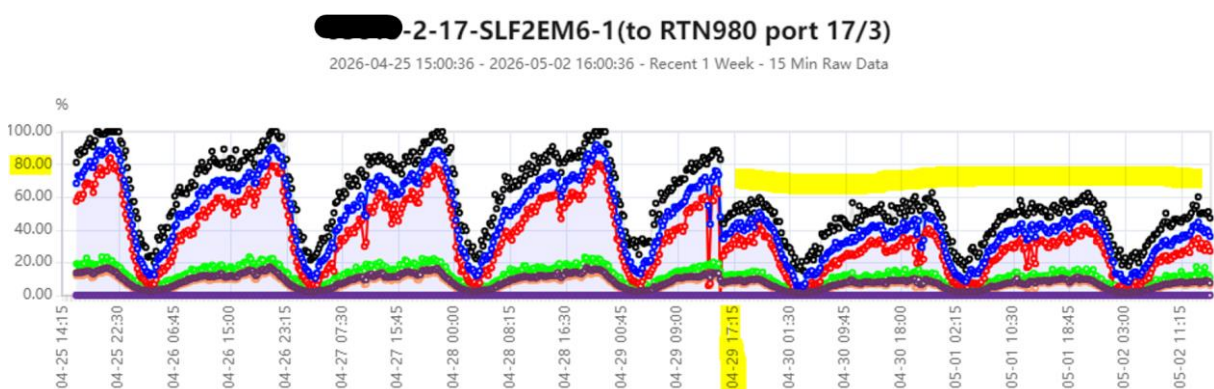


Figure III.6: Illustration of FE/GE Congestion Before and After (Bandwidth Utilization)

III.6 Conclusion

Congestion in mobile microwave networks represents a critical challenge for maintaining service quality in modern cellular systems. While radio access congestion is often the first visible symptom, many performance issues originate in the transmission layer, particularly in microwave links.

A systematic troubleshooting approach based on KPI analysis, traffic monitoring, and alarm correlation is essential for accurate root cause identification. Mitigation strategies such as interface upgrades (FE to GE), microwave capacity enhancement, and software optimization are effective solutions to ensure network stability and scalability.

III.7 References

- [1] 3GPP. (2020). *E-UTRA and E-UTRAN; Overall description (3GPP TS 36.300)*. 3rd Generation Partnership Project. <https://www.3gpp.org>
- [2] 3GPP. (2021). *System architecture for the evolved packet system (EPS) (3GPP TS 23.401)*. 3rd Generation Partnership Project. <https://www.3gpp.org>
- [3] ITU-T. (2017). *E.800: Terms and definitions related to quality of service*. International Telecommunication Union. <https://www.itu.int>
- [4] Andrews, J. G., Buzzi, S., Choi, W., Hanly, S. V., Lozano, A., Soong, A. C., & Zhang, J. C. (2014). What will 5G be? *IEEE Journal on Selected Areas in Communications*, 32(6), 1065–1082.
- [5] Dahlman, E., Parkvall, S., & Skold, J. (2020). *5G NR: The Next Generation Wireless Access Technology*. Academic Press.
- [6] ITU-R. (2021). *Fixed service microwave engineering: propagation and transmission characteristics*. International Telecommunication Union.
- [7] Cisco Systems. (2020). *Carrier Ethernet and Backhaul Network Design Principles*. IEEE Communications Surveys.



General Conclusion



This work has presented a comprehensive study of congestion phenomena in mobile transmission networks, with particular emphasis on microwave communication systems and network monitoring mechanisms. The study demonstrated that the continuous growth of mobile traffic, driven by modern digital services and increasing user demand, places significant pressure on telecommunication infrastructures and creates major challenges in terms of capacity management and Quality of Service.

The theoretical analysis highlighted the importance of transmission networks within mobile communication architectures and examined the characteristics of different transmission technologies, including microwave links operating in K band and E band frequencies as well as optical fiber systems based on DWDM technology. The study showed that although these technologies provide efficient transport solutions, they remain vulnerable to congestion under high traffic conditions or inadequate network dimensioning.

The work also emphasized the essential role of network management and monitoring systems in congestion analysis and troubleshooting. Centralized platforms such as NCE, combined with local management tools such as Web LCT, provide operators with both global and detailed visibility into network performance. Through the analysis of Key Performance Indicators, it becomes possible to identify congestion sources, evaluate network behavior, and implement appropriate optimization strategies.

Furthermore, the analysis of congestion within the Mobilis network infrastructure demonstrated that congestion may occur at multiple levels, including microwave links, Fast Ethernet ports, Gigabit Ethernet interfaces, and optical transport systems. Each network segment presents specific technical constraints and requires adapted management and optimization techniques.

Overall, this study confirms that effective congestion management depends on accurate capacity planning, continuous performance monitoring, efficient traffic distribution, and proactive optimization strategies. The findings of this work provide a valuable foundation for improving network reliability, enhancing transmission performance, and ensuring better service quality in modern mobile communication networks.

Abstract

This dissertation focuses on the study of congestion in mobile telecommunication networks, with particular emphasis on microwave transmission systems. The work aims to analyze the causes and effects of congestion and to examine the methods used for its monitoring and resolution. The study presents an overview of mobile network architectures and transmission technologies, including microwave and optical fiber systems. It also explores network management and monitoring tools, particularly the Network Cloud Engine (NCE) and Web Local Craft Terminal (Web LCT), used to supervise network performance and detect congestion issues. As part of the practical work carried out at Mobilis, several congestion cases were analyzed using network performance indicators (KPIs), traffic measurements, and alarm monitoring. Different types of congestion affecting microwave links, Ethernet interfaces, and optical transmission networks were investigated. Various optimization solutions, such as capacity upgrades, traffic rebalancing, and interface migration, were proposed to improve network performance. The results highlight the importance of continuous monitoring and efficient resource management in ensuring service quality and network reliability.

Keywords

Mobile Networks, Network Congestion, Microwave Transmission, Backhaul Network, NCE, Web LCT, KPI Analysis, Troubleshooting, Network Optimization, Mobilis.