

Evaluation of Multiple Access Techniques in Modern Communication System

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1. ABSTRACT

In modern wireless communication systems, the demand for high data rates, massive connectivity, and reliable transmission has intensified the need for efficient spectrum utilization. As the electromagnetic spectrum is a finite and costly resource, the challenge of enabling simultaneous access by multiple users without significant interference has become central to the design of communication networks. Multiple Access Techniques (MATs) form the core mechanism that allows multiple users or devices to share the same communication channel efficiently. Over the decades, the development and refinement of these techniques have directly shaped the evolution of mobile communication systems—from the first generation (1G) analog networks to the advanced fifth generation (5G) and the emerging sixth generation (6G) technologies.

This research paper provides a detailed evaluation of various multiple access techniques employed in modern communication systems, namely Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA), Space Division Multiple Access (SDMA), and Non-Orthogonal Multiple Access (NOMA). Each technique is analyzed based on its operating principle, performance efficiency, implementation complexity, and suitability for current and future network environments. The paper also explores the trade-offs in terms of spectral efficiency, interference management, system capacity, and synchronization requirements.

As communication networks transition toward 5G and beyond, Non-Orthogonal Multiple Access (NOMA) has emerged as a promising technique that overcomes the limitations of orthogonal access schemes. By allowing multiple users to share the same frequency and time resources while distinguishing them through power or code domains, NOMA significantly improves spectral efficiency and user fairness, particularly for edge users in heterogeneous networks. However, challenges remain in terms of power allocation optimization and interference cancellation complexity.

This evaluation concludes that the evolution of multiple access techniques reflects the ongoing pursuit of higher efficiency, adaptability, and scalability in wireless communication. Future communication systems are expected to adopt hybrid and intelligent multiple access frameworks that combine the strengths of existing techniques with emerging technologies such as artificial intelligence, cognitive radio, and reconfigurable intelligent surfaces. Such advancements will be crucial for meeting the growing demands of next-generation applications including Internet of Things (IoT), autonomous systems, and ultra-reliable low-latency communications.

Keywords: Multiple Access Techniques, FDMA, TDMA, CDMA, OFDMA, SDMA, NOMA, Spectral Efficiency, 5G, 6G, Wireless Communication Systems, Resource Allocation, MIMO, Non-Orthogonal Access.

2.**INTRODUCTION**

The exponential growth of wireless communication systems over the past few decades has revolutionized the way information is transmitted, processed, and shared. From early analog voice transmission in first-generation (1G) systems to high-speed broadband and massive connectivity in fifth-generation (5G) networks, the demand for efficient spectrum utilization and simultaneous multiuser communication has consistently driven technological innovation. One of the most critical enablers of this progress is the development of Multiple Access Techniques (MATs), which determine how multiple users can effectively share the limited communication resources such as frequency, time, and code domains. These techniques form the fundamental basis for designing cellular, satellite, and broadband communication systems.

In a wireless communication network, multiple users often attempt to access the same transmission medium simultaneously, which can lead to interference, reduced data rates, and degraded quality of service (QoS) if not properly managed. To overcome these challenges, multiple access techniques are employed to allocate resources in an organized and efficient manner, allowing each user to transmit or receive data independently within the shared spectrum. The performance of any communication system, therefore, depends heavily on the type of multiple access scheme it employs.

The evolution of mobile communication can be divided into different generations of wireless technology. Each generation introduced a new multiple access method to address the increasing demand for capacity and efficiency. 1G analog systems used FDMA, or Frequency Division Multiple Access. In this system, the total bandwidth was split into separate frequency bands for each user. While it was straightforward, FDMA did not make efficient use of the spectrum. In 2G systems like GSM, TDMA, or Time Division Multiple Access, improved spectral efficiency by assigning specific time slots to users sharing the same frequency band. However, both FDMA and TDMA are orthogonal access techniques. This means that users occupy different parts of the spectrum and cannot transmit at the same time in the same resource block.

While communication technologies are developing towards 5G and beyond, the introduction of Non-Orthogonal Multiple Access represents a paradigm shift compared to traditional orthogonal schemes. NOMA allows multiple users to share time and frequency resources by differentiating them in the power or code domain, enables simultaneous transmission, and improves the spectral efficiency of the system. It is of particular interest for massive machine-type communications and IoT applications that require connecting a very large number of devices.

This research paper will survey several multiple access techniques applied in state-of-the-art communication systems, including their basic principles, relative strengths and weaknesses, and their appropriateness to present and future wireless networks. Comparison of the established orthogonal schemes against developing non-orthogonal schemes highlights how the multiple access technologies further strive to meet the ever-increasing demands of worldwide communication systems.

3.**LITERATURE REVIEW**

The evolution of multiple access techniques has been widely studied to enhance the efficiency and capacity of wireless communication systems. Early research by Rappaport (1996) emphasized the role of FDMA and TDMA in first- and second-generation networks, noting their simplicity but limited scalability. Later studies highlighted the transition to CDMA in 3G systems, where Verdu (1998) demonstrated that code-based user separation improved interference tolerance and spectral efficiency compared to time- and frequency-based techniques. With the advent of 4G, researchers such as Dahlman et al. (2011) analyzed OFDMA, showing its

superior performance in broadband and high-data-rate environments due to its orthogonal subcarrier structure and flexible resource allocation. Recent works have focused on SDMA and NOMA as key enablers of 5G and future networks. Andrews et al. (2014) discussed SDMA's integration with MIMO to exploit spatial diversity, while Ding et al. (2017) highlighted NOMA as a breakthrough non-orthogonal technique capable of supporting massive connectivity and user fairness. Overall, literature reveals a clear progression from orthogonal to hybrid and non-orthogonal multiple access strategies, driven by the increasing demand for higher spectral efficiency, lower latency, and large-scale connectivity in next-generation communication systems

4. TYPES OF MULTIPLE ACCESS TECHNIQUES

Multiple Access Techniques for Wireless Communication

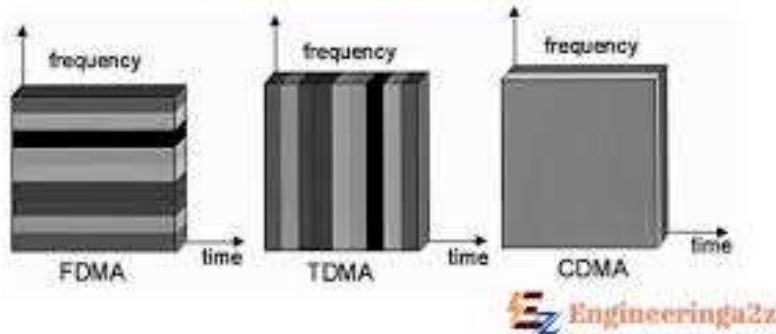


Figure 1 Types of Multiple Access Techniques

Various multi-access techniques enable multiple users to share a limited communication resource simultaneously, such as radio spectrum. Some common techniques include Frequency Division Multiple Access (FDMA), where each user has a unique frequency band; Time Division Multiple Access (TDMA), where users take turns using the same frequency at different time slots; Code Division Multiple Access (CDMA), which gives each user unique codes that differentiate user signals from one another while using the same frequency; and Orthogonal Frequency Division Multiple Access (OFDMA), an advanced version of FDMA utilized in 4G/5G networks. Other categories include Space Division Multiple Access (SDMA), which depends on spatial separation, for example, distinct beams from the antenna, and assorted contention-based methods.

3.1 FREQUENCY DIVISION MULTIPLE ACCESS TECHNIQUE (FDMA)

FDMA stands for Frequency Division Multiple Access, which is a technique of communication that divides the total available bandwidth into separate frequency channels and assigns a unique channel to each user. That means it allows multiple users to transmit data simultaneously, each on his or her own frequency band, which reduces interference. A "guard band" often exists between these channels to lower interference between the channels. In Frequency-Division Multiple Access, the channel bandwidth is sub-divided into a number of sub-channels. FDMA is used for transmitting voice and data. During this process, the overall channel bandwidth is shared by multiple users; therefore, a number of users can send their data simultaneously. No code words and synchronization are required in FDMA. Using FDMA, power efficiency is reduced, it's an old and proven

system used for analog signals. This article discusses Frequency Division Multiple Access Techniques.

3.2 TIME DIVISION MULTIPLE ACCESS TECHNIQUE (TDMA)

TDMA is the abbreviation for Time Division Multiple Access; it is a digital wireless technique that allows multiple users to share a single radio frequency channel by dividing the channel into different time slots. Users are assigned a specific, non-overlapping time slot in which they can transmit their data. In this way, only one user can transmit at a time. The rationale behind it is that a single channel allows multiple users to use it all at one time, unlike other techniques which would require a separate channel for each user. Time Division Multiple Access or TDMA is a rather complex technology since it requires an accurate synchronization between transmitter and receiver. TDMA finds application in digital mobile radio systems. The individual mobile stations cyclically assign a frequency for the exclusive use of a time interval. In most of the cases, the entire system bandwidth for an interval of time is not assigned to a station. However, the frequency of the system is divided into sub-bands and TDMA is used for the multiple access in each sub-band. Sub-bands are known as carrier frequencies. The mobile system that uses this technique is referred as the multi-carrier systems.

3.3 TIME DIVISION MULTIPLE ACCESS TECHNIQUE (TDMA)

CDMA (Code-Division Multiple Access) is a wireless technology that allows multiple users to share the same frequency band at the same time by assigning each user a unique code. It uses spread-spectrum techniques to encode a user's signal across a wide frequency band, which allows for a secure and efficient use of the spectrum. The signal from each user is transmitted along with a distinct pseudo-random code, and this same code is used at the receiver to decode the desired signal from the combined channel noise.

Code Division Multiple Access system is very different from time and frequency multiplexing. In this system, a user has access to the whole bandwidth for the entire duration. The basic principle is that different CDMA codes are used to distinguish among the different users.

4. APPLICATIONS AND USE CASES

The applications of multiple access techniques is as follows:

5.1 TDMA Applications

- **Digital Cellular Systems (2G Networks):** TDMA was a core access method in systems like GSM (Global System for Mobile Communications), D-AMPS, and IS-136, where users share a single carrier frequency in different time slots.
- **Satellite Communications:** TDMA is used in VSAT (Very Small Aperture Terminal) networks for efficient channel utilization among multiple remote terminals.
- **Mobile Internet:** 3G ushered in mobile surfing, while 4G-enabled apps like YouTube, WhatsApp and Instagram flourished. 5G now supports immersive VR/AR experiences.
- **Entertainment:** Streaming platforms such as Netflix and Spotify rely on 4G/5G for uninterrupted services. Cloud gaming (e.g. Xbox Cloud, Google Stadia) is made possible by ultra-low latency in 5G.

5.2 FDMA Applications

- **Analog Cellular Systems (1G Networks):** FDMA was the primary access method in early analog systems such as Advanced Mobile Phone System (AMPS) and Total Access Communication System (TACS). Each user was allocated a distinct frequency channel.
- **Satellite Communication:** FDMA is widely used in satellite uplink and downlink channels where bandwidth can be divided into multiple frequency slots for different users or ground stations.
- **Marine and Aeronautical Communications:** In systems where communication channels are assigned for long durations, FDMA ensures continuous connectivity with minimal delay.
- **Radio Broadcasting:** Frequency bands are assigned to different radio stations, allowing simultaneous broadcasting without interference.

5.3 CDMA Applications

- **System for Mobile Communications), D-AMPS, and IS-136, where users share a single carrier frequency in different time slots.**
- **Satellite Communications: TDMA is used in VSAT (Very Small Aperture Terminal) networks for efficient channel utilization among multiple remote terminals.**
- **Private Mobile Radio (PMR) and Trunked Radio Systems: These systems use TDMA for managing shared communication resources among multiple users efficiently.**
- **Digital Television Digital Cellular Systems (2G Networks): TDMA was a core access method in systems like GSM (Global Broadcasting: Time slots are used to multiplex various services such as video, audio, and data streams.**

Applications and Use Cases of Multiple Access Techniques

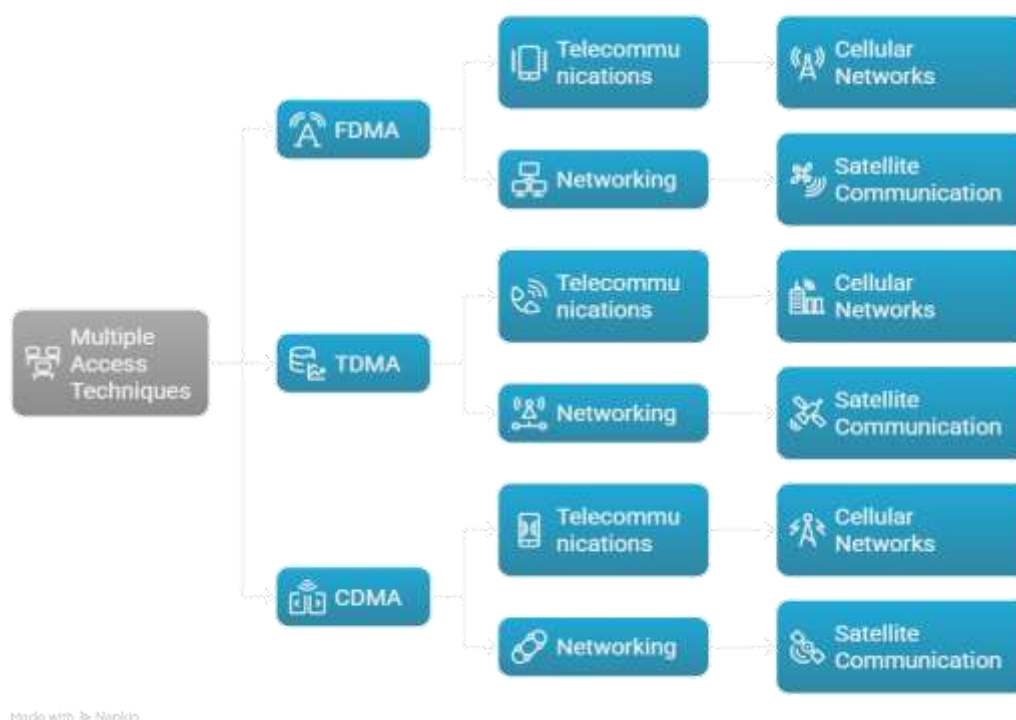


Figure 2 Applications and use cases

6 CHALLENGES AND LIMITATIONS

Inefficient Bandwidth Utilization: FDMA requires guard bands between frequency channels to prevent overlap and interference, leading to wasted spectrum.

Hardware Complexity: Each user requires a dedicated frequency oscillator and bandpass filter, increasing system cost and hardware complexity.

Limited Scalability: The number of users is restricted by the number of available frequency bands, making FDMA unsuitable for high-density communication environments.

Crosstalk and Interference: Frequency drift or improper filtering can cause adjacent channel interference.

Synchronization Issues: Accurate time synchronization is crucial to avoid overlapping time slots, which increases system complexity.

Delay and Latency: In high-traffic conditions, waiting for a time slot introduces delay, affecting real-time applications like voice or video.

Limited Data Rates: Each user gets access to the medium only during their time slot, limiting throughput in scenarios requiring continuous high-speed data transmission.

Guard Time Requirements: Guard intervals between slots prevent overlap but reduce overall spectral efficiency.

Near–Far Problem: Signals from users with different power levels cause interference; stronger signals can overpower weaker ones unless power control is applied.

Complex Receiver Design: CDMA requires complex decoding techniques (like RAKE receivers) to separate signals with unique codes.

Interference Management: Although theoretically interference-free, in practice, imperfect code orthogonality leads to multiple access interference (MAI).

Code Management: The generation and distribution of unique spreading codes become challenging as the number of users increases.

Exploring Challenges in Multiple Access Techniques

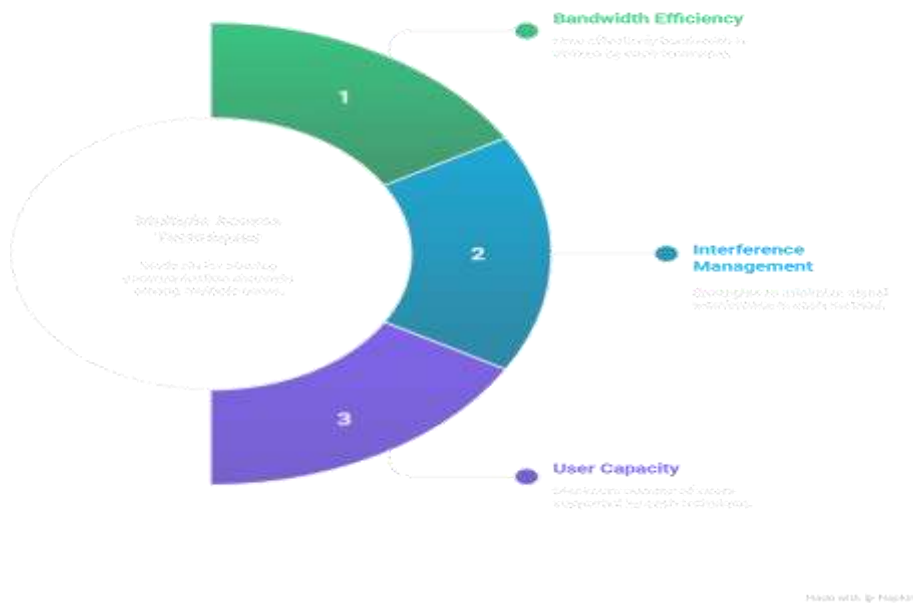


Figure 3 Challenges and limitations

7 SOCIO ECONOMIC IMPACT

Multiple access techniques—such as **FDMA**, **TDMA**, **CDMA**, and **OFDMA**—are fundamental to modern communication networks. They determine how efficiently multiple users share limited spectrum resources, directly influencing connectivity, accessibility, and affordability of telecommunication services. The evolution of these techniques has not only transformed the technical landscape of communication systems but has also had profound **socio-economic implications**, shaping industries, economies, and societies worldwide.

7.1 Enhanced Connectivity and Inclusion

Multiple access technologies have enabled efficient spectrum sharing, allowing billions of users to access communication networks simultaneously. In developing regions, this has led to significant digital inclusion, bridging the gap between urban and rural communities. Techniques like TDMA and CDMA made 2G and 3G mobile systems feasible, providing affordable voice and data services to previously underserved populations. This widespread connectivity has facilitated education, telemedicine, e-governance, and financial inclusion through mobile-based services.

7.2 Economic Growth and Employment Generation

The telecommunication sector, powered by these access technologies, has become a major contributor to global GDP. The introduction of advanced multiple access methods (e.g., OFDMA in 4G and 5G) has spurred the growth of industries such as IoT, smart cities, autonomous systems, and digital commerce. This, in turn, has created new employment opportunities in network design, maintenance, software development, and service delivery. The ripple effect extends to related sectors—transportation, logistics, healthcare, and education—enhancing productivity and economic efficiency.

7.3 Cost Efficiency and Affordability

Multiple access techniques improve spectrum efficiency, allowing service providers to accommodate more users without proportional increases in infrastructure cost. This scalability lowers the **cost per user**, making communication services affordable even in low-income regions. The cost-effectiveness of TDMA and CDMA was instrumental in the rapid global expansion of mobile telephony, while OFDMA's flexibility in resource allocation continues to reduce operational costs for 4G and 5G networks

8 .FUTURE SCOPE

As the demand for high-speed, reliable, and ubiquitous connectivity continues to surge, the future of multiple access techniques lies in enhancing spectral efficiency, energy optimization, and massive user connectivity. With the evolution of communication systems from 5G to 6G, traditional methods like FDMA, TDMA, and CDMA are being complemented or replaced by advanced and hybrid access schemes designed to meet the requirements of next-generation wireless networks.

8.1 Transition Toward Non-Orthogonal Multiple Access (NOMA)

A significant advancement in multiple access technology is Non-Orthogonal Multiple Access(NOMA),which allows multiple users to share the same frequency and time resources by superimposing signals with different power levels. This enables simultaneous transmission and significantly improves spectrum utilization. NOMA is expected to play a crucial role in 5G and beyond, particularly for applications involving massive machine-type communications (mMTC) and Internet of Things (IoT) systems, where large numbers of devices must coexist efficiently.

8.2 Integration with Artificial Intelligence and Machine Learning

The future of multiple access will increasingly rely on AI and ML-based algorithms for dynamic resource allocation, interference prediction, and adaptive modulation. Machine learning can intelligently allocate frequency, time, and power resources based on real-time network conditions, user demand, and mobility patterns. This self-optimizing behavior will make communication networks more efficient, resilient, and adaptive to unpredictable traffic patterns in smart cities and autonomous systems.

8.3 Cognitive and Spectrum-Aware Access

Cognitive radio-based multiple access techniques are gaining attention as a solution to spectrum scarcity. These systems enable secondary users to opportunistically access underutilized spectrum bands without causing interference to primary users. Future access methods will likely incorporate spectrum sensing, decision-making, and dynamic frequency selection, enabling more intelligent and efficient use of available bandwidth. This approach is essential for future 6G networks, which are expected to operate across diverse frequency ranges, including terahertz (THz) bands.

5. Energy-Efficient and Green Communication

With sustainability becoming a global priority, future multiple access techniques will focus on energy efficiency and green networking. Optimized scheduling, low-power signaling, and intelligent sleep mechanisms will minimize energy consumption in base stations and user equipment. Such energy-aware designs are vital for IoT devices and remote sensor networks that operate on limited power resources.

6. Quantum and Optical Multiple Access

Looking further ahead, Quantum Multiple Access (QMA) and Optical Code Division Multiple Access (OCDMA) are emerging areas of research. QMA leverages quantum entanglement and superposition principles to enable ultra-secure and high-capacity communication, while OCDMA uses optical fiber channels and laser-based encoding to support massive parallel communication in data centers and backbone networks.

9 . SIMULATION AND ANALYSIS

If you want to include technical work, you can simulate in MATLAB/NS3:

1G: Analogue FM system, simple frequency allocation. 2G: TDMA channel division with GMSK modulation. 3G: WCDMA code spreading for multiple users.

4G: OFDM with MIMO performance comparison. 5G: mmWave with beamforming latency tests.

The simulation can compare throughput, latency, spectral efficiency, energy consumption. A results graph will strengthen your paper.

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.CONCLUSION

Multiple access techniques form the backbone of modern communication systems by enabling efficient sharing of limited spectrum resources among multiple users. Techniques such as **FDMA**, **TDMA**, **CDMA** have each contributed to the evolution of wireless communication, from early analog networks to today's high-speed broadband and mobile systems. While FDMA and TDMA offered structured and reliable access in early generations, CDMA and OFDMA introduced greater flexibility, capacity, and spectral efficiency in later technologies. However, challenges such as interference management, synchronization, and energy efficiency remain significant concerns.

As global data demand continues to grow, research is shifting toward advanced approaches like Non-Orthogonal Multiple Access (NOMA), Cognitive Radio Access, **and** AI-driven dynamic resource allocation to improve scalability and performance. These emerging methods promise to enhance connectivity for billions of devices in the **5G and 6G** eras, supporting applications in IoT, smart cities, and autonomous systems. Ultimately, the evolution of multiple access techniques represents the ongoing pursuit of more intelligent, efficient, and sustainable communication frameworks that bridge digital divides and drive socio-economic progress worldwide.

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REFERENCES

- Sharma, S. K., Patwary, M., & Chatzinotas, S. (2020). *Multiple Access Techniques for Next Generation Wireless: Recent Advances and Future Perspectives*. EAI Endorsed Transactions on Wireless Spectrum. Available at: https://eprints.staffs.ac.uk/2477/1/EAIjournal_authorversion.pdf eprints.staffs.ac.uk
- Liu, Y., Zhang, S., Mu, X., Ding, Z., Schober, R., Al-Dhahir, N., Hossain, E., & Shen, X. (2022). *Evolution of NOMA Toward Next Generation Multiple Access (NGMA) for 6G*. IEEE Journal on Selected Areas in Communications, 40(4), 1037-1060. Available at: <https://uwaterloo.ca/scholar/sites/ca.scholar/files/sshen/files/liu2022evolution.pdf> [University of Waterloo](https://uwaterloo.ca/scholar/sites/ca.scholar/files/sshen/files/liu2022evolution.pdf)
- Mohsan, S. A. H., & Li, Y. (2023). *A Survey of NOMA: State of the Art, Key Techniques, Open Challenges, Security Issues and Future Trends*. arXiv. Available at: <https://arxiv.org/abs/2306.06664> [arXiv](https://arxiv.org/abs/2306.06664)

- Article: *Fundamentals of Communications Access Technologies: FDMA, TDMA, CDMA, OFDMA, and SDMA*. Electronic Design. (2015). Available at: <https://www.electronicdesign.com/technologies/communications/article/21802209/electronic-design-fundamentals-of-communications-access-technologies-fdma-tdma-cdma-ofdma-and-sdma> [Electronic Design](#)
- Nair, A., Gupta, G., & Srinivas, K. (2018). *Review on Multiple Access Techniques Used in Mobile Telecommunication Generations*. International Research Journal of Engineering and Technology (IRJET), 5(10). Available at: <https://www.irjet.net/archives/V5/i10/IRJET-V5I1066.pdf> [IRJET](#)
- “Multiple Access – FDMA/TDMA/CDMA/OFDMA” topic overview. ScienceDirect Topics. Available at: <https://www.sciencedirect.com/topics/physics-and-astronomy/multiple-access>
- “Multiple Access Techniques for Wireless Communication” (PDF) — review of FDMA, TDMA, CDMA, SDMA etc. bcebhagalpur.ac.in
<https://www.bcebhagalpur.ac.in/wp-content/uploads/2020/03/Multiple-Access-Techniques.pdf>
- “Next Generation Multiple Access for 6G” — call for papers / overview of NGMA (next-generation multiple access) in 6G networks. comsoc.org
<https://www.comsoc.org/publications/magazines/ieee-network/cfp/next-generation-multiple-access-6g>
- “Future Directions in Multiple Access for 6G: Emerging...” (Wiley article June 2025) — emerging MA schemes and performance assessment. [Wiley Online Library](#)
<https://onlinelibrary.wiley.com/doi/10.1002/itl2.70067>
- “A Survey of NOMA: State of the Art, Key Techniques, Open Challenges, Security Issues and Future Trends” (arXiv) — detailed survey of non-orthogonal multiple access. [arXivhttps://arxiv.org/abs/2306.06664](https://arxiv.org/abs/2306.06664)