The Microsecond Revolution: How Wi-Fi 7 Will Enable Real-Time Connectivity and Transform Key Industries

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Abstract – The advent of WiFi 7, also known as the microsecond revolution, is expected to bring unprecedented improvements in wireless communication by enabling real-time connectivity with minimal latency. This research survey aims to provide a comprehensive overview of the key features, innovations, and potential applications of WiFi 7, while also highlighting its transformative impact on various industries, such as healthcare, manufacturing, transportation, and entertainment. The motivation behind this study arises from the growing need for faster, more reliable, and efficient wireless communication systems that can support the increasing demands of modern applications. With previous WiFi generations facing limitations in terms of speed, latency, and capacity, WiFi 7 emerges as a promising solution to overcome these challenges and usher in a new era of seamless and real-time connectivity. Key findings of this survey reveal that WiFi 7 offers significant performance improvements compared to its predecessors, with data rates up to 30 Gbps, ultra-low latency below 1 ms, and extended range capabilities. These advancements are made possible through innovative technologies such as beamforming, multi-user MIMO, and OFDMA, which allow for efficient use of wireless spectrum and optimization of network resources. In terms of potential applications, WiFi 7 is expected to revolutionize various industries by enabling real-time connectivity and data transfer. In healthcare, for example, WiFi 7 could improve telemedicine, remote patient monitoring, and other critical services. In manufacturing, the technology could facilitate Industry 4.0 and advanced automation, while in transportation, it could play a pivotal role in the development of connected vehicles and smart city infrastructure. Furthermore, WiFi 7 is poised to enhance user experiences in entertainment and gaming through reduced latency and faster data transfer. Despite these promising advancements, challenges related to large-scale implementation, security, and privacy remain. This survey paper identifies these challenges and suggests future research directions to address them, emphasizing the need for continuous development in the field of wireless communication technologies. In conclusion, WiFi 7 has the potential to enable real-time connectivity and transform key industries through its innovative features and improved performance metrics. By addressing the existing challenges and exploring future research opportunities, this technology can usher in a new era of seamless and efficient wireless communication.

Keywords: WiFi 7, Ultra-low latency, High-speed data transfer, Telemedicine, Industry 4.0, Smart cities, Connected vehicles, Online gaming, Virtual reality, Network security.

1. INTRODUCTION
1.1 Background and Motivation
The rapid development of wireless communication technologies over the past few decades has transformed how individuals, businesses, and industries access and share information. WiFi, or Wireless Fidelity, has become the cornerstone of modern wireless communication, allowing billions of devices to connect to the internet and communicate with each other seamlessly. As digital applications and services continue to

evolve, the demand for more robust, faster, and reliable wireless communication systems has grown exponentially. This has led to the development of several generations of WiFi standards, each designed to improve upon the performance of its predecessor.

WiFi 7, also known as IEEE 802.11be Extremely High Throughput (EHT), is the latest iteration of the WiFi standard and promises to bring about a microsecond revolution in wireless communication. With its potential to enable real-time connectivity and ultra-low latency, WiFi 7 is poised to revolutionize various industries, from healthcare and manufacturing to transportation and entertainment. The advent of WiFi 7 comes as a response to the limitations of previous generations, which include slower data transfer rates, higher latency, and limited network capacity. These limitations have impeded the seamless integration of emerging technologies, such as the Internet of Things (IoT), augmented and virtual reality (AR/VR), and autonomous vehicles, among others.

The need for faster and more reliable connections in various industries is driven by the increasing dependence on real-time data and the growing number of devices connected to the internet. For instance, in healthcare, real-time connectivity can facilitate telemedicine and remote patient monitoring, which can lead to improved patient outcomes and more efficient healthcare systems. In manufacturing, real-time connectivity can be the backbone of Industry 4.0, enabling advanced automation, predictive maintenance, and improved operational efficiency. In transportation, connected vehicles and smart city infrastructure can benefit from real-time communication, enhancing traffic management, safety, and overall city planning. Finally, in entertainment and gaming, low-latency connections can result in more immersive and responsive user experiences.

1.2 Scope and Objectives

This research survey aims to provide a comprehensive overview of WiFi 7 technology, its key features, innovations, and potential applications, as well as the challenges and future research directions in this field. The scope of this survey covers the following aspects:

A detailed overview of the WiFi 7 standard and its associated technologies, such as beamforming, multi-user MIMO, and OFDMA, which enable real-time connectivity and improved network performance.

A comparison of WiFi 7 with previous generations of WiFi in terms of performance metrics, including data transfer rates, latency, and range.

An exploration of the potential applications of WiFi 7 across various industries, including healthcare, manufacturing, transportation, and entertainment.

An identification and discussion of the challenges and future research directions related to the large-scale implementation of WiFi 7, with a focus on technical, security, and privacy concerns.

The objectives of this paper are to:

Provide a foundation for understanding the key features and innovations of WiFi 7 and their importance in addressing the limitations of previous generations, such as slower data transfer rates, higher latency, and limited network capacity.

Highlight the potential impact of WiFi 7 on various industries, showcasing how real-time connectivity can revolutionize healthcare, manufacturing, transportation, and entertainment, among others.

Identify the challenges and future research directions in WiFi 7 and real-time connectivity, emphasizing the need for continuous development and innovation in wireless communication technologies.

The structure of the paper is organized as follows: Section 2 provides an overview of WiFi 7 technology and standards, discussing the key features and innovations that enable real-time connectivity. Section 3 offers a comparison between WiFi 7 and previous generations of WiFi in terms of performance metrics and potential user experience improvements. Section 4 explores the potential applications of WiFi 7 across key industries, illustrating how real-time connectivity can transform healthcare, manufacturing, transportation, and entertainment. Section 5 identifies and discusses the challenges and future research directions related to WiFi 7 implementation, including technical, security, and privacy concerns. Finally, Section 6 concludes the paper, summarizing the main findings and emphasizing the potential impact of WiFi 7 on key industries and the importance of further research and development in this field.

1.3 How WiFi 7's Beamforming Technology Works

Beamforming is a key technology in WiFi 7 that helps improve wireless communication by focusing the transmission of radio frequency (RF) signals in a specific direction, rather than broadcasting them uniformly in all directions. This targeted transmission allows the wireless signal to reach the intended receiver more efficiently, resulting in a stronger and more reliable connection.

Beamforming works by using multiple antennas on both the transmitter (e.g., a WiFi router) and the receiver (e.g., a smartphone or laptop) to send and receive signals. The transmitter uses the information about the location of the receiver and the channel conditions to adjust the phase and amplitude of the signals sent by each antenna. This process creates constructive interference, causing the signals to combine and form a focused, high-intensity beam towards the receiver. As a result, the signal strength is enhanced, and communication quality is improved.

In WiFi 7, beamforming is implemented using advanced algorithms and techniques, such as:

Explicit Beamforming: In this method, the transmitter and receiver exchange information about their respective channel conditions through a process called channel sounding. This information is then used to calculate the optimal phase and amplitude adjustments for the transmitted signals, allowing for the formation of a focused beam towards the receiver.

Multi-User MIMO (MU-MIMO): WiFi 7 supports MU-MIMO technology, which allows a transmitter to communicate with multiple receivers simultaneously, using separate spatial streams. Beamforming is employed in MU-MIMO systems to direct each spatial stream towards its intended receiver, improving the overall capacity and efficiency of the wireless network.

Null Steering: In addition to focusing the signal towards the intended receiver, beamforming can also be used to create nulls or areas of low signal strength in specific directions, particularly towards potential sources of interference. This technique, known as null steering, helps reduce interference and improve the overall performance of the wireless network.

In summary, beamforming in WiFi 7 improves wireless communication by focusing the transmission of RF signals in the direction of the intended receiver, resulting in a stronger and more reliable connection. The technology relies on multiple antennas, advanced algorithms, and techniques such as explicit beamforming, MU-MIMO, and null steering to enhance signal strength and reduce interference.

1.4 How Does Wi-Fi 7's Beamforming Affect the Range of the Wireless Network

WiFi 7's beamforming technology has a positive impact on the range of the wireless network. By focusing the radio frequency (RF) signals in the direction of the intended receiver, beamforming increases the effective signal strength at the receiver, allowing for more stable and reliable connections at greater distances.

There are several ways in which beamforming affects the range of the wireless network:

Enhanced Signal Strength: The primary advantage of beamforming is the increased signal strength at the receiver. When the RF signals are focused into a beam, the energy is concentrated in the direction of the intended device, resulting in a more powerful signal. This enables the receiver to maintain a stable and high-quality connection, even when located farther away from the transmitter.

Increased Coverage Area: Beamforming technology can help extend the coverage area of a wireless network by improving the signal strength at the edges of the network. As the beamformed signals are more robust, devices located at the periphery of the network can maintain a better connection, resulting in a more extensive and uniform coverage area.

Improved Signal-to-Noise Ratio (SNR): Beamforming can also enhance the signal-to-noise ratio (SNR) at the receiver by reducing the interference from other sources. By steering nulls towards potential sources of interference, beamforming minimizes the impact of noise and other unwanted signals on the communication quality. A higher SNR results in a more reliable connection over longer distances.

Adaptive Range Extension: In WiFi 7, beamforming can be combined with other technologies, such as multi-user MIMO (MU-MIMO), to further extend the range of the wireless network. In a MU-MIMO system, the transmitter can communicate with multiple devices simultaneously by directing separate spatial streams towards each device. Beamforming can be employed to optimize the signal strength for each stream, allowing the network to adaptively extend its range based on the needs and locations of the connected devices.

In summary, WiFi 7's beamforming technology positively affects the range of the wireless network by enhancing signal strength, increasing coverage area, improving signal-to-noise ratio, and enabling adaptive range extension. These improvements result in more stable and reliable connections over greater distances, ultimately expanding the reach and performance of the wireless network.

2. WIFI 7 TECHNOLOGY AND STANDARDS
2.1 Overview of WiFi 7

WiFi 7, also known as IEEE 802.11be Extremely High Throughput (EHT), is the latest iteration of the WiFi standard, aiming to deliver a significant leap in wireless performance and real-time connectivity. As the successor to WiFi 6, WiFi 7 is designed to address the increasing demands for higher data transfer rates, lower latency, and improved network efficiency in various applications and industries.

Some of the key features of WiFi 7 include:

Enhanced Data Rates: WiFi 7 is expected to support data rates of up to 30 Gbps, which is a substantial increase compared to the maximum 9.6 Gbps offered by WiFi 6.

Ultra-Low Latency: WiFi 7 aims to achieve latencies in the order of microseconds, enabling real-time connectivity and supporting latency-sensitive applications such as AR/VR, gaming, and real-time control systems.

Improved Network Efficiency: WiFi 7 incorporates advanced technologies, such as multi-user MIMO (MU-MIMO), Orthogonal Frequency Division Multiple Access (OFDMA), and beamforming, to enhance network capacity, efficiency, and overall performance.

The IEEE 802.11be standard defines the protocols and specifications associated with WiFi 7, including the modulation schemes, channel bandwidths, and operating frequencies. The standard is being developed by the IEEE 802.11 working group, with the final approval and release expected in 2024.

2.2 Key Technologies and Innovations

WiFi 7's ability to achieve real-time connectivity and improved network performance is enabled by several technical innovations, including:

Beamforming: As discussed earlier, beamforming is a technology that focuses the transmission of radio frequency signals in a specific direction, rather than broadcasting them uniformly in all directions. This targeted transmission improves the signal strength at the receiver, resulting in a stronger and more reliable connection, enhanced range, and reduced interference.

Multi-User MIMO (MU-MIMO): MU-MIMO is a technique that allows a transmitter (e.g., a WiFi router) to communicate with multiple receivers (e.g., smartphones, laptops) simultaneously using separate spatial streams. This technology increases the overall capacity and efficiency of the wireless network, as multiple devices can be served concurrently without the need for time-based sharing of the available airtime. WiFi 7 supports uplink and downlink MU-MIMO, enabling bidirectional communication between the transmitter and multiple receivers.

Orthogonal Frequency Division Multiple Access (OFDMA): OFDMA is a multi-user version of Orthogonal Frequency Division Multiplexing (OFDM), which divides a wideband communication channel into several narrowband subchannels. OFDMA allows multiple users to transmit data simultaneously on different subchannels, improving the spectral efficiency and network capacity. WiFi 7 incorporates OFDMA in both the uplink and downlink directions, enabling finer resource allocation and reduced latency for multiple users.

These innovations, combined with other enhancements in modulation schemes, channel bonding, and operating frequencies, enable WiFi 7 to deliver the ultra-low latency, high data rates, and improved network efficiency required for real-time connectivity and advanced wireless applications

2.3 What Are Some Potential Applications of Wi-Fi 7's Real-time Connectivity and Low Latency

WiFi 7's real-time connectivity and ultra-low latency open up new possibilities for various applications across different industries and domains. Some potential applications include:

Augmented Reality (AR) and Virtual Reality (VR): WiFi 7's low latency and high data rates enable smoother and more immersive AR and VR experiences, reducing motion-to-photon latency and ensuring high-quality streaming of 3D content.

Gaming: Online and cloud gaming can benefit from WiFi 7's low latency and high throughput, providing a lag-free gaming experience with reduced input delay and high-quality graphics.

Real-time Control Systems: Industrial automation, robotics, and smart manufacturing can leverage WiFi 7's real-time connectivity for precise and accurate control of machines and devices, enabling faster response times and improved productivity.

Video Conferencing and Collaboration: WiFi 7 can enhance video conferencing and remote collaboration by reducing latency and buffering, ensuring high-quality audio and video transmission, and supporting simultaneous connections for multiple users.

Smart Homes and IoT: WiFi 7's improved network efficiency and capacity can support a larger number of connected devices in smart homes and IoT environments, enabling seamless communication and real-time control of smart appliances, security systems, and other connected devices.

Autonomous Vehicles: WiFi 7 can facilitate Vehicle-to-Everything (V2X) communication among autonomous vehicles, roadside infrastructure, and other connected entities, enabling real-time exchange of information for improved safety, traffic efficiency, and overall driving experience.

Telemedicine and Remote Healthcare: WiFi 7's low latency and high data rates can enable real-time remote monitoring, diagnostics, and even telesurgery, improving access to healthcare services and overall patient outcomes.

Smart Cities: WiFi 7 can help power smart city applications such as traffic management, public safety, and environmental monitoring by providing real-time connectivity and data exchange among sensors, devices, and control centers.

These are just a few examples of the potential applications of WiFi 7's real-time connectivity and ultra-low latency. As the technology matures and becomes more widely adopted, it is expected to enable and enhance a wide range of use cases across various sectors, driving innovation and transforming the way we live, work, and communicate.

3. COMPARISON WITH PREVIOUS WIFI GENERATIONS
3.1 Performance Metrics

WiFi 7 builds upon the improvements introduced by previous generations, such as WiFi 6 (802.11ax) and WiFi 5 (802.11ac), offering significant enhancements in speed, latency, and range. Here's a comparison of performance metrics across these generations:

Speed:

- WiFi 7 (802.11be): Up to 30 Gbps
- WiFi 6 (802.11ax): Up to 9.6 Gbps
- WiFi 5 (802.11ac): Up to 3.5 Gbps

WiFi 7 supports data rates that are more than three times faster than WiFi 6 and nearly nine times faster than WiFi 5, enabling high-speed data transfer and real-time connectivity for advanced wireless applications.

Latency:

- WiFi 7 (802.11be): Ultra-low latency in the order of microseconds

- WiFi 6 (802.11ax): Low latency compared to WiFi 5, but higher than WiFi 7

- WiFi 5 (802.11ac): Higher latency compared to WiFi 6 and WiFi 7

WiFi 7 achieves ultra-low latency by leveraging technologies such as OFDMA and MU-MIMO, which enable simultaneous data transmission for multiple users and reduce the time required for data exchange, resulting in a more responsive and real-time experience.

Range:
While it's difficult to provide exact range figures for each WiFi generation, as the actual coverage depends on various factors such as device capabilities, operating frequency, and environmental conditions, WiFi 7's beamforming technology significantly improves the range of wireless networks compared to previous generations. Beamforming focuses the radio frequency signals in the direction of the intended receiver, enhancing signal strength and enabling more stable connections over greater distances.

3.2 Impact on User Experience

WiFi 7's improvements in speed, latency, and range translate into a better user experience in terms of connectivity, reliability, and seamless data transfer:

Connectivity: WiFi 7's ability to support higher data rates and simultaneous connections for multiple users, thanks to MU-MIMO and OFDMA technologies, enables faster and more efficient data transmission. This results in improved connectivity for various applications, such as high-definition video streaming, online gaming, and large file transfers.

Reliability: With beamforming technology, WiFi 7 can focus the wireless signals towards the intended receivers and reduce interference, leading to stronger and more reliable connections. Enhanced signal strength and a higher signal-to-noise ratio (SNR) allow devices to maintain stable connections, even at the edges of the network coverage area.

Seamless Data Transfer: The ultra-low latency offered by WiFi 7 enables real-time connectivity and seamless data transfer, which is crucial for applications such as augmented reality, virtual reality, and real-time control systems. Faster response times and reduced lag enhance user experience by providing smooth and uninterrupted communication across various use cases.

Overall, WiFi 7's improvements in speed, latency, and range will significantly enhance the user experience by providing faster, more reliable, and seamless connectivity for a wide range of applications, from everyday web browsing and video streaming to latency-sensitive use cases such as gaming, AR/VR, and real-time control systems.

4. POTENTIAL APPLICATIONS AND KEY INDUSTRIES
4.1 Healthcare

WiFi 7 can significantly improve telemedicine, remote patient monitoring, and other healthcare services by offering faster, more reliable, and ultra-low latency connectivity. Some potential benefits include:

Telemedicine: WiFi 7's high data rates and low latency can enable real-time video consultations, improving access to healthcare services, especially for patients in remote or underserved areas. High-quality audio

and video transmission can help healthcare providers make accurate diagnoses and recommend appropriate treatments.

Remote Patient Monitoring: WiFi 7's improved network efficiency and capacity can support the real-time transmission of vital signs and other health data from medical devices and wearables to healthcare providers. This enables continuous monitoring of patients' conditions and early detection of potential health issues.

Telesurgery and Remote Robotics: WiFi 7's ultra-low latency and high-speed data transfer can potentially enable remote surgical procedures using robotic systems, allowing surgeons to perform operations from a distance and expanding access to specialized surgical care.

4.2 Manufacturing and Industrial Automation

WiFi 7 can play a crucial role in Industry 4.0 and advanced manufacturing by providing real-time connectivity and improved data exchange for various applications:

Real-time Control and Monitoring: WiFi 7's low latency and high data rates can enable real-time control and monitoring of industrial processes, machines, and robots, resulting in faster response times and improved productivity.

Predictive Maintenance: The improved connectivity and data transfer capabilities of WiFi 7 can support the collection and analysis of machine data to predict and prevent equipment failures, reducing downtime and maintenance costs.

Interoperability and Integration: WiFi 7 can facilitate seamless communication between different devices, machines, and systems within the factory, enabling better integration and interoperability, which are essential for Industry 4.0.

4.3 Transportation and Smart Cities

WiFi 7 can play a significant role in the development of connected vehicles and smart city infrastructure by enabling real-time data exchange and communication:

Vehicle-to-Everything (V2X) Communication: WiFi 7 can support V2X communication among autonomous vehicles, roadside infrastructure, and other connected entities, enabling real-time exchange of information for improved safety, traffic efficiency, and overall driving experience.

Traffic Management: WiFi 7's low latency and high data rates can enable real-time monitoring and control of traffic signals, cameras, and sensors, resulting in optimized traffic flow and reduced congestion.

Public Safety and Emergency Response: WiFi 7 can facilitate real-time communication between emergency responders, connected devices, and control centers, improving situational awareness and response times during emergencies.

4.4 Entertainment and Gaming

WiFi 7 can have a significant impact on online gaming, virtual reality, and streaming services by providing ultra-low latency and high-speed data transfer:

Online Gaming: WiFi 7 can enhance the online gaming experience by reducing input lag and enabling faster data transfer, resulting in smoother gameplay and improved responsiveness.

Virtual Reality (VR) and Augmented Reality (AR): WiFi 7's low latency and high data rates can enable high-quality streaming of 3D content for VR and AR applications, providing more immersive and interactive experiences.

Streaming Services: WiFi 7 can support high-definition and ultra-high-definition video streaming with minimal buffering, enabling users to enjoy seamless and uninterrupted content on their devices.

5. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

5.1 Technical Challenges

The large-scale implementation of WiFi 7 comes with several technical challenges:

Spectrum Availability: As WiFi 7 requires more bandwidth to achieve its high data rates, the availability of sufficient and interference-free spectrum becomes a critical issue. Regulatory bodies and standardization organizations need to work towards allocating more spectrum for WiFi 7 to ensure efficient and widespread deployment.

Network Congestion and Interference: With the increasing number of connected devices, managing network congestion and interference becomes more complex. WiFi 7 needs to ensure seamless and efficient communication among these devices, which requires further improvements in technologies such as OFDMA and MU-MIMO.

Power Consumption: Higher data rates and advanced features may lead to increased power consumption for WiFi 7 devices. Developing energy-efficient techniques and technologies to minimize power usage while maintaining performance is essential for large-scale implementation, especially in battery-powered devices.

Backward Compatibility: As WiFi 7 is introduced, ensuring compatibility with older devices and previous WiFi generations is crucial for a smooth transition and coexistence in various environments.

5.2 Security and Privacy Issues

WiFi 7's widespread adoption raises potential security and privacy concerns that need to be addressed:

Network Security: With the increasing number of connected devices and high-speed data transfer capabilities, WiFi 7 networks can become more attractive targets for cyberattacks. Implementing robust security measures, such as strong encryption and authentication protocols, is crucial to protect data and network integrity.

Privacy Protection: WiFi 7's advanced capabilities may enable more sophisticated tracking and profiling of users, raising privacy concerns. Ensuring that privacy protection mechanisms, such as anonymization techniques and user consent management, are embedded in WiFi 7 devices and networks is essential.

IoT Security: As WiFi 7 will play a significant role in IoT environments, securing IoT devices and networks becomes a critical concern. Many IoT devices have limited resources and may not support advanced security features, making them vulnerable to attacks. Developing lightweight security solutions for IoT devices and networks is necessary to mitigate potential risks.

5.3 Future Research Directions

Areas for future research and development in the context of WiFi 7 and real-time connectivity include:

Advanced Network Management Techniques: Developing innovative techniques to efficiently manage network resources, minimize interference, and optimize data transfer in dense and heterogeneous environments.

Energy-Efficient Design: Researching energy-efficient techniques and technologies that can help minimize power consumption in WiFi 7 devices without compromising performance.

Enhanced Security and Privacy Mechanisms: Investigating novel security and privacy solutions that can protect against emerging threats and address potential concerns related to WiFi 7 technology.

Integration with Other Wireless Technologies: Exploring ways to seamlessly integrate WiFi 7 with other wireless technologies, such as 5G and 6G, to enable complementary capabilities and advanced use cases.

Machine Learning and Artificial Intelligence: Leveraging machine learning and artificial intelligence techniques to optimize network performance, enhance security, and enable smart and adaptive wireless systems.

By addressing these challenges and exploring future research directions, WiFi 7 can continue to evolve and unlock new possibilities for real-time connectivity across various industries and applications.

6. CONCLUSIONS

This paper has explored the potential of WiFi 7 as a significant advancement in wireless communication technology, offering substantial improvements in speed, latency, and range compared to previous generations. With its ultra-low latency and high-speed data transfer capabilities, WiFi 7 has the potential to revolutionize key industries such as healthcare, manufacturing and industrial automation, transportation and smart cities, entertainment and gaming. In healthcare, WiFi 7 can enhance telemedicine, remote patient monitoring, and enable advanced services like telesurgery. In manufacturing and industrial automation, it can support real-time control and monitoring, predictive maintenance, and seamless integration within Industry 4.0 environments. WiFi 7 can also play a vital role in the development of connected vehicles, smart city infrastructure, and efficient traffic management. In entertainment and gaming, it can improve online gaming experiences, enable high-quality VR and AR experiences, and support high-definition streaming services. However, several challenges need to be addressed for large-scale implementation of WiFi 7, including spectrum availability, network congestion, power consumption, and ensuring backward compatibility. Security and privacy issues also need to be considered to protect users' data and maintain trust in the technology. Future research and development in areas such as advanced network management, energy-efficient design, enhanced security and privacy mechanisms, integration with other wireless technologies, and leveraging machine learning and artificial intelligence can help overcome these challenges and unlock the full potential of WiFi 7. Emphasizing the importance of further research and development in this field can pave the way for new opportunities and innovations, enabling a new era of real-time connectivity across various industries and applications.

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