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Investigating the Potential of Wi-Fi-6 (802.11ax) for URLCC

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ABSTRACT

URLLC, Ultra-Reliable and Low-Latency Communications, is the most customer-beneficial 5G feature. These technologies will be used in urgent communication, such as mobility coordination and remote robot control. Many networking protocols now use time synchronization to improve communication efficiency, adaptability, and dependability. Automation systems, real-time healthcare, autonomous driving, and networked arts-based professional film use physical networks. Applications are one of the most amazing and unimaginable capabilities of high-reliable communication. IEEE 802. TSN technology and standards provide strong, reliable, real-time, deterministic communications with low latency and no bottlenecks. IEEE 802. The best and most adaptable Wi-Fi is 11ax. IEEE 802. The 11ax focuses on smooth wireless provision for regular devices, unlike Wi-Fi, which handles data transfer rates. The research focuses on and defends URLLC and Wi-Fi 6 parts where IEEE 802. 11ax can be most effectively incorporated. Then, the communication channel's effectiveness and relevance for future hardware use are assessed (IEEE 802). Wi-Fi 6 and 802. 11ac, its predecessor, complete the next dimension. This aim shows the growing importance of communication-based technologies in the information system. We try to make the system more helpful, effective, and fast. This research aims to determine if modern models' emergent technologies fill a big and stable gap. The report clearly reveals that funds were wisely spent and capital was used efficiently, demonstrating the wisdom of these measures.

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Introduction

Fundamentally distinctive from its preceding versions of mobile wireless systems, it is recognized now that 5G inherently supports massive MTC (mMTC) and Ultra-Reliable Low-Latency Communication (URLLC). These are two generic modes of Machine-Type Communications (MTC). URLLC, with little space of any conflicts is the most revolutionary feature introduced by 5G, as it will be implemented in mission-critical communications, such as vehicle coordination or dependable remote action with robotics [1].

To make this application model more effective, future-ready and unfaltering, time-sensitive communication (TSN) is serving as characteristic of numerous communication networks, including those utilized in systems for manufacturing automation, real-time healthcare applications, autonomous driving, and Internet-based professional audio/video execution [2]. The utilization of ultrareliable communication has the potential to facilitate an extensive array of applications, some of which remain undisclosed at this time.

As for example, the integration of embedded processing and wireless connectivity has brought about substantial changes to numerous products by surpassing conventional product boundaries and augmenting functionality. For instance, a product remains linked to its manufacturer for maintenance and updates throughout its lifetime. Extending wired TSN networks to the wireless domain could lead to reconfigurable and adaptive communication systems, lower installation and maintenance costs, and support for future use cases like mobile devices.

A wireless technology is "wireless TSN" if it can support network QoS configuration through integration with wired technology (like Ethernet) or on its own and provide TSN-level reliability, deterministic communication (limited latency), and time synchronization. The next generation of industrial wireless communications may be enabled by 3GPP's 5G cellular system and IEEE 802.11 (called "802.11ax" in the article), which enable wireless TSN capabilities [3].

IEEE 802.1 TSN technologies and standards provide reliable, low-latency, real-time deterministic communications. Most TSN implementations use Ethernet, despite the goal of agnosticism toward the physical and data link layers. Time-sensitive networking, worth USD 0.2 billion in 2023, is expected to grow 58.3% to USD 1.7 billion by 2028. IEEE 802.11ax is the fastest and most versatile Wi-Fi standard. IEEE 802.11ax optimizes the wireless ecosystem for everyday devices, unlike previous Wi-Fi versions, which focused on data rates. IEEE 802.11ax, built for capacity, is six times quicker than IEEE 802.11ac. Additionally, it supports more of the 23 billion Wi-Fi-connected devices and their users [4].

This paper aims to analyze and justify the areas where URLLC can be most effectively integrated with Wi-Fi 6 (IEEE 802.11ax). Subsequently, a comparison of the communication channel's potency and worth with respect to the future version (IEEE 802.11be (Wi-Fi 7)) and previous version (IEEE 802.11ac) are done. So is done keeping in mind the growth of communication-based technology and according to importance of rapid and fast upgrade in systems.

Fundamentally, this study tries to determine if the market demand and capacity that these developing technologies and models are aiming for are in the proper balance. The study so confirms the utilization of funds and investments that these models are truly valuable.

Related Works

Reviews of the most recent academic works conceived and developed in the fields that are expected to be inspiring and creative for this study make up this section. The topics covered are new networking technologies, 5G market capacity and demands, its future and prospects, developments in modern Wi-Fi technology, and other relevant and informative publications. The review reveals the present research deficit. Thus, the solutions found in the previous research are included into the conceptualization of the current work.

Siddiqui et al. accepted that it is advisable to understand and mitigate different kinds of interference associated with each URLLC technology, deployment scenario, and wireless transmission mode [5]. Here, the authors examined a number of modern designs, frameworks, access modes, and enabling technologies for B5G and sixth-generation (6G) communication networks. The study contains cutting-edge research, a study of interference challenges, and proposals for future communication networks and technologies, namely 6G URLLC.

Siddiqi et al. presented their analysis attempting to locate the future technical and industry demands in mind and aiming to highlight the significance of URLLC [6]. The study discusses some of the difficulties in implementing URLLC. At the same time, the study discusses on issues with IoT devices that depend on URLLC's reliable connections and low latency.

Artetxe et al. pointed that even for time-critical activities, such as in closed-loop control systems with sluggish dynamic processes, it's currently that the models are getting scope of use [7]. Nevertheless, with the availability of multiple pertinent technologies, wireless technologies have been undergoing rapid evolution in recent years. Because of this, picking the optimal option could get challenging.

Ohta et al. anticipated that ultra-reliable and low latency communications (URLLC) is one of the primary innovations that NR supports [8]. The study mentioned Internet of Things (IoT), such as workplace automation, is a common way that URLLC is used. Three communication network technology frameworks are put forward in this study. It has been identified that architectures with the recently added "bearer aggregation" handle URLLC better. One unanswered query is talked about, and it is shown that the writers' improved WLAN system might be able to answer the inquiry.

Yeow You examined the latest 5G and 6G Internet of Things protocols, standards, apps, and access networks [9]. Based on selection of correct technology and communication channel, this study examines aerial radio access architectures and infrastructure. This poll aims to educate people on 5G IoT's technical state and 6G IoT's key goals and milestones.

As per Deloitte's 2021 Report, the survey has identified that in spite of much commercial importance given on 5G in the media and ads, among 437 networking executives from nine different countries revealed that 45 percent of organizations are either testing or implementing 5G for their advanced wireless initiatives. This indicates that Wi-Fi 6 plays a significant role in enterprise wireless networks [10].

Erez et al. provided a detailed summary of the new 802.11be amendment's expected features and improvements, its main goals and implementation timeframes, and wireless technology coexistence [11]. We also provide simulated results to assess 802.11be's potential throughput gains over 802.11ax.

Sinha & Mishra stated that 21st century saw multiple digital technology revolutions [12]. As a new internet standard, widespread and meaningful connectivity is needed worldwide. High-speed internet is essential for Work from Home (WfH), e-learning, healthcare, and UHD video consumption. Wi-Fi provides high-speed connectivity for various services.

The aforestated reviews make it clear that although communication technologies are growing to give rise to 6G, ultra-reliable and low latency communications (URLLC) study, the chief technology on mission-critical communications needs development and more attention in interference detection and load reduction. Based on the diverse deployment circumstances and wireless transmission the current state of communication frameworks and their network systems are found still evolving to meet the real demand. Despite URLLC's importance for IoT devices, little study has been done on its application. Fixing these issues and developing real-world URLLC deployment tactics requires more research.

Problem Statement and Study Motivation

"Mission Critical Communications" refers to the kinds of communication systems that are used in real time during emergencies, like, disruptions, when public contact is interrupted or suddenly cut off. URLLC is a new way of communicating over wireless flexible networking condition (5G, commonly used in most cases) that is intended to make sure the network is very reliable, with very few lost packets, very low latency, and multiple links for control that is important for the mission. Furthermore, as technology improves and users' needs grow, current Mission Critical technologies become less useful and standard broadband services become unavailable. In this case, fast, flexible, and compatible WiFi networking is becoming a new way to solve the problem and thus need proper evaluation with 5G networking features. Hence, this study is conceptualized to analyse and justify the compatibility of WiFi 6 (IEEE 802.11ax) networking with mission critical communication system and their future.

Conceptualization, Methods and Tools

Typical of cutting-edge technology in industrial settings are Ethernet and customised protocols. Nevertheless, with wired communication networking systems it is hard or sometimes impossible to achieve the required networking configuration, especially in dynamic or mobile automated systems. As previously said, wireless technologies are emerging as a suitable replacement for dynamic mission-critical communication networks.

The next generation of Wi-Fi will help meet 5G performance requirements in public, residential, and enterprise settings while reducing 5G installation costs. Three IMT-2020 criteria set international 5G cellular technology benchmarks. Ultra Reliable and Low Latency Connections, eMBB, and mMTC.

Based on the results of the studies done by Schneider et al. and Broadcom, we think it's a good idea to look at the benefits and downsides of WiFi 6 (802.11ax) merging with 5G in more detail, taking into account the following [4,13].

Strengths of WiFi

- Reduced latency in Light Network Conditions: In the absence of network congestion, WiFi 6 showed lower latency (10-20 ms) than 5G (25-35 ms), indicating quicker reaction times.

- As WiFi has spread to homes and companies, a lot of people who know how useful it is have started using it. People in the industry work together to quickly change WiFi standards to meet new needs.

- Software-defined wireless networks could make WiFi more reliable and sturdy, which would make it good for many industries.

Weakness of Wifi

- Sensitivity to Latency: WiFi 6 may have lower latency than 5G, but the high density of network devices may make it more sensitive to delay, which could affect real-time apps.
- With varying protocol versions, packet sizes, network loads, test durations, and packet speeds, the research contrasted WiFi 6 (IEEE 802.11ax) with 5G.
- WiFi is less scalable than cell phone networks because its performance rests on how many devices are connected to it.
- GPS-based solutions and radio communication methods that don't work well for time synchronization make URLLS less useful indoors and in all environments.
- Problems with WiFi's performance and dependability, such as changes in signal quality and frequency range limits (e.g., 2.4 GHz vs. 5 GHz), need to be carefully looked into, especially with the 6 GHz frequency range of WiFi 6E.

Findings and Discussion

URLLC, the technology that is particularly designed comprised of various use cases, including Ultra Reliable or Low Latency communications, or a mix of both. To accomplish these purpose, among 5G's many notable features, these requirements are given utmost consideration:

1. Massive Multiple Input Multiple Output (mMIMO) technology
2. Boost the usage of tiny cells
3. Employ advanced coding and modulation technique
4. Separate the control and user plane
5. Implement Beamforming
6. Enable full duplex data transfer and many other features.

Improved spectrum efficiency, higher data rates, and more reliability in varying spectral conditions are all aspects of 5G that have been enhanced. Note that edge computing mechanism adopted currently is not new or exclusive to 5G networks. Cellular and Wi-Fi networks are among its multi-access possibilities. Virtualization is included into 5G's design, ensuring stability and 99.9999% automated process success. Its data rate is under 100 Mbps, and its end-to-end latency is under 1–2 ms on the user plane and 10 ms on the control plane.

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Wi-Fi, on the other hand, is effective for many simple workplace applications, but it has problems in congested and demanding industrial settings. Low data throughputs, variable latency, AP handover signal loss, etc. Thus, many companies are establishing 4G LTE private networks with a 5G migration path to overcome Wi-Fi's limitations. However, Wi-Fi 6 (802.11ax) and 6E are projected to behave like 4G LTE (Long-Term Evolution) and 5G NR, making them acceptable for URLLC applications.

To evaluate whether WiFi 6 (IEEE 802.11ax) fits to meet the requirement of URLLC, we present this comparative table. Note that the resources are taken from the research done by Oughton et al. :

Category	Variable	3GPP 5G	WiFi 6 (IEEE 802.11ax)
Technical	Peak data rate	2Gbps (DL), 1Gbps (UL)	10Gbps, 8x8 (DL), 5Gbps (UL)
Technical	MU-MIMO	128x128	8x8
Technical	Coverage range	100–300 m for small cells up to tens of km for macro cells	<50 m indoor, up to 300 m outdoor
Technical	Carrier aggregation interference	Yes	Yes 40, 80, 160 (or, 80 + 80)
Technical	Inter-cell	Controlled	Mainly uncontrolled
Technical	Channel Access Scheme	OFDMA	OFDMA
Spectrum	License type	Mostly licensed	Unlicensed
Spectrum	General bands	Low, mid, and high	Low and mid
Spectrum	Specific frequencies	Low-band (<1 GHz), mid-band (1–7 GHz), high-band (~24–29 GHz)	2.4 GHz, 5 GHz, 6 GHz, 60 GHz
Spectrum	Channel Bandwidth	20, 40, 80, 100 MHz	20, 40, 80, 160 MHz
Business model and cost	User equipment price	High	Low
Business model and cost	Public versus private	Traditionally publicly provided by an MNO	Traditionally privately provided
Business model and cost	Chip/modem cost	High	Low

Table 1: Comparative Features of 5G and WiFi 6 (802.11ax) to Evaluate WiFi 6 Efficacy in URLLC Implementation [14].

From the capacities presented in the above table, we analyze the comparative capacities of WiFi 6 (802.11ax) and 5G for URLLC applications:

Network Architecture and Deployment

- **WiFi 6:** Its current configuration capability makes it ideal for local stable infrastructure with reduced power that may be installed utilizing WLAN (Up to 10 Gbps) in densely populated, usually indoor regions.
- **5G:** Macro cell deployment for the purposes of widespread coverage and micro cells to densify and increase capacity in urban areas and to effortlessly invent handoffs.

Capacity and Spectral Efficiency

WiFi 6: It supports 8x8, MU-MIMO order that improves it peak capacity over cellular network. Cellular network is limited in its capacity on per-user capacity due to its macro cell design.

5G: Enhanced with capacity of wide area support by means of higher order multi user MU-MIMO (128x128) and enable more flexibility to mobile network operator (MNO) with macro cell integration.

Mobility and Handoff

- **WiFi 6:** Useful for the stationary or mobile users. Allows the slow-speed roaming given local access points (AP).
- **5G:** Purpose-built to offer superior flexibility with built-in inter-AP interference prevention and smart handoffs so that consumers could travel throughout zones continuingly.

Experience Quality

- **WiFi 6:** With improved capabilities for enterprise-class QoE with a higher level of performance, low latency, and local installations WiFi 6 (802.11ax) is well tuned to the needs of high-reliability applications, like safety and mission-critical automation.
- **5G:** Cater to the most stringent QoE requirements of industrial IoT, intelligent cities and driverless cars by focusing on wide-area coverage and eavesdropping-proof communications.

Business Models and Cost

- **WiFi 6:** It is useful for boosting little private and local networks indoors with the prevalent of lower prices, unlicensed spectrum availability and off-the-shelf kits.
- **5G:** It aims at trading point in the industrial Internet of Things and vertical markets where it may need mNOs co-operation or own spectrum to provide high QoS applications.

Conclusion and Recommendation

In context whether WiFi 6 (802.11ax) fits with the specificities and necessities of URLLC platform thus benefitting 5G networking purposes, the comparative evaluation mentioned above can be concluded as: Despite its lack of network speed, it has a comparative advantage in cost effectiveness, ease of deployment, and quick access to local high-capacity connectivity, which puts it in various advantageous positions [15].

Nonetheless, 5G that is improving with in terms of area coverage and MIMO to incorporate more of URLLC features, WiFi 6 (802.11ax) as found in the study analysis needs betterment in its availability of broader area coverages, technological strategies and security terms to enhance its capacity in fitting the technology specific needs of URLLC.

In the future, the convergence of WiFi 6, 5G, and other technologies will create significant opportunities for advancements in networking, smart cities, and Internet of Things (IoT) applications. The user did not provide any text. The optimal level of service and quality can be achieved by integrating WiFi 6 and 5G technologies, depending on the application environment and the specific requirements of modern enterprises.

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