5G and Wi-Fi6 radio: options for operational technology

White paper

Wi-Fi is widely used to deliver home and enterprise indoor wireless connectivity because it is low cost and simple to deploy on global unlicensed bands. Most deployments use Wi-Fi5, which is based on IEEE 802.11ac. However, Wi-Fi5 has performance limitations when ultra-reliable low-latency communication (URLLC) services are needed for operational technology (OT) such as industrial control systems. Several other solutions can overcome some of the limitations of Wi-Fi5, including Wi-Fi6 (based on IEEE 802.11ax), 4G Long Term Evolution (LTE) and 5G New Radio (NR). This paper considers the differences between these technologies.

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Executive summary

Wi-Fi will continue to dominate the market for indoor connectivity where there is no requirement for ultra-reliable communication. This includes residential and some industrial applications. Wi-Fi6 brings significant improvements in terms of greater capacity, lower latency and higher reliability when compared to Wi-Fi5, but remaining drawbacks include limited coverage and a lack of mobility. It will continue to benefit from the wide availability of low-cost devices for domestic use. Wi-Fi6 will also be used for industrial applications where medium reliability will suffice and mobility is not needed.

LTE and 5G deployments can benefit industrial applications by delivering wider coverage, increased mobility and more stable latency than Wi-Fi5. This enables new wireless applications beyond the capabilities of Wi-Fi. Private LTE or 5G on a licensed band offer 20 times the coverage area compared to Wi-Fi6, which is important in outdoor situations. But it is the combination of extreme reliability and low latency that promise the biggest benefits. The power of 5G lies in its built in URLLC capability, high radio efficiency and the combination of licensed and unlicensed spectrum.

WiFi6, LTE and licensed band 5G solutions are all available commercially today, while the specifications for a version of 5G on unlicensed bands was completed by 3GPP during 2020.

Table 1 summarizes how the different technologies stack up when benchmarked against one another.

Enterprise users will enjoy the greatest advantages through the co-deployment of Wi-Fi and 5G across different applications. A single network orchestration and automation solution will be needed to enable such blended deployments.

Table 1. Radio technology capabilities for the industrial connectivity

	Wi-Fi		LTE / 5G			
	Wi-Fi5	Wi-Fi6	Private LTE licensed band	5G licensed sub -6 GHz	5G mmWave	5G unlicensed 5 GHz
Coverage	50-100 m	Similar to Wi-Fi5	20x area	20x area	Similar to WiFi	4x area
Guaranteed latency	Load dependent	Partly load dependent	<20 ms	<5 ms	<5 ms	<5 ms
URLLC	-	With proprietary features	Partly	Yes, pre-defined APIs	Yes, pre-defined APIs	Yes, pre-defined APIs
Mobility	No handovers	No handovers	Handover break <20 ms	Handover no break	Handover no break	Handover no break
Device support	Very wide support	Growing support	Wide support	Growing support	Growing support	No devices yet
Device cost	Very low cost	Low cost	Low-medium cost	Medium cost	Medium cost	Medium cost
	Indoor	Indoor	Indoor & outdoor with mobility		Indoor & limited outdoor	
	Low cost IT	Low cost & medium reliability	Medium reliability with evolution to ultra high reliability		Up to ultra high reliability	

Technology overview

Wi-Fi5 has several performance limitations that force enterprises to look for alternatives in the form of Wi-Fi6 or private LTE, and in the future, 5G.

Coverage. Wi-Fi5 is not designed to cover outdoor areas or large indoor areas, mainly because Wi-Fi uses unlicensed 5 GHz at limited power levels. This makes it unsuitable for providing coverage in important areas such as harbors and airports.

Latency variance. Wi-Fi5 can sometimes deliver 2 ms latency, but that can vary by up to several 100 ms owing to packet failure, mobility or interference avoidance. It may not be important to have ultra-low millisecond latency in every application, but it is important in many cases to have precise, predictable latency. Stopping a robot in an emergency is a good example.

Mobility. Connection reliability is lower when users are moving around because Wi-Fi uses device-based mobility and not network-controlled handovers. Mobility may even be an issue when the device itself is stationary but the surrounding environment changes and affects signal propagation.

Efficiency. The overall performance and total network efficiency degrade fast if there is any congestion, because Wi-Fi5 does not have a centralized scheduling solution.
Thankfully, there are several options for providing more reliable radio connectivity and guaranteed low latency for local industrial applications.

Wi-Fi6 is the next version of Wi-Fi based on IEEE 802.11ax. Some of its main improvements over Wi-Fi5 include better data rates and greater efficiency. It is also more scalable for a higher number of Internet of Things (IoT) connected devices, thanks to the use of Orthogonal Frequency Division Multiplexing (OFDM), Multiuser MIMO (MU-MIMO) and wider bandwidth (especially with Wi-Fi6E, which uses the 6 GHz band). The 5 GHz unlicensed band has up to 600 MHz of unlicensed spectrum. An additional 500 MHz of unlicensed spectrum is also available in the 6 GHz band. This new spectrum allows Wi-Fi6 users to benefit fully from the new capabilities, since there are no legacy Wi-Fi5 devices degrading the performance. Improved scheduling and proper over-dimensioning offer low latency with medium reliability of 99.99%. Wi-Fi proprietary enhancements such as packet duplication and scheduling improvements can also improve reliability. Nokia Bell Labs results show that using three independent Wi-Fi links in parallel can provide less than 2 ms latency with five 9s reliability.

Private LTE can provide substantially larger and more reliable coverage than Wi-Fi, which makes LTE an attractive solution for outdoor areas and challenging industrial environments, such as manufacturing sites cluttered with metal structures that can block the signal. LTE can also connect low power consumption narrowband IoT modules.

5G is expected to be the main solution for connecting OT for industrial and other local use cases requiring URLLC. 5G has URLLC capabilities designed in during the specification phase, with industrial partners playing a role in the system definition process. For example, 5G includes Application Programming Interfaces (APIs) for URLLC requests. 5G can also support Time Sensitive Networking (TSN) and Time Sensitive Communication (TSC) features for accurate timing control. In addition, 5G can use a combination of licensed and unlicensed spectrum, whereas Wi-Fi can only use unlicensed spectrum. Licensed spectrum provides a larger coverage area and higher reliability than unlicensed spectrum.

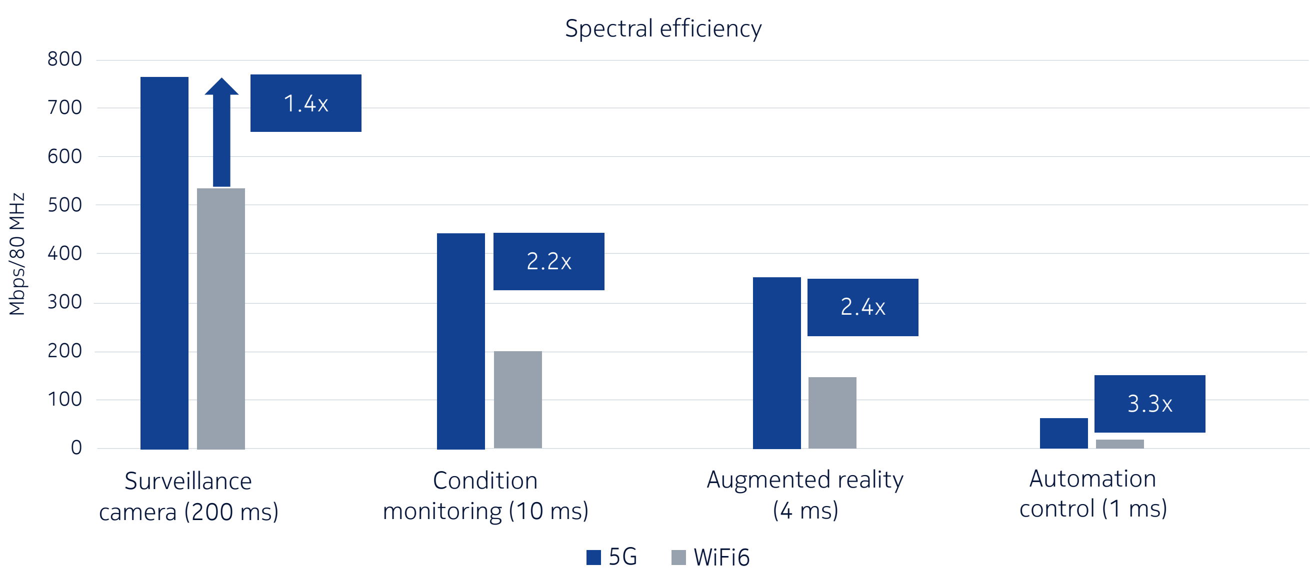
Radio efficiency and latency benchmarking

5G and Wi-Fi6 can provide peak data rates of several Gbps in good signal conditions without interference. The peak rate is mostly defined by the number of antennas and by the available spectrum. 80 MHz of bandwidth and 4x4 MIMO can provide ~1 Gbps peak rate, while the practical data rate is limited by co-channel interference and by the number of simultaneous users.

We have studied the performance of 5G and Wi-Fi6 for industrial use cases. Figure 1 shows the practical spectral efficiency for four different industrial use cases: surveillance camera, condition monitoring, augmented reality and automation control. The use cases have different latency requirements ranging from the delay-tolerant surveillance camera with a 200 ms requirement to highly delay-critical automation control requiring 1 ms latency.

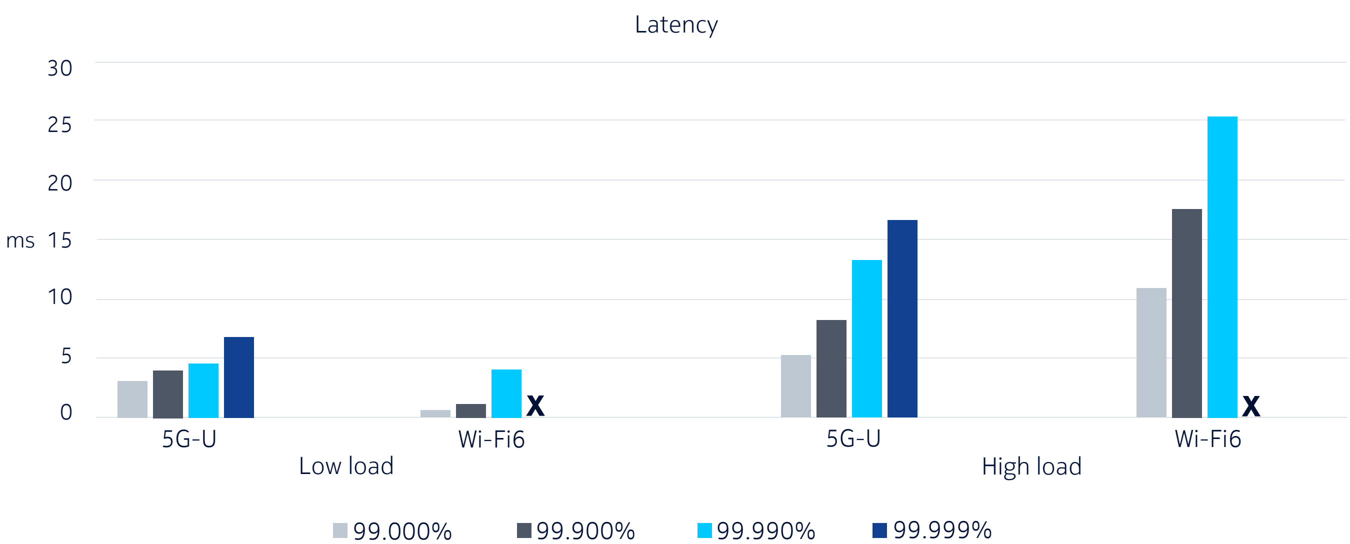
The results indicate that 5G delivers 40% higher efficiency than Wi-Fi6 for the surveillance camera. When the latency requirements get tougher, the efficiency is lower for both 5G and Wi-Fi. If we want to provide 1 ms latency for automation control, 5G is 3.3 times more efficient than Wi-Fi6. Wi-Fi6 can also support low latency services by over-dimensioning the system accordingly, while 5G can provide clearly higher efficiency and reliability. In short: the choice between Wi-Fi6 and 5G will depend on the ratio of latency-critical applications and the required reliability in a private network. Also, Wi-Fi6 can provide low latency with heavy dimensioning.

Figure 1. Spectral efficiency with 5G and Wi-Fi6. Assumptions: 80 MHz, TDD, 4x4MIMO



5G radio is designed for URLLC, with very fast retransmission, handovers and packet scheduling. Figure 2 illustrates 5G and Wi-Fi simulations for latency when using the same unlicensed band. The results show that Wi-Fi provides lower latency than 5G with low loading and with reliability up to 99.99%. Wi-Fi will provide low latency when the portion of latency-critical traffic in the network is low, because unscheduled transmission in Wi-Fi provides low latency if the signal level is high, the interference level is low and there are few concurrent users. However, if the loading is high or if we want higher reliability (99.999%), then 5G provides lower latency.

Figure 2. Comparison of 5G and Wi-Fi6 on unlicensed band. 5G gives lower latency than Wi-Fi6 with high loading and can provide five 9s reliability. Wi-Fi provides only four 9s in this study

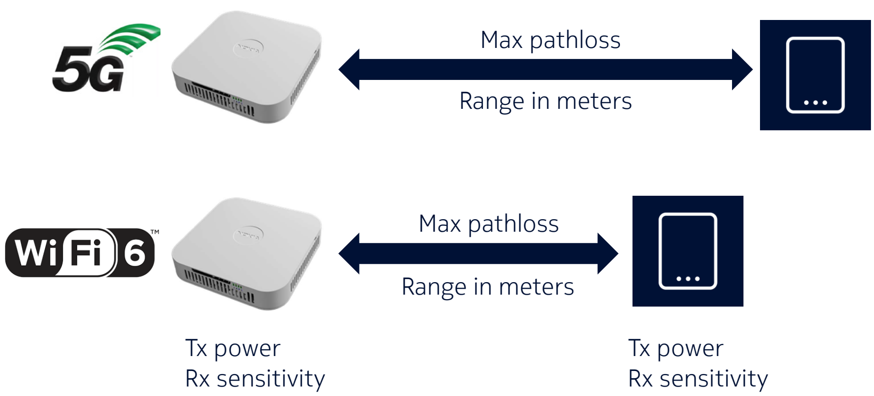


Coverage benchmarking

Coverage is one of the main considerations for any wireless system, but especially for large areas and outdoors. Here we consider the coverage of 5G and Wi-Fi6 technologies on the unlicensed 5 GHz band and compare it to the coverage of 5G on the licensed 3.5 GHz band. Public LTE and 5G networks can use many existing bands. In addition, private LTE and 5G networks can be deployed to cover industrial sites in the licensed local spectrum, including 3.5 GHz and 2.6 GHz bands in some countries.

The maximum pathloss between the device and the access point antenna is defined by the transmission power level and by the receiver sensitivity. These are dependent on the spectrum rules and on the technology capabilities. The pathloss values can be converted into the maximum cell ranges in typical deployment cases using propagation models.

Figure 3. Maximum pathloss and cell range



The link budget illustrates the maximum path loss between the device and the access point antennas. The maximum pathloss in the uplink is shown in Table 2 and the downlink in Table 3. The transmit power of a 5G device is assumed as 26 dBm for the licensed band and 23 dBm for the unlicensed band, while the Wi-Fi6 terminal output power is typically between 15 and 20 dBm. We assume 16 dBm in this case. The 5G access point transmission power is assumed to be 40 dBm for the licensed band and 30 dBm for the unlicensed band both for 5G and for Wi-Fi6. The maximum pathloss for 5G is higher than for Wi-Fi6 because 3GPP provides more advanced radio layer optimization and well-defined RF requirements. The maximum pathloss on the licensed band is higher than on the unlicensed band because of higher transmission power levels.

Table 2. Uplink link pathloss

	5G licensed 3.5 GHz	5G unlicensed 5 GHz	Wi-Fi6 5 GHz
UE transmit power	26 dBm	23 dBm	16 dBm
AP sensitivity	-104 dBm	-102 dBm	-93 dBm
Maximum path loss	130 dB	125 dB	109 dB

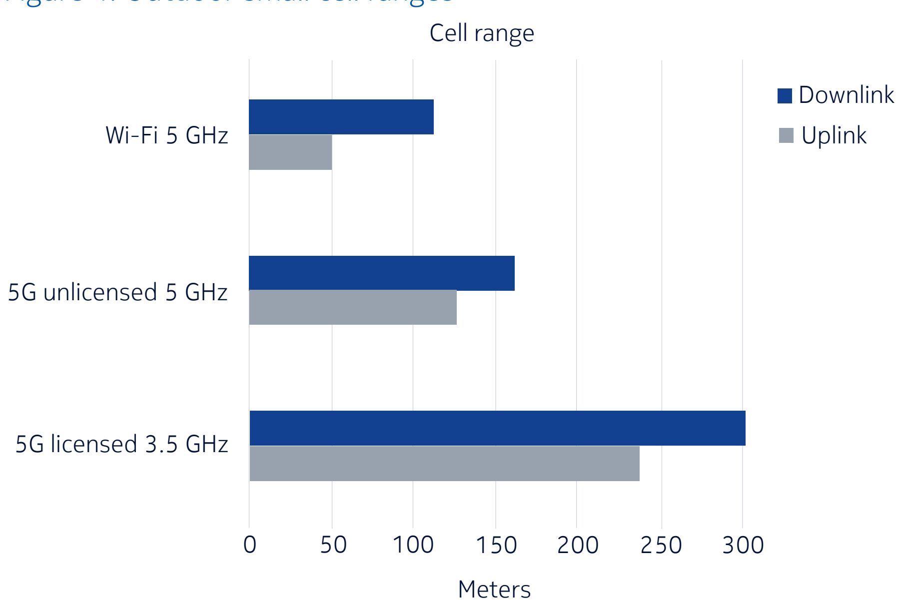
Table 3. Downlink link pathloss

	5G licensed 3.5 GHz	5G unlicensed 5 GHz	Wi-Fi6 5 GHz
AP transmit power	40 dBm	30 dBm	30 dBm
UE sensitivity	-101 dBm	-99 dBm	-93 dBm
Maximum path loss	141 dB	129 dB	123 dB

The resulting typical cell ranges in small outdoor cells are illustrated in Figure 4. Our assumption is that Wi-Fi6 on the 5 GHz band can provide 50 m cell range. The other cell range values are estimated based on the assumption of a path loss exponent of 4.0. We further assume that the unlicensed band at 3.5 GHz has 6 dB lower pathloss compared to the 5 GHz band.

The results show that uplink is clearly the bottleneck in terms of coverage because of low device transmission power. Importantly, the 5G cell range is at least double that of Wi-Fi6 on the unlicensed band and the cell area is four times larger. 5G cell range on the licensed band is between four and five times that of Wi-Fi6, and the cell area is 20 times larger. This benchmarking illustrates why private LTE based solutions have been popular for private networks in outdoor areas. Nokia's private LTE deployments on frequencies between 2.3 and 3.6 GHz confirm the LTE coverage performance. Nokia has also conducted LTE measurements on the unlicensed band at between 5.1 and 5.8 GHz, validating the LTE coverage capability.

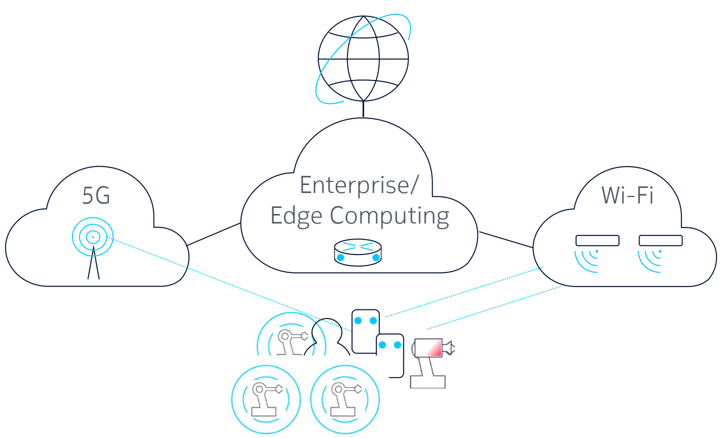
Figure 4. Outdoor small cell ranges



Co-deployment of 5G and Wi-Fi

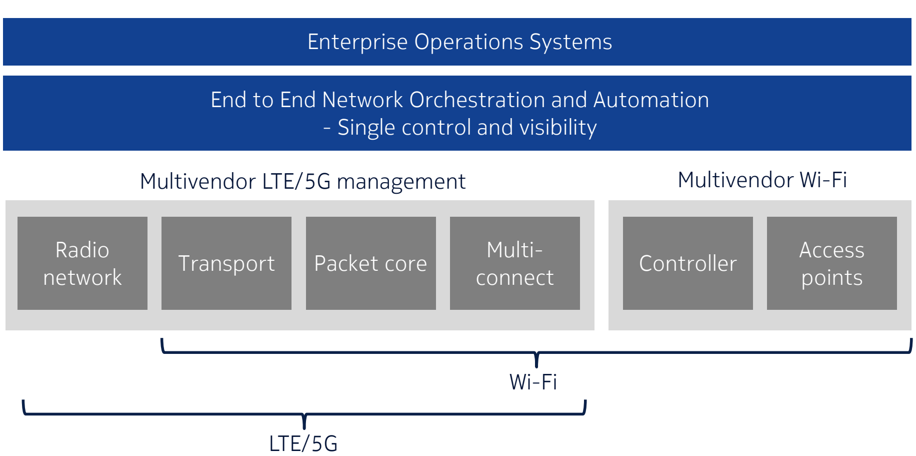
Deployments, particularly in enterprises with incumbent Wi-Fi infrastructure, are likely to present scenarios where both Wi-Fi and 5G access networks are needed to meet diverse requirements on cost, throughput, latency, connection density, coverage, availability and reliability. For instance, Wi-Fi is an attractive and low-cost solution for supporting massive capacity applications, while use cases requiring URLLC and high radio efficiency, 5G access would likely be deployed. 5G can be inserted in a cost-effective, phased way by building on the existing Wi-Fi deployment. To maximize performance and capacity when Wi-Fi and 5G access networks are co-located, multi-connectivity with smart algorithms can optimize the distribution of traffic from multiple devices and different applications across 5G and Wi-Fi networks.

Figure 5. Integrated 5G and Wi-Fi networks



In a co-located Wi-Fi and 5G deployment it is crucial to provide uniform, single access control and visibility of the combined network. End-to-end (e2e) network orchestration and automation across LTE/5G and multi-vendor Wi-Fi provides e2e visibility of faults, status and performance and simplifies operations. Improved reliability, the ability to control the customer experience and enabling e2e slicing orchestration are all differentiating advantages available with network orchestration and automation.

Figure 6. End-to-end orchestration of 5G and Wi-Fi networks



Conclusion

5G is the first radio designed to provide ultra-reliable wireless connectivity for OT use cases. 5G brings benefits in the areas of mobility, reliability, low latency and spectral efficiency. The power of 5G lies in the inbuilt URLLC capability, high radio efficiency and the combination of licensed and unlicensed spectrum. There is a lot of interest in 5G technology from industry, as demonstrated by multiple applications for local 3.5 GHz licenses in Germany. The number of private LTE deployments is growing globally and these have been shown to deliver some of the benefits of 5G in the areas of coverage, stable latency and mobility.

Wi-Fi continues to dominate indoor connectivity where mobility and low latency with extreme reliability are not required, as is the case for information technology and low-cost device connectivity in enterprise and home applications. The power of Wi-Fi is the wide availability of devices at low cost. Wi-Fi6 over the 6 GHz band brings improvements in Wi-Fi performance in the areas of latency and reliability.

As many future enterprise networks will likely see a combination of both approaches, a single network orchestration solution will present an important opportunity for differentiation, thanks to the ability to optimize reliability and customer experience across different applications.

Abbreviations

AP	Access Point
API	Application Programming Interface
IoT	Internet of Things
IT	Information Technology
LTE	Long Term Evolution
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
NR	New Radio = 5G
NR-U	New Radio – Unlicensed
OFDM	Orthogonal Frequency Division Multiplex
OT	Operational Technology
TSC	Time Sensitive Communications
TSN	Time Sensitive Networking
UE	User Equipment
URLLC	Ultra Reliable Low Latency Communication

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