The Future of Smart City Wi-Fi

How Wi-Fi 7 Enhances the Way of

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Smart City Concept

The origin of the smart city concept may be tracked to a time earlier than expected. Since the beginning of the Internet in the 1960s as a project of the Defense Advanced Research Projects Agency, the technological revolution has been growing. Although the beginning looks humble enough, the current on-hand technologies are beyond early expectations.

Because of this revolution, information and communication technologies (ICT) have become more advanced in many ways. These ICT technologies may be adopted into city operations, providing more enhancements.

The smart city concept guarantees, using different types of technologies like IoT, cloud solutions, Industry 4.0, extended reality, and many more technologies to achieve other goals, a better quality of life, sustainability, health care, and in the end better services for citizens.

One of the formal definitions of the smart city is the following: A city "connecting the physical infrastructure, the information-technology infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city" [1].

Smartness, in the technology context, implies automatic computing principles like self-configuration, self-healing, self-protection, and self-optimization.[2]

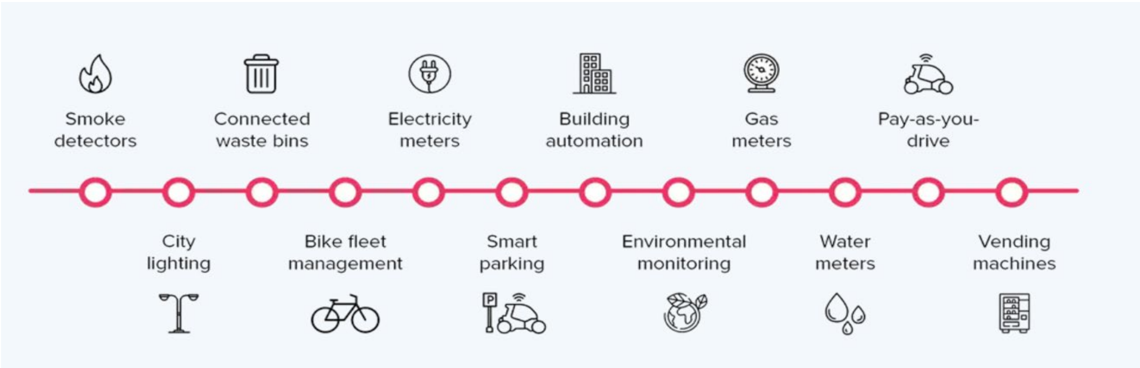


Figure 1 Smart City Connected Devices Example [3]

There are different methods to achieve the smart city concept, like having innovative systems for education, transportation, waste management, government, health, and the buildings themselves.

The core element of the smart city is the urban dwellers; according to the World Health Organization (WHO), 55% of the population lives in urban areas, which means that massive work must be done to involve the civilians in the smart city system. These people are the primary input for building a smart city, as the resulting systems should serve them the way they should.
Sensors play an essential role in creating a smart city, but on the other hand, they will engage with urban dwellers in different aspects. This will produce a massive amount of big data, which needs to be managed to have feedback for the city. This is what makes the city alive and smart.

The simple structure of the smart city can be created by having connected devices like IoT devices and then collecting data which will produce big data to be analyzed. Based on that, there should be systems for citizens to benefit from all these infrastructure sensors and extensive data management.

By 2025 the IoT trends suggest the number of connected devices worldwide will rise to 75 billion. The increasing number of objects that interconnect generates an unprecedented volume of data that the city can analyze locally to make more informed decisions about what changes or new projects will most benefit residents [3].

Smart traffic lights, smart streetlamps, parking lots, and garbage bins are using sensors to achieve more monitoring services throughout the system of a smart city. For example, the excellent management of these sensors can help the truck platoon. We are allowing the trucks to move on all green lights, saving fuel.

Figure 2 Smart City Transportation Concept [4]

One of the most apparent examples is smart transportation; people can feel it's impact once it's implemented in the right way. The rush hour is time killing and consumes fuel, but smart transportation can give a hand to this problem.

According to the US Department of Transportation, "Intelligent Transportation Systems (ITS) apply a variety of technologies to monitor, evaluate, and manage transportation systems to enhance efficiency and safety." Putting visions of science fiction-style transportation aside for the moment, this definition can be simplified into the following concepts for what makes up smart transportation: management, efficiency, and safety. In other words, smart transportation uses new and emerging technologies to make moving around a city more convenient, more cost-effective (for both the city and the individual), and safer.[4]

Wi-Fi 7 will be a leading technology for a smart city to utilize in many different aspects as cutting-edge enhancements power it. The following section introduces the main features of Wi-Fi 7.

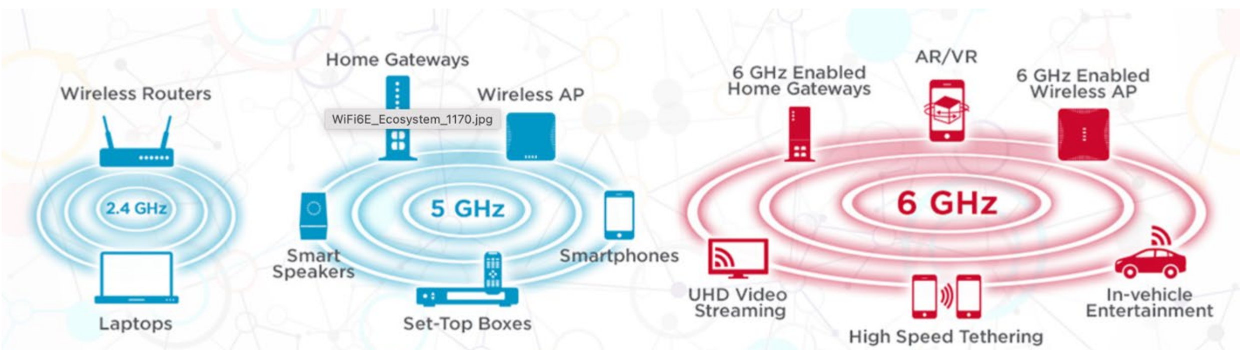


Figure 3 Wi-Fi 7 Uses Cases [5]

The Dawn of Wi-Fi 7

Introduction

It is named with the most reflecting noun for its Extremely High Throughput (EHT) function. Wi-Fi 7 is coming, opening a new level of communication of wireless networks. It is also known as IEEE 802.11be. Unlike Wi-Fi 6 and Wi-Fi 6e, which work only on a 160 MHz bandwidth channel, Wi-Fi 7 offers 320 MHz bandwidth for its channels which opens new opportunities and presents new design challenges. Wi-Fi 7 may utilize three spectrum bands, 2.4 GHz, 5 GHz, and 6 GHz, which was launched with Wi-Fi 6e and 802.11ax.

Although the Wi-Fi generations started with a modest data rate in 1997, then it was able to increase rates over the years up to the offered data rates by Wi-Fi 6e, which is around 10 Gbps. Wi-Fi 7 will provide more than this reaching 40 Gbps, at least, which is four times the 802.11ax standard. This can be achieved by using the new modulation scheme like 4096-QAM (also known as 4K QAM) in addition to other technologies like MAC MLO (Multi-Link Operation) and MRU (Multiple RU).

The following section addresses the new technological enhancements to achieve the new capabilities of the IEEE 802.11be Wi-Fi7 protocol.

Multi-Link Operation

Wi-Fi 7 introduces a new way of utilizing the three bands intelligently increasing the user data rate; this technique is called MLO (Multi-Link Operation). MLO provides channel aggregation for the 2.4 GHz, 5 GHz, and 6 GHz bands. Figure 4 shows the example of MLO for Wi-Fi 7.

Figure 4 MLO for Wi-Fi 7 Example

It creates a bundling or bonding of multiple links (radios) in different bands and channels to work as one virtual link between the connected peers. Each link (radio) can work independently and simultaneously with other links or coordinate for optimal aggregate speeds, latency, range (coverage), or power saving. Wi-Fi 7 MLO is a MAC-layer solution for concurrently using multiple links and is transparent to the higher-layer protocols and services [6].

x 11.5 → x 1.3 → x 4.8

	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6/6E	Wi-Fi 7
Standard	**802.11n**	**802.11ac**	**802.11ax**	**802.11be**
Max Speed with 1 Spatial Stream	150 Mbps	866.7 Mbps	1.2 Gbps	2.9 Gbps
Max Speed with 2 Spatial Streams	300 Mbps	1.73 Gbps	2.5 Gbps	5.8 Gbps
Max Speed with Max # Spatial Streams	600 Mbps	6.92 Gbps	9.6 Gbps	46.4 Gbps

Figure 5 Wi-Fi generational speed evolution [7]

Figure 5 shows the evolution of the Wi-Fi speed starting from Wi-Fi 4 with one spatial stream to Wi-Fi 7 with 16 spatial streams, the maximum number of streams in the standard, which are infrequently implemented, but the potential is there.

Multiple Resource Unit

One of the major technologies used to accommodate the need to serve several users simultaneously is OFDMA (Orthogonal Frequency Division Multiple Access). OFDMA works based on dividing the channel into subcarriers, making it even smaller by dividing subcarriers into resource units (RU). So, an RU is a group of frequencies that can be assigned to different users.

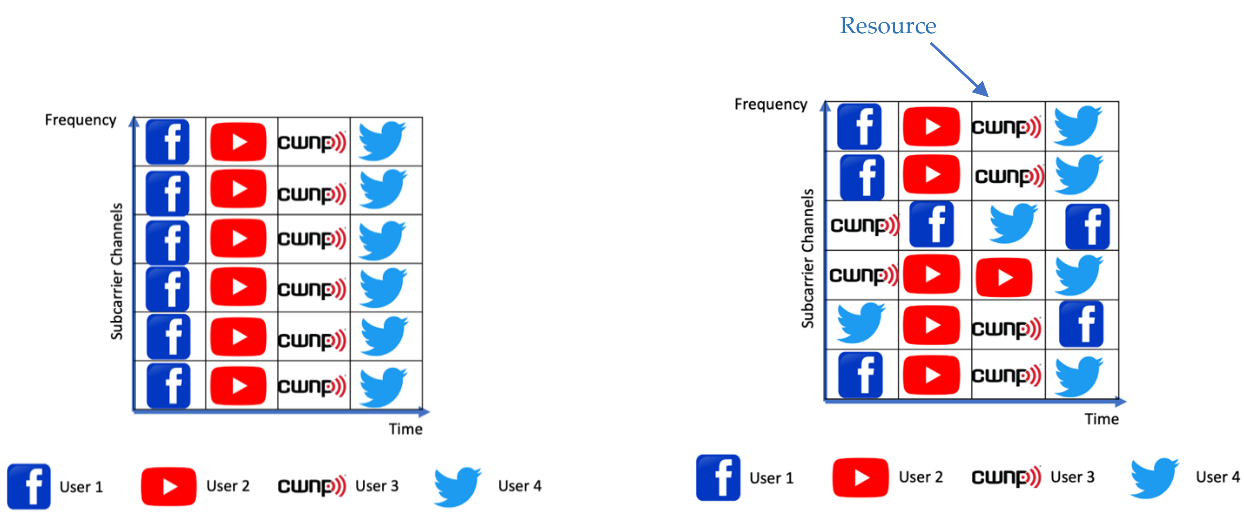


Figure 6 OFDM vs OFDMA

Wi-Fi 7 builds on this foundation with a new MRU (Multiple RU) feature supported in the EHT PHY. An MRU consists of combinations of either 26-, 52-, 106-, 242-, 484-, 996-, 2x996-, or 4x996-tone RU. RUs under 242-tone RU are defined as small size RUs, while those that are equal to or larger than 242-tone RUs are defined as large size RUs, and they can only be combined with other large size RUs to form large size MRUs [8].

The RU tones can be variable based on the number of users. Wi-Fi 7 can accommodate up to 74 users over 160 MHz bandwidth, but with fewer users, they can have better RU tones. Figure 7 shows RU tones versus bandwidth versus the number of users.

4096-QAM

The modulation using 4096-QAM (Quadrature Amplitude Modulation) consists of 12 bits per symbol. This scheme comes with a cost, as the SNR required is around 43 dB to achieve the extremely high throughput. This means that it will only be beneficial in very close proximity of the APs.

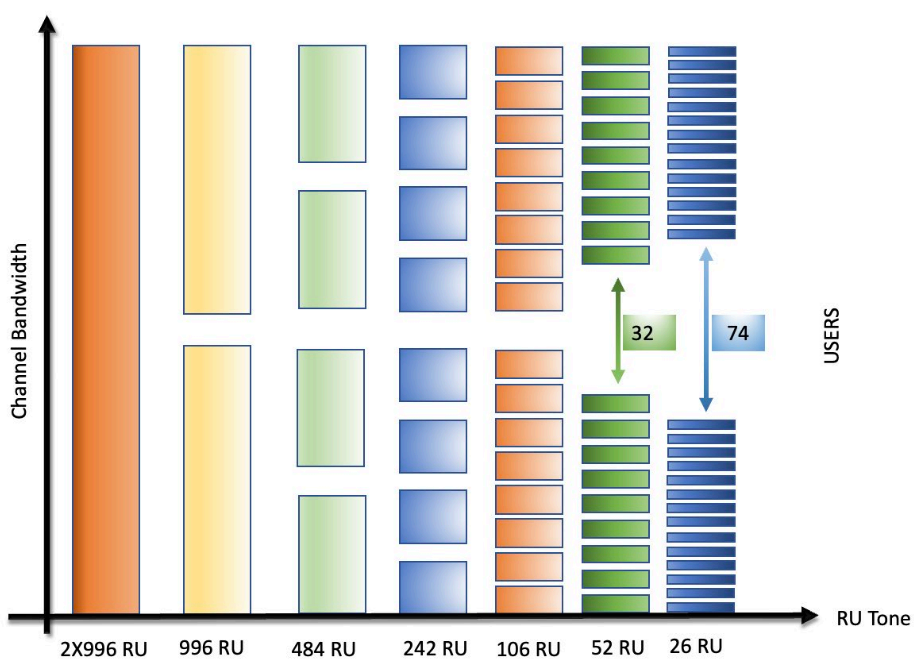


Figure 7 RU tones vs. Bandwidth vs. Number of Users

Wi-Fi 7 Channels

Although there are 11 channels in 2.4 GHz, only three non-overlapping channels can be used. This offers a limited-frequency reuse option. In 5 GHz, there are 25 channels on 20 MHz, while in 6 GHz, channels can reach 59 on 20 MHz.

Channel bonding is blending one or more channels to achieve wider bandwidth; this reflects on the data rate, which increases accordingly. Using these techniques reduces the number of channels in 6 GHz to 3 channels only which implies using it in a specific application greedy to higher data rates or even mission-critical needs. Figure 8 shows the number of channels utilized over each bandwidth.

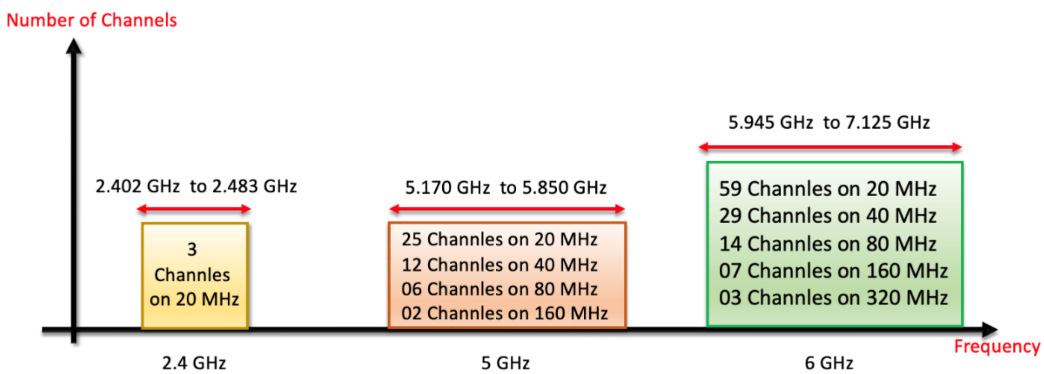


Figure 8 Wi-Fi 7 Channels

Figure 9 shows the generations of Wi-Fi. The number of spatial streams and channel sizes doubled since Wi-Fi 4. On the other hand, the modulation has been doubled eight times.

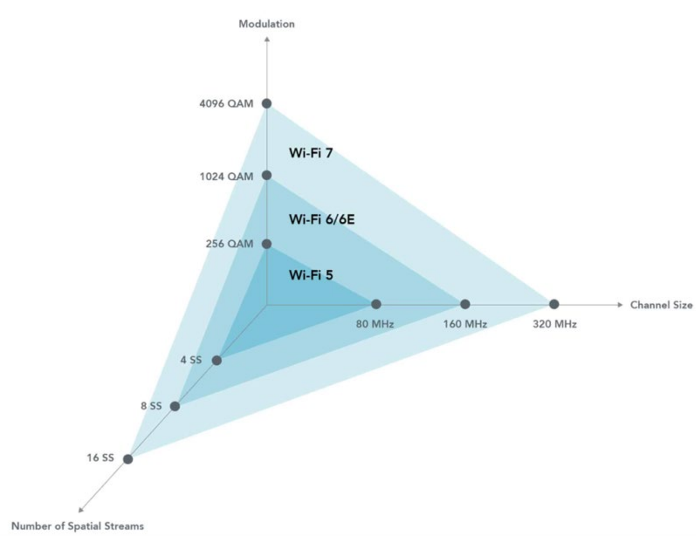


Figure 9 Wi-Fi PHY generational evolution [7]

Smart City Technologies

This section addresses some smart city needs that depend on different technologies like IoT and big data. These types of technologies are crucial for a smart city to develop and Wi-Fi 7 may play a significant role.

IoT: Internet of Things

The concept of the "Internet of things" and the term itself first appeared in a speech by Peter T. Lewis to the Congressional Black Caucus Foundation 15th Annual Legislative Weekend in Washington, D.C, published in September 1985 [9].

IoT is based on devices with different types of sensors; these sensors collect data based on their design and send it to the cloud as big data. The analysis of these data is what makes it valuable. This can be reflected in a better user experience.

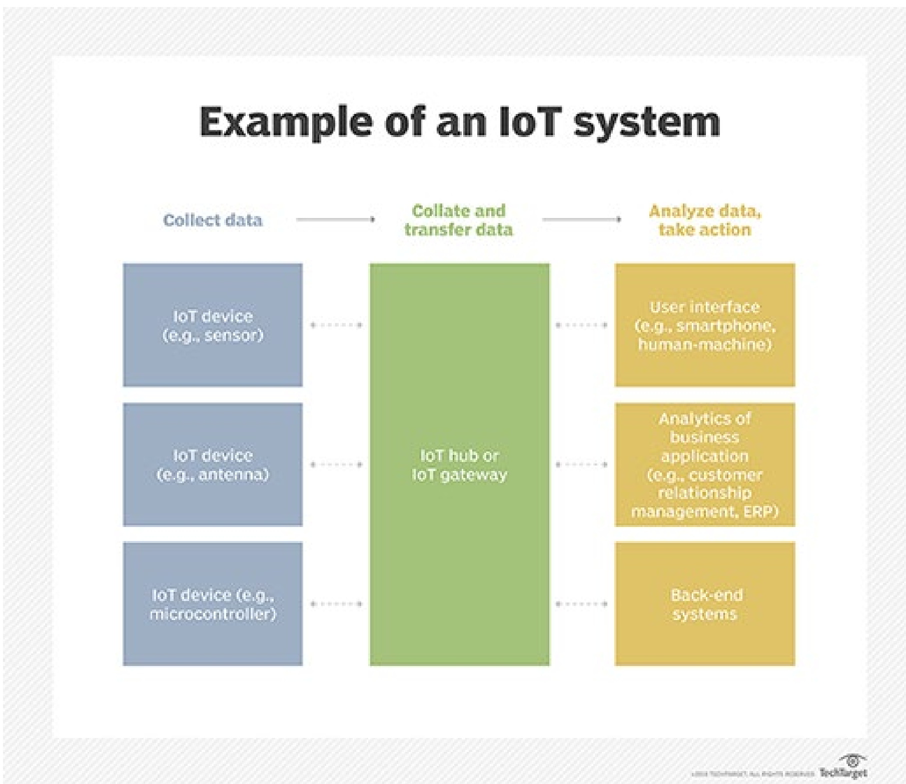


Figure 10 IoT System Example [10]

IoT can be used in car parking lots by implementing sensors in each car parking location. These sensors can connect to the Wi-Fi 7 access point. Multiple sensors can connect to one access point. The parking data will be available on the cloud system. On the other hand, the smart city municipality can offer applications for all city residents to help guide people to free parking slots.

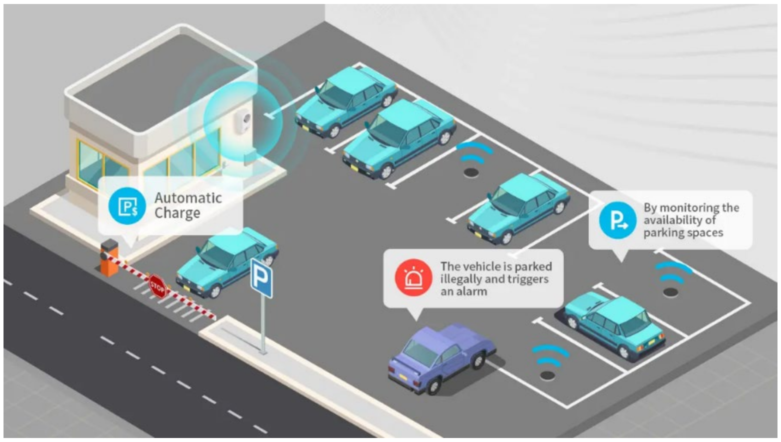


Figure 11 Car Parking IoT Example [11]

Figure 12 shows the enhancement introduced by 802.11be Wi-Fi 7 on the spatial streams. Although 802.11ax Wi-Fi 6 offers eight spatial streams, the vast need for wireless coverage on different applications demands more. This means that one access point ability can accommodate this need.

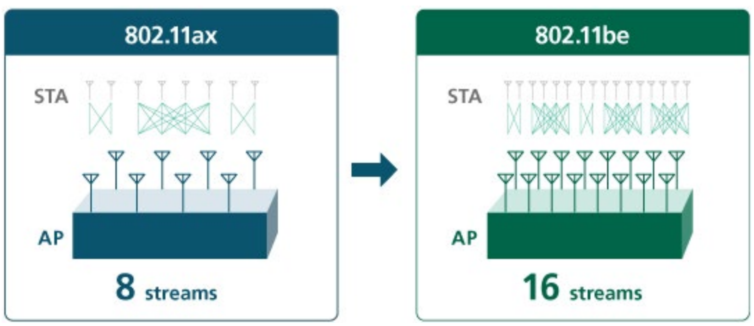


Figure 12 Comparison of IEEE 802.11ax and 11be Max. Spatial Streams [12]

IIoT industry 4.0

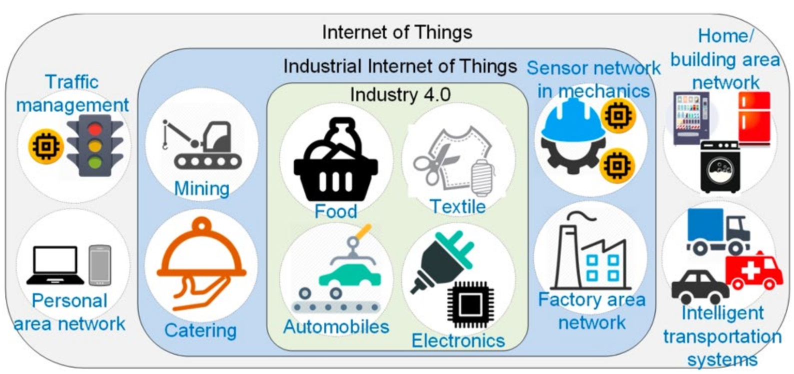


Figure 13 IoT for Industry 4.0 [13]

IIoT and Industry 4.0 are two terms that are often used interchangeably, however, there is a slight difference between them. Industry 4.0 is the term coined in 2011 and is an initiative of the German government. It refers to the fourth generation of the industry - the current one. Industry 4.0 mainly focuses on the manufacturing industry. In other words, Industry 4.0 is the computerization and digitalization of manufacturing. IIoT was first introduced in 2012 by GE as an industrial Internet which entails the adoption of the IoT in the perspective of industry in general (both manufacturing and non-manufacturing)[13].

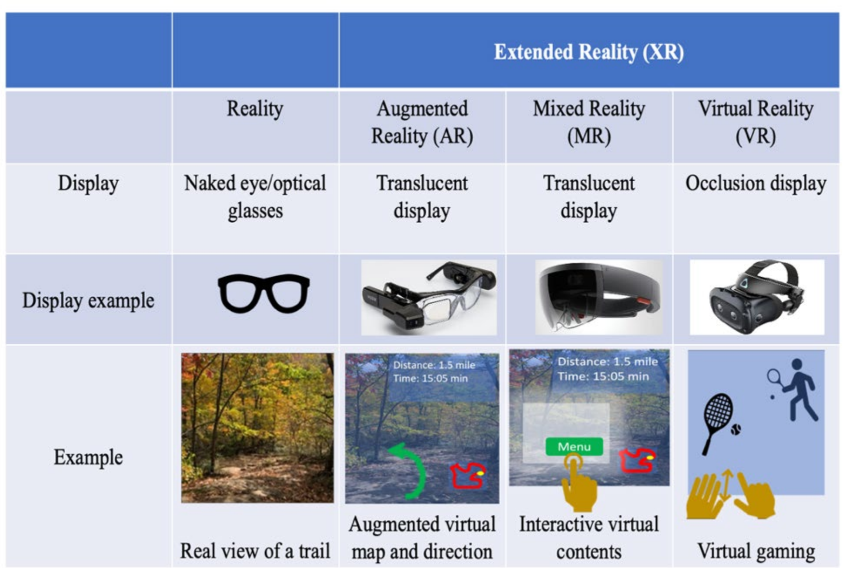
The 16 spatial streams of Wi-Fi 7 play a crucial role in IIoT, where the need is to achieve simulations connection simultaneously with maximum security for the connectivity between machines. Security in Wi-Fi 7 is also the next level, as it offers WAP3 security that fits the need.

XR: Extended reality

Extended reality is a new concept that includes three different technologies. These technologies are VR (Virtual Reality), AR (Augmented Reality), and MR (Mixed Reality).

VR is a totally virtual experience in which the user tests a new virtual world or knowledge, whereas AR is to add more knowledge or information to the real world; on the other hand, MR allows the user to interact with a mix between AR and VR.

These technologies can offer essential use cases in smart cities like distance shopping, where customers can interact with the product before buying it. It is also instrumental in education as students can interact virtually with materials and courses.



		Extended Reality (XR)		
	Reality	Augmented Reality (AR)	Mixed Reality (MR)	Virtual Reality (VR)
Display	Naked eye/optical glasses	Translucent display	Translucent display	Occlusion display
Display example				
Example	Real view of a trail	Augmented virtual map and direction	Interactive virtual contents	Virtual gaming

Figure 14 Extended Reality [14]

One of the essential parameters in XR is 6 DoF (six degrees of freedom) which offers a more immersive experience than 3 DoF. 6 DoF requires more data rates as it displays a massive amount of data and video in all 6 directions based on the user's motion.

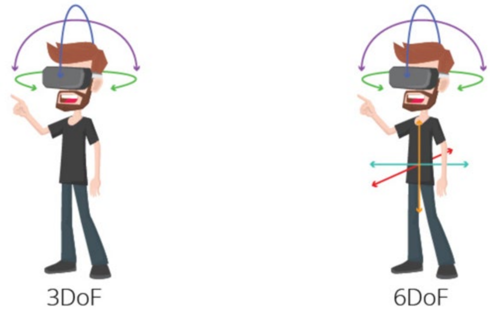


Figure 15 3DoF Vs 6DoF [15]

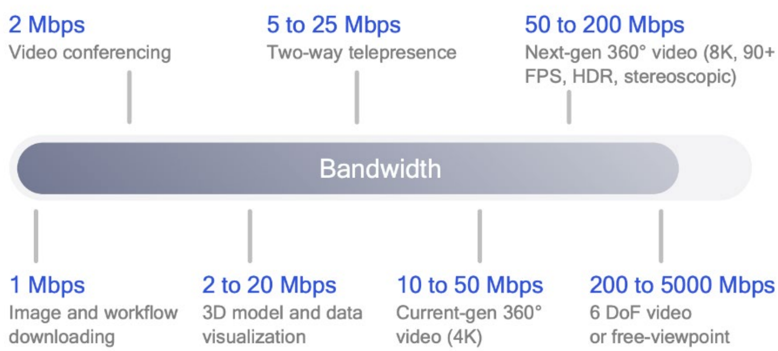


Figure 16 Data Rates of XR [16]

Figure 16 shows the insatiable need for data rate when using 6 DoF in XR at can reach 5000 Mbps for seeking an immersive experience. Wi-Fi 7 can fulfill this need by utilizing earlier stated techniques and the broader bandwidth of 320 MHz. Figure 17 shows the fulfillment of 6 DoF on two spatial streams that provide 5.8 Gbps.

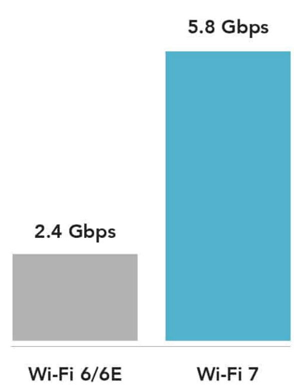


Figure 17 Wi-Fi 6/6E and Wi-Fi 7 Speed Comparison for 2 Spatial Stream devices [7]

Conclusion

The smart city contains different types of systems to facilitate and enhance the way of living of dwellers. The examples examined were IoT, Industry 4.0, and XR (Extended Reality). With the giant leap of Wi-Fi 7 offering data rates up to 40 Gbps on 320 MHz channels with 16 special streams and 4k QAM, these needs can be achieved with great satisfaction.

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