





Bringing the Edge Home: Edge Computing in the Era of Emerging WLANs

Sampath Edirisinghe¹  and Chathurika Ranaweera² 

¹ Department of Computer Engineering, University of Sri Jayewardenepura, Nugegoda, Sri Lanka

essedirisinghe@sjp.ac.lk

² School of Information Technology, Deakin University, Geelong 3220, Australia
chathu.ranaweera@deakin.edu.au

Abstract. With the massive number of devices being added to Internet every day, the cloud infrastructure is struggling to serve them on timely manner with the required quality of service. In addition, the sheer volume of data that needs to be transported between the user devices and the cloud servers is massive and poses bottlenecks on the network infrastructure. In light of these challenges, Edge Computing is seen as a solution that can serve the user devices with less latency and ease the network congestion. Multi-Access Edge Computing (MEC) is one of the prominent solutions proposed recently with the primary focus of mobile cellular networks. However, a closer look at the user applications that require Edge Computing shows that having the Edge Computing facility at houses, offices or factories enable more effective operation and utilization of the capabilities of Edge Computing. Furthermore, the emerging WLANs such as Wi-Fi 6/6E/7, Li-Fi, and Optical Wireless Communication are addressing the indoor network capacity barriers that prevented Edge Computing being deployed closer to the user. Therefore, in this article, we introduce an Edge Computing architecture for wireless local area networks (WLAN) which resides in user premises. The viability and the performance of the architecture is evaluated with the use of Wi-Fi 6 WLAN network.

Keywords: Edge Computing · Wi-Fi · WLAN · MEC

1 Introduction

Edge Computing (EC) is being developed with a predominant focus on the mobile cellular networks. These developments were called mobile edge computing, however, it was later standardized by ETSI as multi-access edge computing (MEC) [39]. MEC is expected to provide low latency, highly reliable, and low energy computational facilities for users who are connected to 5G/6G and beyond

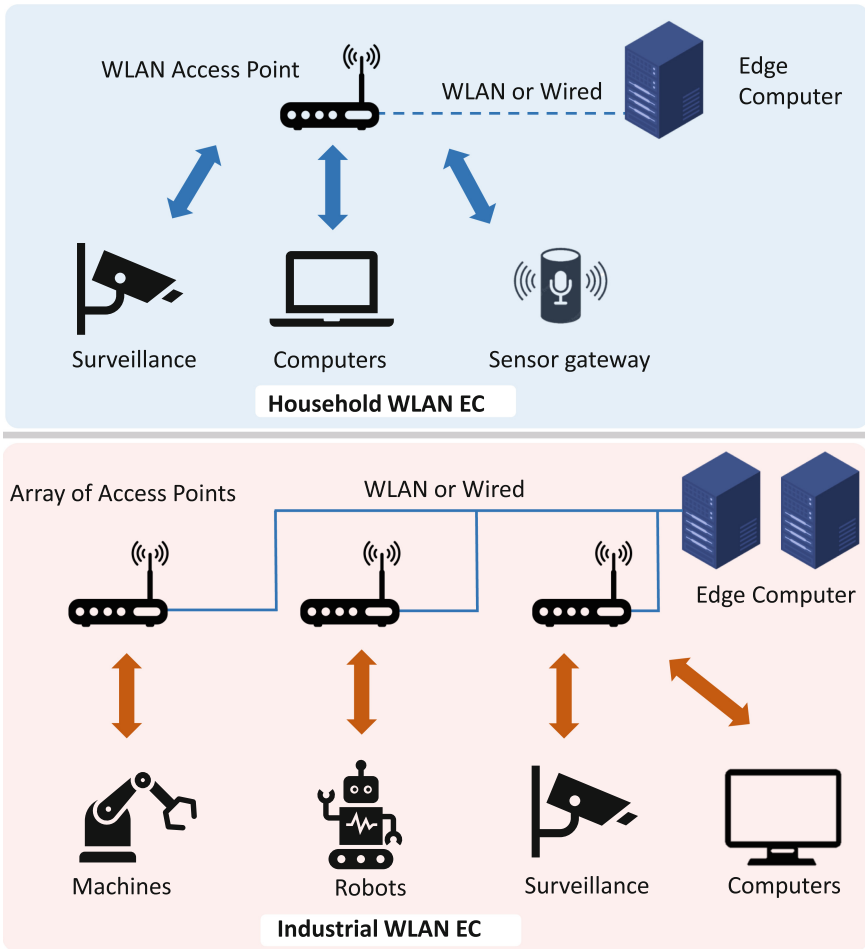


Fig. 1. Deployment of WLAN Edge Computing in household and industrial scenarios.

networks [34, 35]. Furthermore, computing at the network edge reduces the congestion in the backhaul networks and brings the cost for network operators down [17].

There are a number of studies that explore the use of MEC in different directions such as smart cities, virtual/augmented reality (VR/AR), Edge Intelligence, unmanned aerial vehicles, vehicular networks, and Internet of Things (IoT) [10, 18, 26, 27, 36, 43–45]. Nevertheless, in order to reap the benefits of MEC, a user needs to be connected to a cellular base-station, which can be a power consuming and costly task for certain user devices such as IoT devices [11]. Moreover, there might be devices that do not have the capability to connect to a cellular network or cannot be connected due to the network failures [42].

Therefore, many devices that we find in houses, offices and factories that can benefit from Edge Computing facilities do not get the opportunity to use it. These devices are usually connected to a wireless local area network (WLAN) such as Wi-Fi or Li-Fi.

A few Edge Computing architectures were proposed for indoor spaces using WLANs. For instance, a 3-tier architecture called Home Edge Computing (HEC) was introduced in [2] to decrease the latency of accessing the cloud resources in applications such as AR/VR and Tactile Internet. This architecture is proposed as an extension to MEC with an additional layer called the local data center or home server. However, the proposed 3-tier architecture have to maintain a constant flow of information with the cloud servers and intermediate nodes which hinders the low latency operation of the HEC. Moreover, the home server is transparent to the users and is completely managed by the Internet Service Provide (ISP). Hence, the users do not get to add custom features, apps, and capabilities to the home server.

Further, authors in [37] also introduced access edge cloud, where a server in attached to the WLAN access points. However, the implementation gives more emphasis on the metro edge cloud and the results are transparent of the particular WLAN technology. Further, the authors introduce a new TDMA-based (time division multiple access) polling for the effective resource management in the metro edge cloud. In [9], authors introduced EdgeAP, where a management server orchestrates different applications in WLAN access points that are connected to it. These applications are decided based on the user demand and the users cannot have a fixed set of applications in a given access point. Therefore, the EdgeAP architecture is similar to HEC proposed in [2].

Cloudlet Computing is also a similar concept where the cloud computing capabilities are brought closer to the user [1]. However, similar to the previous approaches, Cloudlet Computing is also managed by service providers. Hence, the exact location of deployment, services that are running in the Cloudlet, and hardware/software specifications are entirely determined by the service providers [16]. Therefore, while Cloudlet Computing can enhance the performance of data processing at the network edge, it does not yield the full autonomy that WEC can provide the users.

In terms of applications of WLAN Edge Computing, authors in [44] highlight that artificial intelligence (AI) in the network edge would play a key role in future IoT and mobile computing landscape. While there are a number of challenges in implementing AI in the edge, there are various techniques such as federate learning, gradient compression, model compression and partitioning that help enable the edge AI implementations. Moreover, providing Industrial IoT as a Service (IIoTaaS) is an upcoming trend in future manufacturing industries. IIoTaaS provides storage and computational resources closer to industrial plants and minimize the latency and risk of data breaches [4].

A common challenge with WLAN-based EC is that the WLANs were not seen as very reliable networks that can provide guaranteed connectivity and latency. Hence, WLAN-based EC was not considered as a viable solution for providing

computational facilities at the network edge. However, the latest versions of the IEEE 802.11 standard series offers compelling solutions to these challenges [13]. The IEEE 802.11ax standard which is better known as Wi-Fi 6 features radical changes such as orthogonal frequency division multiple access (OFDMA) that enables Wi-Fi to provide guaranteed access to all or a subset of its users [22]. Moreover, Wi-Fi 6 comes with increased bandwidth support and it is set to be expanded to 6 GHz range as well (Wi-Fi 6E) [12]. In addition to that Wi-Fi 7 (IEEE 802.11be) is also underway with more features like multi-link operation and time-sensitive networking to further enhance the capacity and reliability of Wi-Fi links [8]. With these enhancements, the most recent and upcoming Wi-Fi standards would provide guaranteed performance in terms of latency and connectivity. The increased bandwidth can be used to easily facilitate the increasing number of IoT devices or any other sensors connected to the network.

Visible light communication, Li-Fi, optical wireless communication are also widely explored for WLAN deployments due to its high capacity and privacy [31–33]. The IEEE 802.11 standards expand into the optical region of the electromagnetic spectrum with the latest IEEE 802.11bb light communication standard [23]. Hence, now it is possible to build visible light communication links that comply with the IEEE 802.11 standards, which encourages a heterogeneous WLAN ecosystem with much higher capacity and link reliability.

Therefore, it is evident that the development of emerging WLANs paves the way to support the WLAN-based EC with their ability to provide guaranteed access [13, 14], higher throughput and bandwidth. Therefore, exploring the combination of EC and emerging WLANs is a timely contribution that can improve how the devices that are connected to WLANs can utilize EC facilities.

In that regard, this article presents a novel architecture for deploying WLAN-based EC (WEC) systems in households and industrial settings. The WEC system implementation in both scenarios are shown in Fig. 1, which will be explained in detail in Sect. 2. With this architecture, the following contributions are made in the article.

- We introduce a novel edge computing architecture where the edge computing device is connected to the household/industrial WLAN. The architecture is a flexible and scalable solution as the user can determine the specifications of the edge computer depending on their requirements.
- We introduce an app-based ecosystem where the user installs the applications (apps) they require and these apps will execute the functions related to different services.
- We evaluate the performance of the proposed architecture using Wi-Fi 5 and Wi-Fi 6 networks to demonstrate that emerging WLANs such as Wi-Fi 6 networks enable smooth operation of edge computing at the WLAN edge.

The rest of the article is organized as follows. The proposed architecture is presented in Sect. 2. The Sect. 3 introduces key applications for WLAN EC and their requirements. The performance evaluations and analyses are presented in Sect. 4. Finally, Sect. 5 concludes the paper.

2 Proposed Architecture of the WLAN-Based Edge Computing

This section will demonstrate the need for WLAN-based Edge Computing using a simple networking scenario and present the proposed architecture for WLAN-based Edge Computing. Furthermore, the last subsection will go into the details of the construction of the Edge Computer.

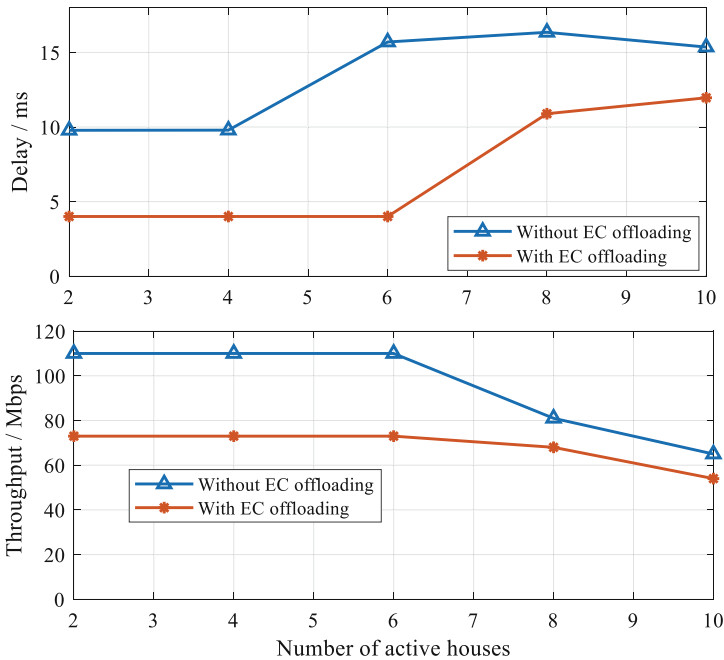
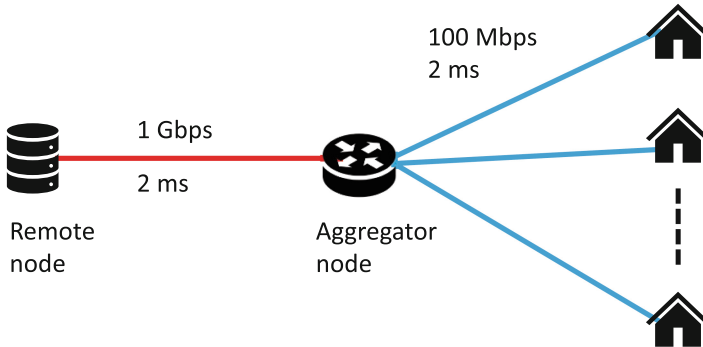


Fig. 2. Impact of offloading traffic to on-premises Edge Computers.

2.1 The Need of Edge Computing in WLAN

Consider the scenario given in Fig. 2 where a network which has 10 user premises with 110 Mbps of peak demand each. All houses are connected to a router with 1 Gbps uplink capacity and the user premises are connected to the router using 100 Mbps links. Two experiments were done with and without WLAN-based EC facilities at user premises. In the first experiment, it is assumed that 100% of the peak demand is sent to the remote node. As shown in the delay and throughput plots shown in Fig. 2, the delay and throughput of users suffer when the total network load is close to the peak (1 Gbps). On the other hand, if 30% of the peak demand can be served on-premises, the traffic that needs to be transported in the core network reduces and the results are reflected in Fig. 2. The overall network metrics experience a significant improvement in the latter case.

2.2 WLAN-Based Edge Computing Architecture

The proposed novel WLAN-based Edge Computing architecture is shown in Fig. 1. The proposed architecture can be equally applied to household and industrial scenarios to carry out different tasks. The architecture features a WLAN access point and it is connected to an edge computer. Edge computers can be built using general-purpose computers, single-board computers such as Raspberry Pi, or more advanced miniature computers such as NVIDIA Jetson Nano [5]. The user devices are connected to the access point via emerging WLAN technologies while the edge computer can be connected via WLAN or wired (Ethernet) connections. As shown in the industrial scenario in Fig. 1, there could be multiple access points to serve the coverage area. However, they are connected a single edge computer which is more powerful than a household edge computer.

2.3 Architecture of WLAN-Based Edge Computer

The architecture of the WLAN-based Edge Computer is shown in Fig. 3. It consists of all the components of a general-purpose computer such as hardware, operating system, drivers, libraries and software applications. In addition to that, the WEC is connected a WLAN access point via Ethernet or WLAN.

The hardware components of the WEC are mainly the central processing unit (CPU), graphics processing unit (GPU), memory, storage, network interfaces and other peripherals to communicate with the external sources. Depending on the user requirements certain components might have high-end specifications. For instance, an industrial WEC that controls robots might need high performance CPU and GPU whereas a household WEC might need more storage capacity.

The operating system of the WEC will manage the hardware and software that run on top of it. The libraries installed in the operating system play a key role in facilitating the applications. Depending on the requirements of the applications, users can install libraries such a machine learning and GPU. In Fig. 3, dashed entities represent industrial WEC components. For instance, industrial

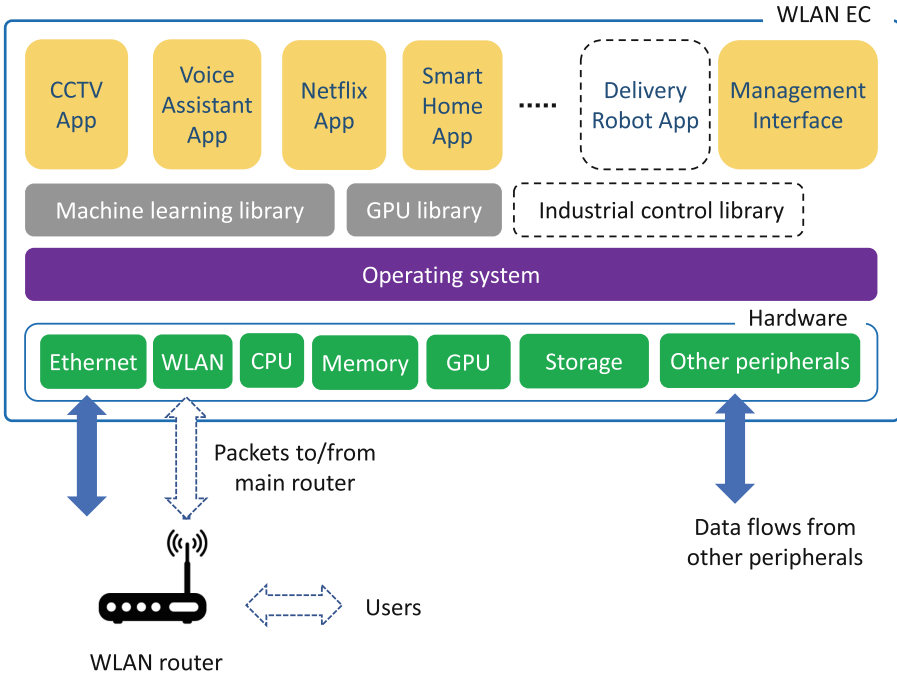


Fig. 3. The proposed architecture of the WLAN edge computer.

robot control would require libraries such as simultaneous localization and mapping (SLAM) [21].

The applications are installed by the user based on their requirements. For instance, if the user needs their Netflix account to cache latest movies in the WEC, they can install the Netflix application and configure it. Similarly, if the user wants to run a certain machine learning surveillance on their CCTV (closed circuit television) feed and send alert, they can install a CCTV application in the WEC and forward the CCTV feed to the WEC. Installation of applications is done by the management interface of the WEC. This management interface can be accessed by a computer by typing in the WEC’s IP address. Using this interface, the user can install/uninstall, configure applications and install libraries. The app-based ecosystem is one of the key differentiators of the proposed architecture from Cloudlet Computing where the edge computer is used to execute a certain set of calculations [1]. The proposed architecture uses fully-fledge apps in the edge computer which runs standalone computational tasks. It should be noted that these apps are different from the apps installed in mobile phones or computers. The apps for the WEC are specifically designed for the WECs to carry out a specific set of tasks. In addition to the standard security measures provided by the computing system, WEC apps can also run the machine

learning based anomaly detection algorithms to identify any vulnerabilities and notify the users.

As discussed earlier, the connection between the access point and the WEC can be Ethernet or WLAN. For instance, the resource allocation mechanisms of Wi-Fi 6/6E/7 greatly suits this task as they can provide dedicated network slices for certain connections. The user devices will be connected to the access point and certain groups of users will have dedicated network slices. In addition to the data flows from the main router, the WEC can interface with other peripherals using its own interfaces such as audio ports, Bluetooth interfaces and USB. This way the WEC can provide additional services via its own interfaces.

3 Application Scenarios of WEC

Emerging user applications can be supported through both cloud and edge computing [15]. These computing paradigms offer distinct advantages that cater to various aspects of application requirements. However, bandwidth intensive applications with a ultra-low delay requirement can greatly benefit from edge computing. In this section, a few application scenarios that can benefit from WEC is discussed with their requirements such as data rate, latency, computational power, and memory.

3.1 Real-Time Security Monitoring Applications

The CCTV systems are widely used nowadays for surveillance purposes. However, security officers are often employed to monitor them on a 24×7 basis. With the increasing number of cameras, it is becoming a costly and ineffective endeavor. Hence, there has been attempts to automate this process using machine learning and cloud computing [40]. However, as we discussed earlier, cloud computing poses its own limitations in data rate and latency. Especially, if the CCTV system is large and consists of high-definition cameras. Therefore, deploying a WEC for this task helps reducing the cost and operational latency to a significant degree. In addition, the CCTV footage will stay local preserving the privacy of the individuals. If the WEC is attached to the other systems of the house or industrial building, it is possible to execute security measure without delays.

3.2 Industry 5.0

Industrial control is another area where edge computing is highly applied. With Industry 4.0, most of the factories and other industrial spaces were equipped with smart machines and sensors to efficiently mass produce different products. However, Industry 5.0 envisions to bring mass personalization and human interaction to the factories [25]. Industry 5.0 requires a version of edge computing that can be modified easily. Therefore, WEC suits well for the upcoming Industry 5.0 spaces for a number of reasons [28]. WEC with emerging WLANs can

provide guaranteed access to the machines and other devices unlike older versions of WLANs (Wi-Fi 5 or older). WEC allows the industries to maintain their proprietary data on their own system without compromising the security and privacy. Since the libraries and apps are locally maintained, updates can be easily done providing a scalable and flexible solutions for industry automation.

3.3 Personalized In-Home Care

With the ageing population in many countries, it is vital to provide in-home care for elderly people and disabled individuals. While there are different sensors that capture visual, auditory and medical sensors that can collect data from individuals, transportation of these data and processing them in cloud servers is a challenging task in terms of data volume, latency and privacy. Hence, there have been attempts to address these concerns using MEC and network slicing [29]. With the proposed WEC architecture, it is possible to address these concerns in an effective way due to the low latency and high privacy. Moreover, since the WEC supports installation and configuration of new apps, the users can install and customize apps to monitor individuals with various medical conditions.

3.4 Work-from-Home Caching

With the advent of work-from-home (WFH) culture, it is necessary to access the workplace data in a fast and reliable manner. At the moment, most companies use Google Drive, Dropbox or Outlook OneDrive for workplace file storage and sharing. Only a small fraction of the companies can afford to deploy their own file servers. Most of the general file sharing services either have long delay or requires to store the files locally. Hence, moving between devices, working with tablets is cumbersome. However, the proposed architecture can serve as a local server and an app can manage the copies and update the versions [3]. Furthermore, specific access restrictions and other custom access policies can be easily implemented using the apps.

3.5 Voice/Virtual Assistants

Voice assistants such as Google Home, and Amazon Alexa are quite popular these days and are helpful in number of avenues of our daily lives. At the moment, these devices come as separate hardware with in-built processing and communication capabilities. However, with the proposed WEC, it is possible to build apps that can serve as voice assistants. Authors in [41] proposes to use EC to improve the performance of existing voice assistants by reducing the cloud access delay. If the WEC is equipped with audio input/output, the whole functionality can be achieved in the WEC and can be integrated to household audio systems. Furthermore, it will give the voice assistants seamless access to the physical aspects such as smart home sensors and control devices for monitoring and controlling.

Table 1. Simulation Parameters

Application	Direction	Packet Size	Data rate
Netflix	Downlink	1500 bytes	8 Mbps
2 × WFH cache	Downlink	1200 bytes	2 × 1 Mbps
10 × General Internet	Downlink	1000 bytes	10 × 0.6 Mbps
5 × CCTV	Uplink	1400 bytes	5 × 1 Mbps
2 × WFH cache	Uplink	1200 bytes	2 × 1 Mbps
Sensor gateway	Uplink	700 bytes	0.2 Mbps
10 × General Internet	Uplink	1000 bytes	10 × 0.6 Mbps

3.6 Internet of Everything (IoE)

With the IoE concept, numerous sensors and other devices are embedding into households and industrial spaces. These sensors and devices acquire sensitive information from the surroundings. With the typical cloud computing systems, this information has to be sent to the cloud which will pose a security and privacy threat [7]. However, most of functionalities in the cloud can be installed in the edge computer and execute at the edge [38]. This will help preserving the privacy and decreasing the latency of the responses. Therefore, IoE devices can be connected to the WEC and the management of the IoE devices can be done through a suitable app installed in the WEC.

3.7 Caching of Content Delivery Services

Video services such as Netflix and YouTube use caching at different levels of the network for seamless delivery. As describe earlier, a personal level content caching and storage can help reduce the congestion in the core/transport networks and scalability of content delivery systems [20, 24]. Furthermore, WEC can intelligently coordinate with the core network to do the caching at low congestion periods to ease the burden the core network.

3.8 In-Home AR/VR Engines

AR/VR technologies are penetrating our daily lives in terms of gaming, entertainment and education. The cloud-based operation of AR/VR is almost impossible due to data rates involved and the stringent latency requirements. A number of studies are carried out to evaluate to the feasibility of using MEC for AR/VR rendering [6, 30]. Therefore, bringing these functionalities home with WEC would further enhance the performance of AR/VR applications.

4 Performance Evaluation

The viability of the proposed architecture is evaluated by implementing the proposed WEC in the ns-3 simulation environment [19]. The ns-3 simulation

environment supports both legacy Wi-Fi 5 and Wi-Fi 6 networks. Two simulation studies are conducted to observe the viability of WEC in Wi-Fi 5 and Wi-Fi 6 networks. These simulations are carried out with the same network and traffic configurations. The latency of the user applications are observed to evaluate the performance of the proposed WECs.

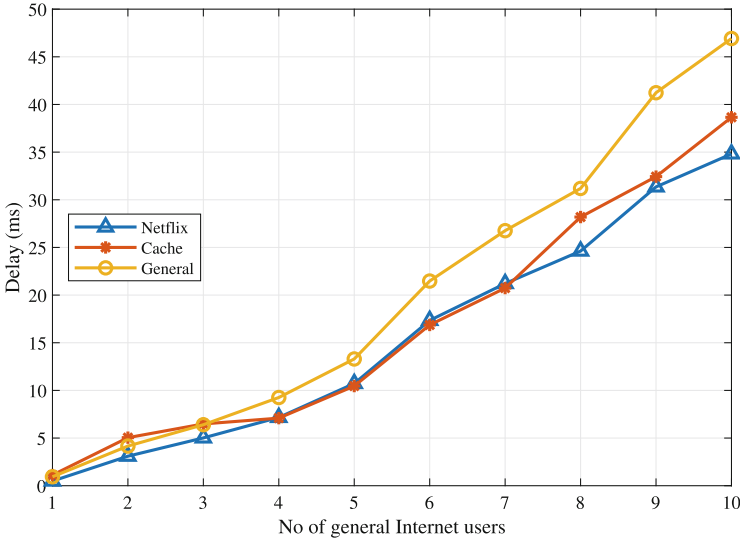


Fig. 4. Latency of downlink user applications using Wi-Fi 5 networks in a WLAN-based EC.

The network considered for the simulations consists of the traffic shown in Table 1. As shown in the table, both uplink and downlink traffic are considered for the simulations. Different types of applications are also simulated. The Netflix, WFH cache, CCTV, and sensor applications implemented where they are using the apps in the WEC, which might use or not use the Internet connection. The general Internet users do not connect to the WEC, however, they use the bandwidth of the Wi-Fi access point to connect to the Internet. The simulation studies increase the load on the Wi-Fi access point by increasing the number of general Internet users from 1 to 10 and observe the performance of all the traffic traversing the WEC and WLAN.

Figures 4 and 5 show the performance of the WEC with Wi-Fi 5 network. As it can be seen from these figures, the latency of the network depends on the load of the network. For the downlink traffic, the latency has increased almost $\times 10$ for all the traffic categories when the general Internet users were increased from 1 to 10. Similarly, uplink also demonstrates a consistent increase in the latency with increasing number of users. Hence, it is difficult to use Wi-Fi 5 networks for WECs as the network performance is highly dependant on the network load. The main reason behind this behaviors is that Wi-Fi 5 networks do not have

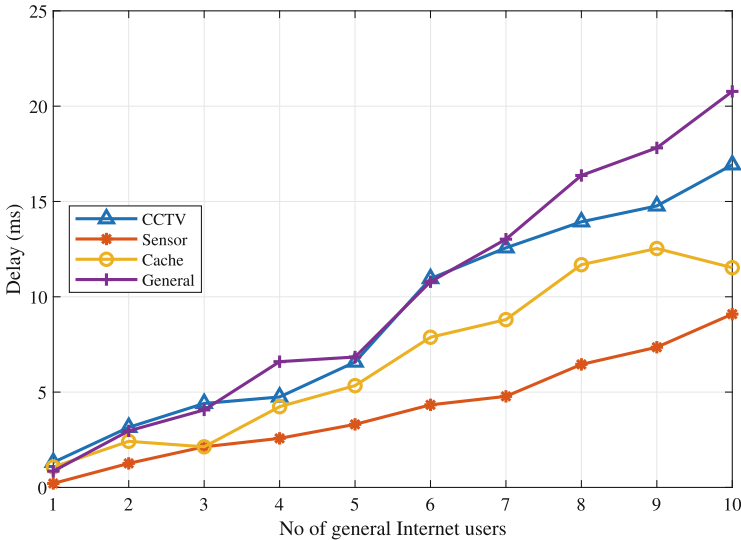


Fig. 5. Latency of uplink user applications using Wi-Fi 5 networks in a WLAN-based EC.

the ability to allocate bandwidth based on the latency requirements. The Wi-Fi 5 networks are based on a contention-based medium access control (MAC) protocol. While it results in low latencies under low load, the latency will quickly rise up with increasing number of users. Therefore, though it is possible to build WECs using Wi-Fi 5 networks, it will not be able to consistently offers the low latency and highly reliable services of a WEC.

On the other hand, the Wi-Fi 6 network can be configured to have a constant latency for required applications. Figures 6 and 7 demonstrate the delay performance of downlink and uplink, respectively. In this configuration, the general purpose traffic is not set to have a constant latency. The rest of the user applications are configured to have a constant latency by allocated bandwidth portions for them. As depicted in Fig. 6, the Netflix and WFH cache traffic stays at the same latency level while the general Internet user latency increased with increasing number of users. In this case, the general Internet user latency can be higher than that of Wi-Fi 5 as the dedicated bandwidth were allocated for Netflix and WFH cache. A similar behavior is observed in the uplink scenario shown in Fig. 7. Only the general Internet users will have an increase in the latency while the rest of the user applications experience a constant delay. Therefore, it is clear that with Wi-Fi 6 networks it is viable to build WECs that can provide guaranteed latency. It is worthwhile noting that some application such as CCTV experience less latency under the Wi-Fi 5 networks due to the contention-based MAC protocol in legacy Wi-Fi networks. However, when it comes to Wi-Fi 6 networks, the scheduled access may result in higher latency, however, it will be consistent with the increasing network load.

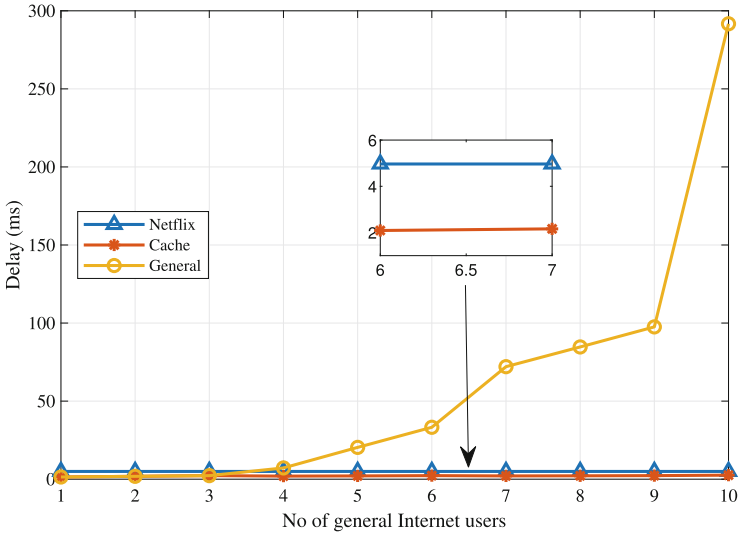


Fig. 6. Latency of downlink user applications using Wi-Fi 6 networks in a WLAN-based EC.

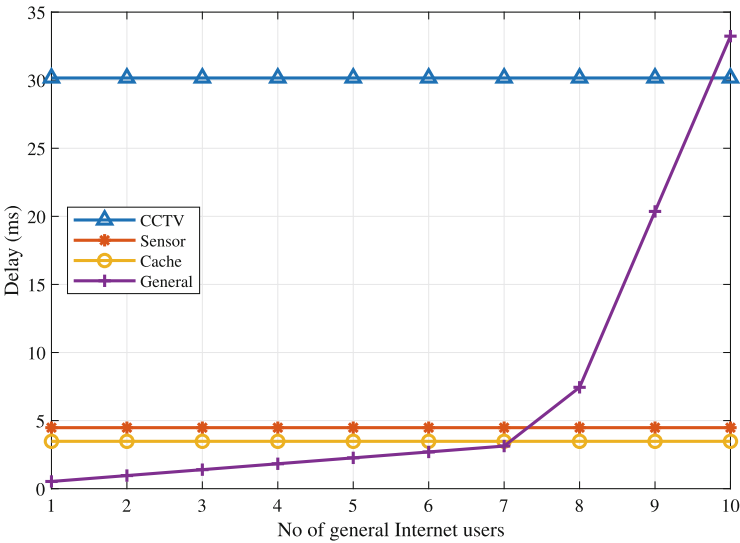


Fig. 7. Latency of uplink user applications using Wi-Fi 6 networks in a WLAN-based EC.

As it can be seen from the above analysis, the Wi-Fi 6 networks appear to be a viable solution for building WECs. The Wi-Fi 5 networks have an unpredictable latency, therefore, are not suitable for WECs as WECs are expected to maintain a constant latency. However, with the improve network resource allocation mechanisms in Wi-Fi 6, it is possible to ensure guaranteed latency and reliability for the user applications. Hence, using Wi-Fi 6, it is possible to build WECs that can bring the advantages offered by MECs into the home environment, bringing the edge computing another step closer to the end users.

5 Conclusion

Bringing Edge Computing facilities to WLANs can provide many benefits for a number of user applications such as IoE, smart home, caching services in terms to latency, privacy and data rate. However, so far, the unreliable WLAN technologies did not provide a proper platform for WLAN-based EC systems. With the emergence of Wi-Fi 6/6E/7, Li-Fi, and optical wireless communications, WLANs are becoming more reliable as they are capable of providing guaranteed latency for user applications. Therefore, it is necessary to evaluate the possible architectures for EC using these emerging WLANs. This article introduces a novel architecture which consists of a WLAN Edge Computing based on Wi-Fi 6. The WEC operates with a collection of apps that the user can install/customize to suit their applications. We analysed the viability of the proposed architecture by using Wi-Fi 5 and Wi-Fi 6 networks. The results confirm the fact though Wi-Fi 5 networks are not reliable enough to build WECs, the Wi-Fi 6 networks appears to be the best platform for WECs at the moment with constant latency and reliability, help bringing the edge computing one more step closer to the users.

References

1. Babar, M., Khan, M.S., Ali, F., Imran, M., Shoaib, M.: Cloudlet computing: recent advances, taxonomy, and challenges. *IEEE Access* **9**, 29609–29622 (2021)
2. Babou, C.S.M., Fall, D., Kashihara, S., Niang, I., Kadobayashi, Y.: Home edge computing (HEC): design of a new edge computing technology for achieving ultra-low latency. In: Liu, S., Tekinerdogan, B., Aoyama, M., Zhang, L.-J. (eds.) *EDGE 2018*. LNCS, vol. 10973, pp. 3–17. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-94340-4_1
3. Bilal, K., Shuja, J., Erbad, A., Alasmary, W., Alanazi, E., Alourani, A.: Addressing challenges of distance learning in the pandemic with edge intelligence enabled multicast and caching solution. *Sensors* **22**(3), 1092 (2022)
4. Borsatti, D., Davoli, G., Cerroni, W., Raffaelli, C.: Enabling industrial IoT as a service with multi-access edge computing. *IEEE Commun. Mag.* **59**(8), 21–27 (2021)
5. Cass, S.: Nvidia makes it easy to embed AI: the Jetson nano packs a lot of machine-learning power into DIY projects-[hands on]. *IEEE Spectr.* **57**(7), 14–16 (2020)

6. Chakareski, J., Gupta, S.: Multi-connectivity and edge computing for ultra-low-latency lifelike virtual reality. In: 2020 IEEE International Conference on Multi-media and Expo (ICME), pp. 1–6. IEEE (2020)
7. Chinchawade, A.J., Lamba, O.S.: Security and privacy challenges in internet of everything (IoE) with security requirements. *J. Eng. Technol.-Suresh Gyan Vihar Univ.* **7**(2) (2021)
8. Deng, C., et al.: IEEE 802.11 be Wi-Fi 7: new challenges and opportunities. *IEEE Commun. Surv. Tutor.* **22**(4), 2136–2166 (2020)
9. Desiniotis, C., Majors, J., Miremadi, C.: EdgeAP: enabling edge computing on wireless access points (2020)
10. Dias, I., Ruan, L., Ranaweera, C., Wong, E.: From 5G to beyond: passive optical network and multi-access edge computing integration for latency-sensitive applications. *Opt. Fiber Technol.* **75**, 103191 (2023). <https://doi.org/10.1016/j.yofte.2022.103191>
11. Ding, J., Nemati, M., Ranaweera, C., Choi, J.: IoT connectivity technologies and applications: a survey. *IEEE Access* **8**, 67646–67673 (2020). <https://doi.org/10.1109/ACCESS.2020.2985932>
12. Drahoš, P., Kučera, E., Haffner, O., Pribiš, R., Beňo, L.: Trends in industrial networks including APL, TSN, WiFi-6E and 5G technologies. In: 2022 Cybernetics & Informatics (K&I), pp. 1–7. IEEE (2022)
13. Edirisinghe, S., Galagedarage, O., Dias, I., Ranaweera, C.: Recent development of emerging indoor wireless networks towards 6G. *Network* **3**(2), 269–297 (2023)
14. Edirisinghe, S., Ranaweera, C., Lim, C., Nirmalathas, A., Wong, E.: Universal optical network architecture for future wireless LANs [invited]. *J. Opt. Commun. Netw.* **13**(9), D93–D102 (2021). <https://doi.org/10.1364/JOCN.426215>
15. Ferreira, R., Ranaweera, C., Schneider, J.G., Lee, K.: Optimal node selection in communication and computation converged IoT network. In: 2022 IEEE International Conference on Parallel & Distributed Processing with Applications (ISPA), pp. 539–547 (2022). <https://doi.org/10.1109/ISPA-BDCloud-SocialCom-SustainCom57177.2022.00075>
16. Fernández-Cerero, D., Fernández-Rodríguez, J.Y., Álvarez-García, J.A., Soria-Morillo, L.M., Fernández-Montes, A.: Single-board-computer clusters for cloudlet computing in Internet of Things. *Sensors* **19**(13), 3026 (2019)
17. Filali, A., Abouaoumar, A., Cherkaoui, S., Kobbane, A., Guizani, M.: Multi-access edge computing: a survey. *IEEE Access* **8**, 197017–197046 (2020)
18. Hasarinda, R., Tharuminda, T., Palitharathna, K., Edirisinghe, S.: Traffic collision avoidance with vehicular edge computing. In: 2023 3rd International Conference on Advanced Research in Computing (ICARC), pp. 316–321. IEEE (2023)
19. Henderson, T.R., Lacage, M., Riley, G.F., Dowell, C., Kopena, J.: Network simulations with the NS-3 simulator. *SIGCOMM Demonstration* **14**(14), 527 (2008)
20. Jayasundara, C., Zukerman, M., Nirmalathas, T.A., Wong, E., Ranaweera, C.: Improving scalability of VoD systems by optimal exploitation of storage and multicast. *IEEE Trans. Circuits Syst. Video Technol.* **24**(3), 489–503 (2014). <https://doi.org/10.1109/TCSVT.2013.2290397>
21. Khairuddin, A.R., Talib, M.S., Haron, H.: Review on simultaneous localization and mapping (SLAM). In: 2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE), pp. 85–90. IEEE (2015)
22. Khorov, E., Kiryanov, A., Lyakhov, A., Bianchi, G.: A tutorial on IEEE 802.11 ax high efficiency WLANs. *IEEE Commun. Surv. Tutor.* **21**(1), 197–216 (2018)
23. Khorov, E., Levitsky, I.: Current status and challenges of Li-Fi: IEEE 802.11 bb. *IEEE Commun. Standards Mag.* **6**(2), 35–41 (2022)

24. Lall, S., Sivakumar, R.: Will they or won't they?: toward effective prediction of watch behavior for time-shifted edge-caching of Netflix series videos. In: 2021 IEEE/ACM Symposium on Edge Computing (SEC), pp. 257–270. IEEE (2021)
25. Leng, J., et al.: Industry 5.0: prospect and retrospect. *J. Manuf. Syst.* **65**, 279–295 (2022)
26. Li, H., Shou, G., Hu, Y., Guo, Z.: Mobile edge computing: progress and challenges. In: 2016 4th IEEE International Conference on Mobile Cloud Computing, Services, and Engineering (MobileCloud), pp. 83–84 (2016). <https://doi.org/10.1109/MobileCloud.2016.16>
27. Liu, Y., Peng, M., Shou, G., Chen, Y., Chen, S.: Toward edge intelligence: multiaccess edge computing for 5G and internet of things. *IEEE Internet Things J.* **7**(8), 6722–6747 (2020)
28. Maddikunta, P.K.R., et al.: Industry 5.0: a survey on enabling technologies and potential applications. *J. Ind. Inf. Integr.* **26**, 100257 (2022)
29. Martiradonna, S., Cisotto, G., Boggia, G., Piro, G., Vangelista, L., Tomasin, S.: Cascaded WLAN-FWA networking and computing architecture for pervasive in-home healthcare. *IEEE Wirel. Commun.* **28**(3), 92–99 (2021)
30. Mehrabi, A., Siekkinen, M., Kämäräinen, T., Jski, A.: Multi-tier CloudVR: leveraging edge computing in remote rendered virtual reality. *ACM Trans. Multimed. Comput. Commun. Appl. (TOMM)* **17**(2), 1–24 (2021)
31. Nirmalathas, A., et al.: High-speed optical wireless communications for local area networks. In: 2018 23rd Opto-Electronics and Communications Conference (OECC), pp. 1–2. IEEE (2018)
32. Nirmalathas, A., et al.: Indoor optical wireless access networks-recent progress [invited]. *J. Opt. Commun. Netw.* **13**(2), A178–A186 (2021). <https://doi.org/10.1364/JOCN.403485>
33. Nirmalathas, T.A., et al.: Gigabit/s optical wireless access and indoor networks. In: 2020 Optical Fiber Communications Conference and Exhibition (OFC), pp. 1–3 (2020)
34. Ranaweera, C., et al.: Design and deployment of optical x-haul for 5G, 6G, and beyond: progress and challenges [invited]. *J. Opt. Commun. Netw.* **15**(9), D56–D66 (2023). <https://doi.org/10.1364/JOCN.492334>
35. Ranaweera, C., et al.: Optical x-haul options for 5G fixed wireless access: which one to choose? In: IEEE INFOCOM 2018 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), pp. 1–2 (2018). <https://doi.org/10.1109/INFOCOMW.2018.8406906>
36. Ranaweera, C., et al.: Rethinking of optical transport network design for 5G/6G mobile communication. *IEEE Future Netw. Tech Focus* (2021)
37. Rimal, B.P., Maier, M., Satyanarayanan, M.: Experimental testbed for edge computing in fiber-wireless broadband access networks. *IEEE Commun. Mag.* **56**(8), 160–167 (2018)
38. Sachdev, R.: Towards security and privacy for edge AI in IoT/IoE based digital marketing environments. In: 2020 fifth International Conference on Fog and Mobile Edge Computing (FMEC), pp. 341–346. IEEE (2020)
39. Shahzadi, S., Iqbal, M., Dagiuklas, T., Qayyum, Z.U.: Multi-access edge computing: open issues, challenges and future perspectives. *J. Cloud Comput.* **6**(1), 1–13 (2017)
40. Shirsat, S., Naik, A., Tamse, D., Yadav, J., Shetgaonkar, P., Aswale, S.: Proposed system for criminal detection and recognition on CCTV data using cloud and machine learning. In: 2019 International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN), pp. 1–6. IEEE (2019)

41. Xu, L., Iyengar, A., Shi, W.: Cha: a caching framework for home-based voice assistant systems. In: 2020 IEEE/ACM Symposium on Edge Computing (SEC), pp. 293–306. IEEE (2020)
42. Yu, Y., et al.: Optimization and deployment of survivable fiber-wireless (FiWi) access networks with integrated small cell and WiFi. In: 2015 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), pp. 1–5 (2015). <https://doi.org/10.1109/ICUWB.2015.7324491>
43. Zhou, F., Hu, R.Q., Li, Z., Wang, Y.: Mobile edge computing in unmanned aerial vehicle networks. *IEEE Wirel. Commun.* **27**(1), 140–146 (2020)
44. Zhou, Z., Chen, X., Li, E., Zeng, L., Luo, K., Zhang, J.: Edge intelligence: paving the last mile of artificial intelligence with edge computing. *Proc. IEEE* **107**(8), 1738–1762 (2019)
45. Zhu, R., Liu, L., Song, H., Ma, M.: Multi-access edge computing enabled Internet of Things: advances and novel applications (2020)