WHITE PAPER

MOBILE AUGMENTED REALITY WITH 5G MOBILE EDGE COMPUTING

Abstract

To survive in the long term, businesses should continuously explore avenues to improve the customer experience. To enhance customer experience, the need is for continuous research and implementation of new features. Taking advantage of breakthroughs in network infrastructure, complemented by compatible data processing hardware, implementation of new features can take place seamlessly. Additionally, enterprises also need to find ways to process and leverage a growing amount of data. Real-time operational data can be used to produce insights and build prediction models for stakeholders to take timely actions. Enterprises with focus on both aspects are best placed to generate ongoing value and attain leadership positions in their respective industries.

Their aspirations require solutions that are achieved with an optimal balance between scale, cost and accountability. This balance is typically achieved through research-based solutions, backed by sustained investments in IT.

The utility of 5G technology combined with Edge computing, can be leveraged to provide a mobile-augmented-reality (MAR) experience to end-users. Edge computing infrastructure can be built on top of an ultra-low latency network and a very high rate of data transfer provided by 5G technology. Edge computing reduces load on centralized data processors/network bandwidth and enhances the speed of application response, which can work as a backbone of MAR implementation. Simulation-driven apps and prediction-models across all industries are features provided by MAR which enable businesses to attain a balance between scale, cost and accountability, resulting in a novel experience for all the stakeholders.

We will discuss the following topics in the article.

- The use cases across industries for mobile-augmented-reality (MAR) and how it is complemented by Edge computing.
- Evaluate different architectural deployments of MAR viz. cloud, edge or hybrid.
- Future possible implementations of MAR with the help of advancement in 5G technology.

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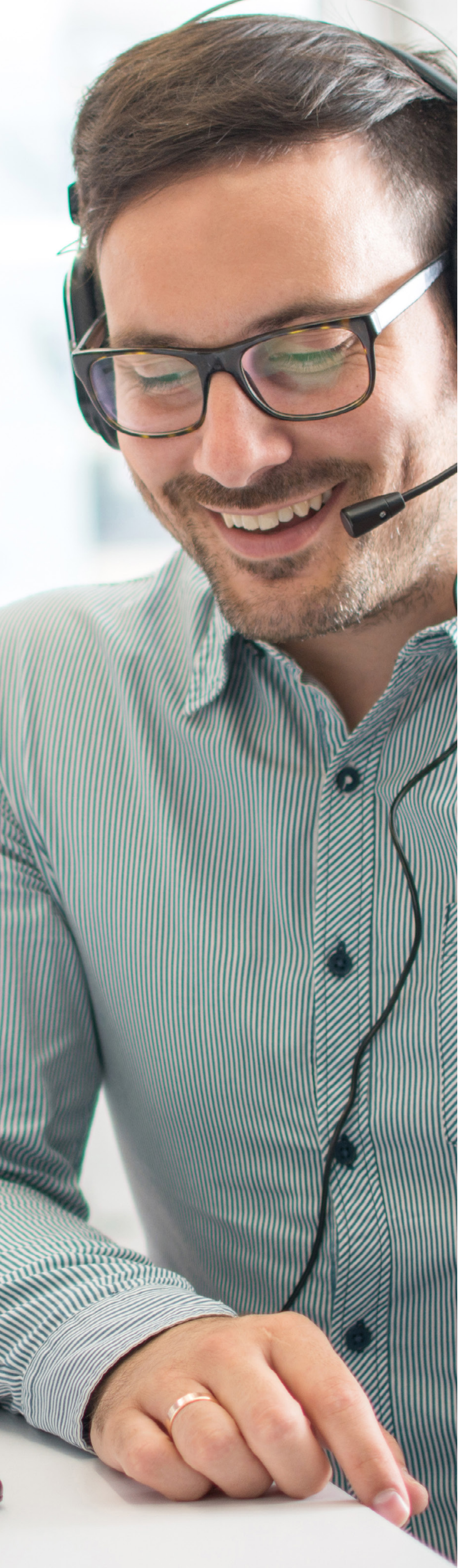

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Introduction:

Augmented reality is a method where real world experiences are enhanced with some digital elements. By superimposing information and images on the real world with the help of a device, a different perception is created. With the growing popularity of mobile devices and advancement in the semiconductor industry, mobile phones, wearable devices, and navigators have become a very efficient platform for running AR functions. Mobile augmented reality can be run on a mobile device as an app or wearable devices can have in-built MAR functionalities.

The future use cases of MAR will require ultra-low latency and extremely high data rates, at an affordable cost. The emerging 5G communication technologies act as critical enablers for future MAR applications to achieve ultra-low latency and extremely high data rates while Multi-access Edge Computing (MEC) brings enhanced computational power closer to the users to complement MAR.

Key differentiator:

a. The key differentiator between 5G and 4G would be 5G's ability to provide infrastructure for interconnectivity and scalability for multiple devices. Data-driven and heavy computation-driven industries require a lot more devices interconnecting reliably and securely than 4G can support. 5G offers higher speeds, less latency, capacity for a larger number of connected devices, less interference and better efficiency over 4G.

b. The key differentiator between edge computing and cloud computing is the latter's ability to perform heavy computing in proximity to the user. MAR-based apps or MAR devices require ultra-low latency in communication between server and user. Additionally, they require real-time data to be processed and cached at a closer distance for faster response to the user.

Use Cases for Mobile Augmented Reality:

Mobile Augmented Reality (MAR) requires running Augmented Reality (AR) on mobile devices. AR gives the user an information-intensive, virtual, and interactive experience while being in the physical environment. MAR allows users to run AR applications on mobile devices with greater mobility and at a lower cost. Additionally, mobile devices provide context-awareness about the user, viz. the location or situation of the user, which can be used to make the MAR experience even more relevant.

Fig 1: Mobile augmented reality devices

Characteristics of Mobile Augmented Reality

- Offloaded processing
- Mobility support
- User friendly form factor
- Limited battery power
- Works in ubiquitous environments

Industrywide use cases of MAR:

a. **Manufacturing and warehouse:** Mobile Augmented Reality can help incorporate vision-picking software into wearable headgear worn by workers. The devices can help with real-time object recognition, barcode reading, indoor navigation, and seamless integration of information with the warehouse management system.

b. **Healthcare:** Mobile Augmented Reality can help doctors and other medical professionals assess the severity of a fracture/wound by pointing a mobile device at it.

c. **Military:** Mobile Augmented Reality can help soldiers visualize enemy formations and build alert mechanisms based on that. Fighter pilots are using MAR enabled helmets which provide a wider range of vision for greater competency.

d. **Tourism:** Mobile Augmented Reality can help a tourist explore a historical building and learn its details by pointing the wearable device at it. MAR can also help a tourist gather information about their local surroundings and identify restaurants, washrooms etc. for better convenience. Netherlands-based "Layar" is one such app.

e. **Learning and Development:** MAR can help students access learning material on-the-go using mobile devices. Additionally, students will learn complex matters with text, image, audio, and 3D models presented together with the help of MAR, rather than reading a book on that subject.

Architecture options of Mobile Augmented Reality:

The architecture options can be broadly categorized into 4 categories viz. Cloud Based, Edge Based, Local and Hybrid, based on the underlying technology, use cases and infrastructure. The Augmented Reality function requires high computational processing. The architecture is identified by whether the AR computation function is hosted on cloud, edge location, local server or a mix of options based on the need.

a. **Cloud based Architecture:** This option follows a client-server model. The mobile/wearable device acts as the client that takes images as input and sends it to the AR server hosted on cloud. The computation intensive work is done in the AR server which processes the image and transfers the augmentations to the client device. The AR server is hosted at a relative long distance from the client's location and accessible by internet.

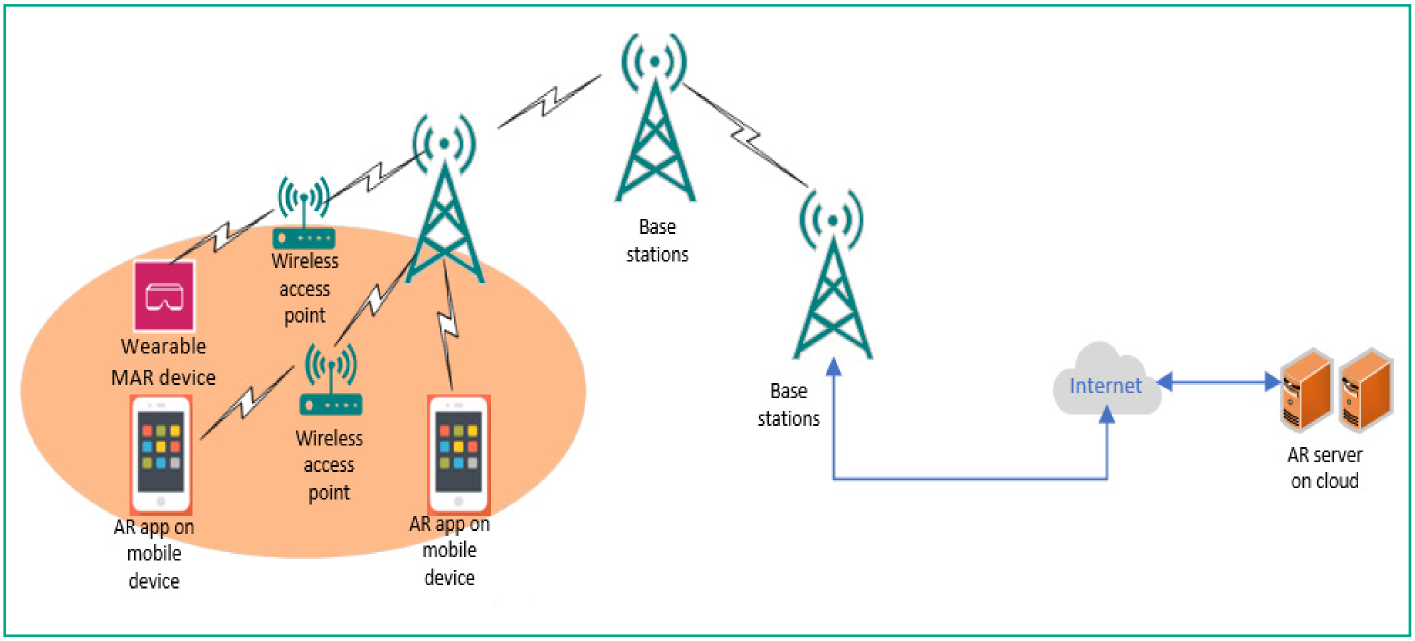


Figure 1a: Cloud based architecture.

b. **Edge based Architecture:** This option also follows the client-server model. The mobile/wearable device captures images and transfers to the AR server. The AR server is hosted on the edge network. The intensive computational work is carried out at the AR server hosted on edge network .

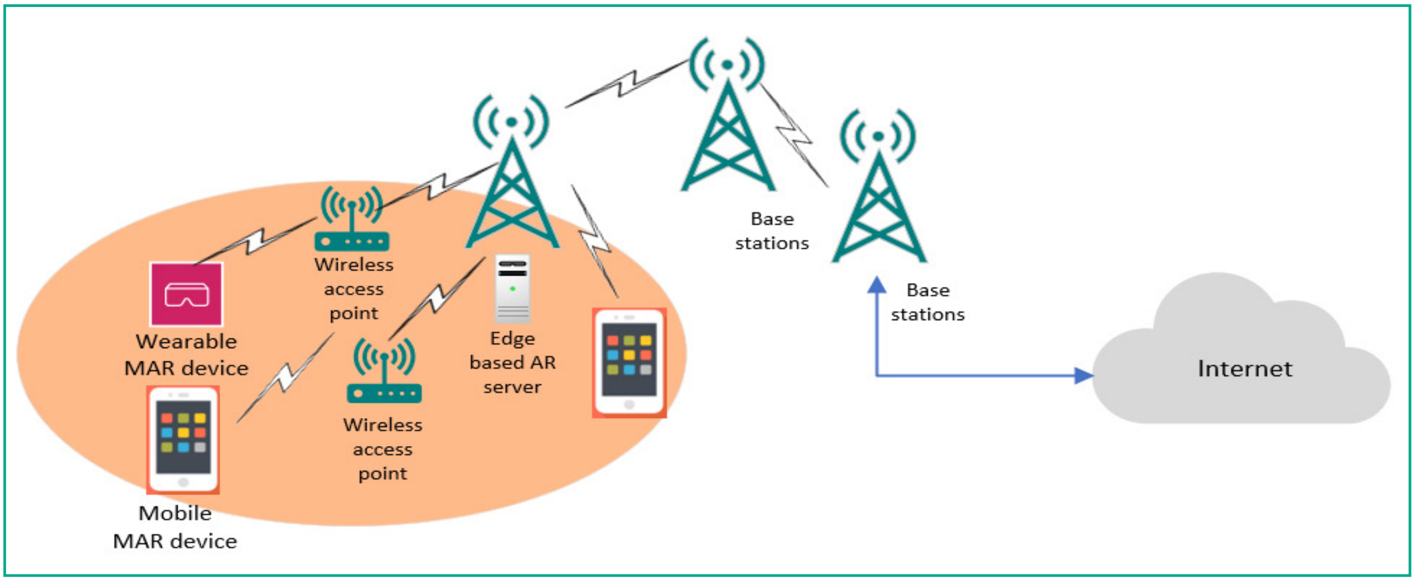


Fig 1b: Edge based architecture

c. **Localized architecture:** This option can be implemented with mobile device and AR server located in proximity. The connectivity between them can be achieved using wireless. It is also possible to transform the mobile device into a MAR server which will process images captured by the same device and render augmentation.

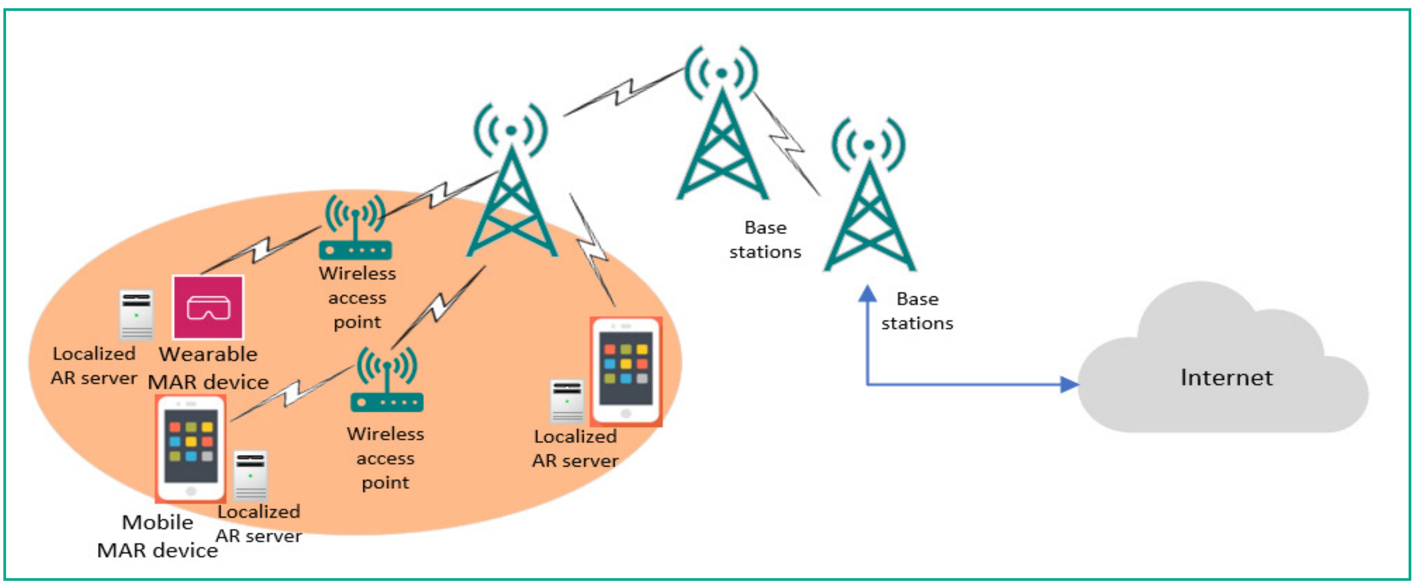


Fig 1c: Localized AR architecture

d. **Hybrid Architecture:** In this model, the AR server is hosted on cloud as well as edge network. Processes requiring low-latency transaction between mobile device and AR server can be made using AR server on edge network. Conversely, processes not requiring that low latency in transaction can be pointed at AR server hosted on cloud.

Comparative study of architecture options:

	Cloud Based	Edge Based	Local	Hybrid
Latency	High Latency	Low Latency	Ultra-low Latency	Low/High Latency depending on use case
Mobile/Wearable devices	Lightweight and high battery life	Lightweight and relatively low battery life	Heavyweight, expensive and short battery file	Lightweight and relatively low battery life
Connectivity	Internet	Ethernet	Wireless/N.A.	Internet/Ethernet
Security	High security risk	Moderate risk	Almost no risk	Depends on use case
Availability	High availability of AR server	High availability of AR server with additional infrastructure cost	Single point of failure	High availability of AR server with additional infrastructure cost against failure
Use cases	Medical training, City sightseeing, Indoor Outdoor navigation	Remote Life support app	Handheld device-based AR applications are used in sports, games, and edutainment	Customizable
Advantages	Mobile devices will do less processing hence it will be more user friendly	• Content caching reduces the E2E latency and congestion in the infrastructure network beyond the edge server. • Higher data privacy due to local caching.	• Ultra-low Latency • Higher data privacy due to local caching.	Customizable

Differentiating factors of Edge Computing from MAR perspective:

Reduced latency: Edge computing architecture reduces latency by shortening the data travel between mobile device and AR server. Low latency is critical for real-time data driven apps. MAR apps related to medical and manufacturing industry usage benefit greatly from low latency.

Operation cost savings: Edge computing helps categorize data based on usefulness. Data can be processed in edge locations which helps limit transmission of non-critical data to cloud server using costly bandwidth. This optimizes the operating cost. It also helps reduce data redundancy by not storing all type of data in the cloud server.

Increased reliability: Edge computing can function with communication channels being slow, intermittently available, or even temporarily down. Processed information can be temporarily stored in edge locations and transferred to cloud servers when connectivity is available.

Limitations of 4G from MAR perspective:

Current requirements for MAR: The present 4G Long Term Evolution (LTE) systems provide decent network bandwidth for MAR devices and apps. Current practical implementations have shown the following performance-related parameter values as necessary.

a. Average downlink and uplink throughput are ~20 Mbps and ~8 Mbps respectively

b. Minimum latency of ~10 ms.

Architecture: Both MAR enabled devices e.g., Google glass, Microsoft holo lens, or MAR app running mobile devices use cloud-based architecture for MAR implementation. They connect to the AR server using Wi-fi or 4G network.

Future requirements: However, the future vision for MAR will require a faster network with mobile devices with more efficient hardware. The next generation of video includes new formats, such as stereoscopic, high dynamic range (HDR), and 360°, at increased resolutions (8K+) and higher framerates (90+ fps).

a. A stereoscopic HDR 360° video used in AR/VR at 8K 90 fps with HEVC video codec requires a data rate higher than 200 Mbps.

b. A 6 Degree of Freedom (6DoF) video that allows translational movement requires a data rate from 200 Mbps to 1 Gbps per user.

c. A 3GPP study on communication services for critical medical applications emphasizes that AR assisted surgery requires E2E latency of less than 1 ms and 12 Gbps data rate for a compressed 4K 120 fps High Dynamic Range (HDR) 10-bit real-time video stream.

These requirements are beyond normal 4G capacity. Additionally, the 4G enabled mobile devices have constrained battery life too.

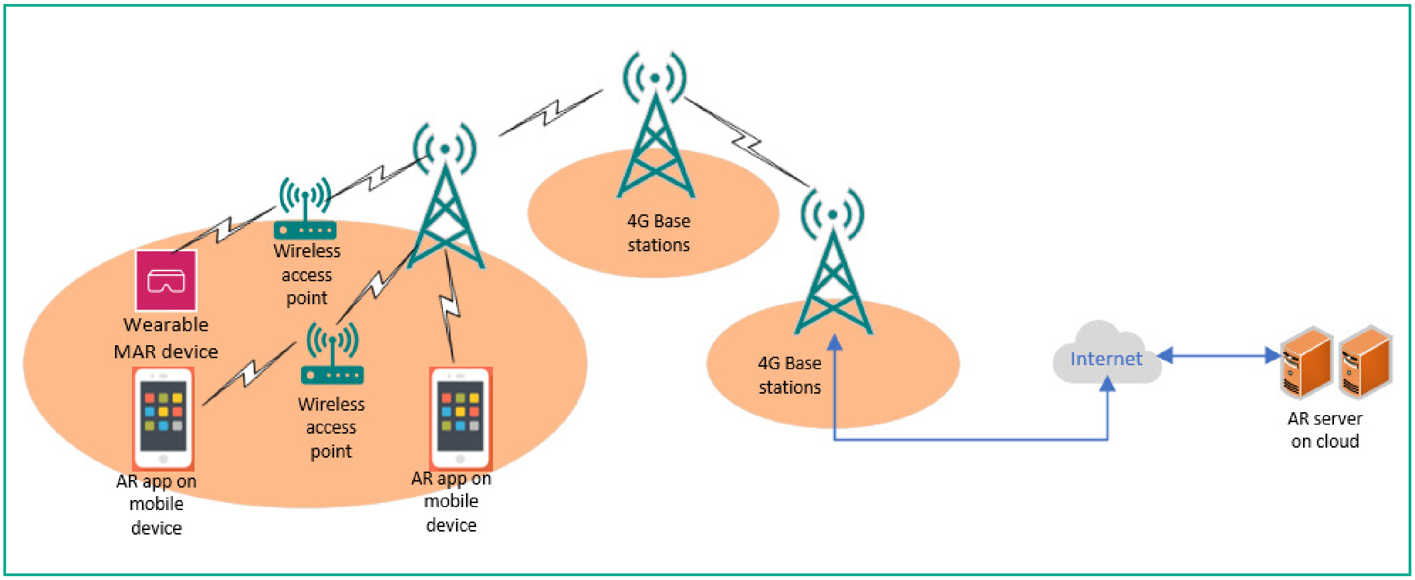
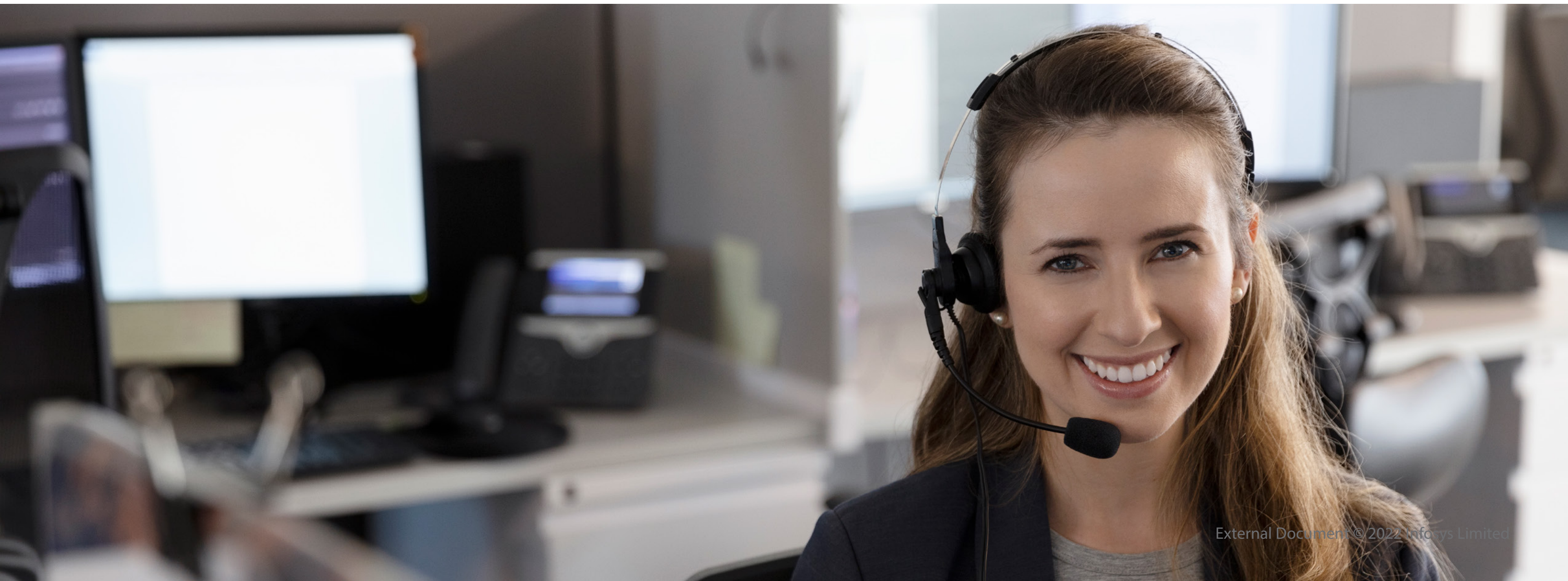


Fig 2: MAR implementation using 4G with cloud architecture



Advantages of 5G over 4G :

5G will be a paradigm shift from present wireless communications technologies. Mobile and wireless communication Enablers for the Twenty-twenty Information Society (METIS) project has described 5G requirements in five technical objectives.

Infrastructure requirements	4G	5G
Latency	60-98 ms	<5 ms
Potential Download speed	1 Gbps	20 Gbps
Cell Density	200-400 users per cell	20k-40k users per cell
OFDM encoding	20 MHz channels	100-800 MHz channels

Important technologies related to 5G:

a. Multiple Input Multiple Output (MIMO): This is a radio antenna technology. Multiple antennas are installed on transmitter and receiver sides to enable multiple signal paths to carry data. These additional paths add robustness to the network and linearly increase the channel throughput.

b. Beamforming : This is a radio frequency technique which directs a signal to a specific receiver. 5G frequencies operate along the millimeter wavelength (mmWave), which are prone to disruption from objects that interfere, such as walls and other barriers. Beamforming helps signal reliability by focusing the signal on a specific receiver.

c. UDN: Ultra dense network contains a greater number of radio resources than regular networks. This kind of network helps increase capacity required for 5G deployment.

The UDN deployment in the 5G era will address the increased throughput and low latency requirements of future applications. The Mobile edge computing (MEC) enables substantial data processing and storage in proximity to user. These 2 technologies complement each other and enable 5G deployment.

Because of the smaller cell radius due to UDN, the data transmission over the network remains short. This leads to increased battery life of mobile devices.

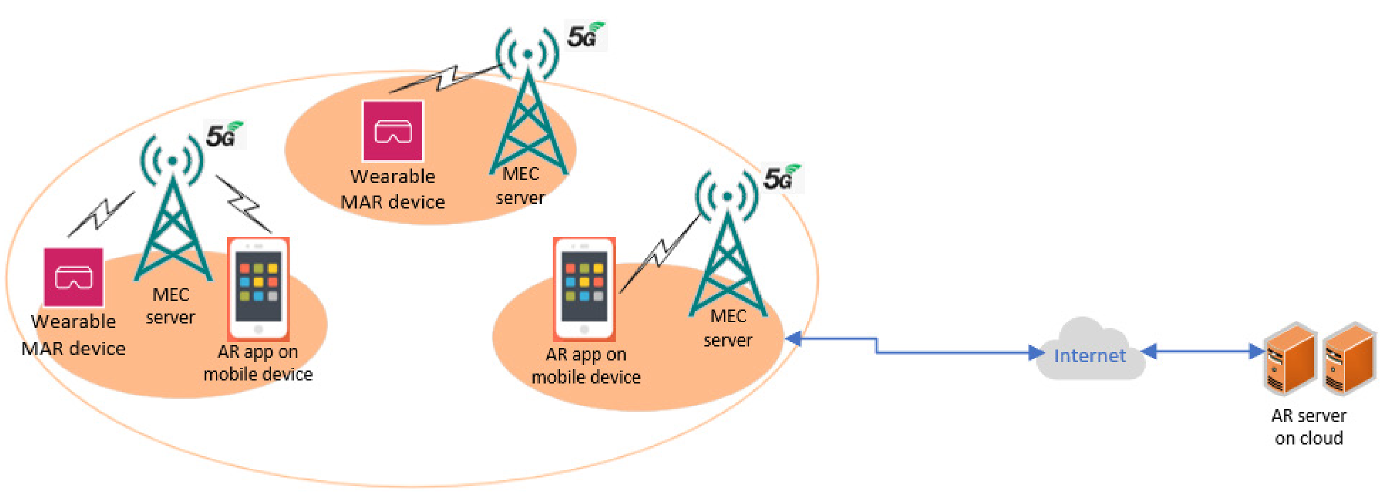


Fig 3: MAR implementation using 5G with edge architecture

Putting the act together (MAR, MEC and 5G):

Since future MAR needs high data rates, ultra-low latency and the possible use of lightweight devices, edge processing on 5G mobile networks is likely to guarantee the requirements of MAR applications.

a. Bandwidth utilization: With the help of edge computing, only summary of processed data or mandatory data may need to go beyond AR server on edge location. This results in efficient bandwidth utilization.

b. Caching: In general, MAR users in each environment request the same data at different points of time. The captured images may consist of overlapping content. Redundant data transfer makes use of network bandwidth inefficient. Caching technique stores the data regularly used at edge AR servers, which significantly improves the processing performance of the MEC server in applications like MAR. Therefore, the MEC architecture with 5G networks will be prominent in satisfying the requirements of future MAR applications.

5G and MEC as differentiator in industrywide use cases

Industry	Use cases	Challenges	Advantages with 5G and MEC
Industry 4.0 is the latest vision to build smart manufacturing industry with the help advanced automation and data exchange. The unison of Internet-of-things, cyber-physical systems, cloud computing, cognitive computing and AI are going to be the enablers for the vision.	a. MAR based remote training to workers in industrial environments b. MAR based remote maintenance work to help semi-skilled workers perform maintenance duty. c. MAR based app for helping workers with assembling parts with instructions	a. Current 4G based MAR services do not support device-to-device communication b. Current devices are heavy and consume a lot of power.	a. MAR can be fully integrated with the IoT infrastructure with 5G systems allowing the integration of IoT into 5G system and MEC enabled IoT, making MAR apps more informative and intelligent. b. Power consumption of devices is lower in 5G with MEC enabled user devices due to process offloading and low power transmissions, allowing the development of more user-friendly devices. Non-functional requirement: Smart manufacturing industry will require high device density due to numerous IoT devices across the facility to collect and transmit data. Massive machine type communication (mMTC) is a feature in 5G that provides scalable and efficient connectivity for a massive number of devices sending very short packets.

Healthcare	a. Assisted surgery with wearable MAR devices. b. MAR based personalized medicine enhanced with eye tracing, speech recognition and motion tracking. c. MAR based medical training . d. Remote surgery or consultation can be facilitated using edge computing.	a. Higher latency in 4G prevents use of edge-based computing to analyze patient data locally. b. Lack of Image clarity due to low 4G network speed. c. Mobile lab deployment is impacted due to low cell density in 4G network	a. AR based solutions addresses the complexity of medical education in the best possible way. To access the educational content using AR from anywhere, MEC enabled 5G UDN would be ideal for server placement and content caching. b. MAR app which uses integration of data from Internet of Medical Things (IoMT) helps with visualization during surgeries by providing enhanced perception for the surgeon. MEC enabled IoT would aggregate the knowledge generated by a vast number of surrounding sensors to facilitate such use cases. Non-functional requirement: Ultra low latency and high reliability of network is required in procedure such as remote surgery. Ultra-Reliable Low Latency Communications (URLLC), a subset of the 5G network architecture, ensures more efficient scheduling of data transfers. The technology enablers of URLLC are '5G New radio', 'Network Slicing' and 'Mobile edge computing'. URLLC supports use cases that require high network reliability, more than 99.999%, and extremely low latency of approximately 1 millisecond for data transmission.
Travel and Tourism	a. The location specific MAR based indoor and outdoor guidance systems to help tourists in parks, museums, libraries, and hotels. The users receive a guided tour with extra information about the place provided to them. b. MAR based translation applications are popular and very helpful for tourists.	a. The users need to point their device at a code to access the AR functionality. This adds a level of dependency. b. There is a performance constraint, based on the movement of the user and his/ her device's network strength.	a. Future AR will take help of lightweight wearable devices viz. glasses to help users navigate more freely. Because of MEC the battery life of mobile devices will also be higher. b. 5G UDN deploys smaller and multiple base stations which provides seamless network strength over a wide area both indoor and outdoor. This enables the user to move from one place to another without bothering about the network. c. XR or extended reality is a futuristic immersive technology which is a mix of AR and VR. XR can add new dimension to travel and tourism industry by enriching tourist experience by manifolds. XR requires caching of virtual content which can be done on MEC servers reducing communication latency. Non-functional requirement: High network speed, bandwidth and mobility is required for securing connectivity of large number of tourists in one place or tourists who are traveling in high-speed vehicles. Enhanced mobile broadband (eMBB) is one of the defining features of 5G which provides enhanced user experience with the help of very high network capacity. Throughput speeds that could eventually be ~20 Gbps when millimeter wave (mmW) frequencies would be available.

Auto industry	a. AR-enhanced windshield displays vital information into the windshield viz. navigation information, current speed, present speed limit and the best possible driving path. This helps driver attain critical information about traffic without manually looking around. b. AR-enhanced driver training with the help of synchronized HMDs allow the trainers to simulate the emergency events during training, making the drivers more experienced before they drive on public roads.	Inter-vehicle communication is still not possible in 4G. Real-time Data from one vehicle to another can help build a system to simulate the traffic condition over an area.	a. Communication between vehicles, pedestrians and roadside devices can help build a robust MAR system. Data sharing solutions to exchange data among vehicles can be implemented with 5G UDN and MEC. With help of that a "see-through" view can be realized which will help drivers see road condition while being at the back of an obstructing vehicle. It can also help drivers become aware of oncoming vehicles which are beyond visual range because of turns or curves. b. Augmenting the text-based traffic signs with driver's preferred language, using the already translated content from cloud/MEC servers and the vehicle GPS data, will help drivers in foreign countries.
Aviation and Aerospace	a. AR based pilot training program helps trainee pilots get accustomed with the flight controls before flying in real, which reduces the chances of accidents. b. Helmets equipped with AR technology helps fighter pilots to view vital information as they maneuver the aircraft.		a. With the integrated information from other flights and air traffic control can alert pilots about potential dangers via the HMDs. The landing and takeoff can be enhanced with the most appropriate path during extreme weather conditions to minimize accidents. b. Passenger movement within airports can be improved using MAR apps to project optimal path towards terminal and locating other airport services. Reliable indoor connectivity provided by 5G UDN deployment can help realize it.

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