



RESEARCH ARTICLE

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UPGRADE INDUSTRIAL COMMUNICATION NETWORK TO ASSIMILATE AUGMENTED REALITY FOR SMART FACTORY USING H265 – BASED EDGE COMPUTING

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ARTICLE INFO

Article History

Received: June 21, 2025

Revised: September 20, 2025

Accepted: November 1, 2025

Published: November 30, 2025

Keywords:

Industry 4.0,
Smart Factory,
Augmented Reality,
Edge Computing,
H265/HEVC

ABSTRACT

Augmented reality (AR) application has the potential to be regarded as one of the newest smart factory applications within the context of industry 4.0. This application is classified as the heavier application in industry 4 from bandwidth consuming points of view. Hence, the excessively high-resolution video streams that are produced by augmented reality causes resources congestion in terms of system capacity. As a consequence, the communication network will suffer extremely to meet the requirements of such applications. This work suggests the H265/HEVC compression technique based on edge computing to assimilation the required data rate. This method contributes in reducing the load on the available bandwidth and decrease the latency. Moreover, this work offers multi scenarios using OMNeT++ regarding AR application with multi compression ratio based on H265 technique. In addition, H265 compression technique has been tested practically on AR data using suitable edge server. Hence, the results demonstrated that the received data reliability improves from 10% in basic scenario to 99% (enhanced network using edge computing) at a compression rate of 10:1 in the proposed scenario with maintaining the AR quality at 42 dB which is considered as a good quality according to the mean opinion score (MOS) criteria. On the other hand, the end-to-end delay for AR application drops from 900 ms in basic scenario to just 8.7 ms at a compression ratio of 10:1 in the proposed scenario.



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I. INTRODUCTION

Industry 4.0 refers to the fourth industrial revolution, which is characterized by the utilization of modern information and communications technology (ICT) to enhance the level of automation and digitalization of production, manufacturing, and industrial processes[1]. However, the management of the complete value chain process, the enhancement of production efficiency, and the generation of high-quality goods and services are the goals of this concept. The term "smart factory" refers to one of the applications created by Industry 4.0, which includes a number of technologies such as: Internet of Things (IoT) for industrial applications which also called industrial IoT (IIoT), big data, cloud computing, edge computing, autonomous robots, and AR [2-4].

AR represents one of the most important applications of the smart factory hence this application connects between the process of integrating digital information with the environment of the user to provide a more immersive experience. The employee of AR encounters a real-world environment with created perceptual information superimposed on top of it, in contrast to the experience of virtual reality (VR), which produces an entirely artificial environment[5]. At the present time, a wide variety of industries are utilizing AR for tasks related to the maintenance, repair, and overhaul of equipment (MRO) or ask an expert to solve the problems. A technician simply needs to point the camera at the machine, electrical wiring, or plumbing, and the system just display the information and video stream that are pertinent to the particular situation on the screen[6]. As a consequence, the quality of the work's highly rises , see Figure 1 [7].



Figure 1: AR in industry 4.0, hand of engineer holding mobile smart phone using virtual AR to check the work of electric machine in smart factory.

Source: Authors, (2025).

As AR uses high-resolution cameras, which generates video stream at high bit rate resulting in the communications network becoming flooded and its resources may be blocked, so to solve this issue, either high-capacity communication technologies are utilized, which considering as an expensive solution[8]. However, another solution may be more effective in terms of cost such as edge computing that is utilized to process the application data near to the source rather than sending it to the cloud for processing. This work suggests an enhanced industrial communication network for AR application using H.265 compression technique based on edge computing.

In addition, this paper offers scenarios based on different compression rate to improve the performance of the industrial network with addressing an accepted data accuracy to handle the requirements of the AR application. The structure of this paper is divided into six sections, in addition to an introduction, section two presents an overview of the previous related works. Section three provides an explanation of the data compression based on the edge computing. Whilst, research methodology has been explained in section four; Section five presents and discusses the results. Finally, the most important conclusions have been concluded in section six.

II. RELATED WORKS

There are many researchers who presented different works in this field, some of them have been reviewed in this section. The authors in [9] have designed an architecture for AR Edge Computing that moves AR tasks that need a lot of processing power from end devices to a powerful edge server. The results showed that a 50ms latency between sending, tracking, annotating, and receiving a 752×480 compressed video frame is fine, but it's still a problem for head-mounted displays (HMDs). To make things even better, the paper suggested that future work should focus on building communication technologies with higher bandwidth and lower latencies. The work [10] presented an architecture for the implementation of edge computing in IoT-based manufacturing, enabling the incorporation of edge computing capabilities into manufacturing processes.

The authors conducted a practical case study that illustrated the execution of active maintenance utilizing a prototype platform-based edge computing. it illustrated the benefits of edge computing in enhancing operational agility and optimizing bandwidth, demonstrating its efficacy in a practical manufacturing environment. The authors in[11] examined a system for augmented reality (AR) that transfers the computing tasks to an Edge server. This approach reduced the constraints of mobile devices in executing complex augmented reality tasks, including three-dimensional mapping, position estimation, and rendering. The authors demonstrated that their implementation achieved competitive performance with an end-to-end latency of approximately 85 ms, significantly reducing energy usage by an average of 50% and increasing available computational resources by a factor of 10 to 100. An architecture that incorporates edge computing into cloud environments for optimized storage and low-latency video streaming has been introduced in [12].

The authors utilized video transcoding and adaption techniques to accommodate diverse network conditions and user preferences, thereby improving the overall quality of video streaming. The results demonstrated a latency reduction of up to 25% and a storage consumption decrease of up to 15%, confirming the efficiency of the suggested edge computing methodology. The paper[13] developed a complete architecture that combines Time-Sensitive Networking (TSN) and Edge Computing to address the specific requirements of IIoT applications, especially in crucial industries such as healthcare and manufacturing. The authors offered many solutions for increasing network performance, including the deployment of Edge Computing nodes to minimize latency and enhance data processing efficiency. it delineated particular simulation scenarios to evaluate the proposed solutions under diverse network situations. This empirical method yielded significant data regarding the impact of various configurations on performance parameters like as latency, jitter, and channel efficiency.

III. DATA COMPRESSION TECHNIQUES BASED ON EDGE COMPUTING

IIoT devices generate enormous amounts of raw data that may exceed the capacity of the traditional cloud computing paradigm. This means that the majority of IIoT data will be consumed at the network edge rather than being transferred to the cloud. On the other hand, the cloud computing model may be insufficient for many reasons. For instance, the volume of data at the edge is excessive, using significant bandwidth and computational resources unnecessary. Moreover, the necessity for privacy protection obstructs cloud computing in IIoT. Therefore, the edge computing concept have been emerged to handle the mentioned cases. It can be described as the model that optimizes cloud computing systems by processing data close to its source at the edge of the network. It enables technologies to processing and storage resources in close proximity to the data source, primarily near the network's edge [14-16]. See Figure 2.

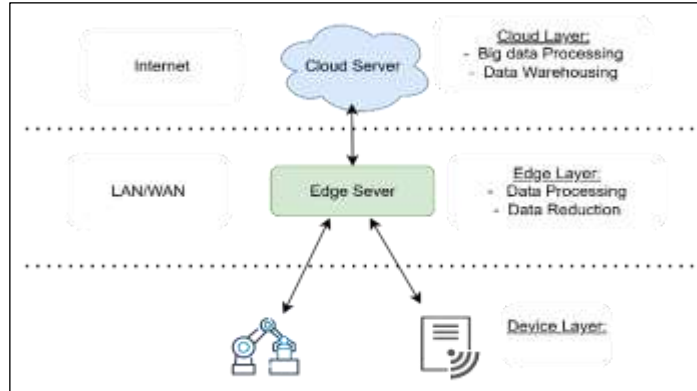


Figure 2: Edge Computing Concept.
Source: Authors, (2025).

However, the edge computing can be offered some benefits such as reduced latency, bandwidth optimization, improved reliability, and enhanced security and privacy. In this context, one of the methods that could be engaged with edge computing is the technique of data compression to improve the behavior of the systems. Data compressions include many types where the most common type of data compression is video compression. Video compression techniques have been designed to remove unnecessary and redundant data from a raw video stream in order to ensure that the coded video stream that is obtained is stored or transmitted over a network in the most effective manner feasible. During the process of encoding, redundant data is removed by the application of specified algorithms. The amount of time that is required to accomplish this task is referred to as encoding latency, and it is primarily utilized in live broadcasting. The term "decoding" refers to the act of replicating the encoded video in a manner that is as close as its raw form[17]. Figure 3 illustrate the block diagram of video compression.

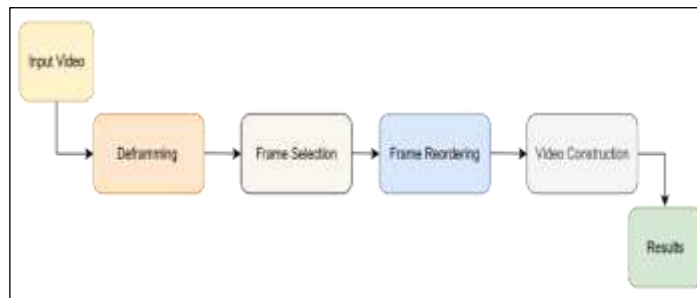


Figure 3: Video Compression Block Diagram.
Source: Authors, (2025).

Different video coding standards have been proposed to guarantee interoperability and broad usage. Commonly used video compression standards consist of VP9, AV1, H.264/AVC, and H.265/HEVC. By defining the parameters and principles for video compression, these standards guarantee compatibility across many platforms and devices[18]. As the demand for high-definition video material continues to rise, streaming services can take advantage of H.265/HEVC to deliver videos of a better quality while maintaining bandwidths that are reasonable, this will improve the user experience while also lowering the costs of data transmission[19]. H.265 is the successor to the H.264 codec, which was specifically developed through the collaborative efforts of ISO/IEC and ITU-T in H.264 encoding. The compression ratio of H.265 surpasses that of H.264 by up to 50%, resulting in its widespread applicability in many domains[20]. Despite the advantages of compression techniques based on edge computing, they still display drawbacks, especially the processing time for compression and encoding, which is estimated of 20 milliseconds per megapixel at a compression ratio of 50:1. Figure 4 represents the block diagram of HEVC encoder[21].

III.1 QUALITY MEASUREMENT OF COMPRESSION TECHNIQUE

Several metrics are taken into consideration in order to evaluate the performance of compression technique [13] which include:

Compression Ratio (CR): This ratio shows the percentage of AR data that has been resized relative to its original size. It can be calculated by dividing the uncompressed size by the compressed size. A higher compression ratio indicates greater compression efficiency.

$$CR = \frac{\text{Uncompressed Size}}{\text{Compressed Size}} \tag{1}$$

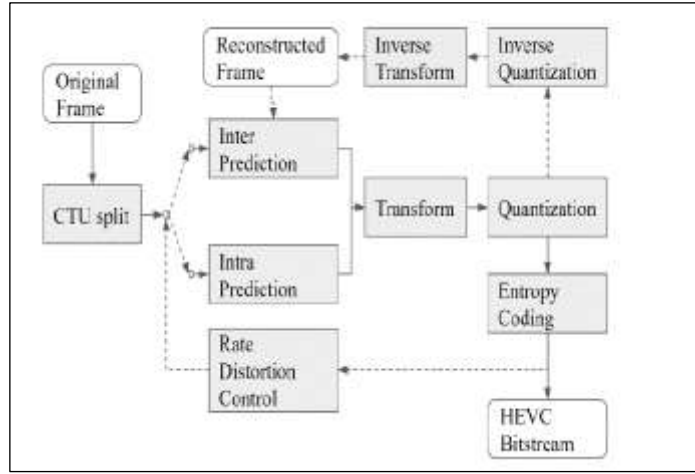


Figure 4: HEVC Encoder Block Diagram.
Source: Authors, (2025).

Peak Signal-to-Noise Ratio (PSNR): The quality of the compressed AR data is a critical factor to consider. Various metrics, such as PSNR, can be utilized to evaluate the similarity between the original and compressed versions. Elevated PSNR values signify superior quality.

$$PSNR = \frac{10\text{Log}((max)^2)}{MSE} \tag{2}$$

max: maximum possible pixel value, MSE: is the mean squared error between the pixel values of the uncompressed and compressed video versions.

Bitrate: represents the volume of processed or sent data within a specified time. It is generally measured in (bps). In video compression, a higher bitrate indicates an increased volume of data utilized to represent the video, leading to better quality but also larger file sizes. A reduced bit rate decreases data consumption, perhaps compromising quality while yielding smaller file sizes.

IV. MEHODS AND MATERIALS

IV.1 MODEL DESCRIPTION

The model which has been proposed in this paper addressing an industrial case which deals with an augmented reality application for the purpose of maintenance and requesting remote support. There are two main parts in such model, the first represents the machine operator in a manufacturing environment, who tries to get advice and recommendations to maintain the machine and fix problems. The expert, who is located in a location that is remote from the operator, is the representative of the second one, after receiving the data from the operator, the expert will provide an advice and recommendations then send back them to the machine operator. The two parties are connected by a wired network. In addition, the edge computing has been suggested to process data close to the source to minimize latency and maximize the utilization of available bandwidth. Table 1 demonstrates the model assumptions.

Table 1: Model Description.

Item	Description
Operator Side	The operator is responsible for capturing a video that sending it with an information to AR receiver (expert). This is accomplished by directing a device with high-resolution camera toward the machine under operation.
Communication Network	In order to send AR application data from the source to the destination, a wired network that is comprised of switches and ethernet cables is utilized.
Edge Computing Server	AR experience is provided to users by edge computing, which should be a server with high performance to receive the video stream that has been sent by the operator, processing the data, using video compression algorithms, and then transmitting it to the network.
Expert Side	An expert displays the AR stream by a PC or tablet, writes notes, draw annotations and gives the appropriate recommendations, then sends these notes back to the edge computing, which processes and delivers them to the operator side to be presented by display device.

Source: Authors, (2025).

Figure 5 shows the general architecture of the support system while Figure 6 explains the flow chart of system methodology.

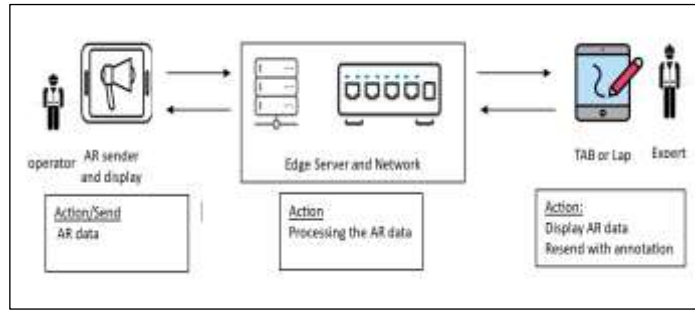


Figure 5: The suggested System Architecture.
Source: Authors, (2025).

IV.2 ADOPTED SCENARIOS AND THE ASSUMPTIONS

IV.2.1 BASIC SCENARIO

The network scenarios have been designed using the OMNET++ simulation due to flexibility and suitable frameworks for industrial models. The basic scenario of the model is shown in Figure 7, it comprises of an AR sender, a device with high resolution camera that transmits video streams via a wired Ethernet network to a remote server, which subsequently forwards the data to an AR receiver. The concept of edge computing has not been used in this Scenario. Table 2 summarizes the assumptions of the basic model.

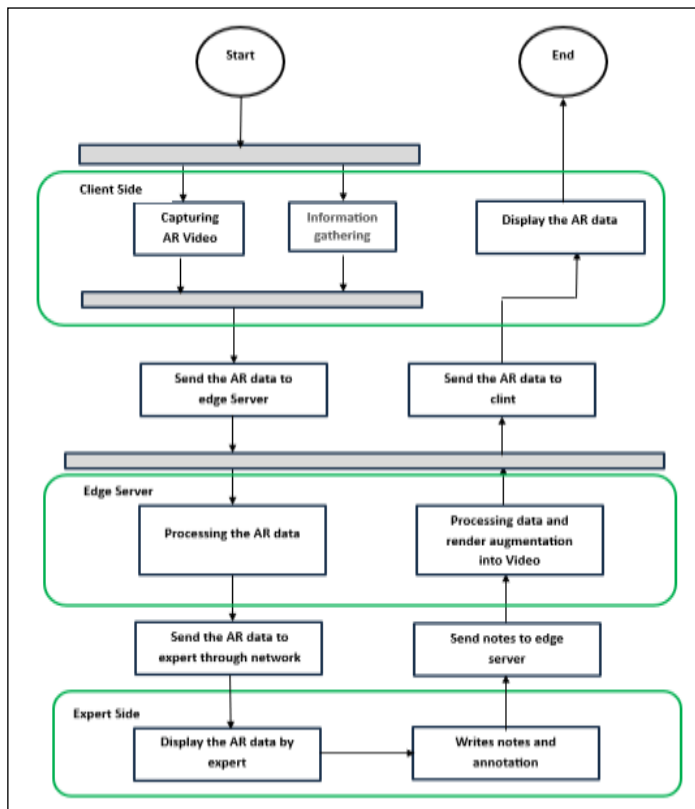


Figure 6: The Flowchart of Methodology.
Source: Authors, (2025).

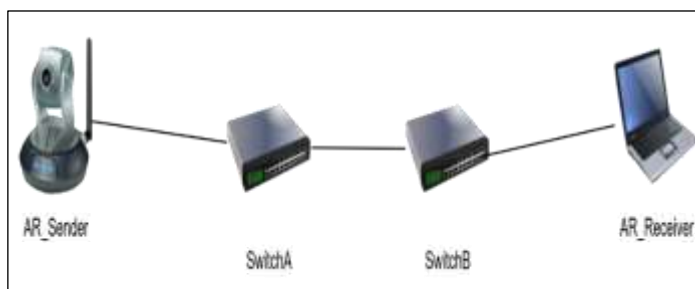


Figure 7 Basic Scenario of Model.
Source: Authors, (2025).

Table 2: Model Assumptions.

Asumption	Value
Work area	100m * 100m
Camera Resolution (HD) For AR sender	1920 * 1080 PPF*, 20 FPS**, RGB*** (24 bit for colures)
Raw data of video stream	~ 995 Mbps
Network Devices	Ethernet Switch 4 ports
Link Type	Eth100Mbps
Simulation Time	1 s

Source: Authors, (2025).

*PPF: Pixel Per Frame, **FPS: Frame Per Second, ***RGB: Red Green Blue

IV.2.2 ENHANCED SCENARIO

This scenario exploits the edge computing to process data proximate to its source, utilizing video compression techniques to minimize data size and facilitate transmission within the existing network resources. Figure 8 represents the proposed scenario of model. In this case, the H265/HEVC compression technique has been utilized in the edge server in this scenario to compress the data stream generated by the AR application. Firstly, it is vital to address the tradeoff between the compression rate and the accuracy [13]. In this context and to handle the AR application requirements, the Hand Break Software [22] has been used to compress video-based AR with same specifications of AR video in order to determine the compression ratio of H265 in a practicable and accurate manner. For instance, to evaluate the quality of the compressed video, another software [23] has been used to calculate the PSNR value of the video after compression process then interrupting this value with the MOS value, which is regarded as a metric of the quality of service, as illustrated in Figure 9. Figure 10 represents the flow chart for enhanced scenario.

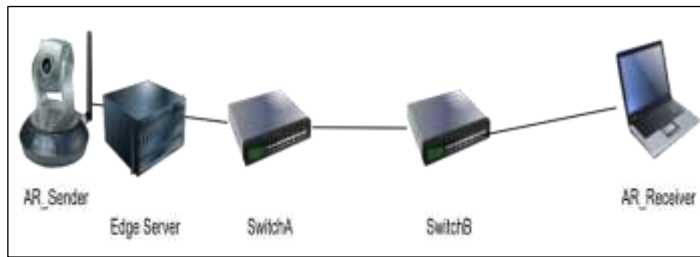


Figure 8: Enhanced Scenario of Model.

Source: Authors, (2025).

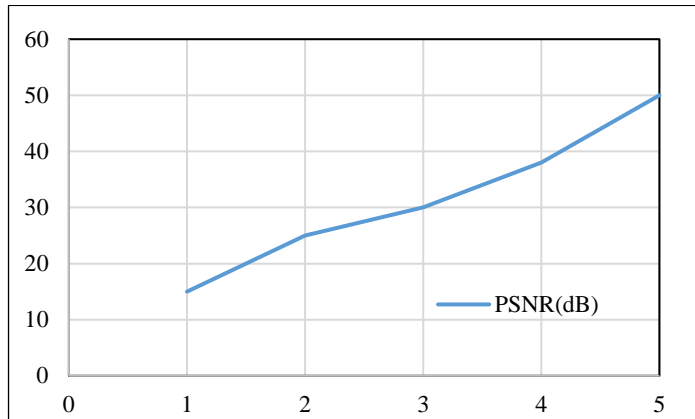


Figure 9: MOS and PSNR Relationship.

Source: [18].

However, the specifications of the adopted edge server that are exploited to compress the data of AR are CPU Intel Core i9, 64 – bit OS (Operating System), 32 GB RAM, Oracle VM VirtualBox, Linux guest, Ubuntu 20, 60 GB dynamically allocated Storage, OMNeT++ 5.6 ver., and INET Framework 4.1.

IV.2.3 UPGRADE SCENARIO

This scenario offers upgrading the network infrastructure from the cable capability point of view. It can be enabling the AR application to send massive amounts of raw data. In this scenario, the link data rate of the basic has been increased from 100 Mbps to 1 Gbps.

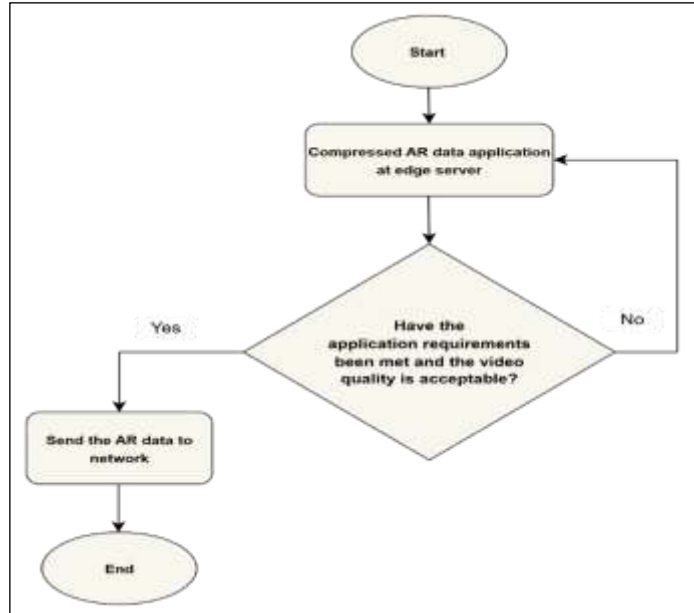


Figure 10: The Flow Chart of Enhanced Scenario.
Source: Authors, (2025).

V. RESULTS AND DISCUSSIONS

In terms of the basic scenario, the results of the generated and received traffic for the AR application, as well as end to end delay have been shown in Figure 11 and Figure 12 respectively. Regarding Figure 11, the amount of sent traffic is approximately equal to 1000 Mbps at 1 second of simulation time. However, it is noticed that the amount of received traffic hits to 98.9 Mbps near to network bandwidth limitation, which leads to loss most of the sent traffic, as the percentage of 90% due to limited available bandwidth.

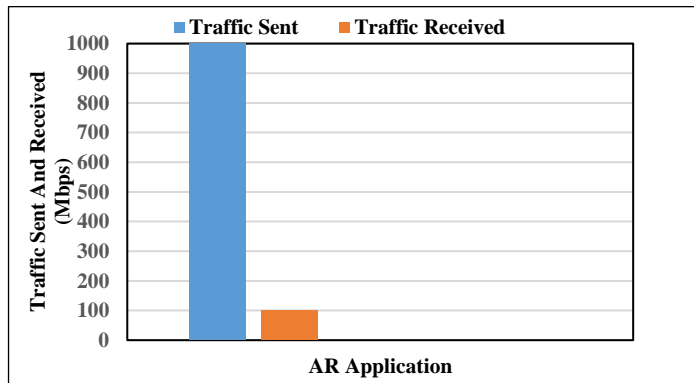


Figure 11: Traffic Sent and Received for AR Application in Basic Scenario.
Source: Authors, (2025).

On the other hand, the end-to-end delay time which shown in Figure 12 reaches to 900 ms at a simulation time of 1 second, which breaks the requirements of semi real time of AR application, this is due to the inability of the network to send all data as mentioned before, which leads to an increase in the waiting time in the queue and it causes bytes lost.

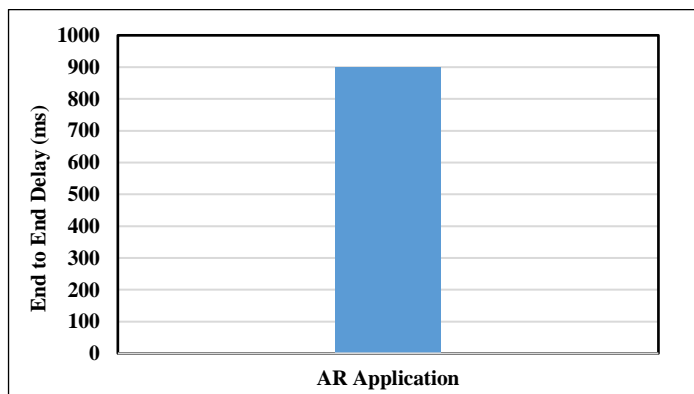


Figure 12: End to End Delay for AR Application in Basic Scenario.
Source: Authors, (2025).

In terms of the enhanced scenario, the results of compressing AR data in a manufacturing environment with the mentioned software earlier [16] explained a notable enhancement. As illustrated in Figure 13, that the ratio of received traffic at AR_Receiver to sent traffic from edge server (Received Data Reliability RDR%) increased from 20% at a compression rate of 2:1 to 99% at a compression rate of 10:1. This enhancement arises from a reduction in bit rate due to video compression, hence enhancing the network's ability to transmit all traffic to the destination.

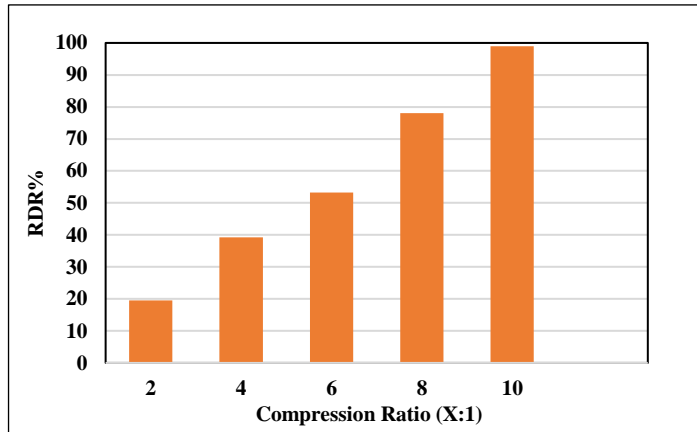


Figure 13: RDR% for AR Application in Edge Computing Scenario at Compression Ratio (2:1,4:1,6:1,8:1,10:1).
Source: Authors, (2025).

The end-to-end delay which has been illustrated in Figure 14, indicating a substantial improvement, as it decreased from 804 ms at a compression ratio of 2:1 to 8.7 ms at a compression ratio of 10:1. This enhancement is related to the AR compact size and the network's ability to transmit data with little latency. The compressed AR data has been analyzed using MSU Video quality measurement [17]. It measures the quality of AR data after compression. The PSNR value for the compressed AR data has been calculated at the rate of 10:1 which was approximately 40 db, and through the relationship between PSNR and MOS which shown in Figure 9, this value indicates good quality of service where MOS.

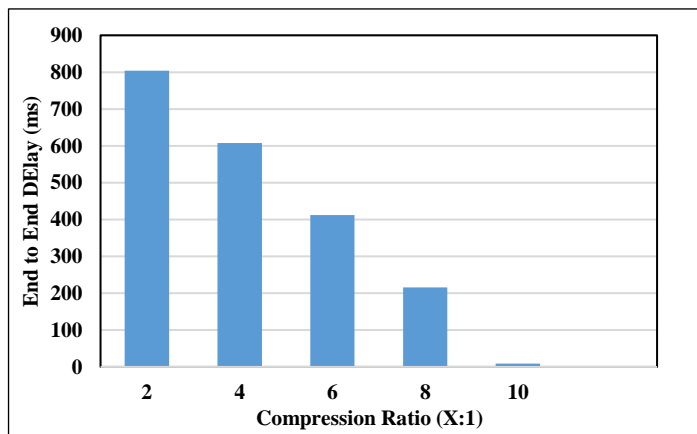


Figure 14: End to End Delay for AR Application in Edge Computing Scenario at Compression Ratio (2:1,4:1,6:1,8:1,10:1).
Source: Authors, (2025).

Equal to 3.8. Figure 15 (a and b) represents a sample of AR before and after compression. Noting that it is possible to lower the size of AR data by increasing the compression ratio, but this will make processing take longer and be more complicated, as well as decrease the level of service quality.



(a)



(b)

Figure 15: AR Video Sample (a) Before Compression (b) After Compression.

Source: Authors, (2025).

Finally, the scenario's results of upgraded scenario demonstrates that the traffic sent and received are approximately equal as noted in Figure 16 so, RDR % has been increased to 99. On the other hand, the delay time, has been shown in Figure 17-, as noticed that the delay decreased dramatically to about 0.37 ms. This is due to the high ability of the network to transfer data quickly and without delay, but this solution comes at the expense of cost and time, especially when the network is large in size.

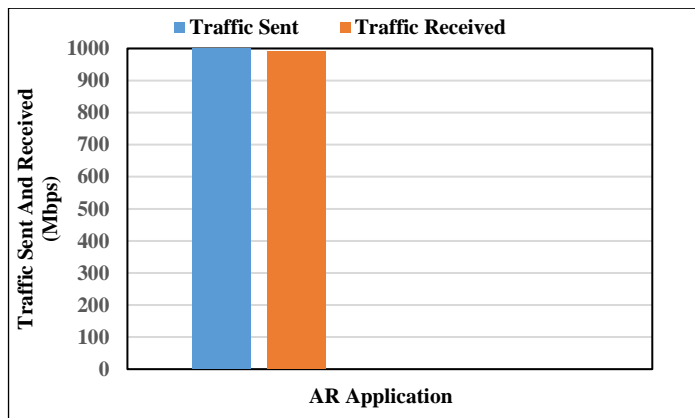


Figure 16: Traffic Sent and Received for AR Application in Upgrade Scenario at 1 Gbps.

Source: Authors, (2025).

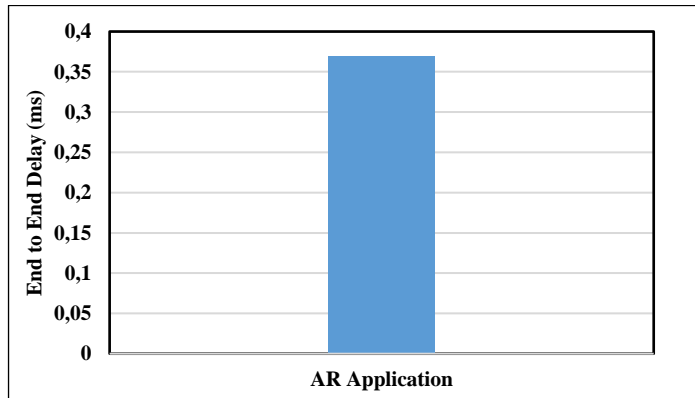


Figure 17: End to End Delay for AR Application in Upgrade Scenario at 1 Gbps.

Source: Authors, (2025).

VI. CONCLUSIONS

The paper presented a comprehensive approach to enhancing communication networks for Augmented Reality (AR) applications within the scope of Industry 4.0 by integrating edge computing with video compression techniques. It demonstrated that traditional network infrastructures face significant challenges when handling high-resolution video streams regarding AR applications, leading to bandwidth saturation and increased latency. The results indicated that implementing edge computing alongside H.265/HEVC compression technology could drastically improve the efficiency of data transmission by increasing in the ratio of received to sent traffic from 10% in the basic scenario to 99% for enhanced scenario. Moreover, the end-to-end delay has been reduced from 900 ms to just 8.7 ms. Furthermore, upgrading the existing network infrastructure to support higher bandwidth has been also explored in the upgrade scenario. However, the results of upgrade scenario could improve the performance of the system with more cost. Overall, the integration of edge computing and advanced video compression techniques represents a viable solution for optimizing AR applications in smart

factories, facilitating enhanced operational efficiency and improved user experiences. The future work aims to exploit these findings to develop the model in terms of scalability and the impact of diverse industrial environments on performance metrics.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Yazen S. Sheet and Firas S. Alsharbaty.

Methodology: Yazen S. Sheet.

Investigation: Yazen S. Sheet and Firas S. Alsharbaty.

Discussion of results: Yazen S. Sheet and Firas S. Alsharbaty.

Writing – Original Draft: Yazen S. Sheet.

Writing – Review and Editing: Yazen S. Sheet, Firas S. Alsharbaty and Mohammed Younis Thanoun

Resources: Yazen S. Sheet.

Supervision: Firas S. Alsharbaty and Mohammed Younis Thanoun.

Approval of the final text: Yazen S. Sheet, Firas S. Alsharbaty and Mohammed Younis Thanoun

VIII. ACKNOWLEDGMENTS

The authors would like to express their gratitude to the University of Mosul, College of Engineering, Department of Electrical, for providing the necessary facilities that contributed to enhancing the quality of this paper.

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