What is Edge Computing?

Paul Loftus  
Department Of Computing  
South Eastern Technological UniversityCarlow, Ireland  
paulloftus20@yahoo.com

# ***With the advent of the Internet of Things (IoT) devices during the last few years and real-time demand for data processing has made fast development inevitable even in our computing paradigms as well. Cloud computing has so far been the dominant model for computing data, also the advantage gap between this and centralized computation is too great to ignore. Edge computing has poured into this breach as one alternative way of addressing both hardware placements on the network. This article examines the trend developing in edge computing because of new chips enabling it. Combined with cloud computing: Feature 1: Low (bad) Latency. is a characteristic of edge computing Feature 2: Security. You can cut down the number of ports that need to be open if you combine cloud computing with edge computing. Feature 3: Optimize Bandwidth Usage. By working in concert with the cloud infrastructure, edge computing devices provide a dual benefit, saving bandwidth and at the same time enhancing service quality. Finally, we predict a potential convergence--in several different types or degrees--of edge and cloud computing.***

# Introduction

Cloud computing has really changed how businesses and individuals handle data. With data centres located all over, cloud services offer flexible computing resources that can grow with your needs. However, as we see a growing demand for real-time processing—especially in areas like self-driving cars, industrial IoT, and augmented reality—cloud computing starts to show its limits in terms of latency and bandwidth.

That’s where edge computing comes in. By moving processing closer to where the data is generated, it reduces our dependence on faraway cloud servers. This not only improves performance but also cuts down on delays, making it ideal for applications that need to act quickly. In this paper, we’ll explore the rise of edge computing, how it works alongside cloud computing, its benefits and challenges, and what the future might look like.

# Edge Computing vs Cloud Computing

## Overview Of Cloud Computing

Cloud computing relies on remote data centres to deliver computing services such as storage, processing, and networking over the internet. Key characteristics include:

* **Centralized Processing:** Data is transmitted to and processed in large-scale data centres.
* **Scalability:** Resources can be dynamically allocated based on demand.
* **Cost Efficiency:** Reduces the need for on-premises infrastructure.

However, cloud computing faces challenges such as:

* **Latency:** Data must travel long distances over an internet connection to reach cloud servers, causing delays.
* **Bandwidth Constraints:** Transmitting large volumes of data (e.g., from IoT devices) can be expensive and inefficient.
* **Security and Privacy Risks:** Centralized data storage increases vulnerability to breaches.

## Overview of Edge Computing

Edge computing moves processing to the "edge" of the network—closer to devices generating data. Key features include:

* **Decentralized Processing:** Computation occurs locally on edge devices or nearby servers.
* **Reduced Latency:** Faster response times for real-time applications.
* **Bandwidth Optimization:** Only relevant data is sent to the cloud, reducing network load.

Edge computing is particularly beneficial for:

* **Autonomous Vehicles:** Requires instant decision-making to avoid accidents.
* **Smart Cities:** Enables real-time traffic and surveillance monitoring.
* **Healthcare IoT:** Supports remote patient monitoring with minimal delay.

# Advantages of edge Computing

I will go over all the advantages that edge computing could bring to the industry in terms of the field today and what it is capable of overall.

## Latency

By processing data locally, edge computing minimizes the delay caused by transmitting data to distant cloud servers. This is critical for applications like industrial automation and gaming.

In a large amount of cloud systems, bringing the processing of the data closer to the actual device would increase performance in both safety features and latency tests. Devices like Autonomous vehicles especially would benefit from edge computing as the response times to things like detected crashes, intoxicated or dangerous drivers could increase, with seconds meaning the difference between life and death for someone behind the wheel of a device such as it.

With real time traffic and surveillance monitoring, local authorities could utilize the speed of these systems to catch criminals faster and more efficiently. They could comb through large datasets in a manner never seen before, upgrading their capabilities to stop criminal acts. Even the healthcare system currently in place in a lot of countries could benefit from edge computing to increase response time to incidents in patient monitoring. Many healthcare providers began having to monitor patients remotely, especially after the pandemic to keep the patient safe but also attempt to stay in touch and contact with patients that required observation. With edge computing, this could make the results and alerts that healthcare providers receive become much more instantaneous, allowing them to respond in a timely manner.

## Improved Privacy and Security

Sensitive data can be processed locally instead of being transmitted to the cloud, and then processed, reducing exposure to cyber threats. With sensitive data being processed locally, the businesses using these services can better secure their sensitive data and in the event of something like a data breach or cyber hack on the cloud platform, Important information can be kept safe from breaches.

## Bandwidth Efficiency

Edge devices filter and process data before sending only essential information to the cloud. Instead of blocks of data being sent over an internet connection, some larger than gigabytes, the data can be pruned, and only pertinent information will be pushed to the cloud platform. This in turn would decrease upload time for services like databases and web servers and overall decrease the amount of traffic on a network. According to a 2022 Cisco Study, edge-based filtering reduced bandwidth usage by 40-60% in IoT deployments [15]. This shows that the efficiency computing brings to industry would allow businesses to spend less on internet connectivity bills and focus more on their other aspects of the business. This alone is very appealing to executives around the world.

Edge devices can even prioritize what data should be sent, in a process known as Selective Data Transmission. This can be used in a plethora of ways like critical alerts having priority to be sent, while things like logs can be batched and uploaded at a normal pace. The filtering and processing of data can also take things like metadata from videos (License Plate Recognition) and upload the needed information without having to upload the entire video, adding even more size to the upload.

Another example of bandwidth efficiency can be even found in the healthcare industry where things like ECG Patches and heart monitors can analyze data locally and only upload alerts to clinicians when there are abnormal patterns.

## Offline Capabilities

Unlike cloud-dependent systems, edge devices can operate autonomously even with intermittent connectivity. The problem with many industries is that their facility locations can be in places where internet connectivity can be lacking, intermittent and unreliable in general. Using Edge devices can combat this in many ways. Edge devices can do the processing that a cloud dependent system would have done, on site without having to upload to the cloud platform/provider.

For data that has to be uploaded to the cloud, with the edge device, it can queue the data to be uploaded so that when a connection fails, it doesn’t put a halt to the system as it still has access to the data, but can be stored securely when the connection to the cloud system is reliable enough to send. Edge devices can also be configured to switch to alternative local networks so that if one connection fails, another can attempt to ensure constant access, adding redundancy to a cloud system which was never really seen before. A study by IBM found that edge computing reduces downtime by 30% in remote industrial sites[10].

Use cases of this technology can already be found in real world examples, like the oil industry. There are offshore oil rigs that use edge servers to locally monitor their equipment’s health in real time, so that the surveillance of their systems and equipment is not reliant on satellite links. This redundancy is another advantage that increases the likelihood of edge computing becoming a large part of the industry.

One more great example of this technology being a huge benefit would be in Disaster Response systems, like earthquake sensors, tsunami alerts, and more. In situations where these systems are active, there is a large congestion of network traffic on cellular networks and depending on the environment, these networks could be unusable due to the destruction caused by these events. In this situation, having edge devices could be a major benefit to the safety of many people by allowing these important systems to function locally even with environmental barriers.

# Challenges of edge computing

Despite the many advantages of edge computing I stated above, no problem in this world comes problem-free. And I will dive into these challenges that the concept of edge computing represents and brings with it into the industry in these next sections.

## Resource And Storage Limitations

Unlike cloud computing data centers, edge computing devices will not have the same processing power or speed that these titans will have. This means slower processing and having the inability to run complex algorithms and machine learning like it normally would in a cloud system.

Trying to find a trade off between performance and cost is also difficult as high performance edge servers from companies like NVIDIA can be very expensive but the alternative like Raspberry Pi’s would have no where near the resources or power to meet application demands of complex systems, especially in industries like healthcare, oil and gas.

Another major problem with edge devices is that they won’t have the same size storage as a cloud data rack. The size of the edge routers storage will decide how frequently uploads to the main server will be required to ensure there is always space to process local data. This can be a tricky calculation to do as you then have to find the perfect threshold of space and cost. Things like recent data regulations(GDPR) also mandate long term storage of sensitive data which can be troublesome on an edge device with very limited storage, meaning engineers would have to find a work around or purchase larger storage units for these edge devices to meet legislation requirements.

## Complex Management Infrastructure

Deploying and maintaining distributed edge infrastructure can be more complex than centralized cloud systems.

## Security Concerns

While edge computing reduces some risks, it also introduces new vulnerabilities, such as physical tampering with edge devices.

As many edge devices can be deployed in locations that aren’t exactly high security, e.g., street corners, factories, public stores, this can open up these devices to a whole number of vulnerabilities. Many of these devices will be exposed for anyone to possibly come and attempt to get into these devices, and with a physical connection to it, some can simply plug in and access the server. Even with authentication policies implemented, brute forcing would not be as hard as one might think when the threat actor could have hours alone with the device before anyone recognizes somethings going on.

Another problem could be device tampering, which can go completely unnoticed. Malicious actors could physically compromise and device and even preform attacks like Man-In-The-Middle attacks, thus becoming apart of the network and sniffing data from the devices themselves. Devices like these can also be low power/resource, meaning they simply don’t have the capabilities to run high level robust encryption techniques like SHA or DES. Even the National Institute of Standards and Technology reported that 60% of edge systems used outdated encryption

With all these notes above, there is an increased cost and requirement in securing these devices, adding real time security monitoring and proper configuration which can add major costs to the setup of these devices.

# *V.* tHE fUTURE OF EDGE COMPUTING

#### Rather than replacing cloud computing, edge computing is evolving into a hybrid model where edge and cloud systems work together:

#### **Fog Computing:** An intermediate layer between edge and cloud that provides additional processing capabilities.

With fog computing, it would act as an intermediate layer between edge devices and cloud data centers. This is a solution from both cloud systems and edge systems, where fog computing would leverage local fog nodes, to provide distributed processing, tiered data handling and low latency decision making. It would also allow companies to increase the power and security of these devices as they could have them in nearby secure locations rather than out in public where threat actors could attempt to access them for malicious purposes. Some key use cases would be in smart cities, healthcare and retail, where these industries could use fog nodes to fix some of the challenges I mentioned above.

#### **AI at the Edge:** Machine learning models are increasingly deployed on edge devices for real-time analytics.

Running local lightweight machine learning models directly on edge devices, training models across distributed edge nodes, and allowing these models to analyze real time analytics could enable instant decisions in applications like autonomous driving, train models without centralized data collection and reduce latency, bandwidth costs and privacy risks across whole systems

# *VI.* Conclusion

Edge computing isn't just another tech buzzword—it's solving real problems that cloud computing can't handle alone. By processing data right where it's created, we're seeing tangible improvements in speed, cost savings, and reliability across industries. But let's be honest: it's not all smooth sailing. Device limitations, security headaches, and complex deployments still keep many IT teams up at night.

What's really exciting is how three game-changing technologies are taking edge computing to the next level:

Fog Computing acts like a neighborhood hub—close enough for quick access but powerful enough to handle what small edge devices can't. It's the missing link that's making smart factories and cities actually work.

AI on Devices means your warehouse robots and hospital monitors can make smart decisions without waiting for a cloud server. The catch? Squeezing complex algorithms into small, energy-efficient chips remains a tough engineering challenge.

5G's Speed Boost is finally making wireless edge computing viable. Imagine surgeons controlling robots remotely or self-driving cars reacting instantly—this is where 5G and edge computing become life-changing, not just convenient.

The big picture? We're moving toward a world where computing happens everywhere—from factory floors to traffic lights to your smartwatch—without everything bottlenecking at distant data centers. But before we get there, we need to solve some hard problems:

How do we manage thousands of edge devices without going crazy?

Can we keep these systems secure when they're physically exposed?

Who's going to pay for all this infrastructure?

One thing's certain: as IoT devices multiply and real-time automation becomes the norm, edge computing will keep evolving from a "nice-to-have" to the backbone of our digital world. The companies that crack these challenges first will define the next decade of tech innovation.

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