

Edge Computing vs Cloud Computing: A Comparative Analysis

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Abstract: *Today, a lot of devices across the world are connected to the internet, from smartwatches to machines in factories. Handling all the data these devices make has become a problem. For a time, cloud computing has been the solution people turn to. It processes data in huge data centres that are far away. As more devices get online and applications need to respond faster, cloud computing is not always enough. This is where edge computing comes in. Edge computing processes data right where it is made, on machines or devices that are close by. This paper compares both methods in terms of performance. We look at how they work, where each one is better, and where they do not work well. We also look at examples from areas like healthcare, manufacturing in factories, and smart cities. Our main finding is that neither method is always better. The right choice depends on what the application needs. In some cases, using both cloud computing and edge computing together works best.*

Keywords: Edge Computing, Cloud Computing, IoT, Latency, Distributed Systems, Fog Computing, Hybrid Architecture, Real-Time Processing, Scalability, Network Bandwidth

1. Introduction

Over the last twenty years or so, the way we're storing and processing data has come on in leaps and bounds. When cloud computing first came on the scene, companies had to shell out big bucks for their own servers, which were a nightmare to manage and keep running. But cloud computing – as its name suggests– changed all that by letting businesses buy computing power and storage over the internet. The likes of Amazon Web Services, Microsoft's Azure, and Google Cloud Platform have made it dead easy and cost-effective to run applications, without having to own any physical infrastructure to go with it [1].

But with all these new devices connecting up, all sorts of new headaches have started popping up. The rapid growth of IoT devices has significantly increased the amount of data generated across networks and cloud systems [2]. Sending all that data to a remote cloud server away takes time– sometimes too much. For self-driving cars, surgery or monitoring a factory in real-time, even a tiny delay can cause big problems. Also, sending raw data to the cloud uses a lot of internet bandwidth and can be costly.

Edge computing is a solution. It helps by processing data where it is created. This can be on a server near the device, on a local gateway or even on the device itself. As a result, responses get faster. The network load also gets reduced. The edge computing market was worth \$23.65 billion in 2024. It is expected to grow to \$327.79 billion by 2033 [3]. This shows just how fast edge computing is spreading its wings.

This paper discusses cloud computing and edge computing in detail. It breaks down the differences between these two types of computing in areas that really matter, looks at real-world examples of cloud and edge computing in action, and tries to provide a glimpse of what the future might hold for these technologies. Here is an overview of what the paper covers: Section II looks back at what other researchers have been saying about these topics. Section III provides the details of

how each system works. Then, in Section IV, we put them right up against each other and compare them head-to-head. Section V looks at some practical real-world examples that show cloud and edge computing in action. Section VI get into some of the ideas behind hybrid models—the best of both worlds. Section VII tries to figure out what the future trends might be, and finally, Section VIII wraps up the discussion to conclude the paper.

2. Literature Review

Many researchers have studied both cloud computing and edge computing over the years. This section summarizes some of the most important findings.

2.1 Research on Cloud Computing

Mell and Grance [4] from NIST wrote one of the most widely used definitions of cloud computing. They described it using five key features: you can use it on demand, it works over a network, resources are shared, it can grow or shrink quickly, and usage is tracked and billed. This definition helped set the direction for a lot of cloud research.

Armbrust et al. [5] explained how cloud computing changed the world of IT by making it possible to run huge workloads without owning physical servers. But they also pointed out problems like data lock-in (being stuck with one provider), unpredictable performance, and concerns about security and availability.

Botta et al. [6] looked at how cloud computing connects with IoT devices. They found that when all IoT data goes to the cloud, it creates traffic jams on the network and causes delays that are too slow for real-time applications.

2.2 Research on Edge Computing

Shi et al. [7] were among the first to formally describe edge computing. They said that for IoT applications that need

millisecond-level responses, processing data at the network edge is not just useful- it is necessary. They also explained the difference between mobile edge computing (MEC), cloudlets, and fog computing.

Satyanarayanan [8] traced the history of edge computing from older ideas like content delivery networks (CDNs) and cloudlets. He argued that the closer you are to the data source, the better your system performs- especially for things like augmented reality or health monitoring.

Dolui and Datta [9] compared fog computing and edge computing and found that edge computing performs better for tasks done directly on or near devices, while fog computing is more flexible in placing computing nodes across the network.

2.3 Research on Hybrid and Combined Models

Liu et al. [10] showed that when edge and cloud work together, they can reduce both delay and energy use at the same time. Their work helped establish the idea of tiered or layered computing architectures.

Khan et al. [11] focused on security in edge computing. They found that because edge devices are spread out and physically accessible, they are harder to secure than a centralized cloud. They recommended using lightweight security tools designed for low-power edge devices.

All of this research shows that neither cloud nor edge computing is perfect on its own. The best solution depends on the specific needs of each application- something this paper explores in detail.

3. Fundamentals of Cloud and Edge Computing

3.1 Cloud Computing: How It Works

In simple terms, cloud computing means using computers and storage that someone else owns and manages, and accessing them through the internet. You do not need to buy a server- you just rent the computing power you need and pay for what you use [4].

Cloud services come in three main forms. **Infrastructure as a Service (IaaS)** gives you virtual machines and storage, like renting a computer. **Platform as a Service (PaaS)** gives you tools and environments to build your own software, without worrying about the hardware. **Software as a Service (SaaS)** gives you ready-to-use applications like Gmail or Microsoft Office 365. Cloud systems can be public (shared by many users), private (only for one organisation), or hybrid (a mix of both).

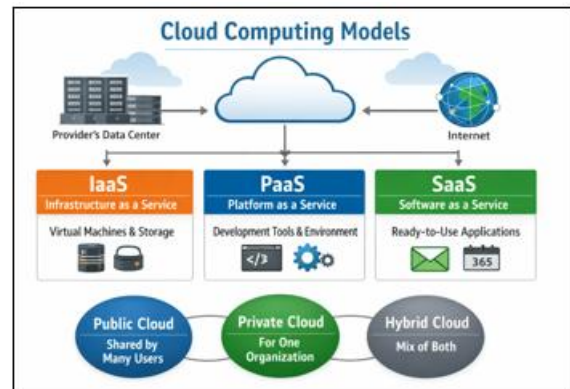


Figure: Cloud Computing Models

3.2 Edge Computing: How It Works

Edge computing processes data near the source, instead of sending it far away. Think of it like this: rather than cooking in a central kitchen far away and delivering the food, you cook it right where people are eating- it's faster and fresher.

An edge computing setup usually has three layers. At the bottom are the **devices**- sensors, cameras and smartphones. In the middle is the **edge layer**- small local servers, gateways or routers that process data quickly. At the top is the **cloud layer**, which stores long-term data and handles heavy analysis [7]. Fog computing (by Cisco) and Mobile Edge Computing, or MEC (by ETSI), are two well-known versions of this idea.

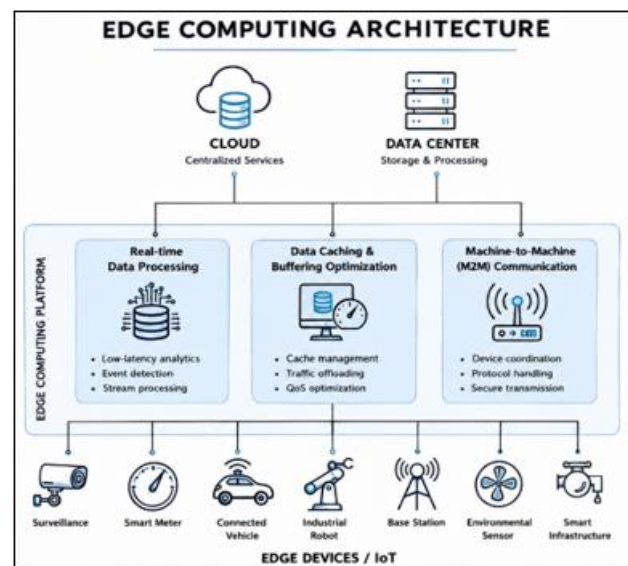


Figure: Edge Computing Architecture

4. Comparative Analysis

This section compares edge and cloud computing across eight important areas. Table I gives a quick overview, and the sections below explain each area in more detail.

Table I: Comparative Analysis of Edge Computing vs Cloud Computing

Parameter	Edge Computing	Cloud Computing
Latency	Very low (1–10 ms); suitable for real-time tasks	Higher (50–200 ms); depends on network distance
Scalability	Limited by local hardware resources	Almost unlimited; resources can be added quickly
Cost	High initial hardware cost; reduces data transfer expenses	Pay-as-you-go model; cost increases with usage
Security	Data remains local; remote updates can be difficult	Centralized security management with established frameworks
Reliability	Can operate even without internet connectivity	Requires internet; providers offer high uptime availability
Data Privacy	High privacy since data is processed locally	Data moves to remote servers; compliance measures required
Energy Use	Varies; small devices may consume more energy per task	Efficient at scale; many providers use green energy
Maintenance	Difficult due to distributed device management	Easier maintenance handled by service providers

Source: Compiled from existing literature and industry reports (2021–2024)

4.1 Latency and Real-Time Processing

Latency is basically the amount of time it takes for data to get from your device to a server and back. Edge computing tends to be super-fast - you're looking at 1 to 10 milliseconds, because the data's got a pretty short distance to traverse. In contrast, cloud computing tends to be slower, typically taking around 50 to 200 milliseconds since the data has to travel all the way to some distant data centre [7]. To be honest, this speed difference usually doesn't make a huge difference in everyday activities like loading a website. But when you're talking about something as critical as a self-driving car that's got to respond in a split second, even 50 milliseconds becomes a potentially major risk.

4.2 Scalability and Resource Capacity

Scalability means how easily a system can grow when you need more computing power. Cloud computing is very strong here- providers like AWS and Azure can give you more resources within seconds, handling everything from a small app to a global service with millions of users [5]. Edge computing is more limited- if you need more capacity, you have to physically install more hardware, which takes time and money. A combined edge-cloud setup handles this well: edge handles the fast, local work while the cloud handles large-scale processing.

4.3 Security and Data Privacy

Security is tricky for both systems, but in different ways. With edge computing, your data stays in one place- it never leaves your building or device, which is great for privacy. This is especially important under laws like GDPR in Europe or

PDPB in India. However, managing the security of many spread-out edge devices is hard- they are easier to physically tamper with and harder to update with security patches [11]. Cloud providers, on the other hand, have large security teams and are certified under standards like ISO 27001. If a cloud provider is attacked, though, many organisations can be affected at once.

4.4 Cost Analysis

Cloud computing is cheaper to get started with because you do not buy any hardware- you just pay monthly based on usage. But as you use more data and storage, the bills can add up quickly, especially for IoT applications that generate huge amounts of data [3]. Edge computing costs more upfront because you have to buy local servers and equipment. However, it can save money in the long run by reducing how much data you send to the cloud. The best approach depends on your specific usage- organisations should carefully calculate the total cost over time before deciding.

5. Real-World Case Studies

5.1 Smart Manufacturing- Siemens and Edge AI

Siemens uses edge computing at its Amberg electronics factory in Germany to check product quality in real time. Cameras on the production line take pictures of each component, and a local edge computer analyses those images immediately- in under 10 milliseconds- to spot defects. If the system had to send those images to the cloud and wait for a response, it would be far too slow. As a result, the factory keeps its defect rate below 11.5 parts per million. This example shows how edge computing is a great fit for situations where you need instant decisions and generate large amounts of data that would be expensive to transmit continuously.

5.2 Healthcare- Remote Patient Monitoring

During the COVID-19 pandemic, hospitals actually found a way to make use of a combination of edge and cloud computing in order to check in on patients remotely. They used wearable devices to track things like heart rate and blood oxygen levels, and a small device near the patient would look over the data to see if there were any red flags. Only the really important stuff got sent up to the hospital's cloud system for the docs to go over, and as a result, they managed to cut back on the amount of data they were sending by over 80%. This worked out just fine because it still allowed them to get to alerts in real time, and they were also able to stay on the right side of health data privacy regulations- stuff like HIPAA [12].

5.3 Retail Analytics- Amazon Go

Amazon Go stores are another example of how edge computing can be really useful. Instead of using traditional checkouts, they use hundreds of cameras and sensors to keep track of what customers are grabbing off the shelves, then just automatically charge their accounts for it. Keep in mind that each store generates over a terabyte of data per hour—way too much to get uploaded to the cloud and processed in time for a real-time checkout [3]. So, what they end up doing is

mostly processing that data on local edge servers right inside the store. They still use the cloud for things like managing stock levels and training up their AI models, though. This setup actually works out really well since it allows them to get customers in and out in record time, while letting the cloud handle those more low-key jobs like keeping an eye on stock and training up their AI.

5.3 Autonomous Vehicles- Tesla and NVIDIA DRIVE

Self-driving cars offer a prime example of why edge computing really makes a difference. A Tesla churns out a whopping 25 gigabytes of data each hour from cameras, radar, and all those sensors. The idea of sending all that out to the cloud and then waiting for a driving decision to come back just doesn't cut it—the lag would be potentially deadly [8]. Tesla's onboard computer does all the live thinking right in the car. Meanwhile, the cloud is only used for things like software updates and map updates, as well as learning from all the data that gets collected from the entire Tesla fleet. This is edge and cloud doing their thing in perfect harmony.

6. Hybrid Edge-Cloud Architecture

Rather than having to choose between edge computing and cloud computing, most modern systems opt to use both together. This setup is called a **hybrid architecture**, and it makes a lot of sense. The idea is straightforward enough: handle the speedy stuff on the edge, while sending whatever needs to go the distance to the cloud to store, scrutinise, or make it available worldwide.

Take a smart traffic system that makes, for instance, use of edge devices at each traffic light to make spontaneous decisions (like flipping green or red) while the cloud is gathering info from the entire metropolis to get traffic flowing a little better in the long run. Both the edge and the cloud are doing what they do best after all.

As you might expect, major cloud players have already built tools that support this kind of hybrid approach. AWS Outposts brings Amazon's cloud services right to your doorstep. While Azure Arc lets you get a handle on both edge and cloud systems from one single place. Meanwhile, Google Anthos does the same but with cloud providers other than just Google [10]. All of this shows that the tech industry has already started to seriously consider hybrid as the go-to way to build systems.

7. Future Scope

7.1 AI at the Edge (TinyML and Federated Learning)

One area that's really starting to get interesting is putting artificial intelligence straight onto small edge devices. TinyML lets you run AI on tiny little chips like the ones found in sensors that use virtually zero power and memory—basically, learning a tiny brain inside a tiny device that can spot patterns without needing to phone home to a central server. Federated learning is another trick up the sleeve—where loads of local devices can train AI models all at the same time, and only the intel (not the raw data itself) gets sent

off to a central server. This means you can keep your data private while still upping the AI's game.

7.2 5G and Network Slicing

5G mobile networks are going to take edge computing and give it a major speed boost. With speeds of up to 20Gbps and latency that's measured in milliseconds rather than seconds, 5G makes all sorts of new applications possible - like surgeons being able to control AR glasses in real time or cars talking to each other on the road to avoid accidents. And Multi-access Edge Computing (MEC) at 5G base stations means you'll be getting computing power right next to where the action is happening—literally on the user's doorstep.

7.3 Serverless Edge Computing

Serverless computing comes down to this: you write your code and run it without having to worry about servers—a big plus for your sanity. Now, platforms like AWS Lambda@Edge and Cloudflare Workers are taking this concept and moving it right to the edge—literally. Developers can write code and deploy it to servers all around the world, and users automatically get routed to the nearest one, giving them super-fast responses without you having to lift a finger to manage the whole shebang.

7.4 Sustainable and Green Computing

As more and more computing gets pushed to the edge, one thing that becomes a major concern is energy use. Future research is taking a close look at how to keep those edge devices running efficiently—so they don't guzzle power like a teenager at a video game tournament—and how to power them with renewable energy. Plus, smarter scheduling of tasks so they run during the times when clean energy is actually available—that way we're keeping growth in the computing space as environmentally friendly as possible.

8. Conclusion

This paper weighed and compared edge computing and cloud computing against each other across several key areas. In simple terms, **cloud computing** is essentially the full package: powerful, scalable and a great fit for large-scale analytics, storage and global applications. **Edge computing**, on the other hand, is all about being super-fast and private. It's really the best option whenever you need to make quick decisions or keep data right where it is.

Truth is, there's no one-size-fits-all choice. A self-driving car can't rely on the cloud for making split-second driving decisions, but it does find the cloud useful for software updates and enabling the whole fleet to learn together. A hospital wearable keeps sensitive health data safe by storing it locally at the edge, but uses the cloud for medical records storage and large-scale data analysis.

The real-world approach, as it's done today, is a hybrid model. That's just a polite way of saying edge and cloud side by side: edge doing what it's good at, and the cloud doing the same. No surprise that major cloud providers like AWS, Azure and Google already have products out the door to make this

happen. Future technologies like 5G, TinyML and federated learning are just going to push forward on this.

The main point is that your architecture needs to be custom-tailored to fit your specific application needs. Think about how fast you need to get information, the type of data you're working with, how quickly it is being generated and where it's coming from, data privacy restrictions, and what your budget is. All these factors will help you figure out the best possible balance of edge and cloud solutions for your particular situation.

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