EDGE COMPUTING TECHNOLOGIES IN NEW IOT ENVIRONMENTS

A Technical Review document on an emerging IoT area by:

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***Abstract*—** Advances in long-range, short-range and personal area wireless networks and technologies have enlarged the frontiers of IoT applications in fields like transport and logistics, agriculture, environment, utilities, smart cities, industrial processes and smart building. Up until the explosion in the massive deployment and use of IoT applications in recent years, many businesses and organizations have had to leverage the use of cloud computing for cheaper, more flexible, scalable and efficient means to process and store data. But as the adoption of Internet of Things (IoT), a major contributor to the fourth industrial revolution, becomes more prevalent across different industries and enterprises, the shortcomings in the use of Cloud computing for IoT-related services and applications are becoming obvious. Many new IoT applications and services require real-time analytics, low latency, stringent data privacy regulations. To overcome these constraints, smart systems and intelligent devices that will handle computations in 'cloud computing' style near the source of data are now being deployed at the edge of networks. This novel approach, known as Edge computing, is driving a trend that shifts some of the functions of centralized cloud computing to edge devices at the perimeter of networks. Several edge computing technologies originating from different backgrounds to support massive machine type of communication have been emerging since 2017. This technical review will examine the concept Integrated Edge computing as it relates to the IoT, benefits and use cases of edge computing, current implementation of Edge computing by some Native Cloud giants (AWS, Google and Microsoft) and finally, challenges of edge computing integration with IoT

I. INTRODUCTION

For many decades, Cloud computing has continued to revolutionize the ways and manner in which IT resources are provisioned and consumed. This is due to its high agility, flexibility, excellent data storage capacity and cost efficiency. Cloud architecture was also easily adapted to handle compute, storage and analytics for Internet of things (a new revolution that gives capabilities to certain endpoints like sensors, actuators, embedded systems or smart devices, enabling them to be connected to network, communicate and exchange data). However, emerging IoT applications and use cases are driving demand for a new kind of agile, modular and cost-friendly IoT architecture to handle the processing of explosive IoT data generation , analysis and some real-time analytics. According to a report by Cisco Systems, by 2019, 45% of the data created in IoT will be stored, processed, analyzed and acted upon close to, or at the edge of the network and about 50 billion devices will connect to the Internet by 2020 [1]So, it's no longer efficient and cost effective to process vast amounts of data by moving them from edge networks to cloud data center. Because emerging IoT use cases and new applications are characterized by low latency, privacy and security, resilience, network scalability and and strict regulatory compliance, a new approach to IoT data storage, processing and real-time analysis is required. The integration of Edge computing and IoT has been emerged as a potential solution. Fundamentally, the idea of edge computing is to do time-sensitive analytics at the edge of networks but retain resource-intensive processing at the Cloud. Edge devices or gateways will send non real-time and time-sensitive data to the Cloud for storage or further processing. This scenario thus implies that smart devices and gateways used in IoT implementation must have computational and intelligent capabilities and must be able to integrate with some modular machine learning or AI models without necessarily depending on the Cloud.

II. INTEGRATED EDGE COMPUTING AND IOT

For a better insight into the need for edge computing one must consider the current explosive growth in IoT systems and applications and the fact that this will continue in the coming years. IoT has increased the number of endpoints and devices in our regular networks. This situation has made it more difficult to aggregate and process massive data from these devices in any one single data point, thus giving rise to the use of "edge computing." Edge computing is a new kind of coordinated or distributed computing where processing and storing of data takes place on smart devices which are close to the network.

As an aspect of IoT, Edge computing has the capability to enhance certain IoT services like processing and analyzing of IoT data, management and control of IoT devices and other auxiliary networking functions. Advances in embedded systems, based on System-on-a-Chip (SoC) architectures, have enabled the development of many commercial smart edge devices that are powerful enough to run operating systems and complex algorithms [2]. These devices are powered by small form factor hardware with flash-storage arrays that provide highly optimized performance [3]. The benefits offered by these processors include low power and better hardware security. These characteristics enable them to collect data at network's edge in real time and to process those data for some actionable processes or hand off to other higher-level computing environments. Top segments that have adopted edge computing are manufacturing, smart cities and transportation, then followed by closely by energy, healthcare and smart homes.

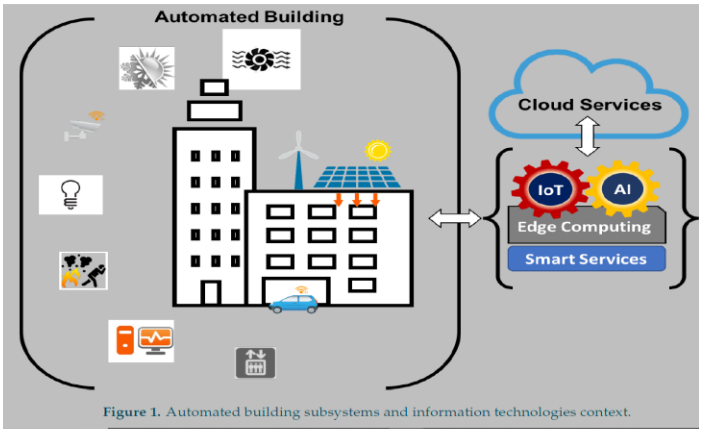

Figure 1.0: Edge computing stack.
source - www.mdpi.com/2071-1050/10/11/3832/pdf

Figure 1.0 shows how edge computing, integrated with the IoT and AI models, is used in a automated building.

Oftentimes, people confuse edge computing and fog computing to mean the same thing. Though both concepts are similar since they both involve data source being close to the point of processing power and intelligence, the actual difference is in the location of these key metrics. In Fog computing the centralized system on a local area network coordinates with smart gateways and other embedded computer systems. This means intelligence resides within the Local Area Network. Edge computing, on the other hand, places intelligence or processing power directly on the edge computing platforms. A few of such devices include HPE Edgeline converged edge system, embedded automation controllers and IBM's Watson IoT analytics.

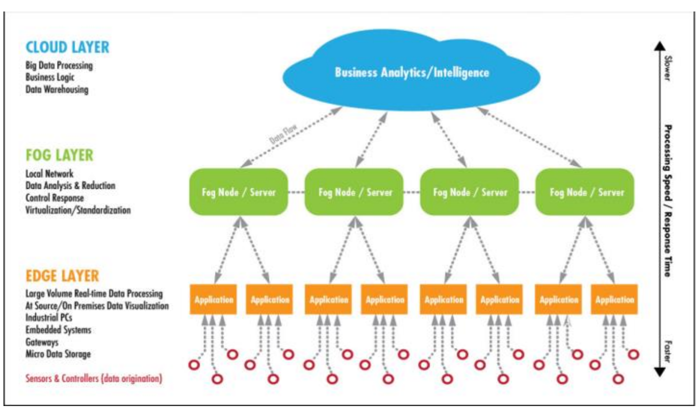

Figure 1.2: cloud stack featuring Edge, Fog and Cloud layers.
Source - https://www.winsystems.com/cloud-fog-and-edge-computing-whats-the-difference/

The figure above shows the scope and the relative positions of edge and fog computing in an integrated cloud architecture.

III. MOTIVATIONS FOR EDGE COMPUTING IN IoT ARCHITECTURE

The followings are motivations for Edge computing in an IoT Ecosystem:

- Delay-sensitive applications: in the context of IoT, latency is the time it takes to receive, process, analyze IoT data. For a lot of Industrial systems, such as manufacturing systems, smart grids, oil and gas systems, end-to-end latency between control node and sensor must be within some milliseconds, for others it is just a few tens of milliseconds. These requirements for low latency are difficult to achieve using the traditional Cloud services.

- Network bandwidth cost: Business Insider reports that "by 2020 more than five million smart sensors and other IoT devices will be in use around the world, and these devices will generate at least 507.5 zettabytes"(1 zettabyte = 1 trillion gigabytes) of data. Without Edge computing, the cost of sending this unfiltered but massive data to the cloud in terms of computing and storage resources and network bandwidth is simply out of reach for organizations.

- Privacy and security concerns : network connectivity is a fundamental requirement for IoT devices but each device which is connected to the internet or cloud increases privacy and security concerns. These concerns range from stealing data to unauthorized access to sensitive information. Integrating edge computing into IoT ecosystem reduces the exposure of these devices, thus preventing hackers from tampering with private data.

- Scalability: There is no guarantee that the Internet will scale to accommodate the massive number of IoT devices that will be deployed in the future. Edge computing will help reduce network load and thus preserve network bandwidth. This benefit is similar to how Network Address Translation (NAT) has helped to prevent the exhaustion of the IPv4 address space.

- Data sovereignty compliance: there are some regulatory requirements that put restriction on what and where data can be exposed, processed and stored. The use of edge computing provides a perfect solution to all sorts of stringent data processing requirements.

IV. FOUR USE CASES OF EDGE COMPUTING

This section discusses four use cases where the use of edge computing is gaining some momentum. Specifically, how edge computing is applied in areas like: autonomous vehicles, industrial automation, smart cities and healthcare delivery will be considered.

1) **Autonomous vehicles.**

The prospect of self-driving vehicles taking over the highways is very high. When this happens, these autonomous vehicles will generate a lot of data. Estimates vary, but a single, self-driving test vehicle can produce a staggering 30 terabytes of data in a single day of driving [4]. Much of this data will be raw and will require processing by some analytics algorithm in order to be actionable. Edge computing will enhance network agility by determining what data should be processed by a vehicle's onboard computing platform and what data should be sent to the cloud storage platform for further analysis. critical data about changing road and weather conditions will be shared with other cars, thus allowing them to learn about imminent hazards early and to adjust accordingly. The only way autonomous vehicles can have access to critical data with minimal latency is when edge computing is widely adopted.

2) **Industrial automation.**

One of the most promising edge computing use cases is in the Industrial manufacturing sector where the adoption of new technologies could potentially bring about huge productivity gains. Interconnected systems incorporating edge computing will have the ability to collect and analyze data in real time, thus reducing the complexities of their operations. In remote sites with poor network connection, edge computing will enhance the ability of smart devices to gather critical data. This data can be analyzed locally, acted upon and later transmitted to a central repository whenever connectivity is becomes better. When Smart factories become equipped with motion, temperature, and climate sensors, environmental controls can easily be adjusted for power efficient use. Failed components can be replaced with the minimal loss of productivity if data is utilized very close to its source. This is known as predictive analytics. All these possibilities are enhanced when Edge computing is fully integrated into IoT infrastructures.

3) **Smart Cities.**

Many Urban cities are turning into information gathering hubs, because of countless sensor devices that gather data on traffic patterns, infrastructure monitoring and other important utility facilities. While such data allows city officials to respond to problems faster than ever before, the response times will be greatly enhanced if data generated by these devices are processed and analyzed and acted upon locally. Devices that regulate utilities are able to respond to changing conditions in real-time, thus contributing to the 'smartness' of our cities. This is what edge computing is set to achieve if it's integrated into IoT architecture.

4) **HealthCare.**

Significant improvements to the delivery of healthcare services in many rural communities can be made if edge computing is widely adopted and integrated into our healthcare systems. Apart from the fact that patients in such regions are very far from medical services, on-site healthcare providers have no access to crucial medical records, but with edge computing, intelligent medical devices could gather, analyze and deliver the needed data in real time, and even use their computing capabilities to recommend treatments.

V. Open source Edge computing projects.

There are many open source projects that provide component capabilities required for edge computing. However, there is **no holistic solution** to address the need for fully integrated edge infrastructure. In this section, we will briefly describe two on-going projects embarked upon by the Linux Foundation Project to address this issue. These projects are **EdgeX Foundary** and **Akraino Edge Stack.**

- EdgeX Foundary

EdgeX Foundry is a vendor-neutral open framework for the Internet of Things (IoT) edge computing. The project is hosted by the Linux Foundation after realizing disjointed efforts in the advancement of IoT edge computing [5]. Targeted at industrial IoT, EdgeX Foundry defines a collection of loosely-coupled microservices that are delivered in the form of Docker containers. These services, communicating via network interfaces, are collected on a single gateway or distributed across a number of nodes based on application requirements.

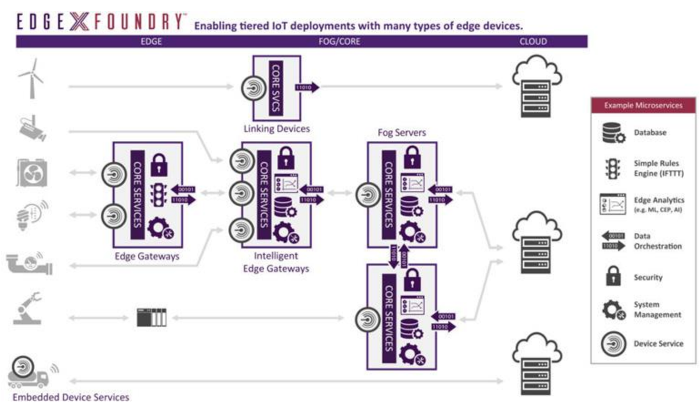

Figure 2.0 : embedded device services in docker container. Source - https://www.edgexfoundry.org/about/

- Akraino Edge Stack

Though initiated by AT&T and Intel, Akraino Edge Stack is another Linux Foundation Project that is focused on high-availability cloud services optimized for edge computing systems. As a **fully integrated edge infrastructure** solution, the stack provides critical infrastructure to enable high performance, improve availability, lower operational overhead, provide scalability and address security needs, not just for IoT use cases, but also for Carrier and Provider networks. Akraino Edge Stack is a collection of multiple blueprints that support VM, container and bare metal workloads and any type of access methodologies such as Wireless (4G/LTE, 5G), Wireline or Wi-Fi. The differences between EdgeX Foundary and Akraino Edge stack are worth noting. While EdgeX is more focused on the intricacies of Industrial IoT gateway/sensor communications, Akraino edge is an infrastructure stack with a broader focus and is more concerned with cloud connections.

VI. EDGE COMPUTING IMPLEMENTATION BY CLOUD GIANTS

Efforts by Cloud giants like Amazon, Microsoft and Google to tap into the Edge computing market have further complicated the challenges of interoperability among the numerous smart edge devices that are being deployed today for edge computing. One reason for this intense competition is that no Cloud provider wants IT workloads to escape its orbits since edge computing is about reducing or removing IT resources from the cloud. The sections below discuss one implementation by each of these cloud providers.

Amazon

"Amazon's AWS Greengrass , launched in 2017, builds on the company's existing IoT and Lambda offerings to extend AWS to intermittently connected edge devices. "With AWS Greengrass, developers can add AWS Lambda functions to a connected device right from the AWS Management Console, and the device executes the code locally so that devices can respond to events and take actions in near real-time. AWS Greengrass also includes AWS IoT messaging and synching capabilities so devices can send messages to other devices without connecting back to the cloud" [6]

Microsoft

"introduced in 2017, Microsoft's Azure IoT Edge allows cloud workloads to be containerized and run locally on smart devices ranging from a Raspberry Pi to an industrial gateway. Azure IoT Edge comprises three components: IoT Edge modules, IoT Edge runtime and IoT Hub. IoT Edge modules are containers that run Azure services, third-party services or custom code; they are deployed to IoT Edge devices and execute locally. The IoT Edge runtime runs on each IoT Edge device, managing the deployed modules, while IoT Hub is a cloud-based interface for remotely monitoring and managing IoT Edge devices." [6]

Google

"In July 2018, Google announced two products for developing and deploying smart connected devices at scale: Edge TPU and Cloud IoT Edge. Edge TPU is a purpose-built small-footprint ASIC chip designed to run TensorFlow Lite machine-learning models on edge devices. Cloud IoT Edge is the software stack that extends Google's cloud services to IoT gateways and edge devices." [6]

VII. CHALLENGES OF EDGE COMPUTING:

For IT, edge computing is not a slam-dunk proposition—it presents significant challenges, which include:

- Programmability: the native cloud infrastructure is transparent to users, but such is not the case with edge computing, where edge nodes are heterogeneous platforms. In this scenario, the runtime of these devices differ from one another, thus presenting a huge challenge to programmers who need to write applications that will be deployed in this new environment.
- Naming: edge computing requires naming scheme for the purpose of data communication and identification of IoT devices, just like DNS is being used for computer systems and domain naming resolution However, an efficient naming system for edge computing is yet to be standardized or agreed upon. This obviously will take a while to resolve.
- Privacy and security: device security and protection will be a huge challenge in view of the large number of smart devices that will be deployed at the edge of networks.
- Cost: the cost of having so many edge devices integrated with computational capabilities, flash storage and intelligent algorithms will be significantly high.

VIII. CONCLUSION

It has been shown that it's more efficient to process data at the edge of networks but such efficiency comes at a cost – the use of expensive smart devices and embedded computing platforms with computational capabilities. Edge computing achieves cost savings in terms of decrease in cloud storage and network bandwidth cost but a significant amount of the savings go into hardware costs. To realize the full benefits of edge computing, a multi-layer cloud stack involving edge computing, fog computing and cloud computing appears to be the best architectural approach. The deployment of limited expensive edge devices, complimented with the use smart or intelligent gateways at network perimeters seems to be the ideal solution.

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