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Original Article

Edge Computing – Benefits, Use Cases, Challenges, and Best Practices

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Abstract *- Edge Computing is becoming a mainstream topic, and a buzzword as Organizations are embarking on various Digital Transformation Initiatives and are posed with new and enhanced end-user experiences to extend cloud infrastructure to on-premises to take advantage of IoT, IIoT, to drive innovation and transformational digital business applications. Bringing data processing and analysis close to the endpoints and devices where the data gets generated can address concerns such as network bandwidth, single-digit millisecond latency requirements to mobile devices and end-users, data residency, data availability, data privacy, and sovereignty. The work in this paper discusses use cases of how organizations and digital leaders have "cracked the code" in deploying edge-computing solutions and the return on investment edge-computing has to offer. There is a section in this paper, which also discusses the challenges edge computing poses and the roadblocks that organizations often stumble upon in early edge computing projects. Read on to the section, which also discusses the best practices and strategies for overcoming such edge computing challenges.*

Keywords *- Edge Computing, Hybrid Cloud, Deployment, Integration, On-Premises, Native Cloud, IoT, IIoT, Operational Technology(OT), Information Technology (IT), Artificial Intelligence, Architecture, Data, Modern Data Platform, Data Lake, Data Warehouse, Data Transfer, Applications, Legacy Systems, Infrastructure, Resilient, reliable, Operationally Excellent, Performance Efficient, High Availability, Fault Tolerance, Scalable, Environments, Infrastructure, Systems, Applications AWS, Azure, Google, VMware, IBM, API, WAN, LAN,*

I. INTRODUCTION

What is Edge Computing

Edge Computing is computing or processing of the data that takes place at or near the location of either the end-user or the source of data, or the actual physical device itself. Edge Computing is a distributed computing model in which processing of the data takes place at or near the location of the physical device, which generates the data, and data is collected and analyzed locally, rather than transporting the data back to the centralized server in the cloud. Cloud Computing has led many organizations to centralize their services within large datacentres[1]. However, new near-real-time business needs and enriched end-user experiences like the Internet of Things(IoT), Industrial Internet of Things (IIoT) require service and data provisioning providing for single-digit millisecond responses closer to the outer "edge" of a network or near the endpoint devices or where the physical devices exist[2]. This new infrastructure of edge computing involves sensors, actuators, and controllers to collect the data, gateways, and various secure network protocols to transport the data to edge servers, and edge servers themselves securely process the data in real-time on-site while also providing the ability to connect various other devices, like computers, laptops, and smartphones, to the network to support and resolve some of the critical real-time responses for crucial safety scenarios, like remote surgeries or driverless driving in autonomous vehicles use cases.

"The edge computing and the IoT, IIoT ecosphere starts with the simplest and basic sensors located in the remotest corners of the planet earth and translates the analog physical signals into digital signals, which is the language of the internet. Data then travels through wired and wireless signals, various conventions and protocols, natural intercessions, and electromagnetic collisions before arriving at the ethernet of the internet. From there, packetized data will traverse various channels arriving at a cloud data ingestion source or large data center owned by enterprises and corporations [3]". One can imagine the long journey that data packets have to go through and compete with several other data packets to traverse their path successfully across the internet to the endpoint device for it to be consumed. This is further augmented by the network bandwidth, which will add to the latency and availability of the data for its ingestion into the data lake to generate and receive rich data in real-time to further extract relevance from the huge amount of data in near real-time for organizations to be able to take smart actions.

Even though latency is often the main reason for deploying workloads to the edge, moving the compute power and storage closer to the user and physical devices, which are the source of data generation, can also help organizations tackle some of the issues such as bandwidth, data privacy, data availability, data residency, and data autonomy issues. Even though we have had embedded systems existing in devices for the last 40 years, edge computing is more than an 8-bit controller or an analog-to-digital converter circuit used to display temperature. Since edge computing brings the nonconventional computing power close to the sources of data, edge computing strives to solve crucial problems as the number of interconnected and interlinked objects, devices, and the intricacy of use cases grows in the industry [4]. Edge Computing supplements and expands the opportunities of today's centralized hyperscale cloud models and supports the diversification of systems and the deployment of IoT technologies, new and disruptive application types, thus empowering and enabling next-generation transformational digital business applications.

Edge servers, network protocols, and gateways will address the role of intercessors and mediatory processing/computing nodes and integrators between multiple "cores"(hyperscale cloud public enterprise model or private enterprise-owned data center models) and a varying set of physical devices, workloads, and users at the edge[4] which will help in bridging the gap of the data generated from sensors to the internet. As companies are moving away from the monolithic-based architecture to a decoupled/loosely connected microservices architecture, this effort will further augment and support the technical evolution at the edge as these business applications can take advantage of the repeatability and reusability of the microservices at scale[5]. Since edge computing comes in layers, 5G infrastructure will further act as a catalyst for multiaccess edge computing use cases and fog computing.

II. EDGE COMPUTING AND FOG COMPUTING IN IIoT/IoT

We all know by now that cloud computing is nothing but a service that delivers shared resources (compute-processing power and storage) on-demand via the internet, and it's a collection of servers comprising a distributed network. In fact, edge computing and fog computing are both a protraction or an expansion of cloud computing. On the surface, both edge computing and fog computing appear very similar as they both involve getting the processing power or the compute power and the storage closer to the physical location or near the data source where data is getting generated. However, the primary difference between the two lies in the location where

The intelligence and the compute/processing power are placed [6], as can be seen in figure 1.

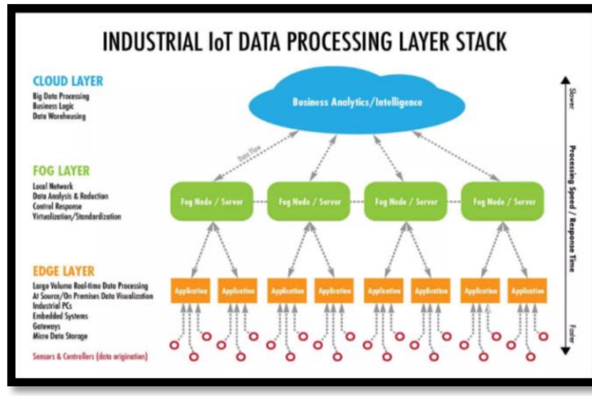

Fig. 1 Industrial IoT(IIoT) Data Processing Layer Stack [6]

In the case of Edge Computing, the processing power consists of the intelligence and the storage mostly in the form of embedded systems, or a microdata storage device like the AWS Snowcone [7] or gateways which ingest the data coming from the sensors, controllers, and actuators (the actual data origination points) into the applications. "Fog environment places intelligence at the local area network (LAN). This architecture transmits data from endpoints to a gateway, where it is then transmitted to sources for processing and return transmission [6]". For instance, in the case of jet engines which have multiple sensors that generate data about the engine's performance and condition, use industrial gateways in such applications to collect the data from edge devices which are then sent over to LAN for processing.[6]

III. WHY IS EDGE COMPUTING IMPORTANT?

According to a recent survey conducted by Gartner, 91% of today's data is created and processed in centralized data centers. By 2022, about 75% of all data will need analysis and action at the edge [4].

A. A. Acts as a Foundation for supporting Transformational Business Initiatives by Organizations

Edge Computing which provides greater computing and processing power at the edge, acts as a foundation to support and enable the next generation disruptive digital business applications and use cases like establishing autonomous systems, empowering companies to increase their operating efficiencies, reduce costs, increase performance excellencies, drive increased employee productivity thus enabling their workforce and IT personnel to focus on higher-value activities within their operation to increase the organization's strategic position in the market providing for enriched customer experiences.

B. Edge Computing ensures for "Always On" availability:

Edge Computing provides for high availability of the applications as it ensures "always-on" availability powering the next generation digital transformations of how companies are envisioning to do business to provide answers to end-users at their fingertips through just clicks and push of few buttons. Edge Computing Capabilities have trusted and catapulted the companies for 'Industrial 4.0" [6], which is the next industrial revolution, transforming and driving seismic business changes in manufacturing industries and service sectors like the Oil and Gas, Pharmaceuticals, Food and Beverage, Water and Wastewater, Power and Utilities, Retail Sector, Transportation and Smart Building to name a few as edge computing can ensure system uptime of these critical services and applications by addressing some of the midstream system challenges like scalability, extensibility, standardization, safety and security of the data, can help address issues with aging and legacy infrastructure [1], shield corporations against unplanned downtime, making the applications and systems fault-tolerant and providing for better asset integrity (Integrating OT and IT) and resource management.

C. Provides the ability to turn data into quick, actionable Business Insights where it matters the most-at the edge:

Edge Computing helps in optimizing data capture at the source of data generation minimizing data losses, and promoting an agile business ecosphere that is more efficient, with faster and improved performance, saving costs, less operational overheads with the ability to analyze the data to extract useful information to turn data into quick, actionable business insights where it matters the most ***- at the edge.*** While most high performing edge applications rely on the cloud for data processing, analytics, storage, backup, archival, and machine learning capabilities, organizations also need to do some data processing for immediate Machine Learning inferences, closer to the physical location of the data source to deliver critical business intelligence and real-time responsiveness and reduce the amount of data transfer to and from the cloud to address issues such as latency and bandwidth. Near real-time responses becomes very pivotal to support and augment mission-critical safety applications and use cases like automated systems, self-driving cars, remote surgeries that require single-digit millisecond latencies. The ability to capture and analyze the data at the edge also enables enterprises to correct the data problems at the data generation point, which might not have been identified as quickly if the data were ported to the central cloud server for processing and analysis. This increases the data integrity and providing for a single version of the truth of the data for the consuming business applications.

D. Improves Safety and Security of the Data

Housing the data on-site can help reduce the data exposure and security risks associated with the data transfer to and from the cloud (data encryption in flight or in transit) for processing and analysis purposes; it will also help address some of the data compliance requirements (like GDPR and CCPA)which can be very important in financial organizations that deal with a lot of PII (Personal Identifiable Information) data. It can also reduce some of the bandwidth costs by processing and storing some of the data at the edge rather than transporting all the data to a centralized server located in the cloud.

E. Provides for Greater Resiliency and increased Fault Tolerance

By keeping the computing power and storage associated closer to the data source, enterprises can greatly benefit from the resiliency, reliability, and costs associated with edge computing. By keeping computer power local, regional sites can continue to operate in an independent manner without relying on their core and centralized site, should there be any issues with the centralized data center having downtime or operation disruption [2].

IV. EDGE COMPUTING USE CASES

Edge Computing addresses those use cases that traditionally cannot be sufficiently addressed by following a centralized approach of cloud computing, often because of bandwidth issues, latency, and other network requirements. Edge Computing focuses on several distributed small computing sites that help in the reduction of network costs, alleviate bandwidth issues, reduce data transmission lags and delays, limit services and applications failure making them highly available, ease of resource management and deployment, and greater autonomy over the movement of sensitive data. Edge Computing can augment and supplement a Hybrid Cloud Deployment model, especially in cases where centralized computing is used for computing concentrated workloads, data curation, cataloging, aggregation, and storage in a massively parallel processing data warehouse requiring that data for operational business analytics, artificial intelligence, and machine learning use cases(like descriptive, diagnostic, predictive and prescriptive analytics)[8], harmonizing operations across various geographical locations and business units, and traditional back end processing which requires that data be integrated with data from other sources housed in the data warehouse to gain a holistic view of the data for extracting useful business information and actionable business intelligence from that data. But, if businesses have the need to do real-time data processing, monitoring, and reporting, then edge computing could be the go-to solution as it can help address the issues with data latency, data availability, network, and bandwidth constraints.

A. Internet of Things(IoT)

IoT refers to the system of physical devices that have sensors and actuators that continuously receive and transmit data over wireless network connections without manual and human interventions. This is possible because of integrating and interlinking compute devices in all kinds of objects. In an IoT ecosystem, there could be a lot of network steps in between sending and receiving a signal or a data request. The greater computing power available and embedded within the physical device itself, or at least closer to the location where the physical device co-exists, the better the user experience[9]. For instance, a smart (smart usually means IoT enabled which can interact and communicate over the internet via apps installed on the mobile-deices) device like a smart Instant-Pot can receive data location of the user from the GPS(Geographical Positioning System) installed in the car while the user is commuting and set the food to cook 'mode' and have steaming piping hot food ready as the user arrives home. Devices like Smart thermostats might connect to the Google Maps API for data about the real-time traffic patterns in the user's area and use that information to set the temperature of the home to heating/cooling mode as the user arrives within the geofence location of the home[8]. Beyond this, IoT data collected from smart thermostat customers can also be utilized by power and utility companies to understand the power consumption patterns of their customers to drive large-scale marketing, targeting pricing and promotion strategies, or even optimization efforts.

B. Enterprise IoT

In consumer-driven enterprises and organizations where the end-user is largely the general public, like in the case of wearable technologies and smartwatches, IoT often gets the necessary heed and awareness as these customer experiences are modulated and driven by intrinsic privacy and security concerns that come with uniform connectivity. Enterprise IoT solutions allow companies to improve their existing business models as it provides them with the opportunities and capabilities to tap groundbreaking new revenue streams by building new connections and partnering with their internal, external stakeholders, vendors, channel partners, and customers in new ways - yes but not without challenges. Although IoT security is a major daunting issue that organizations face while building new IoT systems to providing enriching user experiences, there are several successful enterprise IoT use cases in nearly every industry. For instance, in Industrial IIoT[8], specialized sensors can be added to parts of machinery that are prone to malfunctioning due to excessive and continued exposure to stress, extreme temperatures, and overheating to help shopfloors and maintenance units to conduct 'predictive maintenance' on such machinery to improve human proficiency (an example of real-time data collection, analysis, and insights) to help manufacturing equipment designers and engineers on how to improve the overall equipment life on their new, improved models and versions (an example of long term data analysis)[10]. In logistics and transportation industries, advancements in IoT have led shipping companies to analyze the movement of their containers and packages in near real-time for a shipment across the supply chain through battery-powered tracking devices that continuously transmit data into IoT applications. In Farming, IoT devices have helped farmers to schedule irrigation periods in real-time through moisture sensors installed across the entire field. In mission-critical sectors like healthcare and pharmaceuticals where lives are at stake, edge computing can provide the "always-on " availability of crucial systems like Electronic Health Records(HER), Hospital Information Systems(HIS), Picture Archiving and Communication Systems(PACS), and other clinical and administrative applications[11].

C. Edge Computing augments and supports Enterprise Mobile Applications

Organizations develop portable, scalable, and secure mobile applications to better engage with customers, partners, and employees to provide an enriching and enhanced user experience. When there are issues with mobile computing, it is most associated with latency issues, overwhelming traffic, network congestion, bandwidth constraints leading to service disruptions. Edge Computing can help address and alleviate most of these problems arising due to signal propagation delays and latency constraints. Additionally, the service failure may affect only a smaller set of the user population rather than the larger group, or it could even provide a degree of continuity of service with sporadic network connectivity[10].

D. Edge Computing augments and supports Network Functions Virtualizations(NFV)

In order to promote better stability and interoperability between the core site and the regional sites of enterprises ad organizations, the European Telecommunications Standards Institute(ETSI) has proposed NFV architecture consisting of Virtualized Network Functions (VFN's), Network Functions Virtualization Infrastructure (NFVi) and Management Automation and Network Orchestration (MANO) which helps in virtualizations of network services like routers, load balancers and firewalls (which have traditionally been run on proprietary hardware) to package these services like Virtual Machines(VM's) so that service providers can run new network services on standard servers instead of the proprietary ones, providing with greater agility and scalability[12].

V. EDGE COMPUTING CHALLENGES

A. Scaling out to Multiple Small Sites or End Points

Since edge computing fundamentally involves scaling out to distributed physical locations in order to get the compute, processing power, and data storage capacity near or at the physical location of the data source, scaling out to many small sites could get more complicated and overwhelming than adding an equivalent additional capacity to the centralized core site or a datacenter. The increased overhead of managing and maintaining the IoT devices and edge computing infrastructure and architecture at these multiple physical locations can be a very formidable effort for small companies and startups.

B. Remote Edge Computing Locations

Edge computing sites may sometimes be in inaccessible remote areas with limited to no technical expertise available to troubleshoot issues should something go wrong. If something fails on-site, there should be an infrastructure in place so that non-technical labor can support the infrastructure to detect the underlying issues or have some sort of centrally remote managed service support functionality[10].

C. Edge Computing Site Management Operations

There should be a process in place to reproduce the site management operations of these edge computing sites at multiple locations to simplify management and orchestration, promoting simple and easier site management and to potentially avoid the configuration of software implementation in different ways at each of these various sites (commonly referred to as 'configuration drift') [10].

D. Security of the Physical Device or Physical Location itself:

While edge computing can provide greater control and autonomy in terms of data residency and constraining the information flow geographically, the security of the physical device or the physical site itself is much lower. This can lead to a higher risk of malicious activity by bad citizens and accidental scenarios like a tripped cable, for instance[10].

E. Business Units or OT Organizations driving Edge Computing Solutions

According to the Gartner report[4], business units or OT organizations are progressing rapidly with edge computing solutions to catch up with their competitors in the market and drive enhanced customer experiences to retain, acquire new customers, reduce customer churn and increase their net promoter scores. There are stepping ahead of IT by involving and partnering with different supplies, vendors, and approaches than what IT uses for its own existing solutions. This will likely create an incompatibility of approaches, tools, and technologies with the existing IT solutions in place, adding more to the already complex edge computing architecture and infrastructure. Gartner[4] coins the word as "Edge Washing" which refers to various approaches and solutions provided by edge computing vendors and partners who want to become more relevant in their fight to gain more cloud businesses from their clients, which will only further augment the disconnect between business units (OT organizations) and IT group within the enterprise.

F. Technical Skills Gap

As enterprises are catching up with the speed of building and deploying their own native and hybrid cloud solutions, they are often faced with the complexity in developing edge-based applications because of the heterogeneity in endpoints, approaches, strategies, or software technology stack itself. Many organizations develop an initial pilot project or proof of Concept (POC), but productionizing such POC's will require the use of system integrators that are already in place with the existing IT solutions, which can be quite challenging.

VI. EDGE COMPUTING BEST PRACTICES

A. Having a Proper Edge Computing Strategic Roadmap In Place

Conducting a 'gap analysis' of the current v/s future state scenarios to support edge computing use cases as part of digital transformational initiatives will prevent this gap analysis exercise from it being a merely academic exercise but also will help access the enterprise's capability, timing-wise as well as from its technological readiness standpoint. According to Gartner[4], it is advisable for Organizations and Enterprises to have a committee or a cloud solutions architect who will serve as a focal point for vendor selection and negotiation, strategy and approach development and discussion, and establishment of enterprise governance guidelines and standards.

B. Taking a Use Case-based approach v/s Big Bang Approach

Organizations who are not cloud mature and just embracing the hybrid cloud strategy to make their applications and systems highly available, reliable, and fault-tolerant, can follow a use case by use case approach of taking the first step to deploy and implement the use case to the cloud by building and deploying the proper cloud infrastructure to support the always-on availability and then further propagate the same to edge computing architecture to support their low latency and high performing business use case goals. This will give organizations a reference point to devise the proper best practices and guidelines, policies and procedures, and an opportunity to enhance and modify these rules along the way as and when they develop and implement further use cases down the road. This strategy will also help in maintaining an 'Edge Strategy and Hybrid Cloud/Cloud Use Case Run Book' by the edge architect/cloud solutions architects, which will acts as 'guardrails' enabling effective and innovative POC's and pilot projects while minimizing ineffective and poorly developed use case implementations for being productionized and being implemented which are in non-adherence to the enterprise governance best practices and guidelines. As per Gartner, there needs to be a clear statement as to what specific business goals the use case intends to solve and the specific milestones, key performance indicators, and success metrics to identify what a successful pilot project/POC would look like.

C. Conducting Applications and Infrastructure Inventory Focusing on Edge Computing

By conducting an assessment of existing applications and infrastructure inventory and identifying which applications would benefit from the capabilities that edge computing has to offer would provide enhancements of edge computing tapestry and topology to applications that have proven themselves mission-critical to the enterprise and business and would simply make them even better. Enterprises would then have to keep four critical factors in mind while assessing the applications and infrastructure inventory which are, reduced latency, enhanced bandwidth utilization, requirements for offline or freestanding operations whilst also keeping the security, compliance requirements, and guidelines of keeping the physical equipment or the edge infrastructure in an explicit location. Also, cataloging what technology stack can integrate well with the business logic can create reusable tools to solve business enabling use cases that could prove as a very valuable resource for the enterprises to showcase the business, the pros, and cons of deploying edge computing applications.[4]

D. Build V/S Buy

Enterprises and organizations without extensive development skills, cloud solutions deployment, management, and maintenance skills and want business outcome-based SLA's, reduced turnaround time, faster solutions deployment, and built-in technical refreshes can often benefit from the solutions from strategic alliance partners, system integrators(buy) or infrastructure providers who often offer edge as a managed service solution rather than advancing promising and innovative POC's to implementation based on an enterprise conceived best practices and technology stacks(build).

E. Following Loosely Coupled/Microservices based architectural approach

From a design standpoint, it is a best practice to make the code reusable as much as possible by following a loosely coupled/decoupled and microservices-based architecture so that the reusable parts of this code can be packaged into containers and can be used to deploy various other applications and integrations to enable faster response time to the market and advancing state of the art by breaking monolithic technology stacks into small reusable catalogs of microservices[4].

VII. CONCLUSION

A. Hybrid Cloud and Edge

Many organizations who are already using some combination of either private and public cloud or on-premises and public cloud are already well versed with the benefits of data partitioning and different configuration patterns around these that work well for their respective business use cases and goals[13]. Edge Computing can be a great addition to the already existing network. For instance: Edge Computing can take the place of private cloud/on-premise infrastructure, taking the primary data processing role, or it can be paired with the existing public/private cloud combinations as well[5].

B. Will Edge Computing replace Cloud

While high performing edge applications rely on the cloud for processing, storage, and analyzing large data at scale, but certain use cases that require single-digit millisecond latency requirements and faster response times like machine learning inferences and mathematical models and algorithms predictions, close to the physical location where the data is getting generated to deliver quick, actionable business intelligence, do require edge computing infrastructure set up near the data source. The edge computing infrastructure may include hardware, software usually managed by the hyperscale cloud service providers and system integrators, and sometimes may even be embedded into customer-owned physical devices itself[14].

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