Fog Computing in IOT: A New Paradigm for Distributed Intelligence

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Abstract - With the rise and accretion of smart devices especially mobile phones, wearable gadgets and sensors brings us to a new era of computing technology known as Internet of things (IoT). The IoT incorporate smart machines interacting with other machines, environments and infrastructures which results massive increase in the volume of digitally generated data. To alleviate the burden of limited storage capacity of a device, cloud computing is considered a growing trend which provides on demand storage, moving computing and easy control of the services to end users. However regardless the various applications where cloud helps in accelerating the IoT growth around physical world, there are some applications scenarios still not getting benefits from this rising computing platform. Some of cloud computing fundamental problems like unacceptable latency, incapable for location awareness services, lack of mobility support, unnecessary network bandwidth consumption and vague security issues from third party are reasons for its dismissal in some interactive and real time applications. To conquer this issue Cisco define a new uprising computing perspective named Fog computing which Fills the technology gaps in supporting IoT that distributes computing, control, storage, and networking functions closer to end user devices.

Keywords- Fog, Fog computing, Internet of things, Cloud computing, Edge networking, Cloud of Things

I. INTRODUCTION

With the rise in use of pervasively connected smart devices Internet of Things (IoT) and its relevant technologies attracting the attention of researchers from academia, industry, and government in the recent years and gaining excessive importance in our real life. IoT is a phenomenal transformation of the twenty-first century and it brings a technological revolution that represents future of computing and communication. The IoT will empower the connected things with new capabilities and ubiquitous intelligence with its omnipresent feature. The IoT promises to bring the connectivity of all smart devices and dumb objects like mobile phones, home appliances, medical devices, cameras, wearable gadgets even it include a leaf of the tree, a bottle of beverage, and everyday objects such as food, clothing, and paper to be a part of IoT environment [1]. Everything in IoT will be connected to a central global network through Internet protocol (IP) based system. Subsequently from technological perspectives IoT gives us another vision which facilitates a new era of interaction among machines, things and people which automatically configure themselves in a heterogeneous environment. Any device of IoT network can use services or resources from other wirelessly connected devices. There is an astounding forecast given by Cisco CEO John Chambers as per which there will be 50 billion smart devices connected to web and aggregate $19 trillion market for IoT based projects by 2020[2]. Based upon this expectation we can state that everything in IoT will tend to infinity like its number (size), data space, need of IP addresses and other. In general IoT network is characterized by billions of devices, widely connected and distributed, with limited storage and processing power, battery and bandwidth, which involve concerns regarding reliability, quality of services (QoS), security, confidentiality, and privacy. On the other hand, cloud computing is considered a promising computing paradigm which provides virtually unlimited storage capabilities, high availability, tremendous fault tolerance, scalability and extensive processing power. Subsequently, cloud computing acts as a complementary and dual technology for IoT paradigms and holds a crucial role in IoT development and growth. Mostly cloud-based architecture, where application intelligence and storage are centralized in server wire centers, satisfies the need of most of the Internet of Things (IoT) applications, but begins to Create bottleneck when ultra low latency and high volume of data passed through a limited network band width deployed model. In the following section the authors have discussed the importance of cloud computing in tremendous growth of IoT industry and what are the reasons currently driving for their Integration.

II. CLOUD AND IOT: THE NEED FOR THEIR INTEGRATION

Since last a couples of years Internet of Things (IoT) has gained convincing attention in academia as well as industry thus becomes a rapidly evolving technology. The IoT paradigm is based on billions of intelligent and self configuring nodes (things) interconnected in a dynamic network infrastructure, enabling ubiquitous and pervasive computing scenarios possible with minimum human involvement. In computing IoT means interconnection of dynamic networks which include everyday objects and equipped with ubiquitous intelligence and have connection with the internet [4]. The essential motivation behind the development of IoT is to have smart devices collaboration based communication without human intervention which leads to a smarter world where objects around us know what we like, what we want, and what we need and act accordingly without explicit instructions. IoT is additionally known by another name machine to machine (M2M) communication and this phenomenon has a tremendous potential to change our lives by connecting the billions of objects that exist around us. As a result of IoT devices communication, gigantic amount of data are generated and that data is being processed into useful actions to make our lives much easier and secure [5] [6]. A general and more specific equation for the IoT is shown in **Figure 1**, in which a physical object (smart or dumb) follows the function of the things being connected to the internet, so that it can easily collect, transmits and interpret data.

Physical Objects
+
Controller, Sensors and Actuators
+
Internet
=
Internet of Things (IoT)

Fig.1: A simple equation which constitutes IoT

The connection to individual objects enables dynamic setup of the system, which can be controlled and monitored through internet. The sensor within or attached to the objects are connected to the internet via various local and short area networks. Sensors to sensors or machine to machine communication in IoT networks happens using various local area wireless technologies like Zigbee, Bluetooth, RFID, Wi-Fi and others. These sensors additionally utilize wide area networks including GSM, GPRS, 3G, LTE, and 5G, for intelligently share information among connected sensors without any centralized control [7]. To date, the world has deployed about 28 billion "smart" connected things and predictions say there will be more than 50 billion connected devices by 2020. **Figure 2** demonstrates Cisco projects of years by year growth of IoT devices.

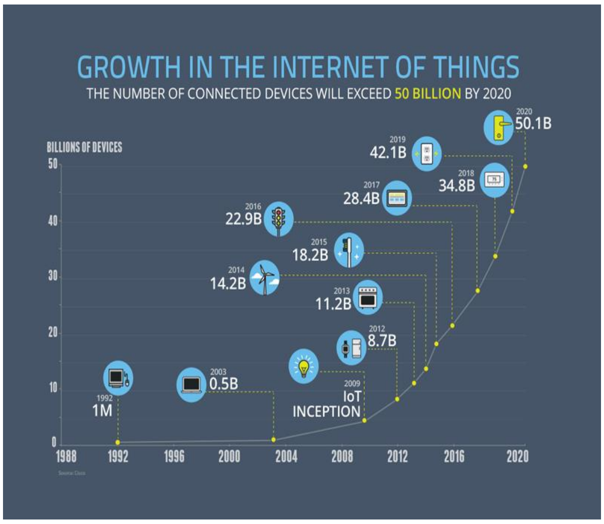

Fig.2: The massive growth of the Internet of things from 1992 to 2020

As per the Cisco Internet Business Solutions Group (IBSG), IoT is a point in time when more "things or articles" were associated with the Internet than people on the planet. As per the U.S Census Bureau in 2003, there were roughly 6.3 billion individuals living on the planet and 500 million gadgets connected with the Internet as indicated by Forrester Research data. Explosive growth of advanced smart mobile phones and tablet PCs conveyed the quantity of gadgets associated with the Internet to 12.5 billion in 2010, whereas the world's human populace expanded to 6.8 billion.

Figure 3 shows comparison of world population vs. connected devices from 2003 to 2020 [8] [9]

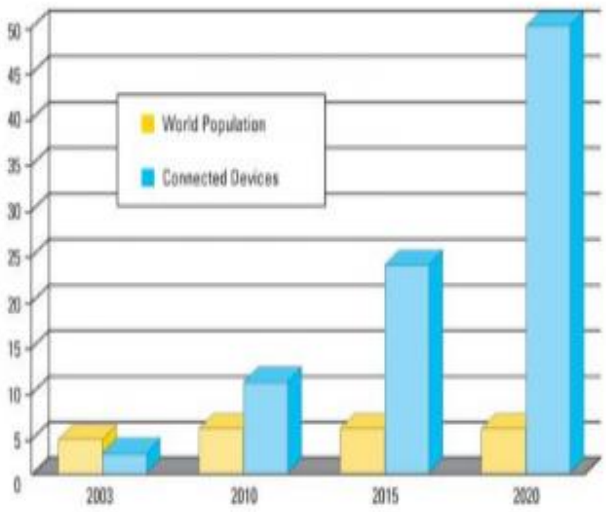

Fig.3: Cisco IBSG comparison of world population vs. connected devices

The proliferation in IoT gadgets and the rapid development of associated technologies in the recent years gives us colossal conveyed system of things. This has prompted the production of unprecedented amounts of data, which thus puts an enormous amount of strain on the internet infrastructure because all generated data needs to be stored, processed and accessed via internet [10]. By 2025, roughly 80 billion devices will be connected to the Internet, according to Vernon Turner, senior vice president of enterprise systems at IDC. The dumbfounding growth of data comes from both the number of devices generating data as well as the number of sensors in each device. IoT based network are generally characterized by billions of devices, widely connected and dispersed, with limited storage and computation power, battery and bandwidth [13][14]. The amount of data being generated and examined from IoT devices will be of massive volume and it is believed that data will be of size zettabytes, yottabytes, and even as high as brontobytes which requires a humongous amount of storage space. Significant data operations like accessing, processing, visualizing, archiving, sharing, and searching which are impractical in IoT device end now can be effortlessly performed after joining of IoT with cloud. Cloud is the most convenient and cost effective solution to deal with data produced by IoT devices. In addition this tremendous data generated by IoT devices in bulk also need to be properly utilized for analytical and decision making purposes [15]. As IoT devices are of very low cost, light weight with limited processing power, this brings us at the door of cloud computing where processing and computation is also available on rental basis [16]. However researchers from all over the globe have seen many issues in the foundational approach of centralized cloud based models. Significant issues like security and privacy, latency, heterogeneity, performance, quality of services, Big data management etc pushed up the researchers to a new platform of computing named “Fog Computing”. Fog computing is a close cousin and expansion of cloud computing, and works on the principle of distributed nature of virtualized resources. To fulfil the expectations of IoT user’s researchers believe that Fog computing will going to play noteworthy role because there is a significant edge of fog computing over cloud computing, in terms of data management and analytics [17].

III. THE EMERGING ERA OF FOG COMPUTING

The rapid development of IoT devices requires speedy processing of data to control automations, efficient processing and better user experiences. In some critical industries, the present arrangements do not work sufficiently quickly. Traditional approaches used in IoT requires each and everything to be sent to the centralized cloud through various smart data generating devices for computation and analysis purposes, which adds unpredictable latency and potentially reduced privacy and security of the data. To overcome all these technology gaps in supporting IoT will require a new computing and networking architecture—Fog—that distributes computing, control, storage, and networking functions closer to end user devices. A fog networking model rely more on localized storage and processing, with some processing capabilities embedded into the devices themselves. Cisco in 2013 presented the concept of fog computing which brings data computations, decision making, and action taking responsibilities nearer to IoT devices i.e. on the edge of network. Fog computing is an emerging type of architecture that enables efficiency in IoT, while overcoming some of the inherent weaknesses of current arrangements. Fog computing acts as a bridge between cloud and IoT devices thus only relevant data produced by fog devices is sent to the cloud data centers which helps in appropriate utilization of network bandwidth [18][19]. One of the principle objective of fog computing is to make ‘big data’ smaller for optimizations of IoT devices through ultra low latency, ultra fast data processing, high security, reliability and highly efficient resource utilization. **Fig 4** demonstrates three-layer, “Things-Fog-Cloud” hierarchy in which fog layer act as a moderate layer between IoT devices and cloud services hosted by third party through internet. Fog framework helps the cloud computing platform by splitting its processing workloads among local clouds named as fog server. The middle fog layer contains geographically distributed fog servers which are local for IoT devices and are mostly deployed at homes, parks, stations, shopping malls etc. Thus fog computing fog servers typically located between users and cloud so it decreased the distance between end user devices and cloud. The data generated by IoT device layer from various smart devices is preprocessed in the local fog server. Fog server processed frequently used tasks and store their results in its local memory while the rest of data is transferred to cloud for pervasive computing and storage. Because of localization of fog server IoT devices quickly transmit data to locally deployed fog or edge nodes rather than transmitting to remotely hosted cloud. The fog computing paradigm is well-suited for real-time big data analytics, where time is a crucial factor in successful implementation. Fog is characterized by its Proximity to end users and thus alleviate problems associated with cloud computing. Due to fog dense geographical distribution framework and its distributed operations fog promotes mobility, fault tolerance, low latency, location awareness, improved QoS, scalability and heterogeneity support [20].

All of above discussion about Fog Computing brings us to a new definition of fog computing, we define fog computing as, “The Fog computing is a new distributed and decentralized computing model where numerous heterogeneous devices communicate and collaborates with one or more devices along with subsequent level of localized control, configurations, management, computational power and storage inbuilt in Fog devices at the network edge rather than existing entirely in the cloud”. Thus in elementary terms fog computing works in conjunction with cloud computing and can be treated as a mini decentralized “cloud”, that function proximity to the end devices where data is generated and most often used. In other words the fog computing is to deploy the virtualized cloud-like device more close to users, and therefore the Fog is interpreted as “the cloud close to the ground”[21].

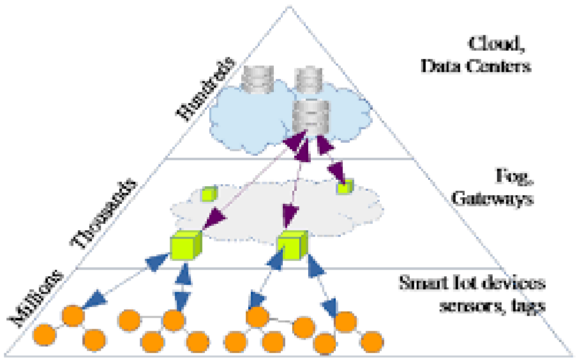

Fig.4: Fog computing works as a bridge between Cloud and end devices

IV. CHARACTERISTICS OF FOG COMPUTING

Fog computing is a distributed virtualised platform that provides built in data computation, storage, and communication services between end devices and traditional cloud computing data centers. The purpose of fog computing is to provide a subsequent level of computation, storage and communication facilities in the close proximity to end users, and accordingly provide fast-rate services to mobile users via the local short-distance high-rate wireless connections [22]. This improves the overall performance and efficiency of the system since amount of data is trimmed and unnecessary data need not to be sent to cloud for analysis and storage. The main characteristics of fog computing that distinguish it from cloud are discussed below.

Low latency and location awareness: Fog computing acts as a promising technology in the areas of real time applications where response time is a critical factor in the success of the entire system. By bringing the computational and storage capabilities near to the users serve a very beneficial role for latency sensitive, and geographically distributed applications. The encouragement factor of fog computing is to place the frequently used data and application services as close as possible to end users [23]. Thus fog computing is committed to serves mobile users by addressing the shortage of location-awareness of cloud computing to their users. Fog computing overcome this issue by providing engaged localized services subject to the specific deployment sites. Fog computing platform make it possible for us to act and respond in real time by partitioning the data into time-sensitive and non-time sensitive parts. The most time sensitive data is locally analysed by fog empowered nodes (fog server), thus results in lower latency and less time sensitive data which include files, reports, device logs and much more is sent to the cloud for storage [24]. A fog server can be selected from existing network components, for example a cellular base station, WiFi access point or router by upgrading the computing and storage capabilities. A fog server can be selected from existing network components, for example a cellular base station, WiFi access point or router by upgrading the computing and storage capabilities.

Geographical distribution: The research on proper optimization and utilization of cloud technology comes with a solution of contents delivery proximity to cloud users using geographically distributed platform. As we mentioned fog computing is a dedicated platform in providing some of important features like ubiquity, reliability, scalability, mobility, location awareness and low latency to end users. All of these features cannot be achieved without the geographical distribution of fog nodes. These features help in better support for streaming video, gaming experiences, monitoring, and control applications. Further, fog will be geographically distributed thus moving vehicles, and autonomous systems will be able to receive high quality streaming content even as they pass between proxies and access points, because fog nodes will be positioned along roadways, highways, and cellular phone towers. The dense, geographical distribution of fog server at numerous points helps in faster processing and analytics of big data generated by IoT devices [25].

Heterogeneity of devices: As we have discussed in three-layer hierarchy of Things-Fog-Cloud, fog computing environment consist of heterogeneous devices which include cellular base station, smart sensors, WiFi access point, routers, set-top boxes, and even end nodes such as vehicles, sensors, mobile phones etc. All these different hardware devices have different amount of computational potential, varying amount of memory to stores the data, various kinds of System software, and different kind of graphical interfaces etc.

Support for mobility: Mobility is one of the important aspects in the fog computing domain, especially in many latency sensitive applications. The main scenario which gets benefitted from Mobility support present in fog computing are smart agriculture, smart transportation, smart healthcare, smart roads, smart waste management etc. There are many interactive applications which require very less response time for better quality of services. As in traditional cloud approach every query gets processed and solved in cloud platform which takes more time than same query gets processed in edge devices. Thus fog computing allow mobile devices to response fast and user gets better response time than in cloud approach [26

V. A GENERAL MODEL FOR FOG COMPUTING

Fog computing is a system level distributed computing architecture that expands the computational, analytical, networking and storage capabilities provided by the cloud to the edge of the network. As appeared above in (Fig 4) three-layer hierarchy of "Things-Fog-Cloud", fog platform sits amongst cloud and end devices. In **Figure 5** we have represented a broader bidirectional model derived from three level hierarchy of "Things-Fog-Cloud", where fog servers are hierarchically distributed between Cloud and IoT devices so that Internet services can be accessed by end devices at M2M level. In this model edge devices communicate with fog empowered nodes and fog nodes with private and public clouds. Communication may also be possible among fog empowered nodes for data and process management to support application requirements, and to exchange fog management data [27].

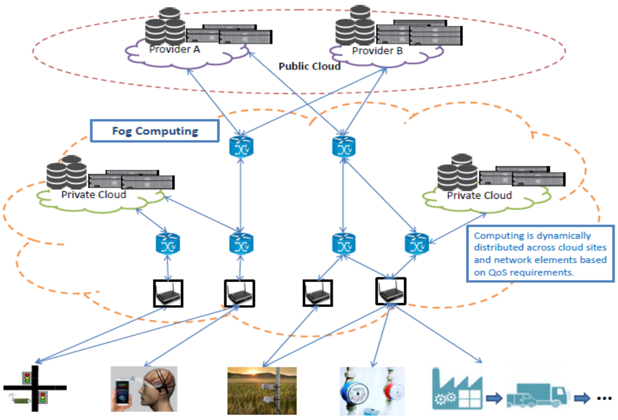

Fig.5: Machine to machine communication in fog computing environment

Fog computing takes advantages of both edge and cloud computing, while it benefits from edge devices' close proximity to the end users, it also leverages the on-demand scalability, resource polling, and device location independence of cloud resources. Proximity to the end users gives potential in fog devices for real-time interaction, allowing for the possibility of high speed streaming data for interactive industrial applications and those that require secure, current data without much latency. Due to fog dense geographical distribution framework and its distributed operations among devices, fog model is dedicated in providing mobility, fault tolerance, low latency, location awareness, improved QoS, scalability and heterogeneity support. The computing scenario delineated in above model shows processing, analytical and storage capacity is one hop away from the data generating devices, which can be beneficial in the following types of applications.

1) Real time application scenario were very low or unsurprising latencies is required. Since in fog computing environment data and applications are located at devices deployed around the network boundary, which made real time analytics possible from complex queries. Applications like traffic security and surveillance, applications for vision, hearing, critical heath tracking in hospitals, and augmented reality can benefit from lower latencies. All of the previously mentioned applications are not appropriately reasonable to work under traditional cloud data analytics models, because data and information live at central location make analysis troublesome. Moreover high bandwidth demands for data movements between devices and cloud cause the data to become less reliable and network latency increases considerably [28].

2) Applications which run under the constraint of limited bandwidth can adopt the fog computing platform for better and timely data processing as fog drastically reduced the demands of net works bandwidth. Since most of the information is locally processed and analyzed by local fog devices, so only more meaningful and summarized information with reduced volume is transmitted to cloud for storage. Thus fog significantly reduced the burden of cloud bandwidth and gives a practical solution for high quality multimedia applications.

3) Applications which are based on the collaboration of heterogeneous devices or services can shift from traditional cloud approach to Fog based model. Due to the heterogeneous nature of the fog networks, enabling services seamlessly across environments requires sound interoperability and smooth handover between varying devices and environments [29].

4) In cloud based services, security is always a concern because issues such as information leakage and unauthorized access are some of major problems for cloud users since every bit of data generated by IoT devices is sent to the cloud. Therefore integrity, confidentiality and availability of cloud resources need to be defended against a number of possible threats Applications which are more vulnerable to data theft in cloud based platform can shift to fog platform for security purposes. As we know in fog based environment data stays closer to the end users and can be accessed and transferred with just one hop from fog nodes. Fog computing is considered much more secure by security experts than cloud computing, because information does not have to travel great distances like cloud computing [30]. Fog computing based distributed computing scenario offers several benefits over its predecessor, cloud computing.

VI. BENEFITS OF FOG COMPUTING

- Fog nodes keep data closer to the user. Instead of storing information at centralized data center which are far from the end-point, the Fog aims to place the data close to the end-user.
- Fog computing uses much less bandwidth, as compared to traditional approaches which means in fog networking there are less chances of bottlenecks and other similar occupancies.
- Administrators are able to support location-based mobility demands and not have to traverse the entire network. As we knows some real time interactive applications needs response with ultra high speed which we cannot except from cloud based centralized models.
- Fog computing environment helps in achieving the desired level of security we needs for IoT networks since communication and networking is carried out at (or near) the end-user device rather than routing all traffic through core networks.
- Fog technology is agile in nature which brings rapid innovation and affordable scaling. It is usually much faster and cheaper to experiment with client and edge devices. Rather than waiting for vendors of large network and Cloud boxes to initiate or adopt an innovation. Fog will make it easier to create an open market place for individuals and small teams to use open APIs (Application Programming Interfaces), open SDKs (Software Development Kits).

VII. FUTURE OF FOG COMPUTING/CONCLUSION

The future of fog computing is much the same as whatever other promising technology, it can change very rapidly, contingent upon evolving needs. In this paper we have outlined specific applications where fog computing performs superior than cloud computing in meeting the demands of the emerging real time applications. Fog computing model presented in this article shows that a fog computing system does not completely replace a cloud computing system, but it works in conjunction with cloud computing. Fog computing utilizes basic cloud Computing model at its foundation, but it addresses many issues of the cloud computing and helps to boost usability and accessibility in different computing environments. Fog computing unique characteristics, provides better means of computing for delay sensitive, geographically distributed and mobile IoT applications. With the continuous advancements in implementation technology data, services and applications are pushed closer to the end-user; technologists are attempting to optimize the delivery process. Fog computing model handle the intensive data produced by IoT devices locally using local fast-rate connections and relieves the long back and forth data transmissions among cloud and end users. So fog computing gives a greatly improved computing experience and better utilization of network bandwidth than cloud computing. As we have talked about all through this whole article, the Internet of Things are keep on growing exponentially with time, consequently in future more and more devices will continue to connect to internet and fog computing services going to be more significant because of its scalable sustainable and effective nature. In the next few years, IoT developers will likely to embed fog computing capabilities in networking as well as IoT devices themselves. Since 2013 industrial IoT platform developers, such as Microsoft, Samsung, IBM, and Intel, are presently moving towards fog gateway devices to perform edge computing. As we knows fog computing is a latest computing paradigm and its exploration is at an underlying stage thus researchers have different interpretation about fog computing systems. So undoubtedly, there is a requirement for a standard fog computing architecture that can be utilized as a source of perspective model in Fog computing based research domains.

Table 1 explained the major issues in cloud that can be solved by fog computing.

Table 1: Some challenges which fog can overcomes from cloud

Cloud Platform Challenges	How Fog Computing Can Help
Not suitable for latency sensitive real time and location based applications because of centralized nature of cloud computing.	Proximity to users and dedicates on localized service applications results in less number of hops and enables real time applications and location based services support.
Data rich mobility	Data locality and local cache
Geographic distribution	Intelligence localized at the edges
Faraway from end users and communication takes place through various IP based public networks, makes it less reliable	In the physical proximity to users and communication through single-hop wireless connection makes it more reliable and secure
Wastage of network bandwidth	Local data processing so reduced bandwidth requirements
Data analytics challenges because of Big data	Analytics and storage near the users
For cloud computing we need more warehouse-size infrastructure with numerous air conditioning systems.	In fog computing most of the fog servers installed outdoor (streets, parklands, etc.) or indoor (restaurants, shopping malls, etc.) So less requirement of big and costlier infrastructure.
Endpoint functional constraints i.e.; limited processor throughput, limited storage etc	Fog capabilities can be more redundant and modules can be added when needed and removed when not in use
Endpoints security constraints and security varies from cloud provider to provider	Fog has better network as well as physical security
Cloud data centers are very large in size, each typically contain tens of thousands of servers.	A Fog in each location can be small (e.g., one single fog node in a manufacturing plant or onboard a vehicle) or as large as required to meet customer demands. A large number of small Fog nodes may be used to form a large Fog system
Because cloud model require sophisticated deployment planning before actual implementation which needs extra time and expert professionals.	On the other hands Fog deployments will require careful deployment planning, Fog will enable ad-hoc deployment with no or minimal planning.

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