Distributed Processing Middleware on Mesh Network for Connectivity Challenged Environments

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***Abstract*—The growth of pervasive computing, such as Internet of Things, increase the number of devices and the amount of context information being generated. Existing frameworks such as Cloud computing simply utilize these IoT devices as end-to-end network gateways. Paradigms such as Edge and Fog computing while able to minimize latency by bringing computing devices nearer to the data source, fail to consider the utilization of computation resource of these IoT devices. For connectivity challenged environments such as rural or disaster areas, cloud and edge/fog systems are not as accessible and devices are limited to wireless sensor networks and cheap commodity computing nodes. The goal of our research is to deliver pervasive computing to these environments by developing a middleware for heterogeneous IoT devices. Utilizing the middleware enables IoT devices to perform distributed machine information processing on available sensor nodes, without Cloud-based computing resources.**

I. Introduction

Due to the increasing number of devices, faster processing and better connectivity, computing has been a permanent and pervasive addition to our daily lives. With the increasing amount of data traffic comes more adaptive and context-aware software to supplement our daily lives. However in developing countries, especially in rural or disaster stricken areas, information-communication technology (ICT) is not as pervasive. People living there have no luxury of instant access to Cloud based systems. Thus it may be beneficial to create a system that would provide a similar service even with the absence of communication infrastructures. The goal of this research is two-fold: (1) provide a network system of IoT devices connected by wireless mesh network and (2) implement an information processing middleware that utilizes the distributed computational resources of the network of IoT devices. Such a system would allow the creation of pervasive software and applications on the middleware that can be utilized by the people in the connectivity challenged areas. This paper introduces the background concepts, challenges, and approaches for building a distributed mesh networked middleware.

II. Background

This section introduces the background concepts that form the foundation of my work: (1) Wireless mesh networks, (2) Information Flow of Things (IFoT) and (3) Middlewares.

A. Wireless mesh networks

In a wireless mesh network (WMN), nodes which form the network can all connect to one another through multiple hops. Each node acts as both a host and router, forwarding packets to other nodes that are not within the direct wireless transmission range of the sender. One of the main advantages of WMNs is that they can perform their responsibilities in the absence of infrastructures. Nodes can be added and removed, the topology changed, and user's will be unaware. Dynamic routing capabilities using various routing protocols such as B.A.T.M.A.N., allow the seamless traffic flows between multiple nodes.

B. Information Flow of Things

Edge and fog computing paradigms executes tasks nearer the source. However, existing edge/fog computing paradigms fail to consider the computational resource of the IoT devices in the data source itself. Information Flow of Things [1], is a data processing framework that was proposed for processing the information flow (raw and aggregated data streams) from the various IoT devices, at the data source itself, in a timely and scalable manner. IFoT aims to flexibly utilize the available resources of the IoT devices at the source to provide services for the area at low cost and low latency using distributed processing.

C. Middleware

Due to the heterogeneous nature of IoT devices and sensors, it is often difficult to develop applications that utilize the sensor data as well as efficiently add devices into the platform. Middleware [2] allow the devices and sensors to communicate easier and allows abstractions for the distributed processing to be developed faster. Docker technology, a lightweight and effective virtualization solution, can be used to develop a middleware [3] on even commodity devices such as the Raspberry Pi. Containerization allows one to manage, deploy and distribute cloud/edge applications into groups of devices called clusters.

III. Challenges

As a result of [4], we showed how devices setup in a mesh network can be configured to perform distributed machine learning in the form of a Random Forest algorithm. The paper also showed that it was able to utilize the sensors, camera, within the wireless mesh network as input for data processing,

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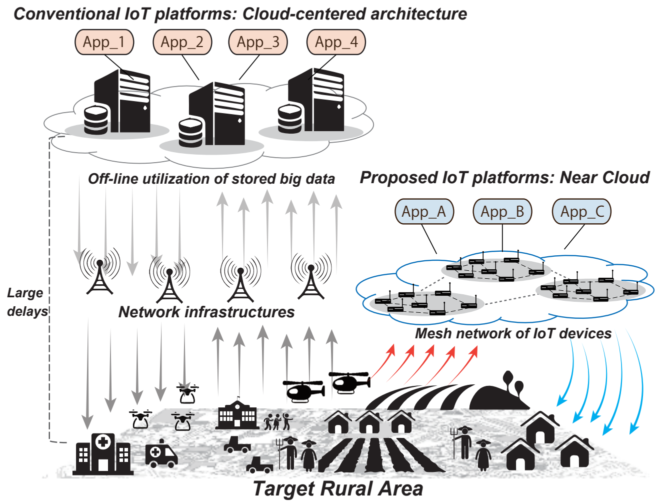

Fig. 1. Paradigm shift from cloud, edge/fog computing to the proposed system, Near Cloud, on a connectivity challenged environment

object detection. However, from a middleware perspective, the approach is limited, since there is no method or functionality to easily add more nodes to the system such that computational resource would be increased.

Figure 1 shows how the expected architecture of the system. The platform is formed by multiple clusters of nodes. Nodes are connected to each other by a WMN through ad-hoc wifi. Due to the characteristics of a WMN, the *services deployed on the clusters should be fault tolerant and resilient to network fluctuations and node loss.*

Another requirement for the middleware is *for it to be able to maintain acceptable quality of service given the WMN's latency*. One way to measure the effectivity of the middleware is to measure the distributed processing times with a wired, wireless and ad-hoc network connecting the nodes. Also the nodes of the middleware should be able to act as gateway for users using various devices to connect to and access the services.

These services are offered by nodes set up as Service Brokers (SB). These SBs communicate with both the users and the worker nodes to perform distributed training and processing. This requires the middleware *to be able to successfully perform distributed cooperative training of machine learning models given data across the system.*

IV. Approaches

The goal of my thesis is to investigate how to build a middleware that would be deployed in connectivity challenged environments such as rural or disaster areas. This requires the middleware to run on multiple IoT devices that are connected by a WMN. The challenges outlined in the previous section must be addressed in order to realize this middleware.

Challenge 1: The current fault resiliency being employed by containers is replication. Multiple services are deployed over multiple nodes. However, data from individual nodes are not easily shared and distributed unless using some form of network attached server (NAS). Extending work by [5], which proposed In-Situ adaptive provisioning, we can modify the clusters such that neighboring nodes will carry pieces of data of other neighbors, increasing fault tolerance. Some method of a distributed hash table may be utilized as well.

Challenge 2: Due to the best effort nature of WMNs with regards to network. Services which require consistent communication between to perform and execute task will be challenging. The current approach is to use QoS, such as those in MQTT protocols, that require acknowledgements between two clients. A system must be implemented between nodes such that data will be sent again in the event of network drop off.

Challenge 3: In order to fully utilize the multiple heterogeneous IoT devices within the system, distributed cooperative training and classification of data must be performed. Current technologies such as Jubatus, perform online distributed machine learning on the data streams of Big Data. Solutions, usually geared for more powerful servers and clusters, must be implemented on commodity devices and single board computers such as the Raspberry Pi.

V. Conclusion

Our first results show how WMNs can be utilized as network gateways for users as well as how Dockers, deployed on commodity devices can be used to perform distributed classification of queries through division of labor and task scheduling [4]. However, the current implementation performs these two functions separately. As the challenges indicate, it is imperative that the limitations of WMNs must be solved or worked around in it's integration with a distributed cluster of nodes. These form the research's future work.

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