Mobility Aware Edge Computing: Challenges and Opportunities in Real-Time Applications

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Abstract—**Recently, real-time applications on edge computing facility rapidly increasing. To cover a larger area, edge devices adhere to mobility. However, mobility increases the scalability of the system but also produces hefty challenges. In real-time applications, data generated by IoT devices must reach the edge computing device in stipulated time deadline which is defined in the Service Level Agreement (SLA) of the application. Traditional challenges in edge computing still apply to mobility aware edge computing and mobility brings new challenges and opportunities to it. Considering the existing literature, in this paper, we study the challenges and opportunities with respect to mobility-aware edge computing in real-time applications. We also study a problem case study of Unmanned Aired Vehicle (UAV) drones flying over agricultural land.**

Keywords— Challenges, opportunities, edge computing, real time applications, IoT, mobility aware

I. INTRODUCTION

Traditionally, the cloud computing paradigm is used for computational tasks of IoT devices but with growing things with the internet, cloud computing platform is not feasible as it leverages high communication delay. This is because cloud servers situated far away from the data origin. To tackle this, the edge computing platform evolved. Edge computing provides computational resources close to the devices generating data. For delay-sensitive applications, the edge computing platform provides low latency, mobility, and location-awareness [1][2][3].

Real-time applications need low latency requirements for sharing information, for example the information regarding fire detection in the forest alert the fire department in time [4]. In this scenario, edge devices will help reduce the latency in transferring data generated by IoT devices like sensors because the computation done is closer to the data source.

IoT devices generally unevenly distributed across the regions. To handle the dense IoT devices, adequate edge devices also should be placed but this will increase the cost of purchasing new edge devices even though there are few IoT devices in certain regions. To solve the problem, we make the edge devices move, i.e., edge devices adapt mobility so that the edge devices can cover the larger area without increasing the cost. The presence of mobility in edge devices for performing analytics on the data received from IoT devices poses a hefty challenge to maintain the constrained communication delay and stable network topology that real-time applications require [5]. The mobility aware edge computing is similar to the works of mobile ad-hoc networks (MANET). In MANET different surveys regarding routing [6], security [7] and clustering [8] are studied and the same techniques can be applied to mobility aware edge computing.

In this study, we consider edge devices that are mobile in nature and data generated by IoT devices must be forwarded to edge devices for processing, storage or both. In Figure. 1 we listed all the challenges and opportunities concerning the mobility aware edge computing.

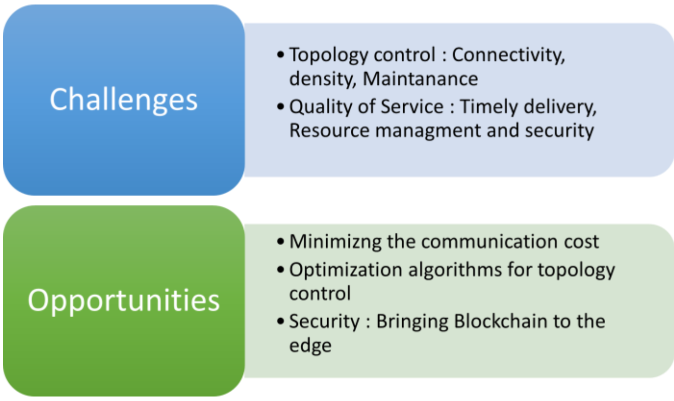

Figure 1: Opportunities and Challenges

II. MOTIVATION

In this section, we study the motivation behind mobility aware edge computing in real-time applications. Real-time applications such as traffic monitoring, autonomous vehicle, military applications etc. require real-time data transmission as well as quicker response. Generally, edge computing should adhere to collective computation rather than application specific. On that note, we need to build an edge computing system that should work according to the application requirements. Without such adaptability in edge computing, we would be unable to cope with the increasing demand of real-time applications [9]

Bringing mobility into the edge devices like Unmanned air vehicle usage in forest fire detection, the agriculture sector is to cover the larger area where different sensors deployed. This will bring down the cost of procuring new edge devices. Besides this advantage there are new challenges also arise. Recently, vehicular ad-hoc networks (VANET) [10] gained a lot of attention where computational capability placed in the vehicle itself, for example, applications like autonomous vehicle, i.e., Tesla Autopilot, which requires real-time actuation responses while monitoring the road conditions [11]. As there is growing application requirements, the study in mobility aware real-time edge computing application is much needed, and not as an independent document. Please do not revise any of the current designations.

III. CHALLENGES

We consider topology control and Quality of Service (QoS) as two broad main challenges for mobility aware real-time edge computing applications.

A. Topology Control

A network topology in the edge computing scenario depicts connection links between the IoT devices and the edge devices. Mobility of the edge devices leads to frequently broken links in the network topology [12] This leads to the topology which is transparent. An ad-hoc network is topology-transparent if the network topology is unknown to all network nodes. If the devices in the topology do not have complete knowledge about the network managing and controlling the network topology is much harder. Maintaining a stable network connection with limited knowledge about the network is NP-Hard [13]. Topology control face challenges mainly in the following aspects

- Connectivity in topology describes the links between different devices. Due to the mobility of devices, link connectivity becomes unstable. Maintaining connectivity across every device is a must in order to perform sensing and actuation without any data loss [14]. For real-time applications, the connectivity across all the devices must be available all the time because the event occurring is uncertain.
- Density in the network topology talks about the number of devices involved. Edge computing requires edge devices to be placed nearer to data generated by IoT devices like sensors. If the deployment is dense there is high connectivity but contention issues otherwise there is less connectivity and packet loss due to the existence of broken links [15]. For real-time applications, deploying adequate edge devices is a must in order to store and process the data generated by IoT devices.
- Topology control involves topology construction and maintenance in order to reduce the costs incurred. In MANET, the topology control is NP-Hard which is studied extensively to increase the lifetime of the network topology. Studies in this regard mainly worked on adjusting the transmission range of the mobile nodes optimally such that the connectivity is maintained and reducing the power consumption [16] [17].

B. QoS

Quality of service in real-time edge computing applications involves constrained delay tolerant information exchange between edge computing devices and the IoT devices, maintaining load balancing with respect to the resource utilization on the edge devices. Real-Time applications have stringent time deadlines, i.e., timely delivery of the data generated from IoT devices to the edge devices in order to maintain service level agreements (SLA) [14]. In order to meet SLA requirements, different offloading methods are introduced. These methods consider latency and load balancing as the main indicator of QoS in real-time applications.

Mobility aware QoS is a real challenge in ad hoc networks. For real-time edge computing application’s data generated by IoT devices must reach the edge devices in stipulated time deadlines. This involves an optimal assignment of IoT generated data to the edge devices, but the assignment problem is NP-Hard, and this becomes more complex by because the edge devices are mobile in nature [15]. Several heuristic approaches are proposed for QoS such as swarm Intelligence [16]. neighborhood search [18], and hybrid methods [17].

Data generated by the IoT devices offloaded to the edge devices causes unbalance load among edge computing devices [18]. Achieving optimal load balancing is an NP-Hard problem. Therefore, approximations are used to maintain load balancing across edge computing [19]. For real-time applications, scheduling the tasks generated by IoT devices to edge computing devices by considering the mobility of edge devices is even much harder. Load balancing in MANET environment studied extensively. This study mostly considered with respect to routing protocols, energy efficiency [20] [21].

QoS is greatly affected by the security aspect as well. One major security issue in the edge computing model is the physical access of the devices. Physical access of the IoT devices and the edge computing devices leads to the cloning of the devices by an intruder. This cloning activity results in rouge devices which is not good for the mobility nature of the edge devices. For example, in military applications, such cloning results in serious threats to the nation. To stop the cloning of the devices, devices should adapt physically unclonable function (PUF) technology [22]. Existing research is working on improving the security in edge computing facility by adopting new technologies like blockchain [23]. In a mobility environment, the edge devices should work cooperatively. Any rouge node in the system creates hefty issues to the entire stability of the system. The increasing number of edge device makes identifying rogue device is challenging [25].

IV. OPPORTUNITIES

Despite the challenges that arise by the mobility aware edge computing following opportunities are there for academic research. There are studies conducted relevant to the opportunities in edge computing, but they are not considered mobility nature into the edge computing facility, to fill that gap. Existing opportunities for edge computing in the literature still applies to mobility aware edge computing. Therefore, we are not considering the opportunities of designing and developing of lightweight algorithms and frameworks, standardization of edge computing services, and the opportunities for industry [26] [28] [29]. We consider the following list of opportunities for mobility aware edge computing.

- Minimizing the communication cost in mobility aware edge computing is the real deal. Since real-time applications have strict time deadlines, the cost incurred to manage the resources of edge devices will also increase. There are opportunities for researchers to work on reducing the cost involved in real-time edge computing applications. One such opportunity is to allocate IoT devices to the edge devices such that communication cost is reduced.

- As we have seen, maintaining a stable network and topology-aware computation in a mobile environment is a hard problem [29]. There is a requirement for new optimization methods that improve the existing computational capabilities of edge devices.
- Physical accessibility of the edge devices and IoT devices will lead to security issues. Cryptographers and systems security experts have a lot of opportunities to work in this field. One such opportunity is bringing blockchain technology to the edge devices makes transactions quickly this will lead to doing micropayments happening in insufficient time [32].

V. A CASE STUDY

In this section we present a case study problem definition of Unmanned Aired Vehicle (UAV) usage in agriculture. Consider a problem statement where Unmanned Aired Vehicle (UAV) drones are flying above agriculture land and sensors like soil, moisture, temperature are placed randomly on the agriculture land. UAV drones will form a cluster and connect to sensors in such a way that communication cost between them is minimized [31].

Let consider a set of IoT sensors I= {1, 2, 3, ...m}, a set of UAV's equipped with single board systems E={1, 2, 3...n}. $C_{i,j}$ denotes the communication cost involved between an IoT device i, where i∈I, and a UAV j, where j∈E. The data collected from sensors must be processed and give alert to the end user in stipulated time period so let α be the maximum tolerable time period and U_j be the delay incurred in receiving data at user from UAV j, where j∈E. Assuming no UAV drone is overloaded from the data, i.e., UAV drones resources are not over utilized when processing the data. We define a binary variable $x_{i,j}$ as

$$x_{i,j} = \begin{cases} 1 \; if \; IoT \; sensor \; i \; allocated \; to \; UAV \; j, where \; i \in I, j \in E \\ 0 \; otherwise \end{cases}$$

Now, we state our problem as an Integer Linear Programming (ILP) [29]. ILP is a NP hard problem [30] therefore heuristic optimization algorithms are applied to solve the ILP problems [31]

$$\min_{x_{i,j}} \sum_{i=1}^{m}\sum_{j=1}^{n} C_{i,j}\, x_{i,j}$$

$$\text{s.t.} \quad x_{i,j} \in \{0,1\} \;\; , \forall i \in \{1,2,..m\}, \forall j \in \{1,2,..n\},$$

$$\forall i \in \{1,2,..m\}, \sum_{j=1}^{n} x_{i,j} = 1,$$

$$\forall j \in \{1,2,..n\}, \;\; U_j \le \Delta$$

VI. CONCLUSION

Mobility aware edge computing in real time applications is still in its early stage of research. This study is conducted to explore the challenges and opportunities for researchers. In future work, we will work on the case study problem.

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