A Fog-Assisted Architecture to Support an Evolving Hospitality Industry in Smart Cities

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***Abstract*—In this paper, we propose a fog-assisted architecture for the hospitality industry in smart cities aimed at improving guest experience, building business insights, and increasing revenue. The proposed architecture integrates cloud services platform with the Internet of things (IoT) devices at the network edge through intermediary fog computing nodes to create an architectural paradigm with the benefits of low cost, high responsiveness, energy-efficient computing and communication, scalability, and local and global analytics. To demonstrate the effectiveness and utility of our proposed architecture for the hospitality industry, we present various use cases that can be implemented and/or enhanced by the proposed architecture. We also present a comparison of the proposed fog-assisted IoT architecture against contemporary cloud-IoT architectures in terms of average latency or timeliness. Results verify that offloading IoT tasks to fog nodes provide an improvement of 37% on average over offloading IoT tasks to cloud for the selected benchmarks. We also highlight research challenges and open research directions for fog-assisted architectures for hospitality industry.**

***Index Terms*—Hospitality industry, guest-facing systems, back-of-house (BoH) management systems, Internet of things (IoT), architecture, cloud services, fog computing, smart cities**

I. Introduction and Motivation

The concept of smart cities has evolved over the recent years owing to the advancements in information technology, wireless communication, Internet of things (IoT), and machine learning. The smart cities utilize these information and communication technologies to help increase the operational efficiency of cities as well as help make cities greener, safer, faster, and friendlier [1]. A smart city has different aspects such as intelligent transportation systems, smart energy grids, smart infrastructure, smart hotels, etc. The hospitality and tourism industry is one of the facets of smart cities.

The hospitality and tourism industry is one of the world's most profitable and largest service industries with a global economic contribution (direct, indirect and induced) exceeding 7.6 trillion USD in 2016 [2]. The future of the hospitality industry in smart cities is being shaped by technology in particular by the advancements in IoT technology. Hospitality service providers (HSPs) must stay on the leading edge of the IoT technology to maintain a competitive edge in the market. The IoT paradigm offers HSPs a subtle means of interacting with guests and collecting their real-time data. This interaction and data collection open new avenues for timely, personalized, and localized services as HSPs can gauge guest behaviors and preferences with high accuracy. The IoT also enables HSPs to increase efficiency of multiple back-of-house (BoH) departments [3] (e.g., front desk, housekeeping, sales, and marketing, etc.) as well as enact cost-saving policies like smart energy management [4]. The advantages of IoT for hospitality industry can be better capitalized by leveraging *fog computing*, which is a novel trend in computing that pushes applications, services, data, computing power, knowledge generation, and decision making away from the centralized nodes to the logical extremes of a network.

While many aspects of smart cities (e.g., smart grids and intelligent transportation systems) have received significant attention in literature; infrastructure, in particular the infrastructure for hospitality industry that mainly includes hotels, resorts, restaurants, and tourist attractions has received little coverage. This paper aims to fill this research gap in literature and focuses on a smart hotel solution in smart cities enabled by advances in IoT and fog computing. The main contributions of this paper are summarized below:

- Proposal of a fog-assisted IoT architecture for hospitality industry in smart cities aimed at improving guest experience, building business insights, and increasing revenue.
- Presentation of several use cases, such as event customization based on hotel location, anticipation of guest requests, and energy management, that can be implemented or enhanced by our proposed architecture.
- Experimental evaluation of the advantages of the proposed fog-assisted IoT architecture over contemporary cloud-IoT architectures in terms of application latency (timeliness).
- Articulation of challenges and future research directions related to fog-assisted architectures for hospitality industry.

II. Related Work

The incorporation of technology in hotels makes hotels an instance of smart buildings. There is abundant literature available on challenges, design, and implementation of smart building solutions. Here, we present a brief summary of selected previous work in smart buildings.

Energy consumption has been the primary focus of many of the articles on smart buildings. Energy consumption significantly contributes to the operational cost of a building as well as to its environmental impact [5]. To create an energy-efficient solution for smart buildings, a tradeoff must be made between the degree of energy efficiency and the

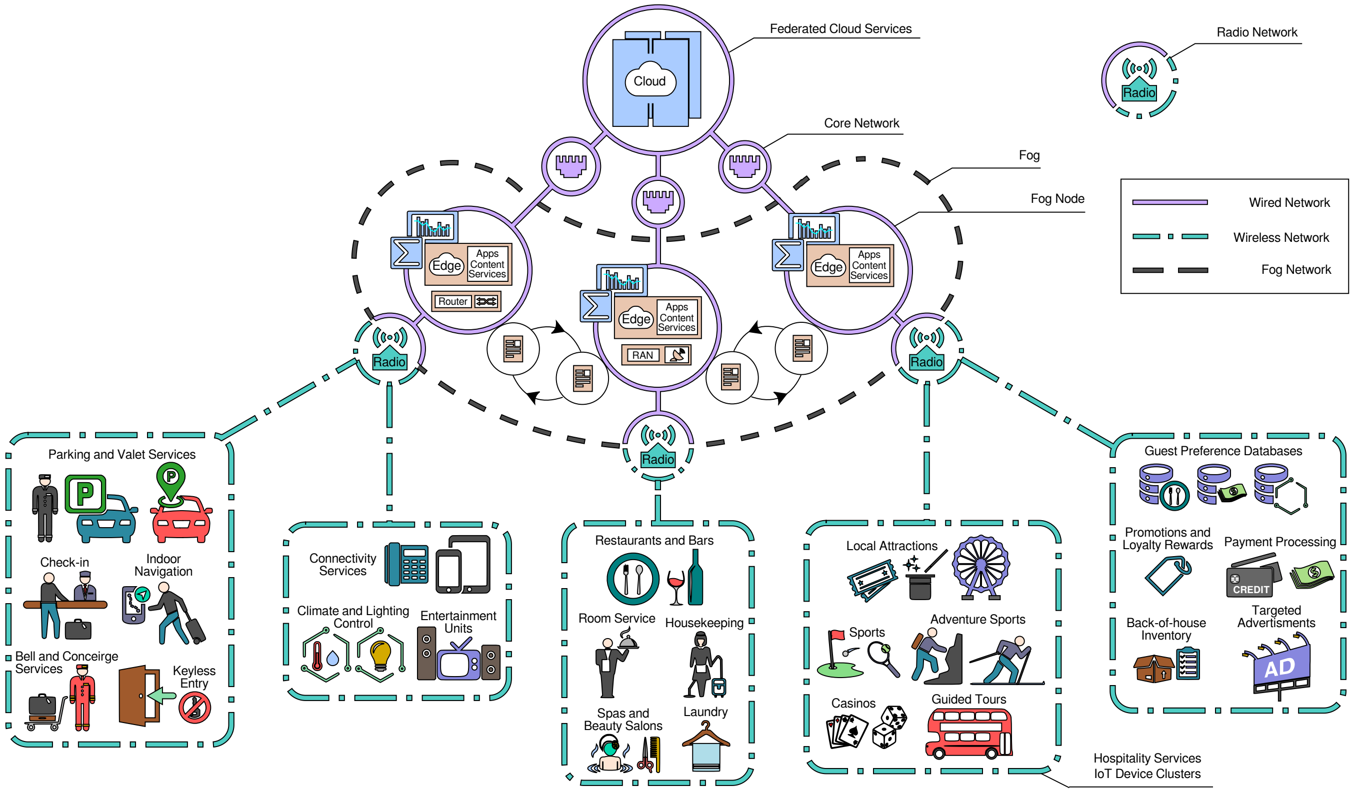

Fig. 1. Fog-assisted architecture for the hospitality industry.

degree of user comfort and wellbeing [6] [7]. Altayeva et al. proposed a multi-objective optimization algorithm in [7] which modeled user discomfort and energy consumption as two different objective functions and tried to minimize both of these objectives. George et al. [8] proposed an energy management scheme that used personalized behavior information for building occupants which was obtained by running a machine learning and neural network algorithm on data gathered from wearable devices. For an energy management strategy in smart hotel context, similar algorithms can be employed. However, the implementation of these algorithms has to be performed at a finer granularity in smart hotels in order to cater to the individual and varying preferences for in-room and on-property environment of each hotel guest.

Apart from energy consumption, maintaining security and privacy of occupants is another major focus of research in smart buildings. Smart buildings are equipped with a multitude of sensors and data-collection terminals that gather sensitive information from the building occupants. The gathered data has to be secured using strong cryptographic primitives so that it cannot be misused or manipulated by any malicious agents. Perez et al. [9] proposed a lightweight and flexible encryption scheme that provided data security and privacy in smart building scenarios. They used symmetric cryptography and attribute-based encryption in their implementation. Similar implementations can be used in the smart hotel context to secure guest data and to ensure guest privacy.

Although work has been done on smart buildings but the application and extension of that research to smart hotels is lacking. A smart hotel can be designed and implemented using a combination of existing technologies proposed for smart buildings. However, management and policy decisions made by the deployed algorithms must give a higher priority to guest comfort and wellbeing.

III. Fog-Assisted Architecture for the Hospitality Industry

We propose a hierarchical network architecture, as shown in Fig. 1, which integrates edge-of-network IoT devices with a centralized cloud server by means of intermediary fog nodes. A fog is defined as the physical and logical network that implements fog computing services [10]. In our proposed architecture, the edge-of-network IoT devices that facilitate the hospitality service exchange, lie at the lowest tier of the hierarchy. Fog nodes lie in the middle tier of the hierarchy. Each fog node manages a cluster of edge-of-network IoT devices. The communication between the fog nodes and IoT devices occurs over a radio network. Fog nodes add computation and storage resources closer to the edge of the network. The IoT devices can utilize these resources by offloading complex applications, computations, and services to the fog. This offloading helps in not only improving the battery life of IoT devices by lessening their computation burden but also decreases the execution time of applications. The dense geographic distribution of fog nodes also ensures precise location-based services and near real-time local analytics. Fog nodes are connected to a central cloud server through the core network. The cloud constitutes the topmost tier in our proposed architecture. The cloud facilitates broader accessibility scopes for guest profiles, comprehensive loyalty or rewards point management, and global data analytics.

The main goal of our proposed fog-assisted architecture is to provide personalized, adaptive, and predictive next generation guest experience. In our proposed architecture, fog nodes continuously monitor guests' activity and their surrounding environment by aggregating data from edge-of-network IoT sensors and devices. HSPs can locally analyze guest activity information, such as behavior, current location, etc., along with the environment data using fog nodes to adjust the services and offers provided to guests. For example, in-room temperature can be adjusted based on guests' body temperature and the time of day. Our proposed architecture also allows HSPs to offer services by predicting the needs of guests. This can be achieved by analyzing current guest activity against historical records maintained in the fog to predict guests' needs. For example, room-service can restock minibars in guests' room with their favorite energy drinks as guests make their way back from the hotel gym.

Fog computing provides an open standardized interface for the integration of systems into a network. It eliminates the dependence on proprietary and single vendor solutions by promoting interoperability between multi-vendor systems and solutions. The vendor diversity significantly reduces system cost and improves the quality of services provided [10]. Moreover, the standardized platform offered by fog computing also benefits data sharing between different entities connected by the network. Fog nodes, deployed in various locations (e.g., lobby, restaurants, spas, etc.) within the hotel property can share guest data among each other.

Fog computing also facilitates timely responses to guests' requests due to proximity of fog nodes to the guests as compared to the distant cloud servers. The computing resources in the fog enable local analytics of guest profiles as well as of the data gathered from local sensors and systems, which helps in providing high quality services to the guests. The distributed storage resources provided by fog can also be used to maintain a distributed backup of guest profiles and critical BoH information. Distributed backup of data can be useful to maintain hotel operation under security breaches, such as session hijacks and ransomware attacks [11].

IV. Fog-Assisted Architecture Use Cases

In this section, we describe some to use cases to demonstrate how our proposed fog-assisted architecture can be used by the hospitality industry in general, and hotels in particular, to provide highly personalized services to their guests. Although we describe these use cases in context of hotels but these use cases can be extended for restaurants and tourist attractions as well.

A. Event Customization based on Hotel Location

Fog nodes in the hotel can be used to keep track of when and why guests visit the hotel. Although many hotel establishments already do this on a regular basis for large conventions, conferences, and festivals, etc., fog nodes can be used to broaden the scope of the events covered. For example, guest data in fog nodes can be leveraged to determine when guests visit the hotel to attend personal events such as birthdays, anniversaries, etc. Such data, which is otherwise easily overlooked in advertising and in special booking offers, can be used to send targeted and highly personalized deals to guests.

Fog nodes also provide a means to deliver highly personalized services across a global scope through interaction with cloud (Fig. 1) that can substantially improve guest experience beyond what could be achievable otherwise. For example, consider the scenario of a conference/convention which is held at different cities around the world every year; (say) the conference is held in a US city in one year and held in a city in Spain the next year. A multinational hotel chain has hotels in both cities and is housing the conference attendees. Most conferences/conventions have repeat visitors. A hotel chain can easily market deals and offers to repeat attendees. With the use of fog-assisted architecture, hotel chains can go a step further in personalization of the services provided to such guests. In the presented scenario, the hotel fog node in the US hotel creates and maintains profiles for all the attendees it houses. The next year, when repeat attendees check into the Spain hotel, the hotel fog nodes there query the cloud for guest profiles from the previous year's records. The cloud forwards the query to the fog nodes at the US hotel and then acts as a relay for sharing of guest profiles between the fog nodes at the two hotels. Using the guest profiles supplied by the US hotel, the hotel fog nodes can enact service policies within the local context to provide personalized services to guests based on their preference and behavior history.

B. Guest Preferences and Behavior

Fog nodes are located closer to the network edge, hence the fog nodes are most suitable to handle local processing tasks whose results are relevant in the local context. These processing tasks are too burdensome to be carried out in the cloud due to the cost, latency, and bandwidth constraints. Thus, hotel fog nodes are more suitable than the cloud to launch local service actions based on guest preferences and behavior. For example, guest preferences such as types of meals, beverages, entertainment and games can be analyzed by the hotel fog to personalize services for guests. Records of a guest's meal preferences (e.g., vegetarian, vegan) as well as any food intolerances (e.g., lactose) or allergies (e.g., peanuts, sea-food), etc., can be maintained in guest profiles on the hotel fog nodes which can then be used by on-property restaurants to present guests with a filtered list of menu items on a digital menu. The hotel fog nodes can also analyze the genre of music a guest enjoys by using information from playlists played by the guest on in-room entertainment units. This data can be used by the hotel fog nodes to send suggestions to guests to try on-property restaurants and bars having live musical performances of their favorite music. The hotel fog nodes can also maintain records of types of casino games a guest plays and stakes at which the guest plays at. This data can be used by the hotel fog nodes to send guided maps to guests of the casino floor with marking tables with their favorite games being played with their preferred stakes.

Although guest preference and behavior profiles have a global scope, it is unnecessary to have a global record for all hotel guests. Global records for guest profiles should be centrally maintained on cloud servers on a case-by-case need basis. Guest profiles which are only relevant on a local context should be maintained in distributed fog nodes. The distributed storage of guest preferences and behavior profiles provided by fog nodes thus not only lessens the storage burden on cloud servers, but maintains proximity between the stored data and the context it is useful in, which allows for fast and easy access.

C. Automatic Connectivity

The hassle of connecting to hotel Wi-Fi is a major complaint among hotel guests. Hotel fog nodes can provide automatic and hassle-free means to connect to hotel Wi-Fi for repeat and loyal guests. Fog nodes can authenticate guest devices belonging to repeat and loyal guests for automatic Wi-Fi connection by means of MAC address authorization and room reservation and booking information. Alternatively, Wi-Fi connection can also be provided to guest devices based on authentication through hotel loyalty applications running on them. The device registration and connection process can also be simplified for new guests. New guests can be allowed to register their devices at the automatic check-in kiosks when they check into the hotel. Since fog nodes have partial control over the local radio network, they function as reliable entities for authentication and authorization.

D. Anticipation of Guest Requests

Hotel fog nodes can utilize data gathered by in-room sensors and devices to anticipate guest requests and to automate certain in-room or on-property services based on guest activity. For example, hotel fog nodes can use in-room lighting sensors to detect the amount of natural light entering the room and decide whether to turn on certain hotel room lights. The fog nodes can also use in-room thermostat to detect the temperature and humidity in the hotel room and adjust the heating, ventilation, and air conditioning (HVAC) accordingly. The data on hotel room waterflow gathered by smart sinks and showers can be used by fog nodes to schedule the supply of fresh toiletries to the hotel rooms. Also, if hotel rooms use radio frequency identification (RFID) tags on their minibar items, the hotel fog nodes can maintain a digital inventory of the minibar and notify when it needs to be restocked. The hotel fog can also improve table turnover rates for on-property restaurants by anticipating guest meal preferences based on order history and preferences. The hotel fog thus can make services available to guests before they even feel the need to ask for them resulting in increased customer satisfaction and loyalty to the hotel brand.

E. Energy Management

HSP can implement various cost saving measures to attain "green" operation of in-room and on-property systems leveraging our proposed fog-assisted IoT architecture. The energy-saving systems currently being used in many hotels include smart lighting, smart thermostat, and low power devices such as LED lights [12]. The proposed fog-assisted architecture can be leveraged by hoteliers to significantly broaden the scope of energy saving systems. For example, IoT-enabled power outlets can notify housekeeping and maintenance service personnel via communicating with the fog nodes on the property if the power consumed by a particular outlet exceeds a defined threshold over a period of time. The service personnel can then determine whether there is power leakage or some negligence from a customer. The fog nodes can also keep track of guests energy consumption behavior and provide incentives to customers with economical energy usage profile.

V. Results and Analysis

In this section, we present a comparison of our proposed fog-assisted IoT system against a contemporary cloud-based IoT system. We follow a similar approach as to the one presented in our previous work [13]. We compare fog and cloud implementations using the average latency metric which is the time taken by the system to complete and return results for the tasks offloaded by IoT devices. These offloaded tasks in the hospitality industry could be, for example, data analytics on customer data to provide customized offers and promotions. Through these results, we aim to demonstrate that fog-assisted architectures provide lower latency response to computation offloading requests from IoT devices as compared to the cloud because of closer proximity of fog to the edge-of-network IoT devices.

In our experiments, we focus on latency metric as the latency metric (or timeliness) is paramount for the hospitality industry. For instance, the location-based services and offers provided to customers will have little value if they are not delivered in time. If a customer moves to a new location/destination and receives offers related to his/her previous location, it is unlikely that the customer will go back to his/her previous location to take advantage of the offers. The agility of services provided to customers is directly related to customer satisfaction and improved experience as well as generated revenue for the hospitality industry providers.

A. Experimental Setup

For running our tests, we use benchmarks of varying complexity with different workload sizes. We used benchmarks from the *dlib* library [14]. These benchmarks loosely model the type of data operated on by the hotel IoT nodes, such as thin client terminals, in-room tablets, room sensors, etc. Table 1 shows in brackets the size of data transfer (sum of the sent and received data) between client (IoT node) and the server for each benchmark (to be noted that data transfer size is proportional to the workload size).

We run our experiments for two computational offloading scenarios. In the first scenario, the tasks are offloaded by the hotel IoT nodes onto a fog node located in the hotel premises. In the second scenario, offloading is carried out to a remote cloud server. We use a linux virtual machine configured to a single core operating at 800 MHz and having 2 GB of

TABLE I
COMPARISON OF BENCHMARKS' EXECUTION TIMES ON AN IOT DEVICE WITH AVERAGE LATENCY FOR OFFLOADING TO A FOG NODE AND A CLOUD SERVER [13].

Applications	T^{IoT} (s)	T^{Fog}(s) @ 1.20 GHz	T^{Fog}(s) @ 3.60 GHz	T^{Cloud} (s)
Data Sort (≈ 2.2kB)	23.34	14.43 (38.2%)	6.34 (72.8%)	10.12 (56.6%)
SVM Rank (≈ 6.6kB)	17.79	10.06 (43.4%)	3.62 (79.6%)	7.80 (56.2%)
Boltzmann Machine (≈ 8.0kB)	6.66	4.74 (28.8%)	1.99 (70.1%)	4.16 (37.4%)
Cost Optimization (≈ 9.3kB)	5.29	3.79 (28.3%)	1.54 (70.8%)	4.38 (17.2%)
Bayes Network (≈ 14kB)	18.02	11.67 (35.2%)	4.25 (76.4%)	8.44 (53.2%)
SVM Pegasos (≈ 33.6kB)	41.58	19.44 (53.2%)	7.40 (82.2%)	12.66 (69.6%)
K-means Clustering (≈ 19MB)	43.18	32.09 (25.7%)	17.44 (59.6%)	15.13 (65.0%)
Running Statistics (≈ 20MB)	12.45	19.42 (-56.0%)	13.77 (-10.6%)	15.63 (-25.5%)

main memory as a client IoT device. We use an 8 core Intel processor operating between 0.80 GHz to 3.60 GHz to serve as the fog node operating at different frequencies. We utilize Amazon Elastic Compute Cloud (EC2) situated in western US (Northern California) region and operating at 2.4 GHz as the cloud server [13]. The client IoT device communicates with the fog node through a wireless ad-hoc network. The IoT devices communicate with the cloud server over the Internet. Mean execution time and mean round trip time values are used (averaged over 10 runs) to calculate the local execution time (without offloading) and the average latency of offloading to fog and cloud, respectively.

B. Average Application Latency for Fog and Cloud

Table 1 provides the comparison of the local execution time of the application T^{IoT} when it is run on the IoT device itself (without offloading) versus the average latency T^{Fog} when the application is offloaded to fog nodes operating at varying frequencies. The table also depicts the average latency T^{Cloud} when the application is offloaded to the cloud server. The results presented in Table 1 clearly illustrate that the average latency of applications when they are offloaded to nearby fog nodes is lesser than when they are offloaded to distant cloud server. This holds true for most of the test benchmarks that are in our test suite. For example, we see an improvement of 49.6% in average latency for the Bayes network test benchmark when it is offloaded to a nearby fog node as compared to when it is offloaded to the cloud server. On average over all the benchmarks listed in Table 1, offloading IoT tasks to the fog node provide an improvement of 37% over offloading IoT tasks to the cloud for the selected benchmarks. Thus fog nodes are ideal for processing locally relevant/contextual tasks due to relatively lower latency (than distant cloud) since fog nodes are in proximity to the IoT nodes and often high bandwidth is available between IoT devices and fog nodes. Offloading to the cloud server requires more latency because the offloaded context data needs to travel long distances on the network (both radio and core network as indicated in Fig. 1) to reach from the hotel premises to the remote cloud location and often bandwidth from hotel IoT devices to the cloud is also limited.

We further observe that the improvement in performance achieved by offloading applications to fog or cloud depends heavily on the size of the data communicated between IoT devices and the fog or the cloud. From Table 1, we see an improvement of 59.6% for the test benchmark K-means clustering having a size of 19 MB which is less than the improvement of 76.4% which is seen for the test benchmark Bayes network having a much smaller size of 14 kB.

C. Effect of Operating Frequency of Fog Nodes on Average Latency

Changing the operating frequency of fog nodes has an effect on the average latency of applications offloaded to the fog nodes. To verify this, we vary the frequency of the fog node used in our experiment in steps of 0.40 GHz between 1.20 GHz to 3.60 GHz. Results reveal that increasing the frequency of the fog node causes the offloaded applications' latency to decrease. For example, we observe an improvement of 58% in average latency of Boltzmann machine test benchmark when the frequency of the fog node processor is varied from 1.20 GHz to 3.60 GHz (i.e., the average latency is decreased from 4.75 s to 2 s). The results also indicate that varying the processor frequency of fog nodes has relatively less effect on the average latency of offloaded applications at higher frequency values as compared to lower frequency values. This shows that the average latency of offloaded applications does not decrease linearly with varying processor frequency of the fog nodes. This is because the average latency depends on several parameters, such as the number of active cores, network bandwidth, and cache size.

VI. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

The research on fog computing and its application to hospitality industry in smart cities is in its infancy. There exist various challenges and open research problems related to fog computing for hospitality industry that require further investigation. We outline a few of these challenges and future research directions in this section.

Scalability: Fog architectures can be deployed to support many different use cases in hospitality industry (some of these use cases have been discussed in Section IV) and are expected to grow seamlessly with increasing application and customer demands thus requiring *scalability* analysis of fog architectures. Scalability of fog-assisted architectures for the hospitality industry can have different dimensions such as capacity, performance, agility, reliability, privacy, and security. The hospitality providers who will install a fog-assisted architecture for the hospitality industry would likely have modest initial capital investment, and then would like to grow the same initial architecture seamlessly in order to serve an increasing customer base, demand, and applications. Hence, fog architectures for the hospitality industry need to designed with scalability in mind.

Adaptive and Interoperable Fog Nodes: The design of adaptive and interoperable fog nodes is another challenge and future research direction for fog-assisted architectures for hospitality industry. Since fog nodes can have different peak load hours at different times [15], there is a need to develop reconfigurable and adaptive architecture for fog nodes/edge servers that can adapt according to the application load being run at a given time to improve the performance of hospitality use cases and thus improve the guest experience as well as the revenue for hospitality providers. The need for interoperability is another key requirement that needs to be taken into account when designing fog nodes. Since the fog nodes need to interact with a multitude of IoT devices with varying computation and communication capabilities, there is a need for flexibility in hardware design of fog nodes. Reconfigurability in computation and communication can be used to provide flexibility in fog deployments. Hardware reconfiguration can enable fog nodes to not only interoperate with diverse existing IoT devices but can also empower fog nodes to be reprogrammed to comply with any future standards or to implement new features and services [16]. Furthermore for scalable fog architectures, fog nodes should allow assimilation of additional computing, storage, and network resources as the demand increases.

Modeling and Simulation: Modeling and simulation of fog-assisted architectures for hospitality industry requires further research. In particular, modeling of fog-assisted architectures for hospitality industry is needed to determine the number of edge servers needed in a hotel/resort area to provide accurate and agile location-based customization of services and offers for customers (guests). The modeling will also assist hospitality providers to perform the cost-benefit analysis of installing new edge servers at the property. Similarly, the development of a simulation platform for fog-assisted hospitality architecture will be a precursor to actual deployment of such systems in the hospitality industry.

Security and Privacy: Security and privacy preservation of customers in a fog-assisted hospitality paradigm is crucial for ensuring customers' safety, protection, and satisfaction as IoT devices and sensors in the hospitality industry collect a myriad of customers data including personal identity, location, credit card numbers, drivers license, preferences, etc. In addition to security vulnerabilities present in traditional cloud-based and server-based systems, fog nodes are also susceptible to additional security vulnerabilities as they are generally deployed near the edge of the network and at places often lacking thorough monitoring and protection. Data security mechanisms such as encryption, integrity, authentication, and access control can help in preserving the security and privacy of consumers in hospitality industry. In particular, since edge servers in fog computing paradigm collect and aggregate sensitive data from various IoT devices and sensors, techniques such as data aggregation based on homomorphic encryption can provide privacy-preserving data analytics (data analytics in hospitality industry is used to provide services such as customized offers, promotions, and anticipation of guest requests, etc.) without the need for data decryption.

VII. Conclusion

In this paper, we discuss hospitality industry as a key component of a smart city. We envision a smart hospitality solution that utilizes a specialized fog-assisted architecture that integrates IoT, fog computing, and cloud computing paradigms. We also present several relevant use cases (e.g., event customization based on hotel location, anticipation of guest requests, and energy management) which can be implemented or enhanced by our proposed architecture. To demonstrate the advantage of our proposed fog-assisted architecture, we conduct experiments to compare the average latency of different benchmark applications executed locally versus the average latency of offloading those applications to the fog and the cloud. The results reveal that offloading IoT tasks to fog nodes provide an improvement of 37% on average over offloading IoT tasks to the cloud for the selected (experimented) benchmarks. We finally highlight various challenges and future research directions related to fog-assisted architectures for hospitality industry.

References

[1] S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything you wanted to know about smart cities: The internet of things is the backbone," *IEEE Consumer Electronics Magazine*, vol. 5, no. 3, pp. 60–70, Jul 2016.

[2] Statista. (2018) Global travel and tourism industry – statistics & facts. [Online]. Available: https://www.statista.com/topics/962/global-tourism/

[3] D. Adelson. (2016) Intelity forecast of hotel technology in 2017. [Online]. Available: http://intelitycorp.com/main/intelity-forecast-hotel-technology-2017/

[4] K. Sunny. (2016) Hospitality and the internet of things - how modern technology is revolutionizing the industry. [Online]. Available: http://www.hotelogix.com/blog/2016/02/16/hospitality-the-internet-of-things-how-modern-technology-is-revolutionizing-the-industry/

[5] F. M. Bhutta, "Application of smart energy technologies in building sector - future prospects," in *International Conference on Energy Conservation and Efficiency (ICECE)*, Lahore, Pakistan, November 2017.

[6] E. Taktak and I. B. Rodriguez, "Energy consumption adaptation approach for smart buildings," in *IEEE/ACS International Conference on Computer Systems and Applications (AICCSA)*, Hammamet, Tunisia, October 2017, pp. 1370–1377.

[7] A. Altayeva, B. Omarov, and Y. I. Cho, "Multi-objective optimization for smart building energy and comfort management as a case study of smart city platform," in *IEEE International Conference on Smart City*, Bangkok, Thailand, December 2017.

[8] S. R. George, A. R. Devidas, and M. V. Ramesh, "Smart personalized learning system for energy management in buildings," in *International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*, Piscataway, NJ, March 2017, pp. 36–42.

[9] S. Perez, J. L. Hernandez-Ramos, S. N. Matheu-Garcia, D. Rotondi, A. F. Skarmeta, L. Straniero, and D. Pedone, "A lightweight and flexible encryption scheme to protect sensitive data in smart building scenarios," *IEEE Access*, vol. 6, pp. 11 738–11 750, February 2018.

[10] "Openfog reference architecture for fog computing," February 2017.

[11] EnsembleIQ. (2017) Ransomware: One of hospitality's biggest threats in 2017. [Online]. Available: http://hospitalitytechnology.edgl.com/news/Ransomware--One-of-Hospitality-s-Biggest-Threats-in-2017108863

[12] P. Kansakar, A. Munir, and N. Shabani, "Technology in hospitality industry: Prospects and challenges," *IEEE Consumer Electronics Magazine*, 2019.

[13] R. M. Shukla and A. Munir, "An efficient computation offloading architecture for the internet of things (iot) devices," in *IEEE Consumer Electronics and Networking Conference (CCNC)*, Las Vegas, NV, January 2017.

[14] D. King, "A machine learning toolkit," *Journal of Machine Learning Research*, vol. 10, pp. 1755–1758, 2009.

[15] A. Munir, P. Kansakar, and S. U. Khan, "IFCIoT: Integrated fog cloud IoT: A novel architectural paradigm for the future internet of things." *IEEE Consumer Electronics Magazine*, vol. 6, no. 3, pp. 74–82, 2017.

[16] P. Kansakar and A. Munir, "A two-tiered heterogeneous and reconfigurable application processor for future internet of things," in *IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, Hong Kong, China, July 2018, pp. 690–696.