A Novel Fog-Assisted Architecture for the Hospitality Industry

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Abstract—The leisure and hospitality industry is one of the driving forces of the global economy. The widespread adoption of new technologies in this industry over recent years has fundamentally reshaped the way in which services are provided and received. However, there are still major challenges that need to be addressed to ensure that this industry maintains a steady pace in adoption of future technologies. In this paper, we identify these challenges and describe the problems they pose for guests and hospitality service providers (HSP). As a means to overcome these challenges, we propose a novel fog-assisted architecture which creates a sound technological framework with specialized guest-facing and back-of-house (BoH) management systems geared towards improving guest experience, enhancing business insight, and increasing revenue. The proposed architecture integrates cloud services platform with Internet of things (IoT) devices at the edge of the network through intermediary fog computing nodes to create an architectural paradigm with the benefits of both distributed computing and centralized analytics. The layered structure of this architecture facilitates interoperability between heterogeneous systems as well as resource sharing and cooperation between multiple deployments and implementations. Moreover, the adaptability of this architecture promotes scalability making it suitable for hotels of different caliber, and guarantees upgradability making it possible to add new and improved hospitality services in the future.

Index Terms—Hospitality services, hospitality service providers (HSP), guest-facing systems, back-of-house (BoH) management systems, fog computing, Internet of things (IoT)

1 INTRODUCTION AND MOTIVATION

Domestic and international tourism has seen several years of steady growth. The revenue generated from accommodation, food and beverage, and other services provided to this large flux of travelers, has propelled the leisure and hospitality industry to become a key driver of the global economy. For sustained growth of this industry, experts in the field argue for major improvements in the type and quality of hospitality services to adapt to the changing consumption and travel behaviors of the evolving customer base. Specifically, these improvements are targeted towards attracting the new generation of technophile individuals traveling on a tight budget [1]. Implementation of these improvements compounds to a complete makeover of the service packages and the underlying technological framework currently used by hospitality service providers (HSP). The goal of these improvements should be: personalization of experiences and digitalization of services [1].

Personalization of experiences is necessary to market services to individuals traveling on a limited budget. Personalization creates individualized guest experiences by incorporating flexibility and customizability to the offered service packages [1]. Most of the current packages marketed by HSP offer rigid and tailored experiences. These packages bundle different combinations of popular services in different price brackets with little to no means of negotiating adjustments. This leaves travelers to choose between all or nothing and they usually end up opting for the latter choice. If HSP have more flexible service package offerings, then guests can plan their experience according to their desires and their budgets. Crafting personalized value propositions for each guest requires a massive effort on both the guests’ and the service providers’ parts. This process can be simplified significantly by using an effective technological platform to manage the interaction between guests and service providers.

Digitalization of services is imperative to appeal to technophile guests. The goal of digitalization of services is to transition to a digital business model by pushing hospitality services to guests’ touch-point [2]. A digital service platform affords guests the ability to browse, plan and pick activities at their own convenience thus facilitating seamless integration of technology into their travel experience. Booking and reservation services, location-based services and personalized communication are a few examples of digital services that entice technophile guests. There are a host of third party applications providing these services which guests are familiar with and rely upon. Revenue erosion to these third party applications and services is a growing concern to HSP [3]. Providing digital services with the same quality as third party application services requires a sound technological infrastructure base with specialized computation and communication capabilities. This warrants the overhaul of current technological framework used by HSP.

The future of hospitality management industry is being shaped by the current boom in the Internet of things (IoT) technology. HSP must stay on the leading edge of IoT technology to maintain a competitive edge in the market. The IoT is the interconnection of everyday physical devices like sensors, actuators, identification tags, mobile devices, etc., such that they can communicate directly or indirectly
with each other via local communication networks or over the Internet. The IoT paradigm offers HSP a nuanced means of interacting with guests and collecting their real-time data. This opens up new avenues for immediate, personalized and localized services as HSP can gauge guest behaviors and preferences with higher accuracy. The IoT also enables HSP to increase back-end efficiency of multiple departments (e.g., front desk, housekeeping, sales and marketing, etc.) as well as enact cost-saving policies like smart energy management. The IoT technology is already spreading through the hospitality industry with public terminals, in-room technologies and mobile applications and some of the promising future IoT applications, such as body area sensor networks, environment monitoring and augmented reality experiences, will certainly usher in new business prospects. HSP should therefore aim to future-proof their technology framework so that their systems can be easily upgraded in tandem with the changing IoT technological landscape.

Overall, the new technological upgrade of the hospitality industry should create a mutually beneficial platform for facilitating partnership between guests and HSP. The platform should ensure that guests are treated to an outstanding travel experience while also improving the operational and managerial efficiency for HSP. Furthermore, the new technological framework must be future proof; providing an easy upgrade schedule for addition of new/improved services. With these requirements in mind, in this paper, we propose a specialized layered computing and communication architecture integrating fog, cloud and IoT computing paradigms. Our proposed architecture implements a geo-distributed infrastructure capable of providing localized information and services, high volume data aggregation, and low latency event responses through energy efficient computing and bandwidth efficient communication resources. Our proposed architecture also enables local, regional, and global analytics of aggregated data which provides valuable insights into improving quality of service as well as building better business models. The layered organization of our proposed architecture makes addition of new computing and communication nodes easier thus making the process of upgrading the base framework fast and simple. In addition, our proposed architecture also has added benefit of being highly scalable and interoperable. It can be scaled for implementation by midrange to luxury-range service providers, based on the number of guests to be served, and the types of services to be provided. Interoperability guarantees the seamless integration of different classes of guest devices into our proposed architecture. The interoperability also makes it possible for our proposed architecture to be added as an extension to existing technological frameworks being used by HSP.

Our main contributions in this work are as follows:

- We provide a detailed overview of state-of-art hospitality services and outline the challenges currently faced by the hospitality industry.
- We propose a novel fog-assisted architectural paradigm for integration of IoT and the cloud to facilitate migration of the hospitality industry to a digital business model.
- We describe potential future hospitality services following the burgeoning revolution of IoT innovation and how our proposed architecture can adapt to and enhance the addition of these new/improved features and services.

The remainder of this article is organized as follows. Section 2 describes the state-of-the-art hospitality services currently offered by providers. Section 3 envisions future services that guests can expect as hospitality industry continues to grow. Section 4 presents the major challenges and issues in designing solutions for the hospitality industry. Section 5 describes our proposed fog-assisted architecture and how it can be used as a solution for hospitality industry. Section 6 discusses a sample use case wherein we describe how our proposed architecture manages a smart hotel room. Section 7 discusses incorporation of new/improved future services into our proposed architecture. Finally, Section 8 concludes our article.

2 STATE-OF-THE-ART HOSPITALITY SERVICES

HSP are making large IT expenditures to revamp their technological infrastructure base. In 2016, midscale hotels led in IT expenditure (7.3%), trailed by upscale hotels (6.1%) and luxury hotels (5.6%) [1]. The expenditures are largely focused on digitalization of the service platform to benefit both parties of the hospitality service exchange – the guests and the service providers. Innovations in smart devices and IoT are driving the reform of technology used in the hospitality service platform. Guest interactions are being migrated towards on-screen and online interfaces through guest-facing systems which apart from being convenient for guests doubles as an opportunity for service providers to collect valuable data and feedback [1]. Digitalization, implemented by HSP through the use of back-of-house (BoH) management systems, has helped improve operational efficiencies, enhance managerial effectiveness, reduce cost of goods sold, increase revenues and improve sustainability [2].

In a digitalized hospitality service platform, guest-facing systems are the primary interfaces for interaction between the guests and the HSP. Therefore, it is imperative that these systems provide easy to use interfaces for guests to manage their travel experience. Guest-facing systems include hospitality service mobile applications, point-of-sale (POS) terminals, hand-held devices, thin-client terminals, etc. [2]. These systems should be integrated seamlessly into all three phases of the guest cycle: pre-sale, point of sale, and post-sale phases so as to provide a complete digital service experience for the guests.

Guest-facing systems improve guest experience in several different ways. Firstly, guest-facing systems ensure guest satisfaction by allowing guests to control their environment. Guest-facing systems empower guests with services such as automatic check-in and check-out services, keyless entry services, control of in-room functions etc. [3]. For example, Hilton and Starwood hotels offer guests automatic check-in and keyless entry service using their mobile apps [4]. Samsung’s Hotel Management Solutions
and SINC entertainment solutions also allow guests to control in-room functions as well as check weather and flight information through a TV remote interface [6]. Hotels like Mondrian SoHo, The Plaza and The Marlin are placing tablets in their hotel rooms to provide guests with interfaces for controlling in-room functions [7].

Secondly, guest-facing systems provide guests with location-based services which is another important service linked to guest satisfaction [3]. More than 30 percent of hotels in 2016 allocated budgets for location-based technology [6]. Guest-facing systems enabled with location-based technology offer on-property and off-property guest services like digitally guided tours, recommendations of local events and attractions, as well as suggestions for dining and entertainment options. These services not only aid the guests in getting around and exploring during their stay, but, also enable service providers to keep guests within the revenue loop by preferably steering guests to sites and establishments that profit the HSP. For example, Fontainebleau Miami tailor their pre-arrival and checkout offers using their guests’ location data [6]. Finally, guest-facing systems make it easy for guests to participate in loyalty programs with HSP [1]. By using hotel loyalty mobile apps, guests can keep track of coupons and bonuses, and get notifications on deals and special offers.

The services offered to guests through guest-facing systems are driven by sophisticated BoH management systems. These systems are tasked with managing service staff and balancing operational costs and revenue without compromising quality of service provided to guests. The BoH management systems include property management system, customer relationship management, revenue and sales management, housekeeping maintenance software etc. [2]. The developments in guest-facing systems and IoT technology are significantly enhancing the capabilities of BoH management systems. For example, in-room IoT units like thermostats, motion sensors and ambient light sensors can be used to control temperature and lighting in hotel rooms when they are unoccupied or unsold which can reduce energy costs by 20 to 45 percent [5] [6].

The innovations in guest-facing systems are also reshaping the customer relations dynamic between guests and HSP. Guest-facing systems enable service providers to closely monitor the guest cycle by collecting data on specific guest preferences, behaviors and locations [2] [5]. Service providers and BoH systems make use of this data to create custom guest profiles which they use to personalize service offers for repeat business. These custom guest profiles can be shared with a large network of partner service providers which ensures that services offered to guests are always highly personalized. Custom guest profiles also grant HSP the ability to entice guests into using their services by means of targeted advertisements and special insiders’ guides and offers.

The BoH management systems also help improve revenue per available room (RevPAR) by speeding up the housekeeping and maintenance processes. By using in-room technologies and guest preference profiles, BoH management systems can schedule housekeeping services efficiently. This effectively reduces the downtime of hotel rooms, improves the utilization of labor resources, and significantly improves guest satisfaction. The use of housekeeping management systems and applications can help in reducing payroll costs by 10% to 20% [2]. The BoH management systems also help in maintenance of in-room and on-property smart systems. These systems help discover faults and failures in near real-time and thus facilitate prompt maintenance.
3 Scope of Future Hospitality Services

As the IoT ecosystem grows and spreads into different facets of everyday life, we can expect a future where every physical device that we use aggregates and analyzes our data and automatically provides us services. The hospitality industry is inclined to follow this growing trend to offer new types of services to its guests as well as to enact cost-saving measures. In this section, we discuss some of potential services and use cases that the burgeoning IoT ecosystem may bring to the hospitality sector in the future. Figure 1 shows examples of IoT sensor and devices the different service categories they can be employed for.

Body Area Sensors: Smart and wearable devices are at the forefront of the IoT revolution. Sales of devices such as smartphones, smart-watches, etc., are soaring and smart technology is beginning to be included in other wearable forms like smart clothing, smart shoes, etc. These devices gather user data like body temperature, heart rate, location, fitness activities etc. Wireless medical sensor technology further expands the scope of data collection by providing detailed data about organs and systems within the body. With proper analysis of data gathered through body area sensor networks, HSP can offer a host of new services to their guests such as, automatic adjustment of in-room temperature based on body temperature, adjustment of in-room lighting based on a guest’s sleep-cycle, provide meal suggestions based on a guest’s desired fitness goal, etc. HSP can also provide special facilities to guest’s based on the type of medical devices they use. For example, service providers can filter out high carbohydrate and sugary meal options for diabetic guests, high cholesterol meal options for patients with heart disease, etc.

Augmented Reality and Beacon Technology: HSP are coming up with new ways to incorporate augmented reality and beacon technology into their on-property systems. This technology can be used to provide guests with services such as digitally guided tours, previews of in-room environment (e.g., decor, facilities and amenities, etc.), immediate translation services for signs and other written materials, interactive restaurant menus with dish previews, critic reviews, food allergy information, etc. as well as interactive trivia games around on-property points of interest [8]. These services can be bundled as part in-house loyalty applications. As guests use these services, HSP can advertise new services or collect data to improve guest preference profiles [9] [10].

Energy Management: HSP can enact several cost-saving measures in the management of on-property energy consumption by leveraging IoT technology. These measures are particularly helpful in achieving “green” operation of on-property systems. Some of the energy-saving systems currently in-place at many hotel properties include smart lighting and temperature control systems as well as use of low power devices like compact florescent bulbs, LED lights etc. IoT technology can significantly expand the scope of energy-saving systems. For example, IoT-enabled power outlets and IoT-enabled smart devices alert housekeeping and maintenance service personnel if a particular outlet exceeds a set limit for power consumption over a given period of time. The service personnel can then track down whether the guests are mindful of the power consumption or whether the power is leaking due to malfunctioning devices [11]. IoT technology can also be employed to limit water consumption. This can be achieved through IoT-enabled smart bathrooms with smart shower heads, smart sinks, flow-controlled toilets etc.

Building Automation and Monitoring: Both guests and service providers benefit from building automation and monitoring. New hospitality services such as keyless entry services, automated check-in and check-out services, digital concierge, etc. which will be brought about by developments in IoT-enabled systems will greatly improve guest satisfaction. These services are not only appealing for technophile users but, they can be specially helpful for guests with disabilities. Building automation also leads to greater operational and managerial efficiency for HSP. For example, in-room monitoring systems can be used to detect whether a room is occupied or unoccupied so as to schedule housekeeping services. IoT-enabled in-room and on-property guest-facing services as well as other utility systems such as elevators, automated doors and windows, powerlines, pipelines, etc., can report faults and malfunctions and schedule maintenance services before any problems are detected with regular physical inspections [11].

4 Challenges

In this section, we identify four major challenges associated with an effective IoT implementation in the hospitality industry. These challenges need to be addressed by the new technological infrastructures being adopted by HSP in order to sustain steady growth.

Interoperability: The hospitality industry lacks standardization. Many HSP are developing their own proprietary solutions based on their own metrics and methodologies in order to accommodate the technological service demands of modern day guests [12]. This has led to a diverse spectrum of implementations which are essentially targeted to provide a similar set of services. Although these implementations work well within the scope of a single property, they lack the potential to be extended to intra-organization and inter-organization scopes [13]. This imposes limitations on the usability of guest preference profiles on a broader scope because of the lack of a standard platform for sharing guest data across different businesses. This can lead to loss in potential revenue for HSP as they may be unable to effectively provide personalized services to their guests. Interoperability issues also impact guest experience as they create hassles and inconveniences that takes away from seamless user experience desired by guests. Non-standardized systems at different hotels introduce unwanted learning periods for guests during their stay. Such systems may also have issues in interfacing and using data from personal devices brought by guests. These problems warrant standardized vendor independent systems and solutions for hospitality industry.

Data Management: Aggregation and analysis of guest data is an integral part of the hospitality service chain. With the introduction of new technologies and service platforms in the hospitality industry, data volume is bound to grow exponentially. Personalization of guest...
experience contributes significantly to increase in data volume. As personalized services become the norm in hospitality industry, HSP must treat each of their guests as unique individuals and maintain accurate and up-to-date records of their preferences and behaviors. HSP can collect guest data through guest-facing systems as well as personal guest devices connected to the hotel network. The BoH management systems in hotels must be capable of properly managing the influx of wide variety of guest data from wide variety of sources. In order to provide personalized services to guests, BoH management systems must analyze guest preference profile along with data about the state of the surrounding environment detected from IoT devices/sensors. This places a considerable computational burden on BoH management systems that can only be tackled through the use of specialized technological infrastructures. Additionally, secure sharing of relevant data from these guest profiles across different intra-organization and inter-organization systems is a monumental logistic challenge that requires both centralized and decentralized data management approaches.

**Security and Privacy:** In order to provide guests with highly personalized services, it is necessary for HSP to track guest preferences, behavior, and location. HSP must ensure that guest data is used and stored properly so as to protect guests from physical, economic, and societal threats. Guest-facing systems and point-of-sale terminals are the most susceptible systems in hotels to security attacks. These systems should ensure that interactions with guests are secure and private by employing robust security measures to prevent data leaks and theft. Security primitives should also be supplemented in the hotel network for added security in interfaces with personal guest devices and in-room and on-property IoT devices. A secure hotel network prevents hackers from gaining access to guest data by attacking personal guest devices connected to the network. It also prevents hackers from reprogramming the hotel’s IoT systems for annoying or malicious purposes. Adding strong security protocols in every guest interaction and every active connection on the hotel network requires significant computing resources. Moreover, these security protocols should be implemented close to the data source so that data is secured in as few number of hops in the network as possible. A decentralized computing platform is necessary to meet these requirements.

**Responsiveness:** HSP must ensure prompt acknowledgement of guest requests and prompt delivery of services to guests. This can be achieved by digitalization of the interaction between guests and HSP. By pushing guest interactions to guest-facing systems and implementing automatic control through IoT sensors/devices, HSP can eliminate the need for human interaction and intervention when dealing with guests. These systems leave little room for miscommunication and confusion when interpreting guests’ requests. These systems can also readily fulfill guests’ requests faster than any dedicated hotel staff/personnel. This greatly improves responsiveness to guest requests and adds to the seamless experience desired by guests. Responsiveness is also crucial for a hotel’s upkeep and maintenance. No or slow response to repair and maintenance needs can lower the hotel’s revenue per available room (RevPAR). For example, a room
cannot be rented if something as simple as the phone in the room is not working [14]. In hotels that have large scale IoT deployments, repair and maintenance requests can be responded to swiftly because most IoT sensors and devices can detect and self-diagnose problems. Timely repair and maintenance makes hotel rooms available for occupancy quickly thus reducing loss of revenue to maintenance. In order to improve responsiveness of hotel systems, they must be equipped with more computing resources and unfettered access to guest and BoH management data which requires a decentralized computing and data management platform.

5 FOG-ASSISTED ARCHITECTURE FOR HOSPITALITY INDUSTRY

In Section 4, we discussed the major challenges that need to be addressed for effective IoT implementation in the hospitality industry. To overcome these challenges, we propose a novel fog-assisted architectural paradigm which provides better interoperability, scalability, centralized and decentralized data analytics and management, privacy and security, and low latency responses. We propose a hierarchical network architecture, as shown in Figure 2, which integrates edge of network IoT devices with a centralized cloud server by means of intermediary fog nodes. A fog node is defined as the physical and logical network that implements fog computing services [15]. 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. IoT devices can utilize these resources by offloading complex applications and services to the fog. This helps in improving battery-life of IoT devices by lessening their computation burden. 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 core network carries locally analyzed data from the fog to the cloud. Thus, fog nodes help to significantly reduce the volume of data communicated over the core network [15]. The cloud server is the topmost tier in our proposed architecture. The cloud facilitates broader accessibility scopes for guest profiles, comprehensive loyalty and rewards point management and global data analytics.

The main aim of our proposed fog-assisted architecture is to provide personalized, adaptive, and predictive next generation guest experience. The fog nodes in our proposed architecture push computation and storage resources towards the edge of the network. These resources make our proposed architecture well equipped for near real-time local analytics. HSP can personalize guest experience by utilizing the near real-time local analytics capability of our proposed architecture to personalize services, promotion offers, and rewards for guests. HSP can also adapt their services to best suit the needs of guests based on analysis of sensor data carried out in the fog. 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. HSP can locally analyze guest activity information, such as behavior, current location, etc., along with environment data using fog nodes to make adjustments to the services and offers provided to guests. For example, in-room temperature can be adjusted based on guests’ body temperature and time of day. Our proposed architecture also allows HSP 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 makes 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 [15]. Open standards and interoperability also play a key role in the scalability of fog computing. The open standards and interoperability make it easier for scaling existing systems by the addition of new features/services or in scaling the overall infrastructure by the addition of new devices and fog nodes into the network. 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. The aggregated guest data can be assimilated into unique guest preference profiles which can then be leveraged by local data analytics to provide quality services in single property scope. The guest profiles created by these fog nodes can be disseminated to other hotel properties that are part of the same hotel chain by means of the cloud. This enables data sharing in the intra-organization scope. The cloud also provides a global data analytics platform using guest data obtained from different participating organizations. Through mutual partnership or purchase and sale deals, guest profiles can also be securely traded via cloud sharing among different organizations to provide data sharing in inter-organization scope.

Fog computing also addresses most of the challenges posed in security and latency of responses. The distributed network of fog nodes in our proposed paradigm push computing and storage resources towards the edge of the network closer to edge of network devices, such as IoT devices and guests’ personal devices. Since most edge of network devices are not deployed with complex computing capabilities, these devices cannot implement the level of security necessary in a connected public network such as fog and cloud. For such devices, the fog node is the first entity in the network that is capable of implementing complex security protocols [15]. The computing resources at fog nodes thus help secure data gathered by the edge of network devices. The distributed computing resources also facilitates timely responses to guests’ requests. These computing resources in the fog enable local analytics of
guest profiles as well as data gathered from local sensors and systems which helps in providing high quality services to 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 [16].

6 FOГ-ASSISTED SMART HOTEL ROOM USE CASE

Fig. 3. A smart hotel room use-case for fog-assisted architecture (adapted from [17]).

In this section, we describe some IoT sensors and devices that can be deployed in smart hotel rooms and how our proposed fog-assisted architectural paradigm can leverage these IoT units to provide quality services to guests. Figure 3 shows an instance of a smart hotel room.

Fog nodes begin gathering guest information as soon as the guests registers their personal devices on the hotel network. The guest device registration process can also double as hotel check-in process. The hotel fog can lookup reservations using guest information collected from guest devices, securely link with payment services on guest devices to charge fees, and assign keyless entry privileges to guest devices. The fog can also refer to guest profiles to ascertain guest loyalty and upgrade reservations.

The fog network can keep track of guest activity and location using their registered personal devices. As guests make their way to their hotel rooms, the fog can adjust in-room climate control settings and in-room lighting based on guest activity, information in guest preferences profiles and ambient environmental conditions. The fog can revert these settings to energy saving mode when guests leave their hotel rooms. When guests enter the hotel room, the fog network assists in syncing up all in-room devices with registered guest devices. This helps in personalizing the in-room experience for guests. For example, the digital signage and artwork in the hotel room can display recent photos from gallery on a guest’s phone, or the media hub and TV can playback videos that the guest may be watching on their personal devices, such as laptops, tablets, smart phones, etc. [18]. The guests can also interact with in-room devices using guest-facing systems (e.g., room tablet, media hub, guest self-service kiosks, etc.). The fog network can also link hotel rooms with BoH management systems. For example, the fixed phone or room tablet linked with the fog can be used by the guests to call room-service, schedule housekeeping etc. The fog network can also help in the upkeep of the hotel room. For example, if the hotel room uses RFID tags on their minibar items, the fog can maintain a digital inventory of the minibar and notify when it needs to be restocked.

7 UTILIZATION OF FOГ-ASSISTED ARCHITECTURE IN FUTURE HOSPITALITY SERVICES

The interoperability and scalability aspects of our proposed fog-assisted architecture helps it adapt to and be enhanced by new/improved future services. In this section, we discuss how some of the future hospitality services we outlined in Section 3 can be incorporated into our proposed architecture.

**Body Area Sensors:** Body area sensing, enabled by smart and wearable devices and medical sensors, has potential for many innovative applications in the hospitality industry. However, there are major security and privacy issues when dealing with sensitive data gathered by these devices. Most of these sensing devices are battery powered so, they are designed with limited computing capabilities. The responsibility of securely using, storing and sharing data gathered by these sensors thus, falls on the fog nodes. The open standardized interface offered by our proposed fog-assisted architecture can integrate different types of sensors/devices from different vendors into the fog network, and the computing resources in the fog nodes can secure sensor data using complex security protocols.

**Augmented Reality and Beacon Technology:** Augmented reality hospitality applications need to process data from a host of different sensors (e.g., accelerometers, eye trackers, environment sensors, etc.) to create interactive scapes for hotel guests to interact with. This requires specialized computing capabilities and large storage space. Beacon technology relies heavily on the precision of user location information. Our proposed fog-assisted architecture pushes computing and storage resources closer towards the edge of network devices that implement these applications. Augmented reality applications can offload compute-intensive tasks to fog nodes as well as use storage resources available on them. Some fog nodes in the fog network may include specialized hardware for signal processing and graphics operations which can help accelerate these tasks. Our fog architecture’s geo-distributed nature allows it to provide accurate location information which can be used by beacon applications to provide high quality location-based services to hotel guests.

**Energy Management:** Proper energy management schemes can help lower hotel operating costs significantly. In order to effectively employ energy management techniques, real-time energy usage metrics are required. In hotels, these metrics can be obtained using in-room energy monitoring sensors. The data gathered from these sensors in conjunction with other in-room sensors, such as ambient temperature, lighting conditions, etc., must be analyzed to determine optimal energy policy for hotel rooms. Fog nodes can perform swift local analysis of these large volumes of sensor data because they have the necessary computing resources and are closer towards the edge of the network where these sensors are deployed. Hotels can also make use of guest location information provided by fog nodes to adjust their energy policies. For example, room occupancy sensors...
connected to fog nodes and occupancy history maintained by fog nodes can be used in local analytics to determine periods for switching to a greener in-room energy policy.

**Building Automation and Monitoring**: Building automation and monitoring schemes not only improve guest experience but also enhance hotel operation and management. Our fog-assisted architecture can neatly combine guest-facing and BoH management systems to provide benefits for both guests and the hotel. Automation of hotel systems and services requires comprehensive and swift analysis of guest data such as location and preferences along with the data from various sensors and devices connected to the network. Fog nodes make computing resources available to edge of network devices on the hotel network to assist in performing these analytics operations. Furthermore, fog nodes can also help hotels monitor different on-property systems (e.g., elevators, powerlines, pipelines, etc.) by means of sensors and devices fitted to them. Fog nodes can diagnose malfunctions or critical faults in these systems by analyzing data from sensors along with the system’s repair and maintenance history.

### 8 CONCLUSIONS

In this paper, we outline many critical enhancements that need to be implemented in the hospitality industry to restructure its service platform to fit into the modern technological landscape. We identified personalization of experiences and digitalization of services as the two fronts in which these enhancements have to be focused. Many HSP have taken radical steps to remodel their services in which these enhancements have to be focused. Many HSP have taken radical steps to remodel their services and we discuss some of these state-of-the-art hospitality services offered by them. We also envision several new services that might be offered by the hospitality industry as some of the bleeding edge of systems, such as body area sensors, augmented reality, etc., enter maturity. In order to overcome the challenges brought about by new and evolving technology being incorporated into the hospitality service context, we propose a novel fog-assisted architecture that ensures interoperability, scalability, data management, privacy and security, and reduced latency responses. Our proposed fog computing architecture enables HSP to use guest data in local and global scopes to provide high quality services to guests. We present a use-case scenario using a smart hotel room example to illustrate the types of services our fog-assisted architecture can provide. We also briefly describe how our proposed fog-assisted architecture can be extended to accommodate future hospitality services.

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