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Cloud Computing for Sustainable Development of Smart Cities

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***Abstract*—Urbanization is an unstoppable trend with the abundance of advantages it brings to a country especially in boosting the economy and lifting overall quality of life. Despite significant benefits of urbanization, it brings challenges if not well planned and managed. Rapid urbanization without adequate management leads to environmental concerns as well as unsustainable energy consumption patterns. Urbanization is one of the key drivers to climate change due to increasing utilization of infrastructure, energy consumption, resource waste and emission of greenhouse gases. Therefore, sustainability is the key, and the future direction of sustainable urban growth is the development of smart cities. The development of smart cities, as the name suggests, deploys smart systems and technologies to support sustainable growth. As such, cloud computing plays a critical role in the development of smart cities to provide support in terms of infrastructure and services. This research will delve deeper into the role of cloud computing in development of smart cities. This research proposes a suitable cloud architecture for sustainable development of smart cities.**

Keywords—cloud computing, cloud services, cloud service provider, smart city

I. INTRODUCTION

The domain of interest is sustainable urbanization of smart cities. According to United Nations, urbanization is the trend for world's population. By 2018, 55% of the world's population were in the urban areas, and the percentage was projected to grow up to 68% by 2050. Urbanization involves spatial distribution and land planning, coupled with investments in infrastructure, construction, and establishments. Urbanization is one of the inevitable demographic megatrends due to the benefits it brings in terms of economic and social growth, poverty reduction and improvement in quality of life [1].

A smart city is an environment that deploys information communication technologies (ICT) and innovative technologies to provide high quality of services to citizens as well as to enhance city operation, management, and performance. A smart city can be characterized as a city that consists of 4 main attributes i.e., sustainability, quality of service, quality of life, urbanization, and smartness; and 4 main pillars i.e., institutional infrastructure, physical infrastructure, social infrastructure, and economic infrastructure. Its intelligence derived from the features that connect physical, social, business and ICT infrastructure. In terms of architecture, smart city comprises 4 layers i.e., sensing layer, transmission layer, data management, and application layer [2]. There are many definitions around the concept of smart cities, mostly share the similar objectives of improving quality of life while reducing environmental adverse impacts with the help of technologies such as Internet of Things (IoT), Artificial Intelligence (AI) and big data analytics. The Internet of things (IoT) play a critical role in developing a smart city due to the need to create a system that allows communication among systems. Some examples of the benefits of IoT include managing city resources and improving efficiency and effectiveness of public services include public transportation and traffic improvements, energy consumption, and waste management [3]. Some cities also provide smart citizen services to the citizens including making communication between city government and citizens more effective and accessible and enhance public safety [3].

With above mentioned key features and services that a sustainable smart city is expected to provide to the citizens, there is a huge need for services such as data storage, data management, real-time data processing, interconnected systems and device management to facilitate communication among various components in a smart city, application services and IoT solutions. Cloud computing is able the provide on-demand computing resources such as storage, networking, and software, thus becoming the backbone of a smart city and support the sustainability of urbanization and improve the quality of life of the citizens [3].

This research focuses on the following objectives. To study the role of cloud computing in the development of smart city. To discuss the cloud computing deployment model in a smart city environment. To identify the cloud features that empower the development of a smart city. To identify popular cloud service providers. To identify potential challenges of deploying cloud computing for the development of smart city

II. SUSTAINABLE URBANIZATION OF SMART CITIES

The smartness of a city largely dependent on the establishment of systems, and the interconnection between systems [4]. A smart city can have several smart elements such as smart transportation, smart parking, smart lighting and smart waste management [3].

With continuous urbanization and development of a city, the transportation network becomes increasingly complex and creates issues such as traffic congestion, inefficient traffic flow, long travelling time and unpleasant transportation experience for citizens. Smart transportation with the use of cloud computing and technologies solves the transportation challenges. For example, traffic cameras on street, sensors, and IoT devices are used to capture real-time traffic flow and position of vehicles or public transportation. With cloud computing, these real-time data can be immediately and efficiently stored, analyzed and accessed by the relevant parties and public for a wide range of purposes including planning the optimal travelling route, monitoring the use of public transportation and shared mobility systems, anticipating the demand for public transportation and thus services provided can be adjusted in time. Besides that, the usage of transportation systems and road conditions can be monitored in real-time, which helps the authority to plan and develop a robust and integrated transportation network that improves the overall mobility of the citizens. In addition, with cloud computing, all the data can be obtained remotely from a central location without the need to be on spot. This greatly contributes to the planning and monitoring by authorities especially with the increasing complexity of the transportation system [3].

In the city, space is usually limited, hence designing a parking system is as important as designing traffic flow. In many cities, searching for parking is still a challenge because it does not only waste time to go round multiple levels of parking floors to physically search for a parking space, it causes congestion and increases carbon footprint. With cloud computing supporting parking systems, cameras and sensors can be used to detect availability of parking and this information can be accessed by drivers in real-time via a dynamic parking map. Besides, municipal and private parking operators can make use of cloud computing to store video footage of parking lots, ensuring the safety and security of drivers. The data collected can be further analyzed to study the parking demand and be used for predictive analysis. Parking payment system is another application of cloud computing where cameras capture the vehicles information such as car plate number, check-in time and check-out time to store and auto calculate the parking fees required. The system can be integrated with payment applications on mobile where the parking fees can be auto deducted via software or applications. This smart parking system brings convenience to drivers and optimizes the use of parking space with the support of cloud computing [3].

Cloud computing is applicable to the build-up of smart lighting systems on the street. Traditionally, lightning systems are costly and contribute to high carbon footprint. A cloud-based lightning system begins to gain attention and popularity due to the benefits it brings based on financial and environmental considerations. With cloud computing, a lightning system that is integrated with IoT and sensors will be able to collect real-time data including time of day, traffic flow and weather conditions, and the condition of lights. With cloud-based analytics, brightness, colour and timing of streetlights can be adjusted; with cloud-based control, the adjustments can be done remotely yet effectively from a central location. This does not only optimize usage of smart lighting systems, it also greatly contributes to the reduction in cost, energy consumption and environmental adverse impacts. In addition, with cameras and security systems integrated into smart lightning systems, the security conditions of cities can be monitored in real-time, which enhance the public safety of the cities [3].

The traditional approach of waste management is inefficient. Waste collection routes and schedules are usually predefined and planned, however not according to the actual needs because every waste disposal unit disposes waste at different pace and is subject to change anytime under different circumstances. As a result, the traditional approach leads to early waste collection or late waste collection. Early waste collection could lead to waste in time, labour cost, unnecessary fuel consumption and carbon emissions. Late waste collection leads to unethical dumping, overflowing trash that affects the surrounding cleanliness and environment and increasing complaints about the public services. With technological advancements and support from cloud computing, IoT sensors can be integrated into waste collection bins or containers that monitor the real-time condition and volume of waste in the bins. This allows public services providers to plan the optimal waste collection route to collect trash based on real needs, thus reducing time taken, labour cost, fuel consumption and carbon footprint. The entire waste management system will then be improved to provide more efficient services. With cloud computing, waste data can be further analysed to improve the overall performance of the waste management system, by continuously tracking waste and updating dynamic waste collection routes to ensure waste collection is efficient at all times. In addition, cloud computing also facilitates the recycling process by integrating cloud system into recycling facilities to identify types of waste and improve waste sorting processes. The data collected from waste management systems can also be used to observe waste collection, disposal and recycling patterns and behaviors which are critical for municipalities to develop strategies in effort to reduce waste and environmental impacts that are associated with waste disposal [3].

III. Types of Cloud Service Models

There are 3 main types of cloud namely public cloud, private cloud and hybrid cloud. Public cloud makes resources available to the public and has advantages in terms of costing as the set-up cost including hardware, application and bandwidth can be covered by service providers thus allowing it to offer economies of scale. Resources can be requested based on needs and the costing model is pay-as-use [5]. Public cloud can be referred to as a type that provides cost-effectiveness, scalability and flexibility. For example, the demand for cloud computing resources for a transportation system might be low during normal days but high during festive seasons or public holidays when crowds are expected. The waste management system might require real-time adjustment as waste volume might increase during special days. The city municipality might consider scaling up or down the resources based on estimated demand and conditions. Public cloud in this scenario provides that scalability and allows sharing of data between various applications that the city municipal requires. That said, public cloud has limited customization and is relatively vulnerable to security concerns when compared to private cloud [6]. However, adopting public clouds raises security concerns. Cloud services providers might be prone to use proprietary infrastructure to maintain pricing advantage, and tend to cover up some bugs and incidents from the public to maintain reputation [7].

Private cloud is the data centre set-up by a single private entity and resources are made available to that private entity only. This type of cloud is relatively more expensive and any plan to increase capacity involves more time and cost; however, allows users to have full control and security management of their own data centre [5]. Private clouds can be managed internally or through third parties. As private cloud is owned by the private entity or organization, vendor identification and security risk are more manageable and controllable, leading to greater security, privacy and control. However, private cloud is costly and not scalable enough to accommodate unpredictable demand [6]. Private cloud is vital, especially data that is highly sensitive, private and critical. In the development of smart cities, private cloud can be used for the processing of payment details in smart transportation and smart parking systems, where users private information including transaction details will be stored.

While public cloud and private cloud each has own advantages and disadvantages, the combination of both using hybrid approaches allows some flexibility especially during peak seasons when users can leverage on public cloud to ensure smooth operation of applications [5]. Hybrid cloud is the connected cloud between public cloud and private cloud. With hybrid cloud, security is higher than public cloud while flexibility, scalability and cost efficiency are higher than private cloud [7]. In a smart city environment, a hybrid cloud model can be adopted where images from sensors, cameras and video footage that are general yet taking up high storage space can be stored in a public cloud. Sensitive and private data such as transaction, banking details and personal information can be stored and processed via private cloud.

IV. Cloud Features

Cloud computing services can be highly scalable which suits the development of a smart city. As a city grows and expands, the demand for cloud resources also increases. For example, with rapid development, the transportation system becomes increasingly complex and the demand for cloud resources to store and process transportation and traffic data including images and videos intensifies. During festive seasons, public holidays and special events where traffic and network traffic are expected to go up, the demand for cloud computing resources could be exceptionally high. The scalability feature of cloud, allows city administrators to make scaling up or scaling down adjustments based on demand, allows smart systems in the city to work optimally, thus facilitates the overall efficiency of the systems and continues to improve the life quality of citizens in the city [8].

Besides that, cloud computing is efficient in that it is able to collect, analyse and generate output in real-time, which provides high convenience and enhances efficiency as a whole. For instance, the waste management system monitors waste collection demand in real-time to generate a dynamic collection route for drivers to follow. This approach optimizes the entire waste management process and ensures carbon footprint and fuel consumption are minimized. The transportation system captures real-time traffic map and generates a dynamic traffic map that assists drivers in planning their trips. The parking sensors detect vehicles and inform drivers in real-time in applications. All of the real-time analysis and decision making requires strong support from performing cloud services.

In smart cities where IoT solutions and devices are largely adopted, cloud computing plays an important role in ensuring the flexibility of accessing data. Data is stored on the cloud and can be accessed remotely from anywhere. For example, smart lightning system in the city that captures images of traffic, weather, and light intensity, can be accessed from a single location by the city municipality for monitoring. Similarly, smart transportation system data can be accessed from any devices connected to the data and traffic flow can be monitored and controlled remotely without the need to send traffic polices to the physical site for traffic control. This feature of cloud computing consolidates data into one and accessed from single location, which greatly contributes to the city planning

strategies, human resources optimization and sustainability of development.

V. Popular Cloud Service Providers

A study from Gartner shows that the leading cloud service providers were Amazon Web Services (AWS), Microsoft Azure and Google Cloud Platform (GCP). Other key players included Alibaba Cloud, Oracle Cloud and IBM Cloud. This section will discuss the services by AWS, Azure and GCP [9].

AWS offers a broad and comprehensive range of services in terms of storage, computation, network, database, analytics capabilities, developer friendly tools, wed administrative tools, etc. and multiple pricing models such as pay-as-you-go that allows great flexibility for organizations to use the resources. In terms of storage, AWS offers Simple Storage Services (S3) for data storage and backup. S3 is a type of object storage service that allows the storage of structured and unstructured data up to exabytes. It is highly durable and provides 99.9999999% data durability and 99.99% of data availability. For the development of smart city, S3 is suitable for storing massive data from various sources including cameras, sensors, detectors, and IoT devices to form a centralized repository for data consolidation and analytics purposes (Amazon S3). S3 Glacier, on the other hand, could be used as a low-cost archiving solution for the municipality of a smart city to store data that are required to persist for years, or to store data for disaster recovery backup plans. Similar to S3, Glacier S3 also has 99.9999999% data durability (Amazon S3 Glacier storage classes). For data processing, Amazon Elastic Compute Cloud (EC2) can be utilised. EC2 offers more than 750 instances including on-demand EC2 Mac instances and offers up to 400 Gbps Ethernet networking (Amazon EC2). This allows the processing of massive data which is suitable for the development of smart systems that collect massive data of the city including traffic, transportation, parking, etc. on a daily basis. In addition, AWS's managed relational database-as-a-service, Amazon RDS can be deployed as a database solution. RDS is easy to manage with the automation of configuring, provisioning, backups and patching. RDS supports the development of web and mobile applications with the easy-to-manage database solution (Amazon Relational Database Service). This can be deployed for facilitating smart city to develop applications for its citizens to enhance communication between municipalities and citizens as well as the communication between various smart systems and the system users.

Azure Blob Storage is a storage solution that provides sixteen nines of durability and storage of data up to petabytes. It supports a broad range of development frameworks and offers Solid-State Drive (SSD)-based object storage for data that requires low maintenance. Azure Blob ensures the security of data by encrypting and decrypting with 256-bit AES encryption (Azure Blob Storage). The storage solution can be used to build a data lake with Azure Data Lake Storage and is useful for the development of a data lake comprising all the data collected from the smart systems. For archiving solutions, Azure offers Azure Archive Storage that can store up to terabytes of data that are rarely accessed. Azure compute services are provided through Virtual Machines. Azure Virtual Machines require businesses/organisations to perform several tasks including configuring, patching and installing softwares (Azure). In terms of database, there are numerous types for selection including SQL database, database for

MySQL, database for PostgreSQL, depending on business requirements and database preference.

GCP offers Cloud Storage for storing unstructured data in any amount. Cloud Storage is interconnected with other Google services in data warehouse, analytics and machine learning models, and is convenient if users are Google users and have been using Google services. Cloud Storage offers automatic storage class transition, which automates the movement of object data across storage classes based on last accessed time. This function is cost-effective for city development where huge data are collected on a daily basis yet not all data will be retrieved frequently. For computation, Google Cloud Compute Engine provides various predefined machine types and sizes and even a prebuilt sample to assist businesses or organisations to jumpstart on using the resources. The compute availability for a single instance is between 99.9% to 99.95% depending on the type of virtual machines selected (Google Cloud). In terms of database, GCP offers a Cloud SQL that is a fully managed relational database for PostgreSQL, MySQL and SQL Server. With complete management by Cloud SQL, database activities and task including backups, patches, encryption, and storage capacity adjustment are automated (Google Cloud). By automating database tasks, it helps businesses or organisations to better focus on providing better service to the citizens instead of taking time and effort to manually maintain databases.

Table I presents a comparison table of services provided by AWS, Azure and GCP.

TABLE I. COMPARISON OF SERVICES PROVIDED BY AWS, AZURE AND GCP

Category	AWS	Azure	Google Cloud Platform
Storage	• S3 for storage and Glacier S3 for archiving • S3 allows storing exabytes of data	• Blob Storage for storage and Archive Storage for archiving solution • Blob allows storing petabytes of data	• Cloud Storage for storage • Cloud Storage allows storing of any amount of data
Compute	• EC2 • Offers more than 750 of instances	• Virtual Machines	• Google Cloud Compute Engine • various predefined machine types and sizes
Database	• RDS • automation of configuring, provisioning, backups and patching	• numerous types for selection including SQL database, database for MySQL, database for PostgreSQL	• Cloud SQL • fully managed relational database for PostgreSQL, MySQL and SQL Server

VI. SECURITY AND MANAGEMENT CHALLENGES

A. Data Security

With increasing use of cloud computing, data security and privacy become top concerns. The data collected and processed may involve sensitive and private data. The data collected through sensors, cameras, detective tools and IoT devices, might reveal important messages about the citizens including mobility patterns, payment details, personal information, and preference. It might also reveal the development status of a city. Adopting a cloud computing approach in most cases does not allow users to have control over the storage of data. The moment data is uploaded to the cloud, data storage security risk arises. In addition, the physical data centre where data is stored may be located in different countries or regions. There might be some local laws and regulations in these regions that the cloud service providers might have to follow. However, users might not have complete information about the cloud environment and how data could be disclosed by cloud service providers to the authority of where data centres are located. There are also worries about the cloud service providers having the access to user's data storage within their facilities. Data leaking might happen from cloud service providers [7]. Different customers might share the same database due to the multi-tenancy nature of cloud computing, which add more risks to the data security. Therefore, it is critical to choose reputable cloud service providers who are compliant to data security regulations such as General Data Protection Regulation (GDPR). As data owner or smart service providers, it is important to establish policies and procedures that details out the SOP regarding data management, data protection, data integrity, and data recovery plan. Laws, regulations, procedures and standard processes must be applied to ensure no data privacy breach. Some approaches taken to tackle the issues include encryption, access management, threat detection and response solution [3]. That said, identity management and access control could be challenging at times as cloud resources are dynamic and IP addresses of cloud service providers could vary each time a different cloud computing model is subscribed. As such the adoption of several encryption methods and access management shall be deployed to minimize the possibility of unintended sharing of data [10].

B. Network Security

Users' accounts may be hijacked so that sometimes unauthorized users with a password could log into users' accounts and have access to the data that users have access to. It is vital for users to keep a relatively stronger password that is difficult to break. For example, if a smart parking system where users tie their personal banking or credit card information with, is hijacked, sensitive banking data and details may be leaked out and misused, which lead to critical threat to the citizens who are using the system. Organizations should take additional steps, for example, using two-factor authentication, to protect citizens from such cybersecurity attack [10]. Virtualization of cloud computing resources although facilitate cloud service providers to allocate resource efficiently and allow flexible adoption of cloud model, it poses security risk to the users as virtualisation opens more entrance points and interconnection density for cybersecurity attack [11]. Data attacked and accessed by unauthorized parties, may be locked and made unavailable. Cloud interruptions, hardware faults, server downtime and insufficient bandwidth could all contribute to data unavailability [12]. Data unavailable to users disrupt the entire smart system in the city which heavily reliant on cloud computing for the collection of data from multiple sources and real-time analysis that facilitates daily activities. Therefore, data backup procedures have to be applied to ensure the availability of data and facilitates fast recovery in the unfavorable event of data security incidents [13].

C. *Application Security*

Cloud configurations, if improperly performed, may open opportunities for malware injections which could impact the entire cloud environment and system. Malware injections are executable codes embedded in cloud services. These malware injections could have occurred long time ago and have been hiding in the cloud services, which brings concerns about the cloud environment [14], [15]. If malware, such as ransomware, attack the cloud system, the entire cloud services will be forced to shut down and the municipal of city or organizations may suffer from huge monetary loss in order to remediate the affected cloud services. If users build own programs and integrate into cloud via Application programming interfaces (APIs), some security concerns may also arise as some systems or applications from users' side could have vulnerabilities which threaten the cloud security.

D. *Management Security*

The provision of cloud computing resources by the cloud service providers and the subscription of cloud services by the businesses, organizations or the city municipal, are not completely automated flow and the process involves people from various background and fields. The involvement of people gives rise to people issues. The cloud security responsibilities are increasingly on cloud services providers when users opt for cloud models such as Infrastructure-as-a-Service or Platform-as-a-Service. In this case the trustworthiness and reputable of cloud service providers are vital. Malicious insiders who have access to data and malicious outsiders who have control over insider to get access to data, also pose security risks that are hard to detect [16], [17].

VII. Conceptual Framework of Cloud Adoption in Smart Cities

Dr. Neetu Agarwal proposed a cloud computing services architecture for the development of smart cities. The architecture comprised of 5 horizontal layers and 2 vertical layers. The horizontal layers are (i) Platform Integration Layer that ensure the integration of multiple platform for the access of data; (ii) Data Acquisition and Analysis Layer that collect data from various sources, devices, sensors and repositories; (iii) Thematic Layer that performs data classification based on service catalogue updates; (iv) Service Composition Layer for workflow design and output analysis, and (v) Application Service Layer that allows users to perform contextual analysis in application domain specific tools. The 2 vertical layers are (i) Management and Integration Layer that manage and automate the flow of data between horizontal layers; and (ii) Security Layer that ensures data security through necessary processes such as authetication, authorization and data audit [5].

The study enabled the authors in this paper to present a cloud architecture for smart cities as shown in Fig. 1.

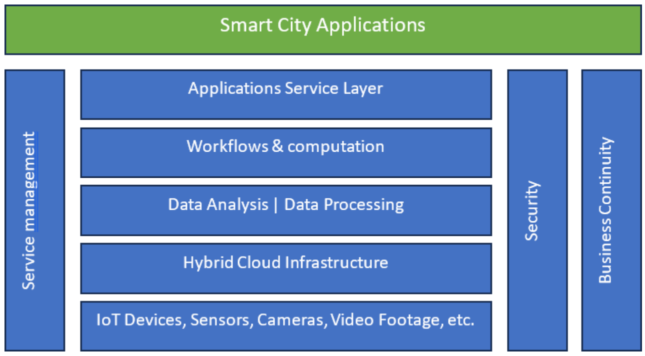

Fig. 1. Proposed cloud architecture for smart cities

The IoT devices, sensors, cameras, video footage, etc. are the source where the data are coming from. These data will be injected into a hybrid cloud infrastructure where public and private cloud resources will be combined adopted to optimized the benefits of public and private cloud in the form of hybrid cloud. The infrastructure includes storage, network and compute. The data analysis and processing layer is used to access data in cloud environment and perform data sorting, classification and processing. The outcome will go through workflows and computation layer, where workflows are executed. The outcome of workflows will be injected to application service layer, to perform contextual analysis for further action. This action will then flow into applications and system in smart cities. There are 3 vertical layers, namely service management that manages portfolio and operations; security layer that protects the data, network, applications and infrastructure from any security threats and attacks; and business continuity layer that ensures the availability of data in event of disasters, incidents or disrupted services.

VIII. Conclusion

Smart cities play a vital role in encouraging the country's growth while ensuring the optimization of resources to achieve maximum effectiveness and efficiency yet not compromising environmental aspect. In order to grow towards that direction, cloud computing undoubtedly becomes the backbone of the development of a sustainable smart city and the development architecture and model can be duplicated to other cities as well. This research discussed the uses cases of cloud computing, type of cloud computing and features that are critical for the growth of smart cities. However, security challenges will always be top concerns. There are multiple ways to tackle the issue, yet it can't be completely resolved. The future research direction may focus more on the challenges of adoption of cloud computing and how each leading cloud service providers is addressing the issues and it will contribute more perspective to city municipal on the adoption of cloud computing journey.

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