Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

An Orchestrated Smart City Data Centre Design for Satisfying Smart City Application Needs

Mohamed Hamdy Naeem[1,*], Hesham H. Aly[2]

[1] Computer Networks and Data Centre-Cairo Arab Academy for Science, Technology and Maritime Transport, Cairo 11799, Egypt
[2] Electronics and Communication Engineering Department Arab Academy for Science Technology and Maritime Transport, Giza 2033, Egypt

ARTICLE INFO

Article history:
Received 31 January 2025
Received in revised form 7 March 2025
Accepted 30 June 2025
Available online 20 July 2025

Keywords:
Smart city; data centre design; cyber security; digital transformation; smart industry; command and control centre; SoC; disaster; pandemic; IPerf

ABSTRACT

Designing a data centre is always sophisticated, especially for a smart city. Understanding smart city requirements regarding hosted services and applications is mandatory. However, there are numerous challenges in designing the data centre for a smart city, but the most challenging points are security and disaster recovery. The data centre's passive and active designs are jointly more challenging to provide minimum cost and delay while maximizing the capacity, security, and availability. There are several efforts in the literature to tackle them individually, while this paper provides an orchestrated data centre design model proposed as a design model and as a distributed per-rack model. The paper design provides a better investigation of the city requirements, the data centre applications, and the service availability perspective compared to previous designs found in the literature.

1. Introduction

Digital transformation is one of the astonishing elements of sustainable development. It aims at providing more luxury and welfare to society [1,2]. Digital awareness is a distinguished element as it seeks a mature, conscious digital society capable of making use of the fourth industry resources [3,4]. Smart cities are the main pillar of digital transformation and it's the steering wheel to enjoy a lot of digital services [5]. Smart cities include several axes, including smart transportation, smart industry, smart education, smart homes, smart clinics, smart hotels, cafes and restaurants, smart security systems, smart energy control, smart resource management, smart waste management, smart ventilation management, smart control of air pollution and smart control in lighting.

Smart cities should always be designed mainly as a sustainable system that represents the icon or slogan of a nation's civilization [6]. In the past decades, they mainly provided architectural development for every civilization and for the same reason, they conveyed its proprietary features. Nowadays, globalization and the development of information and communication technology ICT bring standards for smart cities. Consolidating the Internet of Things IoT and cloud services, including machine learning and artificial intelligence [7-9]. Maintaining the smart city sustainability with an

* *Corresponding author*
E-mail address: mohamed.hamdy@aast.edu

https://doi.org/10.37934/ard.138.1.8195

astonishing service that dazzles its residents is maintained through nonstop development. In the past centuries, it relied on architectural design development. In recent decades, it’s merged with the required integration of consolidated emerging technology [10,11]. The evolving design has two main elements, a passive design and an active design that depends on technology [12]. This approach is extremely controlled by the communication systems from the city edge to the city data centre. Passive design depends on materials' interaction with nature for deriving its sustainability. Perhaps one of the most prominent examples is the smart windows, which interact actively with both the summer sun and the winter sun [12]. Over time and its way of evolving and developing, the passive design decays concerning the active design. This reflects a natural phenomenon as technology development evolves, the less dependency on passive design. However, both the passive and active designs depend mainly on the city activities, applications and services it delivers to its residents.

Therefore, it is essential to study the city requirements to effectively provide a data centre design capable of hosting plenty of smart services. Notably mentioned, one of the most important features of the smart city data centre is the unified dashboard [13]. Which manages the city services, outlets and resources of the projects for saving time, effort and wastage in raw materials and resources.

Smart City Governance is also an essential part, for some of the possibilities available may become a curse [14]. There must be a legal firm to protect both users and the system from any inappropriate usage or possible attack. Both should be covered as well in the digital awareness stage for city residents and riders. The ICT system represented in the electronic services, things and terminal devices that are connected to the central DC is considered a cyber-physical system CPS [15]. The CPS may suffer from availability, integrity and encryption attacks by disrupting control, downgrading the city services and returning them to the era of ancient cities. The command-and-control centre CCC of the DC should be proactive and on time for detecting and predicting any attack wave and always be ready to counter them. This research is concerned with studying the design of the DC while considering the requirements of the ICT in SC to achieve a prosperous life and the ability to act in case of challenges and disasters. The research paper is divided into the following sections: literature review, methodology and methods, results and discussion and conclusion.

2. Literature Review

Today, most of the population on Earth lives in cities. That is pushing the architect developers to provide an attractive design that may offer more living demands. The design is a sophisticated mission that cares by providing a sustainable design with top-quality service and minimum use of energy and running costs. The reduction in energy levels provides a better economy and better air quality with less carbon emissions. One of the most creative sustainable designs in considering air quality is found [12,16]. The author provided great insight into the role that the sustainable passive design plays in reducing energy consumption. Moreover, the author highlighted the integration between ICT active design and the architecture passive design for climate adaptation and intelligent infrastructure. The ICT plays the magic role in SC design and provides the required mechanisms for economic development [17]. One of the distinguished rules of ICT is the adaptation of the smart city against climate change [18]. Moreover, ICT with digital twins offered the possibility of having a virtual living experience [19]. Notably, the architect can simulate and analyse the design efficiency before establishing it [20]. ICT also utilizes booming IT services based on the IT infrastructure, besides the sustainable urban design [21].

ICT solutions are necessary as well for disaster recovery purposes and for predicting natural disasters [22]. There is no doubt that early warning of a natural hazard is priceless, especially in an early call for an emergency and evacuation plan [23]. Social networks, terrestrial networks and an unmanned aerial vehicle AUV provide the major route to reaching the support team on time [24]. ICT played a great role during the COVID-19 pandemic period by providing the services of smart health care, remote clinics and digital transformation and aided in better public awareness [25]. The authorities insist on offering awareness through a social network to report the occurrence of a disaster on time [26]. Connectivity is a hard mission, as usually communications facilities are deactivated [27]. So, building a smart data centre that offers rich services and a robust control centre is a very sophisticated matter [28]. The design problem can be considered a no hard problem [29]. To solve this problem, there are several approaches found in the literature, perhaps the most important of which is defining the design requirements and its main objective [25]. There is a design objective to adopt the discrete or segmentation of the data centre [30]. Others recommend the data centre design according to the provision of the operating rate's objective [31]. Others offer a design according to the requirements of smart cities and their applications [32]. Perhaps all designers must agree on maintaining data security and cybersecurity [33]. This research aims to provide an efficient network design that integrates some of the approaches found in the literature, along with considering recent standards and recommendations.

3. Methodology

The Methodology depends mainly on the profound study of the smart city requirements outlined in the literature and illustrated in Figure 1. The design considers the application requirements, integration of design approaches found in literature and careful consideration of recent standards and recommendations [34].

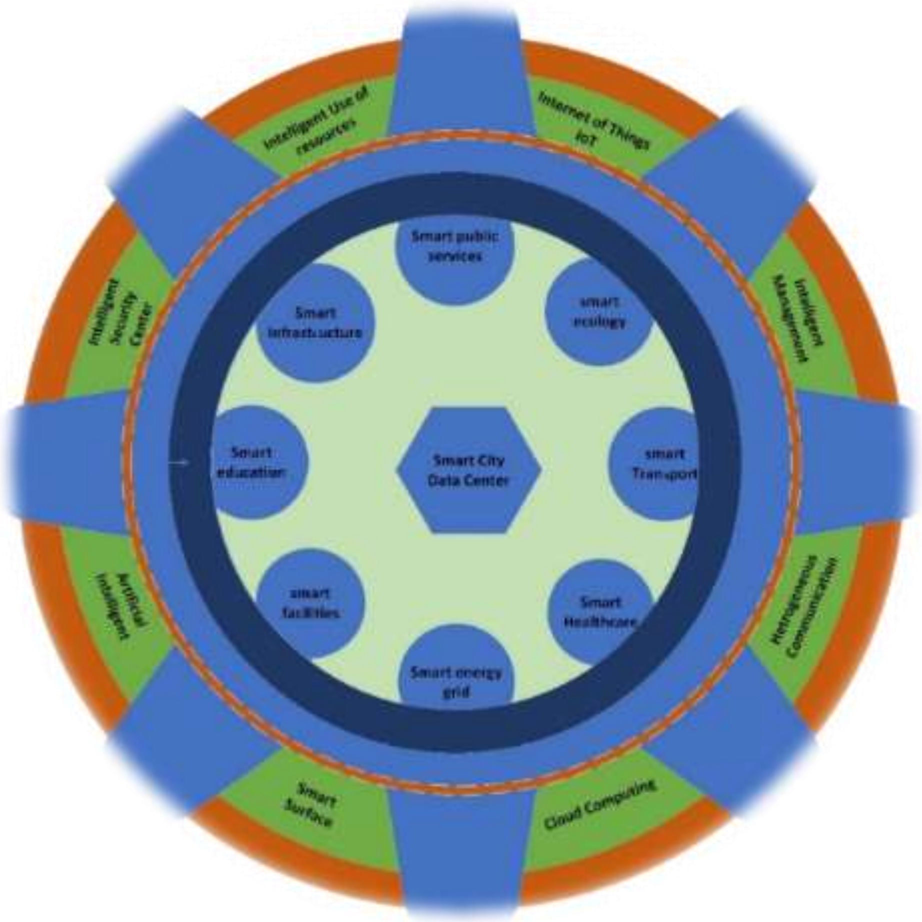

Fig. 1. Smart City application requirements and readiness

The design of smart cities is converged from the architectural, electrical and mechanical aspects. Smartness comes into the ICT design, which is classified into two main categories: passive and active. The passive design aims at maintaining sustainability, scalability and availability and seeks to achieve the lowest rate of service operation costs. The active design object is to provide rich service cities with robust design and control. The Methodology is concerned with studying the design of the data centre, along with validating it.

3.1 Passive Sustainable Design

Passive design is the major design part that maintains sustainability. As mentioned before, the historical giant cities like the ancient Egyptian, Greek, Roman and other civilizations depend only on it. Those giant cities have smart construction and architecture that can dazzle their owners with their facilities. Passive design includes mixed architecture design (as was found mainly in ancient cities), mechanical design, electrical design and IT design. The Passive design that the methodology is concerned with is the Passive IT design. This design should be optimized in terms of minimizing the overall delay (D) and the cost (C) while at the same time maximizing the availability (R) and the capacity (T). So, the passive design may be represented in Eq. (1) as the joint optimization of maximizing the throughput and redundancy while minimizing the overall delay and cost for a link of maximum n links between two communicating nodes inside a smart city:

$$\text{Efficient Passive Design} = \text{Minimize}\left(\sum_{k=0}^{n} \mathrm{D} * \mathrm{C} \right) \text{ X Maximize} \left(\sum_{k=0}^{n} \mathrm{R} * \mathrm{T} \right) \quad (1)$$

The methodology investigates which network topology based on standards and recommendations achieves this objective.

3.2 The Active Environmental System Design

As illustrated in Figure 1, smart city services act as a steering gear and its core is the data centre. The active design rule is to host those services in luxury and act as a main rescue element for a disaster recovery plan. The alerts and threats offer the prediction and enough time to deal with the disaster within a zero-day strategy and the first rescue call. The system design elements depend mainly on SC application requirements, which are illustrated in Table 1 along with the proposed luxury and disaster design readiness.

Table 1
Smart city application requirements for luxury and disaster

Smart City Application Requirements for Luxury and Disaster Human/Nature Threat	Readiness and requirements	Luxury/ Disaster	ICT dependency
Connectivity disruption(both)	High-density network coverage	Both	Edge of the ICT design
Cyber Attack (Human)	Cyber security, data backup and recovery plan.	Disaster	ICT as cloud, software security, HFW and NFW.
Natural Disaster	Evacuation plan monitoring and a highly available interface with the command-and-control centre.	Disaster	Highly available control services.
Pollution (Human)	Sustainable monitoring and sensing. Provide an automatic penalty.	Both	Integration of the sensing, monitoring, reporting and coordination with the city management centre.

Energy (both)	Requires efficient passive design and intelligent active design.	Luxury	Provide a PV system to operate the smart city units along with sustainable sensing and monitoring.
Waste recycle (Human)	Quantitative and intelligent systems to efficiently recycle the waste.	Luxury	Requires monitoring, action control and legal integration within the command-and-control.
Pandemic/ illness (both)	Smart health for better treatment.	Disaster	Remote clinic with digitalization of clinic service.
Smart Education (Human)	Digital transformation services, multimedia infrastructure, remote class applications and class recording.	Luxury	Remote class applications, smart board, smart data show, smart recording, smart student evaluation services.

The active design should consider the SC application requirements along with the recommended DC design readiness parameters for maintaining an efficient data centre design of connected layers.

3.3 Methods

The free and open-source software IPerf, sometimes known as IPerf or IPerf3, is used to assess and optimize the proposed network's performance. It's very helpful for determining the highest bandwidth that networks can provide. Which aids in proving the design in terms of the capacity, delay and availability objective. IPerf as well, is characterized by the following:

i. Client-server setup: it provides a measure for the traffic transfer between the client and the server.
ii. Compatibility with various operating systems
iii. Reliability, as it supports and understands all the network protocols
iv. Durability: Supports different features and customization, including ports, buffer, delay and test duration.

The setup of the assessment is hosted in a virtual machine running VMware workstation version 2.2.48, with GNS3 software version 2.2.48, Ubuntu 24 and Python 3. The hardware configuration is a Lenovo workstation with a CPU Intel Core i7 8th generation, NVIDIA GeForce MX110, 4 GB DDR4 + 8 GB DIMM of memory, 2 TB HDD + 256 GB of storage and a 14-inch display. The hosting operating system is MS Windows 10 and the setup of the evaluation is maintained as illustrated in Figure 2:

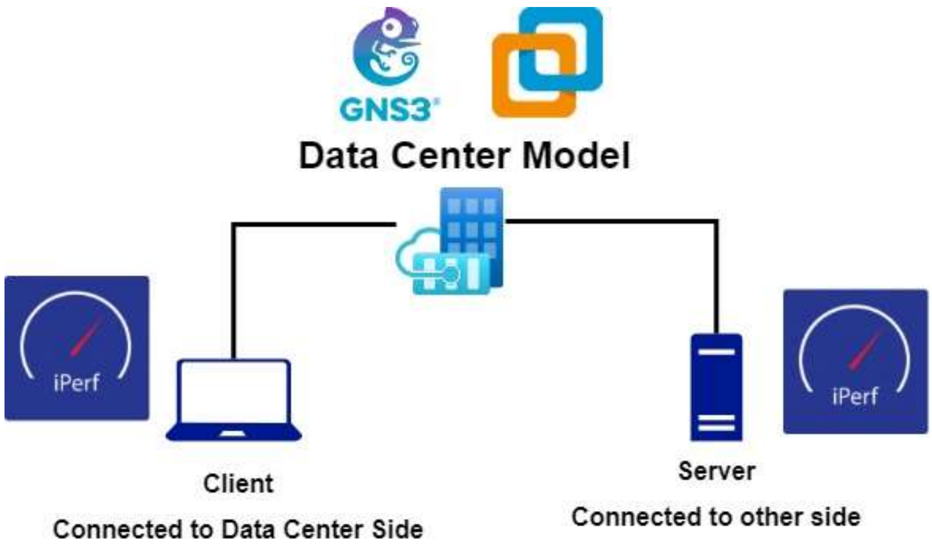

Fig. 2. IPerf evaluation setup

As illustrated in Figure 2, the client device is connected to the data centre model from one side and the server device is connected to the same model from the other side. While the setup of the evaluation is maintained as the following steps:

i. Download the IPerf package
ii. Extract the IPerf package and move it into a new directory “IPerf”, for instance, the c directory for both the client and the server devices.
iii. Run the IPerf
On the server, run the following code:
CD IPerf
C:\IPerf> IPerf3 -s
On the client, run the following code:
CD IPerf
C:\IPerf>IPerf3 -c 198.168.40.4 % The client sends the data to the server
C:\ IPerf>IPerf3 -c 198.168.40.4 -t 30
C:\IPerf>IPerf3 -c 198.168.40.4 -t 30 -R
Observe and document the three data centre models, then plot them into one figure

4. Data Centre Design

The paper so far discussed briefly the detailed components of the data centre facility; however, this section studies the design of the data centre itself from two perspectives:

i. The interconnection (Mainly concerned with the passive design)
ii. The network topology (Concerned by active design)

According to the literature conducted in this work, we have found the following interconnection methods:

i. The centralized interconnection method
ii. The zoned interconnection method

iii. The top-of-rack interconnection method

4.1.1 The centralized interconnection method

That kind of interconnection is suitable for small DC models that are appropriate for street/ venue DC. All cabling interconnections are terminated in the core switch to provide a centralized topology as shown in Figure 3.

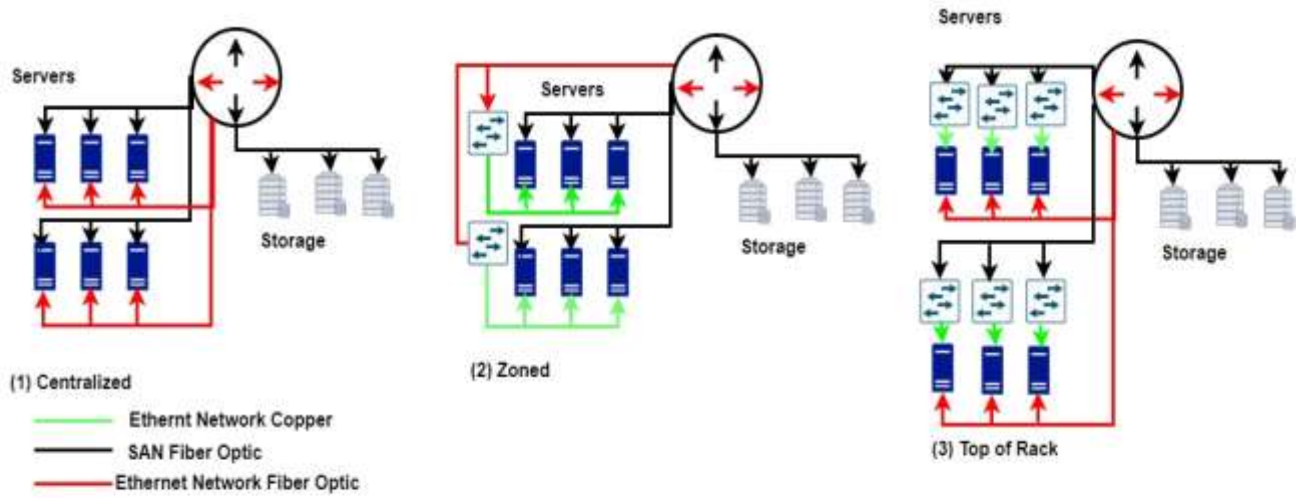

Fig. 3. Network interconnection types

As illustrated in Figure 3, the topology can't scale for the hall SC facilities and applications and it may be applied in small-scale designs like micro-DC design per street or avenue.

4.1.2 The zoned interconnection method of rack (EoR).

The recommended interconnection by the TIA-942 standard (known as the end-of-rack method) provides structured cabling for the servers in a layered method. The servers are connected to access switches, then aggregated in an aggregate/ distribution switch and finally collected in the core switch. The topology is shown in Figure 3. The topology scales well, cost and operational effectiveness; however, it outperforms when there are huge amounts of data traffic that need to be transmitted among numerous servers and span racks. (chosen as an edge rack in city streets, buildings and enterprises).

4.1.3 The top of rack (ToR) interconnection method

More efficiency, better cable management, ventilation and cooling and what is more, all-time working is the slogan of that solution as illustrated in Figure 3. That solution, as illustrated in the Figure 3, provides per rack connection. The access rack contains the servers that are terminated in redundant cabling type, then the dual access switches are connected to the aggregation/ distribution switch units. Finally, the core switch interconnects all switch disciplines for internetworking (widely used in the proposed design).

4.2 The Network Topology

The network architecture is the core of the DC design. The language that all designers understand, with different spoken languages, is mainly illustrated in the form of network topology. The three recent and widely deployed network architecture topologies are:

i. Mesh Network
ii. Multi-Tier Model
iii. Point of Delivery Model (PoD)

4.2.1 Mesh network

The mesh network model considers mesh interconnections between access switches (spine) and aggregation switches (leaf). The mesh connections provide high-speed transmission, redundancy and high availability. As illustrated in Figure 4, the mesh network provides highly available data transmission services and cloud suitable architecture. The design provides lower cost and high transmission speed.

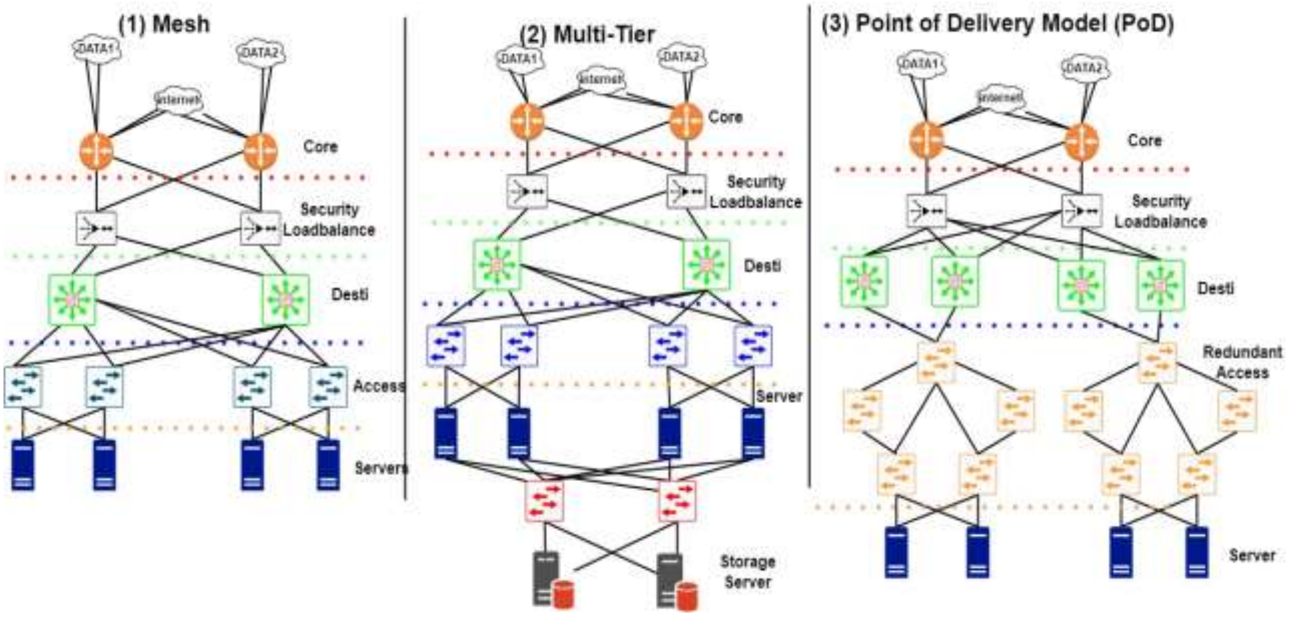

Fig. 4. Data centre as a discrete network topology types

4.2.2 Multi-tier model

With the migration to cloud computing, the multi-tier model has become more popular. The capital cost of purchasing the DC racks and servers is summarized in cloud expenditure. As illustrated in Figure 4, the design consolidated the on-premises servers in main racks and applications only, while the rest migrated to the cloud. That provides lower cost and more simplicity in designing, building, operating and management.

4.2.3 Point of the delivery model (PoD)

The evolving model of the multi-tier model provides a solution for the consolidated data delivery zones. The issue is due to the simplicity of the multi-tier model; more requests require instant processing on the same cloud service. That situation results in a time-out and failure of service delivery. As illustrated in Figure 4, the design provides more servers and existence at the required point of delivery. Cloud services are used as well in case of local congestion or out-of-point requests.

4.3 The Proposed Design

The proposed design adopts the PoD and ToR topology and architecture. The design provides a micro-DC design for each street/venue or service aggregation layer. For example, smart transportation, smart education, smart healthcare, smart grid, smart agriculture, smart manufacturing, smart government and smart retail each are provided a PoD or micro-DC and then aggregated to the north/south main facilities, finally synched with the cloud services.

As illustrated in Figure 5, the DC architecture provides the following design features:

i. <u>High-density Heterogeneous Networks:</u> This network accommodates the wireless connectivity to serve the SC both in crisis and welfare. The heterogeneity of communication networks and the connectivity access points. Finally, there is a point of presence in case of crisis. An assembly point for communication is identified and provided by the command-and-control centre.
ii. <u>High scalability to accommodate edge devices, both wireless and wired:</u> There are heterogeneous edge device types in function, scale and specs. It scales for edge devices that include IoT sensors and personal computers. implement policies, quality of service QoS and traffic priority, network access control NAC and call admission control CAC services.
iii. <u>High-speed backbone connections through fiber optic communication FOC that evolved for the trendy Terahertz Ethernet:</u> The backbone is the communication path to maintain sustainability, capacity and availability. The emerging and trending terahertz communications are highly recommended.
iv. <u>Accommodates PoD data centre requirements for every application field and per city geographic area:</u> The micro-DC design provides a high point of availability. The design provides more efficient communications per SC service field and street/venue communication as well.
v. <u>Highly available redundant central DC facilities with north and south city units:</u> The High-Availability DC facilities are recommended for maintaining the sustainable presence of ICT services. Moreover, ensure the operation and synching with the command-and-control centre.
vi. <u>Highly available and redundant cloud services through dual cloud provider connections:</u> Cloud services provide the required integration of the services, command and control centre availability and simplicity in the usage for the citizen. The city security operation centre SOC is more available and sustainable to manage security and detect threats in a better manageable way.
vii. <u>Integration with the social network, mass media and the command-and-control centre:</u> The command-and-control centre provides a unified dashboard. The dashboard provides services for the citizen/operator, administrator and manager. Every user, based on their credentials the services listed on the assigned privileges.

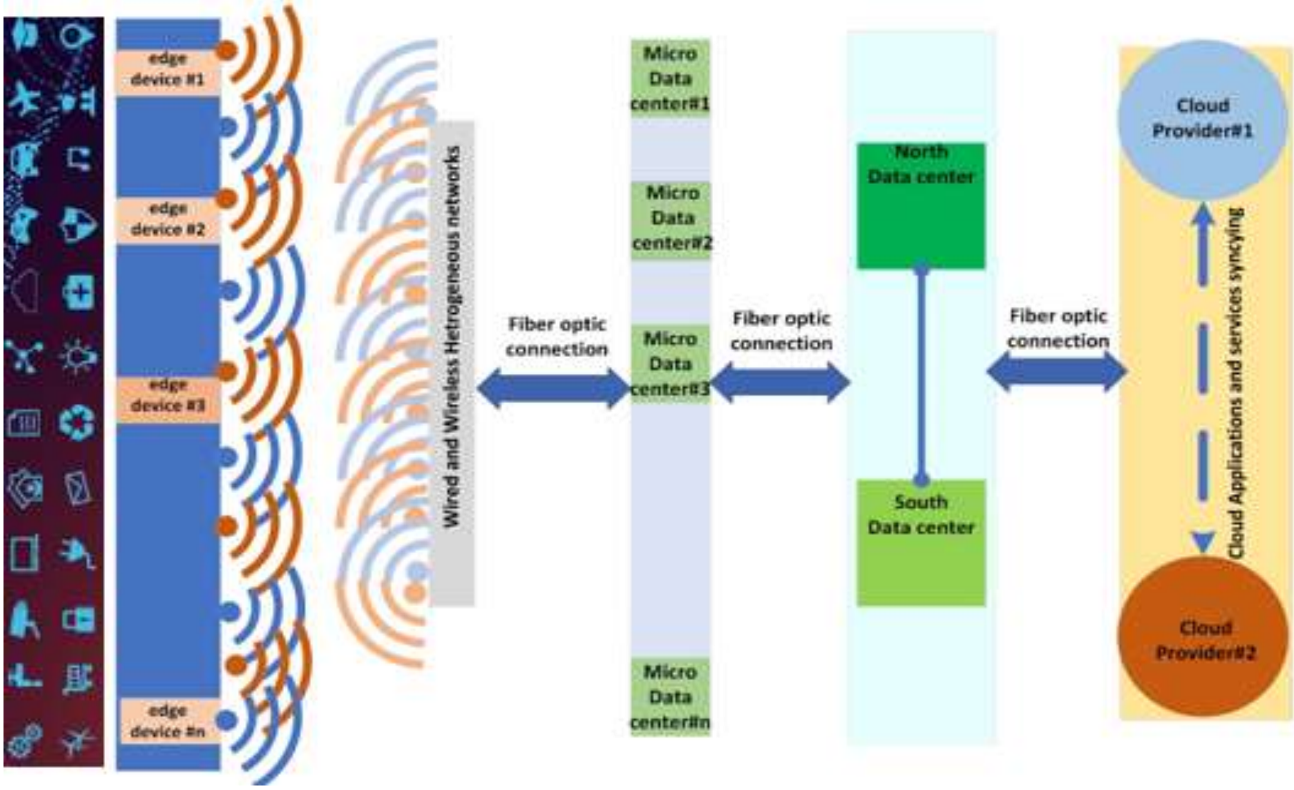

Fig. 5. The proposed Smart City ICT data centre design

The detailed network connections and topologies are defined as a discrete DC as shown in Figure 6. Every unit in the proposed design in Figure 5 (like edge device unit, micro data centre unit, north data centre and south data centre) is represented in detail in the discrete DC design as in Figure 6. However, each unit differs in the active device hardware specifications and configuration, but the main topology is kept the same. The proposed design adopts the ToR design. The edge devices with heterogeneous types connect to the access layer switch. The redundant access layer switch on the top of the rack is stacked together and is connected to the distribution switch. The distribution switches are the aggregation switches that are required to execute the required QoS policy, routing, Security policies and NAC services. The firewall FW service module is required to be added after the aggregation layer to define the separation perimeter among the local area network LAN, wide area network WAN and demilitarized network DMZ. Each region has its defined services, policies and permissions. The core layer that is required to provide high-speed switching and routing is maintained using high-speed fabric devices that scale for such huge traffic and forwarding rates. The core router requires specifications for a virtual private network VPN, security bundle, unified communications bundle and huge data traffic processing. Some edge routers' forwarding rate may scale up to the rate of the service provider level as the city's DC may act the same functions as well.

The WAN FW module is required to filter data that enters and exits the data centre. The filtered-in data is then forwarded to the internet or the cloud based on the defined services and policies. The filtered-out data is then forwarded to the router module for processing as ingress traffic, which is the replies to the city residents' requests. The router module processes it and forwards it to the concerned aggregated switch, which in turn reviews the policies and if it matches a permit, it forwards it to the concerned access rack switch; else it's denied and rejected. The access layer switch provides the required access point in terms of both wired and wireless. The traffic to the edge device and the concerned edge device collects the data from the access switch and use it per the appropriate application.

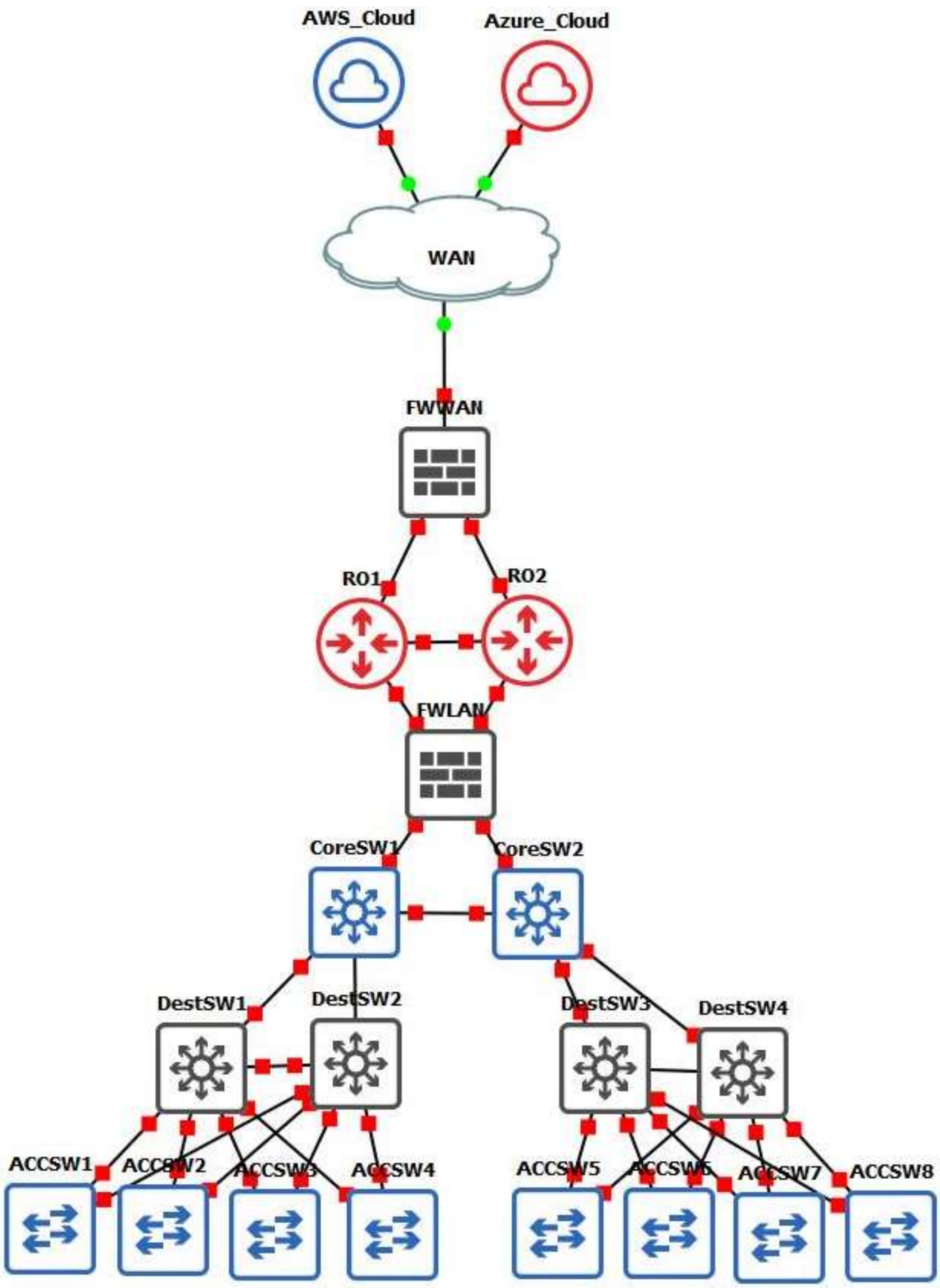

Fig. 6. The proposed DC discrete network topology

The design is scalable and highly available however, the design may require continuous change to adapt to more trendy technology that may add value or reduce the cost of implementation, design and/or management.

5. Results and Discussion

The results of the IPerf evaluation that was outlined in section III are listed in Tables 2, 3 and 4 below:

Table 2
IPerf for the mesh topology

ID	Interval	Transfer	Bitrate
1	0.00-60.01 sec	1.87 GBytes	268 Mbit/sec
2	0.00-60.01 sec	1.38 GBytes	197 Mbit/sec
3	0.00-60.01 sec	1.5 GBytes	215 Mbit/sec
4	0.00-60.01 sec	75.5 MBytes	10.6 Mbit/sec
5	0.00-60.01 sec	5.31 GBytes	7560 Mbit/sec

Table 3
IPerf for the multi-tier topology

ID	Interval	Transfer	Bitrate
6	0.00-60.01 sec	1.87 GBytes	402 Mbit/sec
7	0.00-60.01 sec	1.38 GBytes	275.5 Mbit/sec
8	0.00-60.01 sec	1.5 GBytes	262 Mbit/sec
9	0.00-60.01 sec	75.5 MBytes	18.5 Mbit/sec
10	0.00-60.01 sec	5.31 GBytes	1300 Mbit/sec

Table 4
IPerf for the point of delivery model (PoD) topology

ID	Interval	Transfer	Bitrate
1	0.00-60.01 sec	1.87 GBytes	505.7 Mbit/sec
2	0.00-60.01 sec	1.38 GBytes	347.8 Mbit/sec
3	0.00-60.01 sec	1.5 GBytes	292.6 Mbit/sec
4	0.00-60.01 sec	75.5 MBytes	19.2 Mbit/sec
5	0.00-60.01 sec	5.31 GBytes	1480 Mbit/sec

The results of the IPerf evaluation of the three network topologies are assessed using MATLAB 2024 to illustrate the comparison results shown in Figure 7.

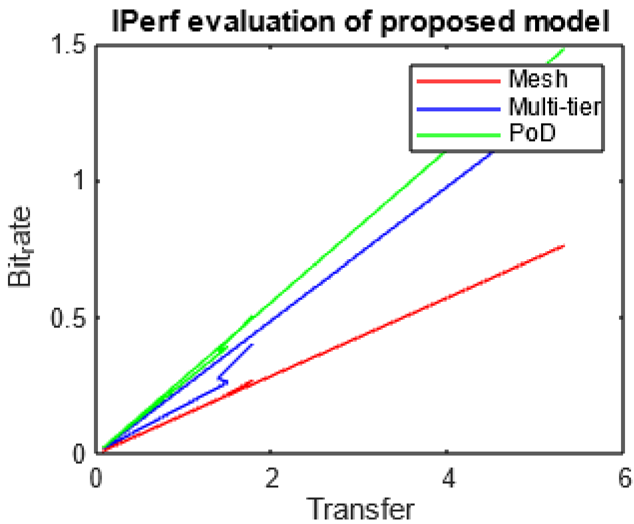

Fig. 7. IPerf evaluation of the three network topologies models

Evaluation of the three topologies proved the better performance of the PoD topology, which is adopted in the proposed design. While comparing the proposed design against the literature design is shown in Figure 8.

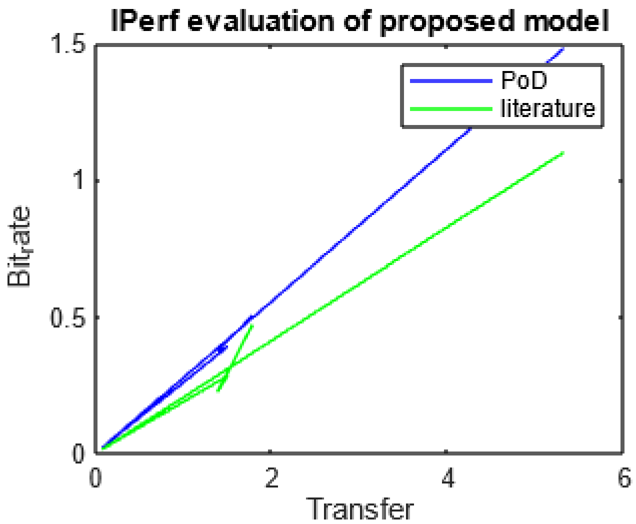

Fig. 8. Assessment of the proposed design against the literature's design

As illustrated in Figure 8, the proposed design provides better performance as evaluated and compared to the design provided previously in the literature [35]. Moreover, the provided design is based on a better assessment of smart city application requirements than the study found in Fang *et al.,* [36].

6. Conclusion

Through the paper, we have provided a critical study of the smart city in terms of the architecture, sustainable design and the ICT active design. The study highlighted the important features of the smart city that are equally important in welfare and disaster. The welfare features of smart cities are illustrated in the existence of the digital transformation, which provides the pleasure and simplicity of using smart services. The crisis provides disruption for life happiness and the smart city proved its readiness via its efficient design of smart health care, extensive heterogeneous networks, smart call and command centre and unified social and management dashboard. The study proposed all the requirements to adapt to the crisis and to offer welfare. The study provided an efficient design of the SC DC design according to the highlighted requirements and consideration of the literature and design standards. As a future work, the study should accommodate hybrid cloud infrastructure technology HCI and network function virtualization, as they are both trending cloud technologies that provide better cost reduction and efficiency.

Acknowledgement
This research was not funded by any grant.

References
[1] Vial, Gregory. "Understanding digital transformation: A review and a research agenda." *Managing digital transformation* (2021): 13-66. https://doi.org/10.4324/9781003008637-4

[2] Muharlisiani, Lusy Tunik, Taib, Idris, Bariroh, Siti, Mulawarman, Widyatmike Gede, Wisnujati, Nugrahini Susantinah, Karjati, Pratiwi Dwi and Idris, Azlina. "Application of Augmented Reality for Independent Learning with Mobile Learning." *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 58(3), (2024): 135–149. https://doi.org/10.37934/araset.58.3.135149

[3] De Bem Machado, Andreia, Silvana Secinaro, Davide Calandra, and Federico Lanzalonga. "Knowledge management and digital transformation for Industry 4.0: a structured literature review." *Knowledge Management Research & Practice* 20, no. 2 (2022): 320-338. https://doi.org/10.1080/14778238.2021.2015261

[4] Mahariya, Satish Kumar, Awaneesh Kumar, Rajesh Singh, Anita Gehlot, Shaik Vaseem Akram, Bhekisipho Twala, Mohammed Ismail Iqbal, and Neeraj Priyadarshi. "Smart campus 4.0: Digitalization of university campus with assimilation of industry 4.0 for innovation and sustainability." *J. Adv. Res. Appl. Sci. Eng. Technol* 32, no. 1 (2023): 120-138. https://doi.org/10.37934/araset.32.1.120138

[5] Kirimtat, Ayca, Ondrej Krejcar, Attila Kertesz, and M. Fatih Tasgetiren. "Future trends and current state of smart city concepts: A survey." *IEEE access* 8 (2020): 86448-86467. https://doi.org/10.1109/ACCESS.2020.2992441

[6] Okafor, Chigozie Collins, Clinton Aigbavboa, and Wellington Didibhuku Thwala. "A bibliometric evaluation and critical review of the smart city concept–making a case for social equity." *Journal of Science and Technology Policy Management* 14, no. 3 (2023): 487-510. https://doi.org/10.1108/JSTPM-06-2020-0098

[7] Hussain, Muhammad Zunnurain, Mohd Hanapi, Zurina and Hasan, Muhammad Zulkifli. "Low Network Power Challenges in IoT-Based Applications in Smart Cities." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 54(2), (2024): 218–237. https://doi.org/10.37934/araset.54.2.218237

[8] Yeh, Lee Hoi, Wong Yoke Seng, Khoo Yin Yin, N. Mohd Nor, Wong Mee Juan, Lee Hoi Ling, and Song Zhiqiang. "Defining the Collaborative-Constructivism Based Learning and Teaching Approach in Malaysian Primary Schools in Supporting the Hybrid Learning of Visual Arts Education: A Fuzzy Delphi Method Study." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 41, no. 2 (2024): 62-81. https://doi.org/10.37934/araset.41.2.6281

[9] Aliu, Abdulmalik Adozuka, Nor Rima Muhamad Ariff, Sheikh Ali Azzran Sh Said, Divine Senanu, Dah John Ametefe, Terdoo Michael Dugeri, and Muhammad Isah. "Adopting Systematic Review in Conceptual Digital Maturity Modelling: A Focus on Facilities Management Sector." *transformation (DT)* 52, no. 1 (2025): 332-355. https://doi.org/10.37934/araset.52.1.332355

[10] Shwedeh, Fanar, Norsiah Hami, Siti Zakiah Abu Bakar, Fadhilah Mat Yamin, and Azyyati Anuar. "The relationship between technology readiness and smart city performance in Dubai." *Silicon Valley* 10 (2022): 19.

[11] M. Nashruddin, Siti Nur Hidayatul Ain, Herman, Siti Sarah, Norazman, Norsafiah, Danial, Sapinah, Ghazali, Nurul Aishah, Abd Aziz, Abdul Razak, Mohamad Hanafiah, Atiqah Nadiah and Hidayat, Benny. "The Strategies to AEC Implement BIM-GIS-Drone-Mobile Apps-AI Towards Future Demands, Case Study: Setiu, Terengganu." *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 65(2), (2025): 1–18. https://doi.org/10.37934/araset.65.2.118

[12] Murtagh, Niamh, Sulafa Badi, Yaling Shi, Shen Wei, and Wei Yu. "Living with air-conditioning: experiences in Dubai, Chongqing and London." *Buildings and Cities* 3, no. 1 (2022): 10-27. https://doi.org/10.5334/bc.147

[13] Rojas, Elizabeth, Viviana Bastidas, and Christian Cabrera. "Cities-board: a framework to automate the development of smart cities dashboards." *IEEE Internet of Things Journal* 7, no. 10 (2020): 10128-10136. https://doi.org/10.1109/JIOT.2020.3002581

[14] Jebaraj, Luke, Alex Khang, Vadivelraju Chandrasekar, Antony Richard Pravin, and Kumar Sriram. "Smart city: Concepts, models, technologies and applications." In *Smart cities*, pp. 1-20. CRC Press, 2023. https://doi.org/10.1201/9781003376064-1

[15] Sengan, Sudhakar, V. Subramaniyaswamy, Sreekumar Krishnan Nair, V. Indragandhi, J. Manikandan, and Logesh Ravi. "Enhancing cyber–physical systems with hybrid smart city cyber security architecture for secure public data-smart network." *Future generation computer systems* 112 (2020): 724-737. https://doi.org/10.1016/j.future.2020.06.028

[16] Fredrik, Torisson. "Strategies of visibility in the smart city." *City, Territory and Architecture* 9, no. 1 (2022). https://doi.org/10.1186/s40410-022-00161-6

[17] Haque, AKM Bahalul, Bharat Bhushan, and Gaurav Dhiman. "Conceptualizing smart city applications: Requirements, architecture, security issues, and emerging trends." *Expert Systems* 39, no. 5 (2022): e12753. https://doi.org/10.1111/exsy.12753

[18] Khavarian-Garmsir, Amir Reza. "Smart cities and sustainable development goals (SDGs): A systematic literature review of co-benefits and trade-offs." (2023).

[19] Hämäläinen, Mervi. "Urban development with dynamic digital twins in Helsinki city." *IET Smart Cities* 3, no. 4 (2021): 201-210. https://doi.org/10.1049/smc2.12015

[20] Lv, Zhihan, Dongliang Chen, and Haibin Lv. "Smart city construction and management by digital twins and BIM big data in COVID-19 scenario." *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)* 18, no. 2s (2022): 1-21. https://doi.org/10.1145/3529395

[21] Anthony Jnr, Bokolo. "Managing digital transformation of smart cities through enterprise architecture–a review and research agenda." *Enterprise Information Systems* 15, no. 3 (2021): 299-331. https://doi.org/10.1080/17517575.2020.1812006

[22] Shah, Syed Attique, Dursun Zafer Seker, M. Mazhar Rathore, Sufian Hameed, Sadok Ben Yahia, and Dirk Draheim. "Towards disaster resilient smart cities: Can internet of things and big data analytics be the game changers?." *IEEe Access* 7 (2019): 91885-91903. https://doi.org/10.1109/ACCESS.2019.2928233
[23] Baduge, Shanaka Kristombu, Sadeep Thilakarathna, Jude Shalitha Perera, Mehrdad Arashpour, Pejman Sharafi, Bertrand Teodosio, Ankit Shringi, and Priyan Mendis. "Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications." *Automation in Construction* 141 (2022): 104440. https://doi.org/10.1016/j.autcon.2022.104440
[24] Messaoudi, Kaddour, Omar Sami Oubbati, Abderrezak Rachedi, Abderrahmane Lakas, Tahar Bendouma, and Noureddine Chaib. "A survey of UAV-based data collection: Challenges, solutions and future perspectives." *Journal of network and computer applications* 216 (2023): 103670. https://doi.org/10.1016/j.jnca.2023.103670
[25] Hassankhani, Mahnoosh, Mehdi Alidadi, Ayyoob Sharifi, and Abolghasem Azhdari. "Smart city and crisis management: Lessons for the COVID-19 pandemic." *International Journal of Environmental Research and Public Health* 18, no. 15 (2021): 7736. https://doi.org/10.3390/ijerph18157736
[26] Allam, Zaheer, and David S. Jones. "On the coronavirus (COVID-19) outbreak and the smart city network: universal data sharing standards coupled with artificial intelligence (AI) to benefit urban health monitoring and management." In *Healthcare*, vol. 8, no. 1, p. 46. MDPI, 2020. https://doi.org/10.3390/healthcare8010046
[27] Kaššaj, Michal, and Tomáš Peráček. "Sustainable connectivity—integration of mobile roaming, WiFi4EU and smart city concept in the European union." *Sustainability* 16, no. 2 (2024): 788. https://doi.org/10.3390/su16020788
[28] Becker, Jörg, Friedrich Chasin, Michael Rosemann, Daniel Beverungen, Jennifer Priefer, Jan vom Brocke, Martin Matzner *et al.,* "City 5.0: Citizen involvement in the design of future cities." *Electronic Markets* 33, no. 1 (2023): 10. https://doi.org/10.1007/s12525-023-00621-y
[29] Qian, Bin, Zhenyu Wen, Junqi Tang, Ye Yuan, Albert Y. Zomaya, and Rajiv Ranjan. "Osmoticgate: Adaptive edge-based real-time video analytics for the internet of things." *IEEE Transactions on Computers* 72, no. 4 (2022): 1178-1193. https://doi.org/10.1109/TC.2022.3193630
[30] Yang, Runlin, and Feng Zhen. "Smart city development Models: A cross-cultural regional analysis from theory to practice." *Research in Globalization* 8 (2024): 100221. https://doi.org/10.1016/j.resglo.2024.100221
[31] Iftikhar, Abeer, Kashif Naseer Qureshi, Ali A. Altalbe, and Khalid Javeed. "Security provision by using detection and prevention methods to ensure trust in edge-based smart city networks." *IEEE Access* 11 (2023): 137529-137547. https://doi.org/10.1109/ACCESS.2023.3338550
[32] Bastidas, Viviana, Markus Helfert, and Marija Bezbradica. "A requirements framework for the design of smart city reference architectures." (2018). https://doi.org/10.24251/HICSS.2018.317
[33] Thumrongvinitchai, Worrawat. "Study of the Requirement for a Central Data Centre Management System for Security and Smart Crime Prevention for Smart City Development." *International Journal of Digital Media Technology and Design* 2, no. 2 (2024): 10-13.
[34] Safitra, Muhammad Fakhrul, Muharman Lubis, Mochamad Teguh Kurniawan, Rd Rohmat Saedudin, and Muhammad Ilham Alhari. "Beyond efficiency: advancing sustainability in data centres through TIA-942 guidelines and case studies." In *Proceedings of the 2023 11th international conference on computer and communications management*, pp. 107-115. 2023. https://doi.org/10.1145/3617733.3617751
[35] Guan, Youbang, and Bong Jun Choi. "Design, implementation and verification of topology network architecture of smart home tree." *Comput. Mater. Contin* 68, no. 2 (2021): 2399-2411. https://doi.org/10.32604/cmc.2021.012365
[36] Fang, Yufei, Zhiguang Shan, and Wei Wang. "Modeling and key technologies of a data-driven smart city system." *IEEE Access* 9 (2021): 91244-91258. https://doi.org/10.1109/ACCESS.2021.3091716