Chapter 7
Taking Cloud Computing to the Extreme Edge: A Review of Mist Computing for Smart Cities and Industry 4.0 in Africa

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7.1 Introduction

Cloud computing concept has been built with the assumptions of good Internet connectivity, adequate bandwidth and low latency. But with the proliferation of Internet of Things (IoT) of resource-constrained smart devices, stringent Internet connectivity demand, high bandwidth, low latency, lower energy consumption, context-awareness, mobility and enhanced security requirements placed on applications and services [2, 39] in Smart Cities and Industry 4.0 concepts, as well as the huge amount of traffic and data expected to be generated, the traditional cloud-centric architectural arrangement no longer holds due to these assumptions. Cloud computing is therefore gradually evolving into new complementary concepts as edge and fog computing and also dew and mist computing to address the concerns mentioned above by extending the capabilities of cloud computing to the extreme edge of the network closer to the data generation source. Mist computing extends the concept of fog computing to the extreme edge of the network at the level of microcontroller and embedded nodes and is based on IoT concept; on the

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other hand, dew computing is based on the Internet and client–server concepts, whereby on-premises computer provides functionality that is independent of cloud services, but also collaborative with cloud services [59]. The overall objective of dew computing is to enable access to cloud computing services in the absence of Internet connectivity.

In this chapter, an overview of mist computing model/architecture is provided together with the scope and evolving nature of the topic, its characteristics and comparison to cloud and fog computing, application scenarios, possible challenges and future direction. There exist several surveys on fog, dew and mist computing, but this chapter, therefore, does not intend to revisit these concepts in their entirety. However, this chapter aims to discuss mist computing in Smart Cities and Industry 4.0 in the context of Africa. The study is an extension of the work done in [19], which focused on how Nigeria and other developing ICT economies in Africa can benefit from cloud computing and its evolving and complementary implementations, challenges, drivers supporting its growth and future vision in the region.

Section 7.2 of this chapter provides overview on the overlapping and complementary key background concepts, namely, IoT, big data, cloud computing, edge computing and its implementation. The architecture of mist computing, its characteristics and its similarity and dissimilarity with cloud computing, fog computing and edge computing is covered in Section 7.3. In Section 7.4, the potential, application and use case scenarios of mist computing with respect to two emerging concepts, namely, Smart Cities and Industry 4.0 with focus on Africa, are discussed. In Sect. 7.5, an outline of the possible challenges in the implementation of mist computing, based on observation and trends, is discussed together with the drivers supporting the growth and technical recommendations in the context of Africa. Section 7.5 also discusses the future perspective of Smart Cities and Industry 4.0, while Sect. 7.6 concludes this chapter.

Several wide-range and inclusive surveys [2, 8, 17] and studies have been undertaken in recent times on cloud computing [13, 45, 56], edge computing [2], fog computing [10, 25] and its implementation in Smart Cities [38] and Industry 4.0 [33], mobile edge computing [1, 29, 30, 53], cloudlet [37, 48, 49], dew computing [44, 52, 59, 60] and mist computing [39, 40].

The web search interest over a period of 12 months as measured by Google search trends on fog, edge, mist and dew computing is shown in Fig. 7.1. The Google trend search shows a very low interest and possibly low awareness overall on these evolving cloud computing concepts, most especially in Africa. This motivates the essence and purpose of the research work presented in this chapter.

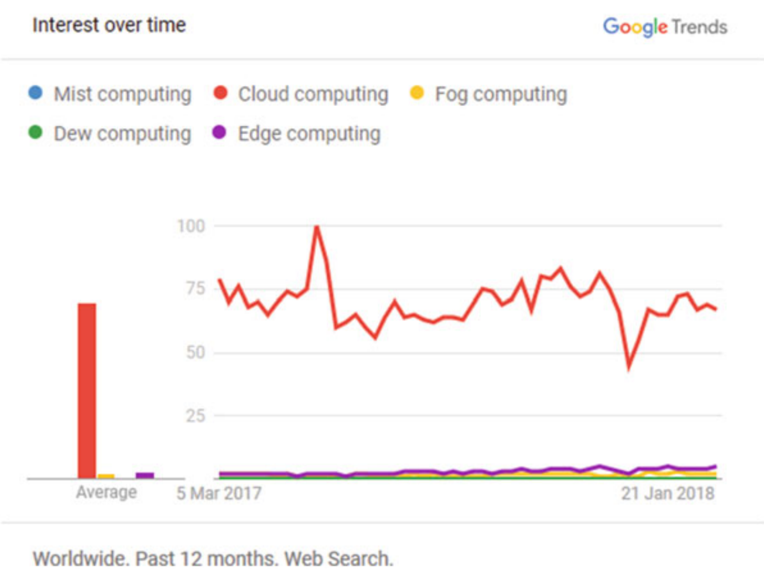

Fig. 7.1 Google search trend over the past 12 months

7.2 Overview of Key Background Concepts

In this section, an overview of key enabling concepts and technologies that are highly intertwined and overlapping with mist and dew computing is given as it relates to Smart Cities and Industry 4.0.

7.2.1 Internet of Things (IoT)

IoT is a communication technology concept that envisions a scenario where objects or things are interconnected with one another, based on standard communication protocols, each with its uniquely identifiable addressing system, forming an integral part of the Internet [6]. IETF categorizes IoT into three: people, machines and information. Figure 7.2 depicts the three-tier IoT functional stack architecture, comprising of the *Things* embedded with sensing capabilities, the *networking* layer and the specific *application* layer. IoT is vast and overlaps with other research fields as depicted in Fig. 7.3.

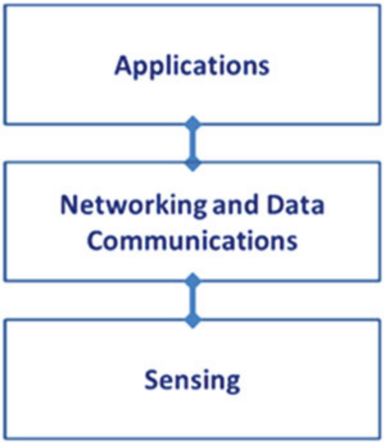

Fig. 7.2 Three-tier Architecture of IoT [31]

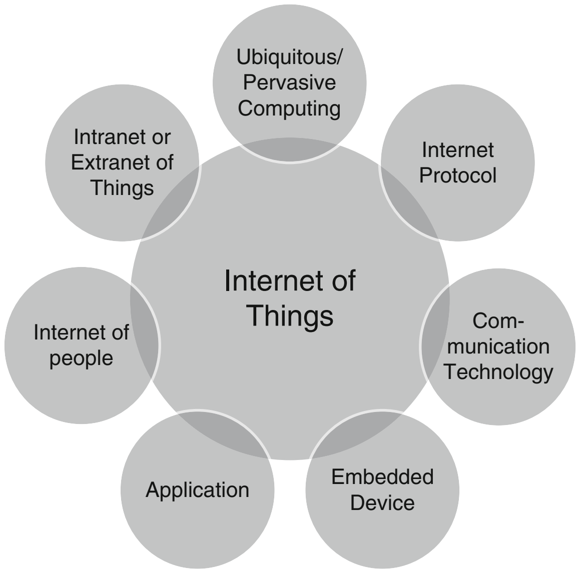

Fig. 7.3 IoT overlap with other research areas [31]

Wireless communication technology plays an important role in IoT, and [11] identifies the key and important aspects of IoT technology such as Radio Frequency Identification (RFID), Wireless sensor networks (WSN), Network Addressing and IoT middleware software. The authors also proposed a new paradigm called CloudIoT, which is the integration of cloud computing and IoT as these two complementary technologies are expected to shape the direction of the current and future Internet. McKinsey & Company predicts a potential economic value of up to $11 trillion by the year 2025 if the policy makers and businesses can link the cyber-physical systems together. On the other hand, IDC predicts that by 2019, 45% of

IoT-created data will be stored, processed, analysed and acted upon close to/at the edge of the network.

The annual IoT Forum Africa (IoTFA), a platform that enables industry and expert practitioners to share their vision on IoT trends, challenges and solutions in virtually all aspects of life and in different industries, reinforces how IoT has the potential of transforming the African continent.

7.2.2 Big Data

The rate of deployment and expansion of devices and sensors connected to the IoT is a major source of data generated and transmitted in real time. Cisco projects that by 2020, the number of connected devices will exceed 50 billion [21], while some experts have even projected higher numbers due to the rapid advancement in the Internet and Internet device technology. It must be mentioned that with respect to these generated data, cloud computing facilitates storage, processing and analysis. Overtime data collection and analytics have evolved into three (3) ways – Analytic 1.0, collection of historical data; Analytic 2.0, social media and unstructured information; and Analytic 3.0, real-time IoT data from a vast number of sensors (heterogeneity) – making it challenging to push data to a single cloud data warehouse, hence the need to bring data analytics closer to the edge of network into routers and gateways, as well as on-board embedded systems with sensors (mist computing).

The characteristics of big data are captured in the 5 V's model, namely, volume, variety, velocity, veracity and value [35]; hence, a data that meets these characteristics is termed big data. Big data in Africa has numerous applications, such as in climate change, poverty and disease surveillance, agriculture, banking and finance, supply chain, media, space research and biological research [34, 41, 54].

7.2.3 Cloud Computing

According to the US National Institute of Standards and Technology (NIST) and the European Network and Information Security Agency (ENISA), "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to shared pool of configurable computing resource (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction, through visualization and multi-tenancy arrangement". Readers are referred to [19] for details on cloud computing concepts and analysis on how it relates to Nigeria and by extension Africa.

7.2.4 Edge Computing and Its Implementations

Edge computing (EC) has evolved from cloud computing due to the tremendous growth in IoT devices, which according to Cisco is estimated to reach 50 billion devices in no distant future. This comes with several challenges to the traditional cloud computing arrangement on several fronts such as the need for low latency, high bandwidth, enhanced security due to several organizations' sentiments on their data residing in unknown third party's data centre and the growing demand and advocacy for a greener technology. Hence, the need to extend cloud computing capabilities closer to the data source on the edge of the enterprise network using the edge gateway's core routers and switches is necessary. Overtime, edge computing has also evolved into other complementary implementations to address challenges and flaws associated with cloud and edge computing. A brief overview of the technological implementations of edge computing is discussed over the next subsections. For a more detailed survey, readers are referred to [8].

7.2.4.1 Fog Computing

Fog computing (FC) was originally proposed by Cisco [10], which extends cloud computing to the edge of the network at the level of routers and gateways. Its emergence is due to developing applications that are sensitive to latency, which cannot be met by the current cloud-centric architectural arrangement. There is currently no globally accepted definition of FC; however, for the purpose of the research work presented in this chapter, the definition formally stated by [10] is adopted, which states that: "Fog computing is a highly virtualized platform that provides compute, storage and networking services between end devices and traditional Cloud Computing data centres, typically, but not exclusively located at the edge of the network" with the fog nodes as its building blocks which are "distributed fog computing entities enabling the deployment of fog services and formed by at least one or more physical devices with processing and sensing capabilities (e.g., computer, mobile phone, smart edge device, car, temperature sensors, etc.). All physical devices of a fog node are connected by different network technologies (wired and wireless) and aggregated and abstracted to be viewed as one single logical entity, that is the fog node, able to seamlessly execute distributed services, as it were on a single device" [20].

Figure 7.4 depicts the fog to cloud architecture, with one cloud layer and two fog layers. Fog layer 1 is directly connected to the edge devices, while fog layer 2 is in between fog layer 1 and the cloud, acting as an intermediate processing layer. According to the OpenFog Consortium, advantages of fog computing include enhanced security due to the distributed architecture, cognition/decision-making on fog node, improved agility, lower latency and overall efficiency.

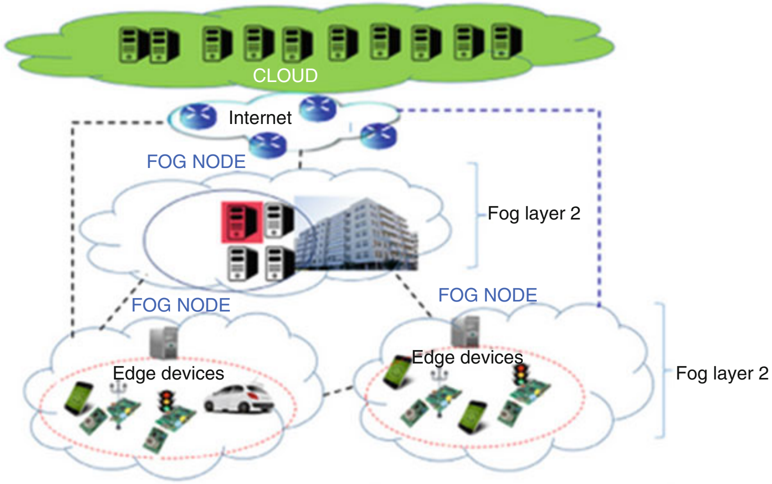

Fig. 7.4 Fog-cloud architecture [20]

7.2.4.2 Mobile Edge Computing

Mobile edge computing (MEC) is a telecommunication concept driven by smart mobile devices, IoT and 5G communications paradigms, which offers cloud computing capabilities and features in terms of storage and mobile computing at the edge of the radio access network (RAN) leveraging on the mobile base stations away from the traditional mobile cloud computing (MCC) arrangement, thereby reducing latency and enabling efficient use of the core mobile network and better mobile user experience [1, 30]. While IoT technology over the years is reaching its maturity, unlike 5G communication technology whose maturity is still being anticipated, there are already very high expectations due to the many potential advantages that next-generation 5G brings to wireless communication technology. Several expert opinions agree on the positive gains that Smart Cities-based [4, 32] and Industry 4.0-based [23, 47, 55] solutions can acquire by leveraging on future 5G network such as dealing with the exponential growth of data, user density, data capacity, low power consumption and data rates for very large connected IoT devices and catering for mission and safety-critical applications [18]. To this end, recently mobile edge computing (MEC) was renamed multiaccess edge computing to reflect the interests of both cellular and non-cellular operators across the industries [2, 53]. Ten (10) key technological components were identified and discussed in detail by [3] that will satisfy the requirement and building blocks of 5G wireless network communication technology, namely, a wireless software-defined network (WSdN), network function virtualization (NFV), millimetre wave transmission (mWT), massive MIMO, network ultra-densification (NUd), big data and mobile cloud computing (MCC), scalable Internet of Things, device-to-device connectivity with high mobility, green communications and new radio access network techniques (RAN).

7.2.4.3 Cloudlets

Cloudlet is the middle layer in a three-tier hierarchical architectural model made up of end-user mobile devices–cloudlet–cloud, similar to the arrangement in fog computing for IoT devices. This model's arrangement provides for an edge–cloud platform that extends cloud services and features closer to the end-user mobile devices [48, 49)]. Cloudlet can be viewed as the edge of the Internet providing computing, storage and networking capabilities to neighbouring mobile devices acting as a thin client to offload resource-intensive task and data caching, thereby improving execution speed and energy savings [37, 53]. Cloudlets are developed with virtualization features to meet the current demands of emerging mobile applications, such as high computational resource demand of mobile applications and service with low latency requirements.

7.2.4.4 Microdata Centre

Microdata centre (MDC) is a modular pre-fabricated standalone data centre unit enclosed with all the features of a traditional data centre such as servers, virtual machines (VM), cooling system, network connectivity, uninterruptible power supply (UPS), security and access control systems as well as flood and fire protection and a high degree of mobility and ease of deployment. Bandwidth constraints, growth in time-sensitive applications and security are some of the driving factors behind the adoption of MDCs by organizations as part of an edge cloud solution, in order to support IoT workloads at the edge of the enterprise network in a distributed manner. This is a viable solution not only for established organizations but also for SMEs and developing regions where real-time data analysis is required. MDC finds application across different industries such as assembly plants, manufacturing industries, exploration and mining, smart cities application solutions and construction industry [8].

7.2.5 Fluid Computing

Fluid computing is an envisioned next-generation cloud architectural paradigm that eliminates the segregation created by cloud, fog and mist computing technologies, unifying them under a single abstraction through provisioning of an end-to-end cooperative platform which can be used for seamless computing, storage and networking to allow application data flow between functionalities regardless of whether the resource has been provided by cloud, fog or mist infrastructure. This is done by leveraging on virtualization and soft computing [12, 16].

7.2.6 Blockchain Technology

Security, privacy and regulatory frameworks [5] are key concerns relating to new and emerging technologies in cloud computing, Smart Cities and Industry 4.0, due to the sensitive information generated and transmitted by resource-constrained smart terminal devices in the IoT ecosystem which are prone to security attacks. Blockchain technology, a peer-to-peer (P2P) distributed ledger technology for transparent transaction devoid of a trusted intermediary, has evolved beyond its original application to support bitcoin cryptocurrency and is seen as a viable option to address these concerns by integrating it with smart devices in smart cities in order to provide a secure communication platform [9] and with cyber-physical systems (CPS) in Industry 4.0 to provide transparent transactions among smart devices [7].

7.3 Extreme Edge Computing

7.3.1 Mist Computing

Mist computing has evolved from fog and cloud computing into a collaborative cloud technology based on the idea that communication should be made at the level of sensors and actuators without burden on the communication network and the Internet, by leveraging on the computational networking resources from the devices at the very edge of the IoT networks. This leads to increased autonomy of the system and reduced latency and bandwidth usage with a corresponding power consumption reduction as communication accounts for five times consumption compared to computation. "Mist Computing represents a paradigm in which edge network devices, that have predictable accessibility, provide their computational and communicative resources as services to their vicinity via Device-to-Device communication protocols. Requesters in Mist can distribute software processes to Mist service providers for execution" [28]. Scalability, reconfigurability, location self-awareness, situation awareness and attention and machine-to-machine communication (M2M) are core features of mist computing [39]. Cisco is leading the vision to move data analytics closer to where the data is generated for better decision support of mission critical services instead of backhauling it to the cloud or even the fog. IoT smart devices should not just be about data collection; most importantly, they should bring intelligence to the extreme edge of the network to derive value from the data for quicker decision support. Fog computing has been able to address a lot of challenges associated with IoT, including bandwidth and latency requirements. In fog computing, the gateway is key to ensuring the coordination and functioning of IoT applications; however, this arrangement has some drawbacks, such as the gateway being the single point of failure since the entire network is dependent on it [40]. For this reason, mist computing is gaining popularity fast and is seen to address some of the concerns on cloud and fog computing architectures with Thinnect, an IoT edge network service provider, at the forefront of the development and implementation of mist computing in real-life scenarios.

7.3.1.1 Architecture of Mist Computing

Mist is made up of a large number of heterogeneous devices at the extreme edge of the IoT network which is capable of providing some form of services to aid the improvement of IoT applications in terms of the computational processes [28]. Figure 7.5 depicts the conceptual framework of mist in the IoT environment, with the sensors and actuators as the generators and processors of data at the extreme edge of the IoT network layout.

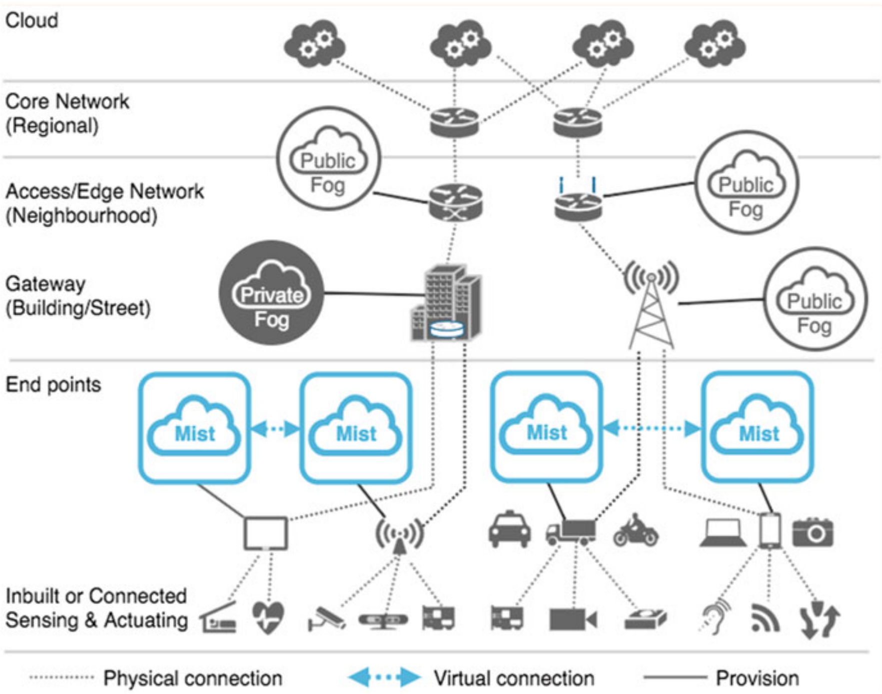

Fig. 7.5 Mist in IoT framework. (Source: Cisco)

7.3.1.2 Characteristics of Mist Computing

1. Hardware: Low latency, limited communication bandwidth, insufficient security, low mobility, low power
2. Situation awareness: Awareness on the physical environment and the local situation in collaboration with cloud and fog computing (see also Sect. 7.3.3)

7.3.2 Dew Computing

Since the emergence of the concept of dew computing originally proposed in [58], other technical definitions have also emerged from various researchers [22, 52]. In the context of the research work presented in this chapter, the definition in Wang (2016) [59] is adopted, which states that: "Dew computing is an on-premises computer software-hardware organization paradigm in the cloud computing environment where the on-premises computer provides functionality that is independent of cloud services and is also collaborative with cloud services". The goal of dew computing is to fully realize the potentials of on-premises computers and cloud services. The vision behind dew computing is based on the concept of the Internet, whereby it envisioned users situated in any part of an enterprise network to access the cloud without the continuous access to the Internet using a client–server model, in a complementary manner to cloud computing [46]. Figure 7.6 depicts a conceptualized model of dew–cloud architecture comprising of dew server, dew DBMS, dew client program, dew client service application and high-speed connection to the cloud server. For more details on the concepts of dew computing, readers are referred to [44, 59, 60].

7.3.3 Comparison of Mist with Cloud, Edge and Fog Computing

A summary of the comparison between cloud, fog and mist computing is shown in Table 7.1, which is based on earlier studies by [25].

7.4 Potentials, Applications and Use Case Scenarios of Mist Computing

In this section, the potentials, applications and use case scenarios of mist computing will be broadly discussed with respect to two emerging conceptual domains, namely, Smart Cities and Industry 4.0.

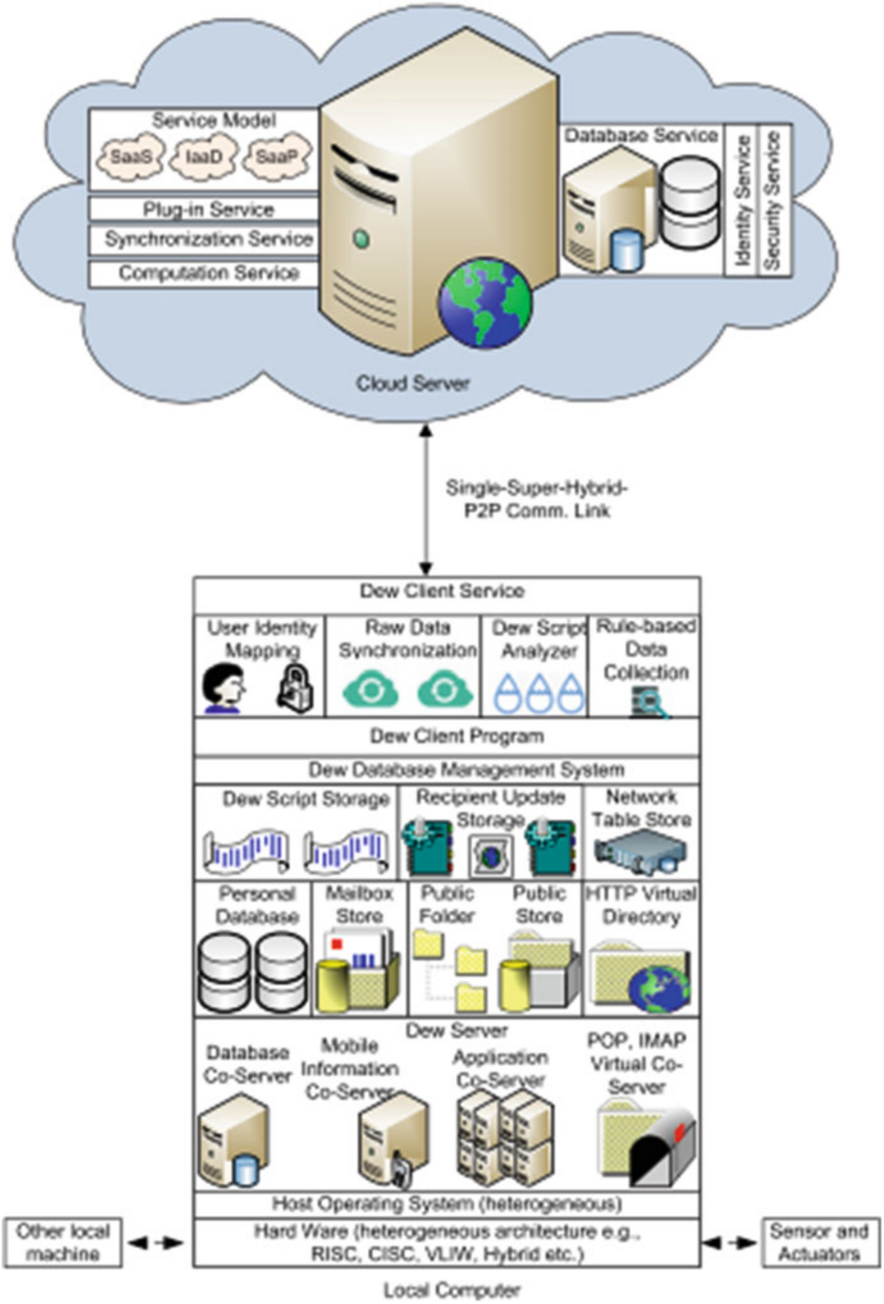

Fig. 7.6 Conceptual cloud–dew architecture [44]

Table 7.1 Comparison of mist with cloud, edge and fog computing

	Cloud computing	Edge computing	Fog computing	Mist computing
Support for IoT	Yes	Yes	Yes	Yes
Infrastructure deployment model	Centralized and accessed via the internet	Centralized	Decentralized LAN or IoT gateway/distributed	Centralized/distributed with the microcontroller network
Efficiency	High	Higher	Higher	Higher
Latency	High 100 ms and above	Low	Low 10–100 ms	Ultra-low 10–100 ms
Bandwidth	High 1Mbps–10Gbps	Low	Low 100 kbps–1Mbps	Low 1–300 kbps
Computational power	High	Moderate	Moderate	Low
Mobility support of IoT services	No	Yes	Yes	Yes
Data status	Data at rest	Data in transit/at rest	Data in transit/at rest	Data in transit
Security and privacy concerns	Higher concern due to sending raw data over the internet	High	Medium concern	Low concern since data reside with the hardware
QoS	Yes	Yes	Yes	Yes (limited)
Geographical availability	Limited spread in hundreds	Limited spread in hundreds to thousands	Wide spread in thousand to million	Very wide spread in million–trillion
Service type	Global	Limited	Limited	Very limited
Hardware	Large	Limited	Limited	Very limited
Working environment	Indoor data centre	Indoor	Outdoor/indoor	Outdoor/indoor
Power consumption	Very high	High	Low	Very low
Online/offline capabilities	Only online		Dual online/offline	Dual online/offline
Addressing	IPv4/IPv6	IPv4/IPv6	IPv4/IPv6	IPv6 (6LowPAN)
Cost of implementation	Medium	Medium	High	Low

7.4.1 Smart Cities

African cities are vital centres of trade, commerce, innovation and many other important activities. Recent statistics estimate that by 2030, over 60% of the African population would be dwelling in cities. In addition to this fact, these cities approximately contribute 70% of greenhouse gas emissions and energy utilization while occupying and accounting for only 5% of the continental land mass [14, 26].

Apart from these environmental trends, African cities are presently experiencing an increasingly huge demand for food, water, shelter and building materials, risk and disaster control strategies, waste management schemes and pollution control strategies [26].

African cities are therefore under constant and immense pressure to provide better standard of living, offer quality amenities and services, address social and environmental issues, foster economic growth and trade competitiveness, promote regional urbanization and industrial mechanization, attract investments and reduce costs [26]. These pressures are necessitating African cities to look into smart solutions in order to tackle the plethora of problems and challenges on the ground. Such solutions will enable African cities to transform into smart sustainable cities where ICT innovations and high-tech social amenities are used to provide improved standard of living, quality services delivery, seamless urbanized operations, economic self-reliance and growth trends that will match up with the environmental demands, social requirements and economic needs of the present and future generations.

Industrial experts and field specialists have shown that mist computing is more suitable for realizing smart city solutions where streets intelligently adapt to dynamic events, conditions, situations and changes in the city [15, 16, 39]. An interesting innovation which can possibly serve as a model for African cities to analyse, adapt and adopt is the smart street light control system developed by *Cityntel* [57]. This system is based on next-generation flat wireless mesh network (for direct application and device layer communications) and mist computing stack where controllers are equipped with data processing and embedded intelligence features. These smart controllers carry out network-based and/or device-specific decision-making operations and rely on wireless communication for data transmission and reception with sensors and detectors, such as movement and road surface detectors and noise, light reflection, air pollution, humidity and temperature sensors [57].

Unlike existing conventional systems, this solution replaces centralized permanent remote server control with distributed intelligent adaptive and autonomous situation- and context-aware devices. In this system, the LED street lights dynamically adjust brightness based on updates and notifications regarding the status of weather condition, human presence and movement and nature of traffic flow or intensity. In a situation where there is little traffic, street lights will switch to energy-saving mode by dimming their lights. Centralized computing is also utilized for processing aggregated data in order to make results of statistical analysis readily available for low-level device programming and learning. Energy conservation, minimized cost, easy upgrade and compatibility, fast and cost-effective deployment and high precision and reliability are ensured due to the adoption of adaptive, local communication and distributed computing strategies among low-cost wireless sensors for desirable system performance [57].

7.4.1.1 Smart Cities and Blockchain Technology

Despite all the numerous potential benefits associated with the concept of smart cities, information security and privacy remain a concern to stakeholders due to the vast amount of vital statistics and transit information generated by interconnected smart devices in the IoT ecosystem. There is, therefore, a need for information to: (i) be confidential, non-disclosure of sensitive information; (ii) possess integrity, information is accurate and reliable; and (iii) not manipulated or corrupted and available whenever/wherever needed by authorized persons. A lot of research has been carried out to address cloud security, but challenges remain due to the heterogeneous nature and resource constraints of smart devices, compatibility and other pertinent factors. A comprehensive review of cloud security is discussed in [27]. Recently, Blockchain which is a P2P distributed ledger technology devoid of a trustworthy intermediary (originally developed to support cryptocurrency) has received a lot of attention as a solution to address security concerns in numerous domains including smart cities [9]. Figure 7.7 shows a proposed smart city security framework across the physical, communication, database and application layers of IoT device to enable a common framework for secured data communication by different smart devices in a distributed community of devices.

7.4.2 Industry 4.0

Industry 4.0 can be conceptually viewed as embracing and infusing the core ideas of mist computing in the factory with the goal of gaining operational and performance efficiencies through rapid and precise decision-making for automated devices in the factory environment [24, 43]. In the context of this research, Industry 4.0 can be technically viewed as the collaborative use of mist computing, smart environmental sensors, robots, big data and mobile devices via cognitive and independent automation in order to achieve flexible mass production, easy product customization, scalability, predictability and greater efficiency during the entire manufacturing process [42].

This fourth industrial revolution goes beyond simply automating production, and it is based on cyber-physical systems achieved through complete and seamless digitalization of the manufacturing industry [24, 42]. Industrial locations and manufacturing operations are unique in Africa since the continental landscapes are vast with scattered and sporadic business hubs. In addition to this, many local corporations and manufacturing industries in Africa have matured to the level of making effective and productive use of data generating technologies and reactive data analysis strategies. It must also be added that a large number of manufacturing organizations in Africa are already aware of the ongoing global trends in Industry 4.0 together with the significant potentials and immense benefits of this explosive technology.

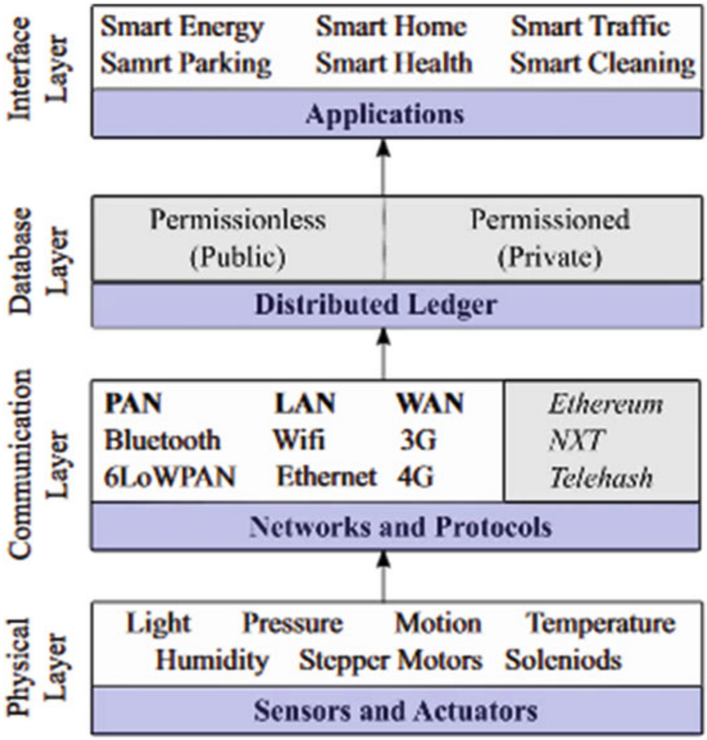

Fig. 7.7 Conceptualized smart cities security framework [9]

However, in comparison with developed ICT economies of the world, the African continent is still yet to attain full-blown maturity with respect to adopting, implementing and deriving maximum benefits from harnessing the potentials of Industry 4.0. Moreover, the widespread adoption of smart technologies and ICT innovations that can rapidly catalyse Industry 4.0 is still at a budding stage in most indigenous manufacturing industries in Africa. This impediment is a result of the general reluctance to venture into and invest in new knowledge and novel technologies by the government and industry of most countries in Africa. This hindrance is also due to the entrenched business culture among African manufacturers where cost-minimization measures are highly prioritized and expenditures on innovative technologies are curtailed to generate maximum profit in the prevailing harsh and competitive economic environment.

An exception to this is the case of African-based large international organizations with cross-continental operations where the level of adoption of smart solutions and innovative technologies is encouraging. From the African perspective, the proper adoption and judicious usage of Industry 4.0 offers limitless opportunities to tackle some socio-economic problems and prevalent industrial challenges associated with supply chain logistics through the development of smart machines, smart factories, smart plants, smart products, smart technologies and smart services. This will foster the development of unique, indigenous, high-tech gadgets, products, devices and services that can successfully leapfrog and dynamically compete with competitors in the global market. A suitable and relevant use case model for this research context is Siemens' *MindSphere*, which has the potential of serving as an underlying platform for mist computing services pertinent to resource optimization, energy data management and preventive/predictive maintenance [50, 51].

7.4.2.1 Industry 4.0 and Blockchain Technology

Blockchain technology which was originally developed for Bitcoin and cryptocurrency as aforementioned is also gradually finding interesting and fruitful applications in Industry 4.0. Supply chain management, smart contract, digital currencies and tighter cybersecurity are applications of Blockchain technology in Industry 4.0. The need for confidentiality, integrity and availability of sensor data is critical to industrial applications and manufacturing systems. Therefore, it is envisioned that Blockchain technology will catalyse remote machine diagnostics and machine-to-supplier transactions which will lead to improved spare parts replacement and overall maintenance practices.

7.4.2.2 Predictive Maintenance

Maintenance is a critical issue in manufacturing, and it goes without saying that maintenance is a prerequisite for effective and sustainable service delivery. Predictive maintenance (PdM) is one of the landmark innovations ensuing from Industry 4.0 which paves the way for predicting future asset failures, forecasting residual machine service lifetime, optimizing timing and scheduling of maintenance, unambiguously ascertaining machine operational statuses, proffering efficient preventive measures and enhancing equipment performance, quality and availability [36]. This is made possible due to the fact that historical and real-time data collected by the Industrial Internet of Things (IIoT) sensors is an integral part of the process of predicting when a failure is likely to occur. In this scenario, mist computing where sensors analyse data in real time close to the source is more viable than sending all the data to a cloud or fog gateway, as this saves time and quicker decision support in a more secure environment.

Benefits of PdM

Cost Reduction PdM with IIoT could benefit industry by improving efficiency, reducing inventory carrying costs, saving material costs, improving the return on asset (ROA), cutting down the cost of engaging service providers, reducing the cost of repairs and spare parts purchase and reducing unwanted costs associated with unplanned downtime and frequent maintenance. In addition to this, PdM with IIoT right on site reduces burden on network and overall cloud cost.

Direct and Impactful Value Creation PdM enables data collection without additional cost as the IIoT sensors are all located where the source of the problem is likely to occur. This makes it possible for prompt and rapid remote intervention in urgent repair and maintenance operations. Resultantly, manufacturing industries employing PdM achieve higher customer satisfaction and add more value and superior quality to the products and services offered to their customers due to their proactive decision-making processes, improved production strategies and pre-emptive business models.

Secure, Safer and Sustainable Operation By adopting PdM, enhanced data security is ensured as data is collected and analysed right in the factory instead of sending to the Internet or external data centre or gateways which are prone to cyberattacks. This enhancement enables manufacturers to deal with unexpected events and better reduce health, safety, environmental and quality risks in the entire manufacturing process. In addition to this, there is the advantage of easily and safely planning service intervals, achieving real-time analytics and attaining ultra-low response time during machine operation.

Uptime Improvement and Availability PdM ensures increased uptime and availability of the machine and equipment due to the reliance on automated intervention of autonomous and cognitive systems that ensure better machine availability and service life, prolong lifetime of aging assets, prevent lasting damage to relatively new equipment and foster quality control and precision manufacturing.

Accurate Predictions and Better Decisions By utilizing PdM, a plethora of new data sources are constantly made available that reliably and accurately reflect the real operational status of equipment for better decision-making. In addition to this, PdM ensures that valuable time is expended on data-driven problem solving and not wasted on brute-force data collection and validation. Another clear advantage of PdM in terms of economy and efficiency is that IIoT sensors, data collection, data analytics and decision support for PdM are all with a local area network (LAN).

7.5 Implementation Challenges in Africa

Skills Gap and Digital Divide The digital divide between developing ICT economies in Africa and developed ICT economies is not an overstatement, but this divide is still present and significantly wide in some regions of Africa. This digital divide, unfortunately, hinders or delays the rate of technical training, capacity building and skills acquisition necessary for the successful implementation of mist computing. In addition to this, the present engineering and ICT curriculum in most African institutions need reforms that will sufficiently enrich the programmes with practical skills that will adequately prepare and equip Africans for mist computing solutions and other emerging innovative technologies. Presently, there is very little research work that decisively investigates and quantifies the real impact of this existing digital divide and skills deficit. Therefore, it is necessary in Africa to embrace a holistic approach that considers the dual goal of investing in smart people and smart technologies.

Technology Transfer, Assimilation and Domestication It would be very challenging to realize the latent benefits of mist computing when solutions are simply imported from developed ICT economies into Africa as turnkey products and services. These smart technology solutions need to be meticulously studied, properly understood and, most importantly, technically adapted to be indigenously relevant, suitable and effective to tackle the specific development needs of Africa. This is necessary because economic situation, geographical context and cultural inclination play an indispensable role in the technology transfer process. Therefore, governments and corporate organizations in Africa need to adopt mist computing solutions in accordance with their prevailing regional socio-economic needs. For instance, adopting a mist computing solution that demands massive data aggregation from a large wireless sensor network for distributed intelligent transport and traffic management system will be prohibitively expensive and unsuitable based on the existing economic realities and social demands in most African countries. In such a scenario, a localized and simplified version of this smart technology solution that ingeniously harnesses the pervasiveness of mobile telephone data and other available cost-effective and easily accessible alternatives will be more suitable to the context of Africa.

Inclusiveness and Governance Smart technology projects involving mist computing call for smart governance models in order for such technological enterprise to thrive in Africa without suffering premature and sudden downfall. The need to develop and implement this pragmatic governance model in Africa is long overdue as there is an evident disconnect, disharmony and lack of synergy between polytechnics, universities, indigenous industries, multinational corporations, civil societies and local, state and federal governments. Such a smart governance model will bring together and carry along all parties during the course of executing the project in order to gain varying perspectives and get robust recommendations and vital suggestions from experts in the economic, legal, educational, political, technical, financial, ethical, social and developmental fields. The current governance model for technology projects in most African countries is still not fully inclusive due to information isolation which acts as a great obstacle to resource integration in the process of executing technological projects at both managerial and technical levels. Therefore, there is a need to reform the existing modus operandi and evolve smart governance models that will enable data and services from mist computing solutions to be useful for citizens, accessible for decision-making, readily available and highly effective in tackling the various developmental needs of Africa.

Failure, Faults and Risk Other challenges hindering the full adoption and implementation of smart technology projects involving mist computing in Africa are the failing infrastructures, resource constraints, high maintenance and running costs, faulty amenities, dysfunctional basic services, deleterious environmental conditions, counterfeit spare parts and unreliable products. These are part of the factors discouraging well-established global data players in mist computing from fully investing in most African countries. In addition to this, the extra cost of importing foreign quality products and services and the worrisomely slow rate of infrastructural development are major inhibitors for the full and permanent establishment of smart technology centres involving mist computing in most African countries.

Funding Opportunities and Business Blueprint Smart technology projects involving mist computing need financial resources and a high level of cooperation and partnership between the public and private sectors in order to ensure smooth running and completion of such projects. Unfortunately, respective governments of African countries are yet to come out with a clear, focused and robust business model and blueprint that will stipulate regulatory framework, infrastructural requirements, taxation guidelines, ownership rights and stakeholder policies in order to genuinely convince and encourage the private sector to invest and innovate in mist computing solutions and other related smart technology projects. Embarking on a smart technology project in Africa without this coherent and realistic business plan will unnecessarily complicate and delay the entire execution process which inadvertently opens the door for many risks and unforeseen setbacks. In addition to this, citizens are, most of the time, not fully and properly sensitized on the actual costs incurred and tangible socio-economic benefits ensuing from these smart technology projects. This makes it very difficult for the respective governments and corporate bodies in various African countries to enable the citizens to fully patronize and comply with the rules and charges associated with using such innovative technologies.

7.5.1 Drivers Supporting Growth in Africa

Trainable and Resourceful Young Population One of the biggest drivers encouraging the establishment of smart technology projects involving mist computing in Africa is the large youthful population who are able, hardworking and willing to learn and be trained on the technical and managerial aspects of these innovative technologies. These vibrant youths are very much cognizant of the global technological trends, and they desire to consume and enjoy the services of the same high-tech quality products as other consumers in developed ICT economies. Moreover, these African youths are relatively more entrepreneurial, dynamic, flexible, trendy, open-minded and computer literate, making it very easy and less costly for them to be trained on the proper understanding, usage, running, handling, operation and management of smart technology systems involving mist computing.

Limited Compatibility and Upgrade Bottlenecks Adopting smart technology projects involving mist computing will be relatively smoother, easier and quicker as issues tied to resource provisioning and the prohibitively high cost of upgrading and maintaining old technological infrastructures and outdated systems are more or less non-existent in the African context. This means that in the case of most African countries, there is the smart choice of starting with the latest and most up-to-date mist computing solutions available which automatically bring these African countries at par with well-established data players and competitors in the global market. Therefore, this makes it easier for African countries to successfully partake in the global market and reach a far wider audience and consumers with considerably less overhead costs and bottlenecks.

Industrialization Wave and Urbanization Drive Respective governments of various African countries are fully aware that industrialization and urbanization are keys to surviving and surmounting the onslaught of socio-economic challenges. Consequently, most African countries are now adopting a vigorous and aggressive innovation and digitalization drive that cuts across for-profit and non-profit organizations: educational, financial and government institutions and all other facets of life. With governments and citizens eager to improve their standard and quality of living, this powerhouse of innovation can significantly act as a catalyst for the widespread reception, successful adoption and effective implementation of mist computing solutions and other related emerging technologies.

Booming Connectivity The advent, upsurge and success of mobile telecommunication industries in Africa have undoubtedly made the impossible achievable and paved the way for the connection of people even in the remote regions of the continent. With the fastest mobile subscription penetration rate in the world, Africa is at a vantage point and strategically positioned to better collaborate with global data players and world technology leaders in developed ICT economies in order to fast-track the development of indigenous smart technology projects involving mist computing.

Industrial Focus and Research Interest It is worth mentioning and highly encouraging to highlight the heightened focus and growing body of research work on innovative technologies, smart solutions and mist computing from the industrial and academic sectors in Africa. This shows that there is a genuine concern to harness the immense potentials of mist computing in order to seriously tackle the plethora of developmental challenges on the ground and achieve a sustainable transformation of the computing landscape of Africa. In addition to this, these progressive efforts will open up more diverse opportunities in African countries for their citizens, local companies and government bodies to properly prepare and make adequate plans for the tangible, derivable benefits attached to the design and development of applications and systems based on mist computing. Therefore, a more favourable and highly receptive atmosphere is created which will support the adoption and sustainable development of mist computing in Africa.

7.5.2 Technical Recommendations

Reform Curriculums and Intensify STEM Education A large portion of innovative technologies and mist computing solutions rest on a solid foundation in science, technology, engineering and mathematics (STEM) education. Therefore, there is the urgent need for pragmatic curriculum reforms in Africa at preuniversity, university, postgraduate and vocational levels that will effectively infuse special skills in these fields needed for smart solutions. In addition to this, it must be mentioned that smart technology projects are multidisciplinary in nature, and they require multidisciplinary teams who can think and make decisions with multidisciplinary perspectives. Therefore, there is the need for relevant institutions in Africa to promote and provide opportunities for multidisciplinary learning and research.

Promote Local Innovation Culture Promoting a culture of technology domestication entails engaging a broad range of stakeholders and concerned parties who are educators, administrators, innovators, legislators, entrepreneurs, researchers and citizen members. This synergy is indispensable in order to effectively implement smart technology projects involving mist computing that will appropriately address the socio-economic needs of citizens of respective African countries. In addition to this, African countries need to create policy environments and devise judicious means of linking existing innovation infrastructures with novel mist computing solutions.

Provide Platforms for Inclusive Governance Respective governments of African countries need to urgently take advantage of the many innovative technological applications and social platforms in order to interactively and regularly engage their citizens and all stakeholders on the trends, recent efforts, progress and proper management of smart technologies and mist computing. This will go a long way in creating accountability, transparency and most importantly, a participatory and inclusive governance.

Establish Quality Control and Maintenance Centres In order to attain and maintain a high standard of smart city solutions and allied manufactured technology products in Africa, there is the pressing need to establish effective technology control and maintenance centres adequately equipped with the constitutional powers to monitor, assess and enforce quality for innovative technologies. The establishment of many of such centres in Africa will instil the culture of quality among various local science, technology and innovation (STI) communities, favourably attract foreign direct investments, improve the quality of mist computing services and, most especially, reduce the cost of adoption, implementation and domestication of mist computing in Africa.

Make Feasible Plans and Seek Concrete Funding Opportunities To achieve sustainable development of smart city solutions, respective governments of African countries should come out with feasible monetization policies, convincing cost recovery mechanisms and practical execution plans that will minimize wastage of resources and maximize efficiency gains. This approach will unambiguously and seriously convince interested local, regional and international investors to provide necessary financial support for smart technology projects involving mist computing in Africa.

7.6 Conclusion

Smart Cities and Industry 4.0 are still in their budding stage in Africa. But with the rapid pace of technological transformation with its envisioned disruption to businesses and society, it is critical for Africa to join, with the possibility of catching up technologically with the rest of the world. The current trend suggests a massive shift away from a centralized cloud architecture towards a distributed architecture with more computing and intelligent capabilities at the edge or extreme edge of the network closer to users. Mist computing has the potential to solve many of the unique socio-economic challenges currently facing Africa in different spheres of life in a collaborative way with the existing cloud and fog computing frameworks. This can be pragmatically achieved by leveraging on IoT solutions and Internet technologies such as smart transportation, smart grid, smart exploration and mining and smart healthcare. With the adoption of these smart solutions, African cities and industries will be adequately equipped with technologies to respond to perennial problems in normal and emergency situations such as industrial hazards, natural disasters, conflicts and insurgencies, scarcity and resource constraints, infrastructural failures and inadequacies, conventional and cybercrime occurrences and other forms of socio-economic challenges embattling the African region in a sustainable manner.

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