Chapter

Communication Technologies and Their Contribution to Sustainable Smart Cities

Menachem Domb

Abstract

Sustainable smart cities (SSC) are becoming a reality as many develop their unique model of smart cities based on vast communication infrastructure. New technologies led to innovative ecosystems where transportation, logistics, maintenance, etc., are automated and accessed remotely. Information and communication coordinate their overall activities. Sensors embedded in these devices sense the environment to provide the required input. Together with artificial intelligence, machine learning, and deep learning, it enables them to facilitate effective decision-making. This chapter discusses the role of integrating technologies in smart cities, focusing on the information and communication aspects, challenges, limitations, and mitigation strategies related to the infrastructure, implementations, and best practices for attaining SSC. We propose a four-layered model covering the main aspects of incorporating communication technology within sustainable smart cities. It covers the basic physical level, providing guidelines for designing a smart city that supports the requirements of a proper communications infrastructure. The level above is the network level where we describe current communication networks and technologies. The rest two upper layers represent the software with integrated and embedded communication components. In summary, we conclude that communication technology is the key enabler of most of the activities performed in smart cities.

Keywords: smart city, sustainable, communications technologies, protocols, infrastructure, signal, wireless communications, urban area communication, signal attenuation, machine learning

1. Introduction

Typical SSCs are equipped with state-of-the-art technologies to support the new and modern lifestyle. Communication technologies are the primary enabler of most electronic interactions and associated operations. The European Parliament states, "A smart city seeks to address public issues via information and communication technology (ICT) solutions." The Japanese definition concentrates on energy, infrastructure, ICT, and lifestyle. Navigant Research [1] pointed out that investment in smart cities covers smart government, smart building, intelligent transport, innovative communications, and smart utilities. Wireless communication using electric signals is the core for accessibility and availability of communication everywhere within the city and at all times. The UN projected that 66% of the world's population will be urban by 2050, and cities consume most of the world's resources, such as 75% of the total energy. They will generate 80% of the greenhouse gases, causing adverse environmental effects. Smart cities with their inherent moderation and control of resource consumption are the ideal solution to address these challenges, population growth, deterioration of energy sources, environmental pollution, etc. The International Organization for Standardization (ISO) provides standards to assure a wide range of smart cities' quality, safety, and performance. Adherence to these standards benefits deploying, managing, and controlling smart cities. Implementing these standards requires embedding sensors within the involved devices and having these devices connected to a local network to establish inter-sensors communications using ICT. Nathali et al. [2] proposed a generic and universal bottom-up smart city architecture for real-world deployment. The architecture comprises four layers: sensing, transmission, data management, and application. Embedded communication means within each layer are critical and mandatory to ensure cooperation and synchronization among the various components of city sustainability.

ICT allows setting energy targets, observing, and enforcing them by deploying sensor networks covering primary energy consumption sources, such as municipal, industrial, hospitals, and citizens. A tool to identify optimal monitoring locations is available. In a case study, the ICT hotspots identified were heating systems, transport systems, and potential transformation of the buildings and roads enabled by ICT solutions. Studies show that a successful implementation requires the timing of ICT-related decisions in the planning process and the actor-networks needed to implement the ICT solutions and their management. The planning process has several decision points: the property owner, meta-network governance coordination, and traveler information systems. A flexible-work-hub solution case study revealed that mobility management systems encourage environment-friendly transport modes to reduce transport demand with minimum impact. All transportation means should be equipped with efficient navigation systems, and flexible work hubs should be located in local nodes closer to people's homes.

To provide a practical framework for this chapter, we propose a four-layer concept, an analogy to the OSI seven-layer for communications. **Figure 1** depicts the layers model, starting from the bottom with the physical city architecture layer, allowing electric and optical signals free of disturbances and delays. Then the network layer

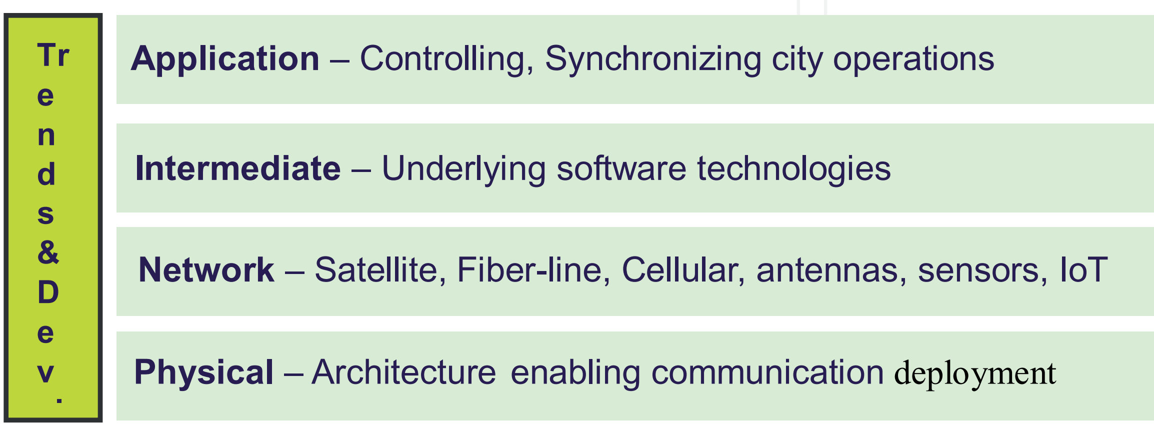

Figure 1.
The multi-layer framework for smart city communications.

where all the communication equipment, wireline, wireless, antennas, sensors, and IoT are optimally deployed. The intermediate layer contains the protocols and third-party software required to support the application layer and manage the lower-level devices. The upper layer has applications enabling the end-user to enjoy the benefits of a sustainable city, such as energy control and waste and pollution management. Each layer is improving over time; this is presented by the vertical column called trends and developments.

2. Trends and developments

The global smart cities market size is expected to expand from $1.226T in 2022 to $6.965T registering a CAGR of 24.2% by 2030. Navigant Research [1], based on 443 projects spanning 286 cities worldwide, will contribute nearly $1.7T to the global smart city technology market until 2030. Rapid urbanization led by government initiatives worldwide encourages sustainable and green technologies investment. Asia Pacific market seems to lead with a CAGR of 27.7%. Advanced cities use IoT to manage sustainable operations. For example, pollution, water, and healthcare. Endeavor Business Media announced the launch of smart-building technology embedding intelligence for new constructions and existing commercial buildings. This technological development reduces energy consumption. Major Asian mobile operators take many 5G deployments, and initiatives to resolve the problem of high bandwidth requirements are anticipated to drive the growth. The list of companies promoting smart cities shows that many leading communication vendors appear there, such as Cisco Systems, Inc., Ericsson, General Electric, Honeywell, IBM, Huawei Technologies, Siemens AG Telensa, Verizon, and Vodafone. The introduction of electric vehicles has been well accepted mainly due to their low pollution and modern look. However, it raised a new environmental issue of recharging stations and how to get rid of the big obsolete batteries.

To complement it, intelligent transportation systems (ITSs) [3] became decisive in minimizing congestion, pollution, and parking space. There is still a need for a closed monitoring system to prevent greenhouse gas emissions and promote efficient energy consumption, awareness, attraction, and broadcast decisions. Smart cities market report posted that the innovative utility section, the intelligent infrastructure, and the travel assistance segment are expected to grow at a CAGR of 22.9, 24.3, and 23.4%, respectively, over the forecast period. Endeavor Business Media, 06/21, announced the launch of intelligent construction technology combining smart communication components, reducing energy consumption. Waste management companies deploy sensor networks and data platforms to generate practical insights, route optimization, and analytics decisions. The growing adoption of new technologies in the smart ticketing market, RFID, QR code, BFSI, and healthcare offer smart solutions across sectors.

Businesses look for new ways to engage their customers, streamline operations, and generate revenue, and many are turning to wireless wide area network (WAN) technology. Wireless connectivity is now essential for enabling agile and secure connectivity of people, places, and things, beyond the reach and limitations of traditional wired network connections, managed wireless. The emergence of 5G, with its faster speed, lower latencies, and enhanced network capabilities, catalyzes wireless WAN adoption as businesses seek to make their WANs cellular simple and fiber-fast for true wireless flexibility. This solution provides businesses with the necessary secure and flexible wireless cellular connectivity to any number of fixed sites managed by network experts, helping organizations save time, money, and removing the burden of ongoing management or upfront infrastructure costs. Customers need an agile network that is quick to deploy, highly scalable, secure, and supports a broad WAN use case. They expect a plug-and-play, managed solution that enables simple and fast deployment of wireless connectivity when wired connections are unavailable, lack sufficient reliability, are too costly, only applicable to fixed locations, and require long lead times. Managed wireless WAN is designed to connect thousands of endpoints while providing end-users with fast and secure access to the cloud, datacenter applications, and the internet. It provides employees with safe and reliable access to be productive anywhere without relying on a network provider to deliver a circuit. 5G wireless edge devices offer connectivity, and plans for future additions to the service include support for in-vehicle and internet of things (IoT) use cases and the addition of enhanced routing and security features. Examples of particular use cases have a temporary connection at a branch site, pop-up store, or construction trailer, expanding to new locations, or using a permanent cellular connection as a failover or WAN link for an SD-WAN deployment. It extends the reach of the enterprise to remote areas https://www.computerweekly.com/news/252516487/European-employers-missing-the-opportunity-to-automate-processes-for-hybrid-work enabling innovative use cases.

3. Application layer: applications with embedded communication

Advanced communications enable the use of new services covering a variety of life indicators applications, such as shorter commute time, clean air, traffic control, street lighting, smart parking, gathering management, accelerated emergency response time, reduced healthcare costs, decreased water consumption, recycled waste, harmful emissions, sustainability, and other saving potential.

Figure 2 presents several key application types used in a typical SSC for managing, coordinating, synchronizing, and managing all city activities, such as advanced metering of water, electricity, and gas consumption control. Real-time metering of measurable elements, anomaly detection, alert systems, sensor-data collection, machine learning, deep learning methods, and big data analysis. The expected impact is efficient, balanced, cost-efficient, reliable, secured, improved power consumption, low air pollution, and tight coordination among city sectors, such as energy, transportation, water supply, healthcare, education, and culture. In parallel, privacy and security issues are handled, and centralized IoT applications for cost reduction and energy saving of LED lighting controls. Applications for managing surveillance cameras, environmental sensors, electronic billboards, charging stations, WiFi coverage, and smart transit systems reduce cost, improve safety, and routing management improve user experience,

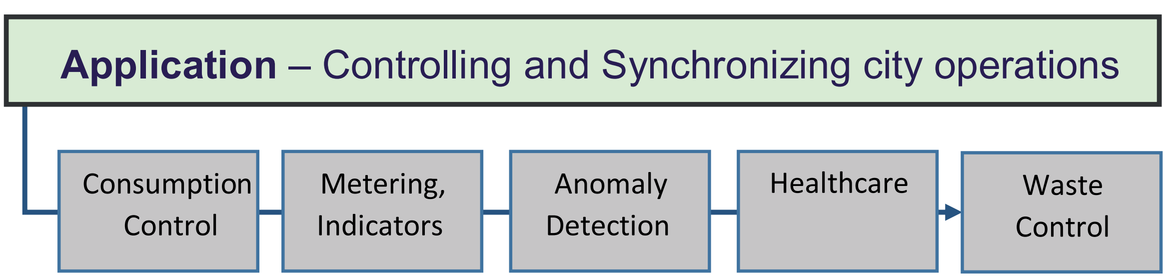

Figure 2.
The application layer detailed examples.

onboard WiFi reduce congestion, provide clean air quality, and priority access management. Other applications, sensing flow rates, tank pressure, water levels, remote management solution, monitoring or the components of the IoT, including a range of radio devices, system on modules (SOMs), sensors, water management applications, gateway to supply the connectivity for a range of application needs, water treatment solutions, evaluate critical environmental data, such as groundwater analytics providing recommendations to customers. Remote monitoring and management solution offer hidden visibility of equipment and customers usage of chemicals.

A collection of vast applications arsenal is the core enabler of SSC. Following are estimated global market values per application type: [4]. Smart metering for the electricity, gas, and water, market is estimated to reach $39B by 2027. The smart lighting market will grow at a CAGR of 18% to $31B by 2025. Intelligent electric vehicle (EV) charging market is expected to reach $70B by 2026. The solar photovoltaic (PV) market is estimated to grow by 5% annually, reaching $185B.

4. Intermediate layer: communication management

This layer provides the underlying generic technologies required by the application layer to operate, giving new ideas and capabilities, and empowering the software intelligence to a leading position in the software domain. **Figure 3** depicts state-of-the-art technologies enabling AI and other libraries to enrich the applications in the first-layer. The API library contains various generic software components the application layer uses. Big data is another component having a warehouse of data collected over a long period enriched with related market data. Data mining, AI, and BI use this data to identify data patterns, rules, and exciting insights. Machine learning (ML) and deep learning (DL) are two modern tools that are able to learn some insights by processing a given training data. These insights are then used to extrapolate and predict the behavior of the system results. Cloud computing transforms computer-owned usage into services without owning the computer environment. It is disconnecting computer services from the organization's site. Consequently, the software can be accessed anywhere and anytime free of maintenance, which is an excellent advantage for a smart city. Cyber security is a comprehensive solution to secure the entire system from cyber-attacks.

The following are typical qualifications representing SSCs [4], as follows: Technological provision, environmental, social, economic sustainability, economic and social development, air quality, energy transition toward renewables, quality of living, waste per population, water sustainability, human infrastructure & networked markets, ESG performance, and smart city ecosystem. Some of the cities provided data regarding their status. One city deployed over 20,000 sensors for capturing

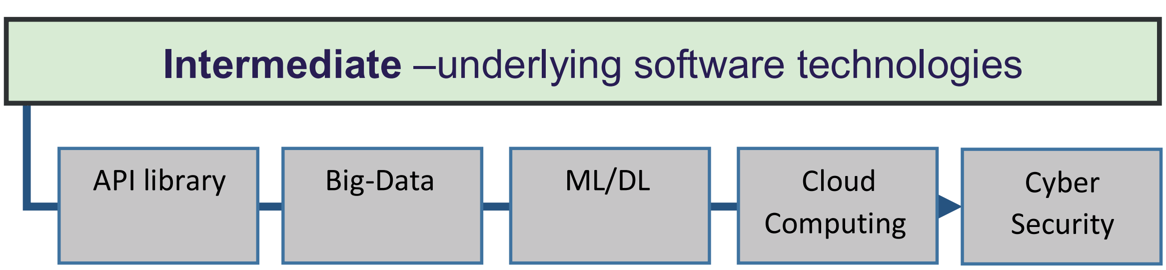

Figure 3.
The intermediate layer detailed examples.

temperature, air quality, mobility data, lighting, noise, and climate. Another city implemented pollution-monitoring sensors and educational campaigns. Some cities stated that all new buildings are built with intelligent controls, low-energy heating, and digitized mobility using accessible WiFi in 755 public spaces. More options are wired bike-sharing, electrical vehicle plug-in spots, activated video feeds in busy intersections to smooth traffic, renewable energy, sustainable mass transit, $70B in total startup valuations, 100 accelerators, incubators, and co-working spaces, using 100% renewable power, implementing real-time meter sensors, reducing emissions from daily commuting by sharing, and deploying sensors for heating, cooling, and lighting based on occupancy. Distribute to the public smart-mobile applications, measure and optimize biogas, energy efficiency, heating and cooling, smart grids, and consider electric buses and green energy systems.

Following are typical declarations of existing smart cities. The city goals are clean air, biodiversity, low carbon, green transportation, waste reduction, artificial intelligence (AI), blockchain, internet of things (IoT), quantum computing helping in their intelligence journey, and cutting 40% of CO_2 emissions by 2025. Becoming the leader in smart and sustainable building solutions. Through the $37N green building masterplan, make 80% of the city buildings eco-friendly by 2030, earn 80% of new buildings super low energy (SLE), and achieve an 80% improvement in energy efficiency for green buildings. Becoming a climate-friendly by 2040. Any services that can be digitized will be digitized. Become the world's first carbon-neutral city by 2025, becoming fossil-fuel-free by 2050.

Some of the recorded achievements are: reducing carbon emissions by 25,000 tons, saving $9.5M, decreasing the electricity consumption of public buildings by 7.8%, reducing overall carbon footprint by 35%, recover 1.64 million tons of municipal solid waste, reducing emissions by about 18,000 T/year, comparable to the electricity use of 4000 residents, Over a third of all transportation, fossil-fuel consumption has been removed through sustainable transport alone, a reduction of 90,000 tons of greenhouse gas emissions each year.

5. Network layer: city wireline, wireless 5G, WiFi7, antennas, sensors, and IoT

Several publications define the requirements for qualifying a city as an SSC. In all of these publications, we realize that communication and sensors are the key enablers of smart cities. Internet connectivity is crucial for smart cities as almost all activities are via messaging. High capacity, high-speed, efficient, and effective internet connection is a key to achieving the smart cities vision. It complies with the forecast that by 2024, more than 23B devices will be connected to cellular networks. It is possible with high-speed internet connectivity associated with local communication networks. **Figure 4** depicts recent trends in modern communication infrastructure, which can cope with a high-volume communication activity. The first component is satellite communications, which is undergoing significant development by SpaceX. The second is cellular 5G, which supports a new magnitude of transmission speed and volume. The third refers to a substantial WiFi version, a newly expanded gateway, and the exploding spread of sensors and IoT devices.

During the past few years, we are evident the intensive launch of more than 2000 small satellites to the LEO by SpaceX, creating a network of satellites communicating with each other via laser beams. The communication with the earth is by electronic

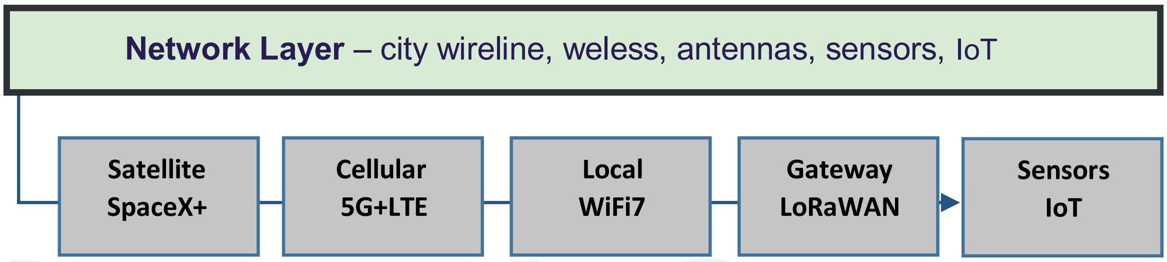

Figure 4.
The network layer details.

signals transmitted toward ground stations for further distribution via wireline and cellular networks. It is the ultimate achievement of satellite communications.

The evolving spread of 5G provides ultra-fast internet, low latency, and improved reliability. It is the ultimate solution that copes with the expected wireless traffic. 5G network's speed is 10–30 Gbps, which is 100 times faster than 4G; the capacity is 1000 Gbps/km^2 area spectral in dense urban environments, 1000 times more than 4G. It decreases energy consumption by 10% times the higher battery life of associated devices and five times lessened end-to-end delay. 5G integrates with long term evolution (LTE) and WiFi to give all-inclusive high-rate coverage and a seamless user experience. 5G networks have a latency rate of 1 ms vs. 40–50 milliseconds in 4G. 5G networks allow smoother handling of spikes and better network traffic optimization than 4G. Lower power consumption and enhanced capacity and speed are part of sustainability.

WiFi wireless communications transport most wireless traffic in enterprises, public and residential environments cost-effectively and continue improving the efficiency in using precious spectrum resources. The new version 7 is to be released in 2024. It is a significant enhancement of WiFi 6. It is more flexible and efficient, supports 16 streams, has a channel size of 640 MHz, has a data rate of 46 Gbps, has lower latency, and uses network and spectrum resources. WiFi 7 integrates well with 5G and 3GPP-based 5G and other standard communication devices and protocols. It supports distributed and cloud architectures, virtualization, and digitalization in the emerging private wireless networks (PWN). Wi-Fi-7 supports applications that require deterministic latency, high reliability, quality of service (QoS), IoT, IIoT, and video-based applications, such as surveillance, remote control, gaming, AV/VR, smart-home services, and more. WiFi deployment provides communication services that save unnecessary wiring, energy, transportation, and contribute to sustainability.

The evolving new services generated for smart cities require numerous sensors connected to new types of wireless communication networks that meet the specific requirements of smart city needs. Sensors [5] interactions require the transfer of small data packages, energy efficiency, the ability to connect devices in remote areas, a high degree of data protection, and interoperability. Connected end devices must operate for a long time, powered by an embedded battery with no connection to the grid. Terleev et al. [6] recommend LoRaWAN as the best gateway for machine-to-machine communication technology. According to experiments, the coverage area of the LoRaWAN gateway is 1500 m, which is fine for a smart city.

The last component required to complement the network layer is IoT, the internat of things, enabling the data collection from the system endpoints, the sensors, and vice versa, transmitting messages from the system toward an IoT device and among IoT devices.

6. Physical layer: city architecture supporting smooth communication

Smart city communication infrastructure supports intra-city and internet interactions. It comprises wireline and wireless mixture networks. The wireline is a network of fiberoptic channels deployed underground with connected antennas.

Figure 5 depicts the typical new generation of communication hardware required to support modern communication services. It includes satellite and cellular antennas, underground fiberoptics wiring, and the construction materials impacting the electric signals. The number of antennas, location, signal strength, and height depend on the city's population density. The wireless portion comprises signals from satellites intercepted by the corresponding antennas and signals broadcasted by the cellular antennas and captured by the mobile phones located within the antenna's spectrum. Wireless signals are disturbed by physical obstacles, such as buildings and other constructions. Therefore, city streets, buildings architecture plans, and used materials should consider optimal deployment of the wireline fiberoptics and the corresponding antenna locations to ensure smooth communication at minimum interference. For example, the building material and the estimated data transmission load apply the suitable communications infrastructure or determine the building's fabric. We provide the knowledge and guidelines for selecting the appropriate communications technologies fitting the specific SSC's attributes and vice versa.

Electric waves are the core of wireless digital communication at free space and ground contacts. However, the transmitted waves are exposed to obstacles, such as rain, dust, topography, urban surface, and magnetic forces, causing signal attenuation and degrading the transferred signal quality up to data loss. To overcome it, we may request the transmission of stronger signals, which increases the power consumption and shortens the transmitting satellite's lifespan. Hence, we propose a machine-learning based model, which predicts the proper signal strength and the correct transmission time, having a high probability of reaching the intercepting antenna on the ground. The model analyses the two path sections, from the satellite to free space close to the ground and then to the ground station. We trained our ML system using training data from the genesis satellite. Experiment results show our system's high accuracy level for frequencies ranging from 2 to 72 GHz.

Several papers cope with the same problem. Some proposed solutions are limited to a geographic region where minimal rain and dust, while others are limited to low frequencies [7]. Analyzed satellite data to discover the elements causing a signal loss in urban environments [8, 9]. Correlate signal loss and construction material [10, 11]. Present materials measurements of low frequencies [12, 13]. Focus on the receiver's position and height disruption inside a building. Entry loss for 2 GHz is reported in [14–18]. Discuss signal spread within facilities and [19] calculate the spread delay as a function of elevation and angle. In [20], a new path loss model and [21] present attenuation differences

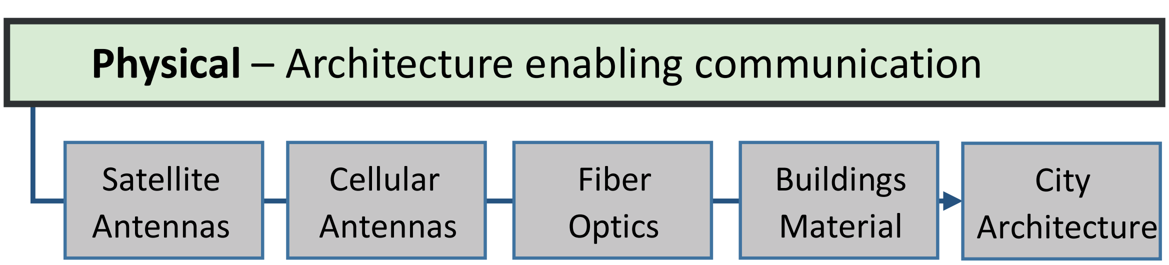

Figure 5.
The physical layer details.

for indoor textures and materials. We selected a concrete building with a horn antenna with vertical polarization. The signal generator, the transmitter, and the receiver are agilent. We use recurrent neural networks (RNN), and MLNNs have a temporal dimension. The MLNN system builds, loads the neural network, trains, and tests the input data. Then it analyzes the data, starting with the input samples reduced in two stages to one instance, identifying the optimal converged parameters. The training results resemble the accurate results. In summary, we provide SSC designers with a tool to determine the optimized materials and positioning of communication equipment so that signal strength will remain effective until it reaches the targeted antennas and mobile devices.

7. Summary and conclusions

This chapter discusses the role and contribution of communication technologies to sustainable smart cities. For a detailed analysis, we divided the subject into four cumulative aspects piled into four layers, starting with the bottom physical layer up to the applications developed to manage, coordinate, and synchronize the activities required to maintain sustainability in smart cities. This study shows the profound necessity of incorporating communication technology into the management and control mechanisms used to assert sustainable smart cities. Based on the detailed content of the chapter sections, it is clear that everything related to management, control, and interaction

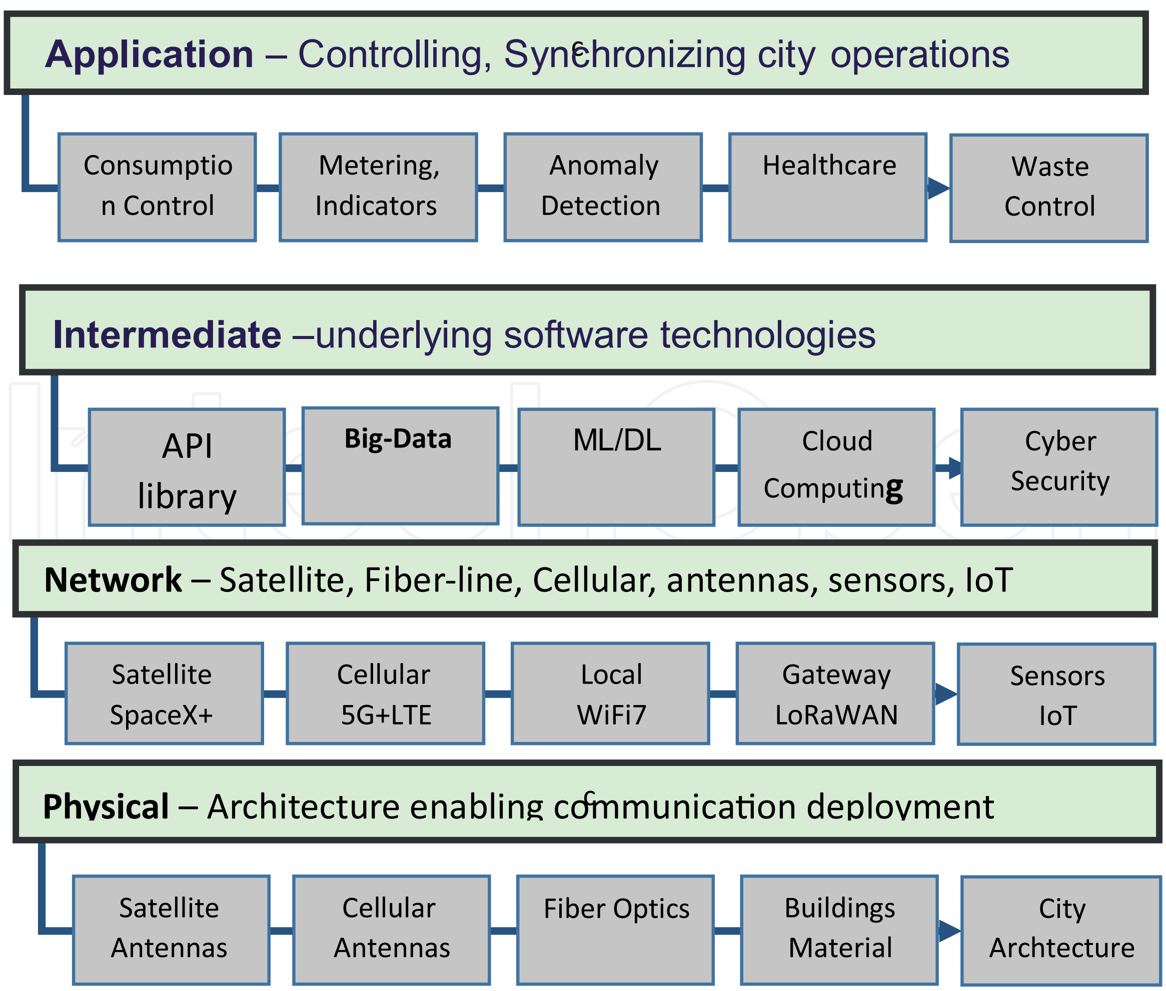

Figure 6.
The multi-layer detailed framework for smart city communications.

among key players of smart cities require communications infrastructure to enable its operations. **Figure 6** encapsulates the complete view of the chapter content and its details. Since SSC is still in its beginning stage and still evolving, this chapter may be updated soon to capture the near future developments in this advanced domain.

Conflict of interest

The authors declare no conflict of interest.

Author details

Menachem Domb
Ashkelon Academy College, Ashkelon, Israel

*Address all correspondence to: dombmnc@edu.aac.ac.il

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