The Smart City: A Holistic Approach

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Abstract— **Internet of things has been gaining popularity and has been forming the basis of various futuristic opportunities in industrial systems, automation, healthcare and many more applications. This has been made possible by the integration of cyber-physical systems with wireless sensor networks and cloud-based data banks. Multiple IoT applications have been deployed in recent years, all these applications have unique architectures and requirements. The concept of generalizing the systems introduces multiple complexities due to the use of plethora of devices, excess of communication protocols designed for specific systems and link layers. The world today has begun an industrial revolution commonly known as industry 4.0 where automated systems form the basis of efficient functions. This gives us an opportunity to bring changes in sensors and actuators, communication protocols and self-aligning infrastructure. This paper primarily focuses on the vision of a smart city with all the basic and advanced amenities relying on smart infrastructure & how the administration and the common man can deploy these systems.**

Keywords—Internet of Things, Industry 4.0, Smart city, IoT Protocols, Cyber-Physical System

I. INTRODUCTION

Internet of things provides a stable option to enable multiple operations with the help of distinct devices in order to provide efficient and time saving operations. Embedded systems, protocol stacks, communication systems and their integration form the basis of IoT. The concept of IoT is not limited to enabling devices to be connected to the internet and store their data, rather the idea of IoT is much deeper and intuitive as it includes connecting devices in remote locations with other devices and forming a robust network of physical devices. The concept of a robust network means that all the nodes in a network may rely on each other for some operations but failure of a group of nodes must not affect the overall function of a network. IoT caters to the needs of not just connecting similar type of nodes but allows the establishment of an heterogenous network that includes home appliances, surveillance systems, healthcare instruments, vehicles, power grids, and so on [1]. A smart city is the culmination of a complex implementation of the internet of things. The concept of smart cities has been introduced by many governments at a global level with a common aim of judicious use of resources with a maximum reach out capacity. The concept of a smart city can help us in optimization of public services while being used to promote sustainable living. A smart city allows the citizens to be fully aware of their whereabouts and surroundings as they can keep a track of the various types of data being produced in the city, this can be a major motivator for the citizens and can increase their turnout as a single stronghold towards their city. [2]. Cyber physical are autonomous systems that enable various physical devices being connected over a layer of communication infrastructures. CPS enhances the reach of embedded systems by reducing the human support to a great extent and by providing uninterrupted services 24/7 [3]. The use of various sensors and data collection devices has helped us generate large chunks of data that can be analysed and used in numerous different applications. Supported by the generation of such data, CPS can used to establish connectivity between devices, machines thus forming a network of self-dependent systems. There are six basic principles that give life to the concept of Industry 4.0. They are as follows: 1) Interoperability, 2) Virtualization, 3) Decentralization, 4) Real-Time Capability, 5) Service Orientation & 6) Modularity [4]. Implementation of industry 4.0 requires the vertical integration of subsystems with the manufacturing plant and horizontal integration of networks to establish internal hierarchy [5]. Industry 4.0 provides automated services in real-time to enable judicious use of resources and to maximise the capability of the infrastructure. All these functions of the model can be facilitated by cyber physical systems. CPS provides a smart infrastructure to allow remote excess of devices and control the flow of information within or outside the premises of the subsystem [6]. Individual subsystems can interact with each other with the help of communication protocols [7]. A city can be viewed as a combination of office complexes, residences, public spaces and the industrial sites. For a complete understanding of a smart city each of these components needs to be individually expressed and its needs must be evaluated independently. This paper discusses the architecture and framework of a smart city and we highlight the basic groundwork required to established a self-sustaining smart city. Further we review the basic protocols and online services required for the smooth and hassle-free working of this city. The rest of the paper is organized as follows. Section II overviews the services that are commonly associated to the Smart City vision. Section III provides a general overview of the layer architecture for an urban IoT. Section IV gives an overview of the communication protocols being used in the Internet of Things.

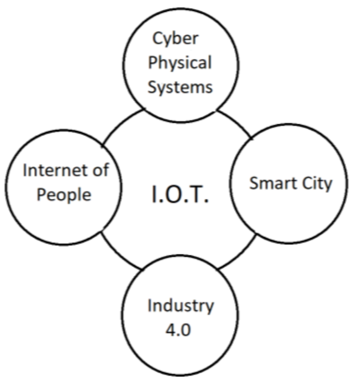

Fig. 1. IoT interoperability

II. RELATED WORK

A. Das et al. [8] propose a multi-tier, meta-architecture for the smart city consisting of 5 layers. These layers include a natural environment, a Non ICT-based Hard Infrastructure, a ICT-based Hard Infrastructure, smart services and a layer of soft infrastructure. The authors in [9] share their overview on the well talked Industry 4.0, it's nine pillars, implementation and the new trends related to it. The paper discusses all the nine pillars ranging from Big Data analytics, autonomous behavior, simulations etc. in order to give a broader prospect to Industry 4.0. The authors have discussed the various challenges of IWN protocols, negotiation mechanisms suffering from low level autonomy, cyber security and various other issues faced during the implementation of industry 4.0. M. Gheisari et al. [10] provide a new age solution to the problems that may occur due to publication of personal information or highly sensitive data by proposing a privacy-preserving architecture. This architecture has been provided for IoT devices used in smart city module. They have also proposed an ontology-based algorithm in order to explain privacy preservation. In [11] the authors provide a holistic review, discussing role of artificial intelligence, machine learning and deep reinforcement learning in order to strengthen the smart cities. The authors even discuss in detail, the applications involving ITSs, energy preservation, cyber security, communications network using UAVs and a broader smart healthcare system. This paper [12] showcases a study conducted by authors, that basically involves all the services that can be done to make the smart cities better in each sense. They have considered about 19 different services. Further, the authors have proposed a Smart City Transformation Framework (SCTF) which lays certain guidelines for policy officials, developers and government officials which further suggest smart solutions for cities. The author in [13] has devised patterns in order to provide and develop manufacturing subsidiaries that directly affect factory economies. The author uses Advanced Manufacturing Technologies (AMT) providers in order to analyze the primary data collected through interviews with various subsidiaries across Hungary. The paper further discusses the impact of Advanced manufacturing technologies (AMT) on subsidiary technology. P. K Muhuri et al. [14] have given a detailed overview about Industry 4.0. They have given a bibliometric analysis based on different sets of performance factors based on work by highly cited authors, series of journals, several countries and acclaimed institutions. The authors have also provided a summarization of how the Industry 4.0 has grown over the last 5 years. The paper [15] discusses the study carried out by authors in order to promote sustainable business performance in SMEs under Industry 4.0. The authors have also prepared a survey in order to collect the data from the SMEs, further analyzing it with the help of Partial Least Square (PLS) – Structural Equation Modelling (SEM). In [16] the authors propose a nine layered representational state transfer architecture for smart home. The sole purpose of this is to provide big-data driven services to smart homes in order to introduce data driven management. The purpose of this data driven approach is to enable smart home services like device control via mobile applications. The authors incorporate two cases of data driven applications namely Smarter Safer Homes (SSH) AND Alborg University Energy Internet (AAU). In the past authors have focused on individual aspects of a smart city or Industry 4.0. But, the present times require the simultaneous working of both these aspects of Internet of Things. Each of the papers analysed in the literature review, address specific issues and aspects of a smart city or the industry, while our work presents a panoramic view of the architecture, individual services and the protocols necessary to form a functioning smart city while keeping in mind the key role of Industry 4.0. When a city offers a residential and industrial component then it is imperative that the needs of its citizens be kept in mind thus underlying the foundation of a smart city while processing the needs of the industry in that city. Based on the Padova Smart City, Symbio-City and Guadalajara projects, we have inferred that these have used IoT paradigm as building blocks for their smart cities. They have collected and processed data using simple techniques to check the behavior of traffic lights systems and other systems that impact the urban environment. The Symbio-City study also involves predicting the density of users in the zone and further working on the cellular service across the area.[17],[18].

III. SMART CITY

A. Air Quality Monitoring

Air quality is expressed in terms of concentration level of various pollutants. These can be carbon monoxide, sulphur dioxide, nitrogen dioxide, ozone etc. The European Environment Agency has specified threshold values for these pollutants which are as follows: 10, 350, 40 120 $\mu g/m^3$, respectively [19] Keeping in mind the alarming air quality conditions in many parts of the world, it is imperative to keep a check on the air pollutants and the citizens must be provided with healthiest paths to take while leaving their houses. Pollution is not just an issue faced outdoors but it can create problems indoor as well which can lead to nausea, and various different syndromes [20]. Multiple mobile nodes can be deployed throughout the city thus form a swarm of nodes to establish a highly communicable networks. These nodes can gather information regarding the various pollutants in the air and calculate the AQI, further this data is transmitted to end users on their mobile phones with the help of android applications hence providing them data in real time [21].

B. Noise Monitoring

Exposure to elevated noise levels for a long period of time can cause adverse effects on the human health and various other life forms. Administrative authorities have taken a number of initiatives to reduce noise pollution which include silencer on car exhausts, banning the use car horns in residential areas. Noise maps can be employed to subside the emissions and permissible noise thresholds can be set to avoid various adverse effects caused by noise. Noise measurements can be collected and analysed and the acoustic pollution can be measured. Moreover mobile and web application are made to make this data available to the end users while suggesting them ways to reduce noise. The microphones in mobile phones have been used to act as sound level meters (SLM) thus each user can collect current , average and peak data individually which is then analysed by the application. This system of data collection by the end users is based on Mobile crowd sensing (MCS) which enables each mobile node to act as a data collecting point [22].

C. Health Infrastructure

For an efficient functioning of the city the healthcare facilities and medical infrastructure has to be well up to date and state of the art equipment must be used to provide the citizens best treatments and medical support. The integration of IoT with healthcare has allowed medical services to be remotely accessed and the patients to be monitored [23] A smart city requires that its citizens are a part of the environment that supports ambient assisted living so that they can engage in activities and facilities that allow an uninterrupted lifestyle. A healthcare monitoring system for homes and hospitals is proposed in [24]. This system includes multiple sensors to record the physical vitals of the patient and doubles itself as a smart pill dispenser which is activated as per individual needs. The dispenser has been designed in a manner that reduces the chances of medicine wastage while ensuring the medicine being taken by the right patient at fixed intervals. In [25] the authors propose UDA-IoT system which is used in case of emergency. The system is used to collect, integrate and interoperate data in multiple medical applications. Kuo-hui yeh et al. depict a network-based advancement in communication systems. In this paper the author proposes a sensor network governed by IoT principles to ensure efficiency and robustness for IoT based public networks.

D. Waste Management

This is an important issue faced by all the cities worldwide as this requires not just collection but the storage and disposal system to be equally developed. IoT can be a key player in facilitating the job of connecting waste containers, waste collecting systems and the disposal process to provide optimal waste management. The authors in [26] propose an waste management system where bins are monitored by infrared sensors and as per the collective readings of the sensors optimised routes and collection plans are established. In [27] the authors propose a waste disposal system based on RFID tags. The RFID tags are installed inside the bin which interact with the RFID on the product being disposed. Based on the details gathered by the RFID tag, the disposed items are segregated into different bins. The proposed architecture is based on HTTP, CoAP & MQTT protocols in order to ensure confidentiality of data over the cloud and internet.

E. Public Transport

Public transport is an essential element of a city and the general public is bound to use this facility day-in and day-out. Worldwide people spend a considerable amount of time travelling and majority of them used public transport like shared cabs, trains and, busses. The authors in [28] propose a system that incorporates the use of sensors installed in the public transport to gather information about the route, speed, positioning of the vehicle while assisting information can be provided by the sensors in traffic lights, street cameras and sensors placed in other cars. Their proposed system incorporates the use of personal cell phones to estimate traffic conditions and potential anomalies on the road. A crowd estimation system has been proposed in [29] where the public trains can avoid over-crowding. The author suggests providing pressure sensitive flooring in train compartments to estimate the crowd density in each coach while displaying information for the travellers to adjust the crowd.

F. Traffic Control

The issue of traffic congestion forms the root cause for various other issues like fuel wastage, noise pollution and air pollution. Minimising the issue would not only decongest the roads but would enhance the quality of the environment. A system to dynamically control traffic in a city has been proposed in [30]. The authors provide a system where the authorised personnel can access and control the traffic light patterns with his/her smart phone. The pattern can be set as per the requirement and by checking the general purpose input output ports of the microcontroller. A predefined algorithm specifies patterns for each GPIO in each state. This system provides complete flexibility to the city administration and improves the traffic congestion situation.

G. Energy Management

For a city to function at its full potential it requires uninterrupted supply of energy and it is imperative to keep a record of the energy consumed in order to keep a check on the total consumption or to keep an eye on malpractices. In [31] an energy efficient framework has been provided. The authors suggest the use of light weight protocols like Extensible Messaging and Presence Protocol (XMPP), Advanced Message Queue Protocol (AMQP), Message Queue Telemetry Transport (MQTT), Constrained Application Protocol (CoAP) to reduce the energy consumption, simultaneously the paper advocates the use of energy predictive models, low power transceivers.

H. Smart Lights

A smart lightening system (SLS) is an automated system that allows remote and decentralised access to the lightening control. In order to integrate the system to IoT a multilayer architecture that includes a sensor layer, communication layer and management layer is required for efficient illumination [32] propose a system where the lights can be accessed via the internet with the help of control software. The most captivating aspect of the architecture includes the monitoring of lights to establish light patterns to maximise efficiency.

I. Smart Markets

Every city needs to provide its citizens with proper shopping centers and market to allow the sale and purchase of goods. Sale and purchase forms a strong part of the economy and facilitating the efficiency of this system will not only ease the process for the citizens but also provide support towards a strong economy. A smart shopping system has been proposed in [33] where the authors make use of RFID technology and social vectors to enable hassle free customer interaction and provide them with product recommendations. Their system allows the customer to keep a note of which store has been visited by which customer and the needs of each customer are used to match similar customers. Moreover the concept of smart carts to ease the process of shopping has been introduced in multiple forms. These automated carts provide various levels of assistance to the customer in product selection, usage check and these carts can also be used to communicate with the near buy supermarket to alert about the needs of a household.

J. Industrial Automation

Expansion of the industry leads to expansion of business and creates employment. Hence every penny invested for the development of the industry is an investment towards a better future. Nations worldwide are willing to invest in IoT to improve the industry standards. The Chinese government is willing to spend $800 million in IoT for the total physical and fundamental changeover for the industry [34] Worldwide organisations like Siemens, IBM, Amazon, Google have taken huge interest in IoT to an extent where they plan to improve the infrastructure and weed out any sort of lag in the system. IoT is being implemented in mining in order to prevent the accidents. Wireless communication, WiFi, biosensors, proximity sensors form a strong IoT based network to locate the position of miners and to detect any sort of hazardous substance being released. All these features work towards improving the safety of the miners working in a mine [35]. IoT can be used to connect all the devices on a factory floor to collect data from machines, operators, assembly lines and to use this data to optimise the process. This incorporates the uses of sensors and smart machine learning based algorithms to collect and visualise the data to provide optimal decisions.

K. Smart Logistics

The increased use of sensors and RFID tags has led to the application of IoT in logistics. This allows instant monitoring of the objects and the logistics bearer. Jianli in [36] has designed a transportation system to record the information of the cargo, the vehicle orientation in order to reduce the chances of error. The designed system uses RFID tags to keep a track of the goods, while Global GPS is deployed to monitor the position of the vessel being used to transport the goods. Finally a GSM based communication technology called as GPRS has been used to transmit all the relevant data to the network for supervision and monitoring.

TABLE I.

Service	Benefits
Air Quality Monitoring	Can be integrated with health monitoring
Noise Monitoring	An elementary feature for industry 4.0. Can provide essential health insights.
Health infrastructure	Enables fast track medical services
Waste Management	essential for city planning.
Public Transport	An essential indicator of AQI and crowd management.
Traffic Control	Enables crowd management
Energy Management	The complete infrastructure relies on power supply hence energy management allows close monitoring of essential needs.
Smart Lights	A subset of energy management and city infrastructure
Smart Markets	Enables the basis of consumer automation with smart devices
Industrial Automation	Offset to industry 4.0
Smart Logistics	An essential contributor towards industry 4.0 and smart devices.

IV. ARCHITECTURE

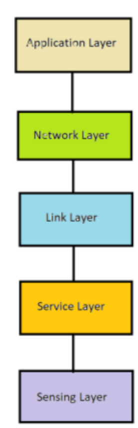

Fig. 2. Conceptual representation of the layer-wise architecture

A. *Application Layer*

The layer is responsible for customer services. This is the reason that this layer has high traffic density carried by the HTTP protocol. Due to complex nature of the protocol which inhibits its use in IoT networks an alternative protocol known as CoAP is used which transfers data over UDP [37]. This layer enables various technologies to be integrated over the network and supports computation of data collected by the sensing layer. In [38] propose an application layer which includes ID management is aimed at assigning an ID that universally identifies all the possible categories of objects. Further an owner control module is used to define the activities that are supported and how the various objects can be classified. A relationship management (RM) module is used in the network to understand the relationship between different objects. The service composition (SC) component allows the components to exchange information with each other about the functionalities of different objects in the network.

B. *Network Layer*

This layer is responsible to transmit and share data by sensor networks. Further it is used to integrate information over the different connected systems inside the network. It is expected that in a IoT ecosystem the devices will support device to device communication. Different technologies like Wi-Fi, UMTS, 5G, ZigBee are used in this layer. This layer needs to be designed in order to adjust the heterogenous networks, changing topologies of the network in order to keep the network stable [39]. The TCP/IP protocols are used for data transmission over the internet but they do not support high level of scalability and the heterogeneous nature of the IoT system [40]. The data collected from the sensing layer is handled in the network layer thus forming this layer the core of IoT technology. This allows the analysis, inquiry and segregation of data which is used to make decisions. [41].

C. *Link Layer*

The efficient transfer of data over a large geographical area requires an additional layer. There are 2 groups under this layer. The first group includes all the area network based technologies like LAN, MAN, WAN. These technologies have a high transfer rate and have low latency hence they can be termed as unconstrained. While the second group of technologies have higher latency and have power saving capabilities which includes IEEE 802.11, Bluetooth, NFC and RFID hence they are termed as constrained technologies [42].

D. *Service Layer*

It is an integrating layer in IoT which provides integration between different IoT services. The design of the service layer is application based hence this can be customized as per particular needs. The service layer designers need to provide compatible protocols and APIs for the user. The layer is responsible for identifying objects and services that may be useful for the user. Reliability is a major requirement for this layer as the relationships between different connected devices needs to be recognized to meet the service request [43].

E. *Sensing Layer*

A cluster of multiple devices equipped with sensors and actuators or RFID tags are used to collect raw data. Smart systems deployed in this layer are capable of automatically collecting data and exchanging it with the neighboring devices. The interconnection of physical nodes improves the performance of the network and allows the data to be verified. The concept of edge computing allows these nodes to have a limited computing capacity rather than relying completely on the server [44]. This layer requires digitization of data so that it can be analysed by the upper layers [45].

V. PROTOCOLS

Protocols are an integral part of any architecture that enable transmission of data as per governed rules. Each device may work on a set of protocols that be different from the neighboring devices. Each layer needs a set of protocols to interact with the adjacent layers and various sensors collect data as per different protocols.

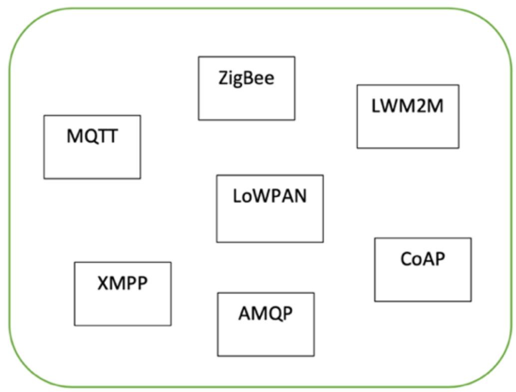

Fig. 3. Cluster of suitable protocols

A. *Constrained Application Protocol (CoAP)*

Designed by RESTful environments for low power or low capacity devices to overcome issues in HTTP CoAP is a UDP based protocol. It is designed for peer to peer communication and can be expanded for one to many communication as well. CoAP supports publish/subscribe architecture, which supports multicast communication where the publisher can transmit data to multiple subscribers [46]. CoAP constitutes of 2 layers, the first layer is called the messaging layer while the second layer is called the request/response layer. It is implemented in the application layer in IoT based architectures [47].

B. *Message Queue Telemetry (MQTT)*

It is a publish- subscribe TCP based protocol architecture by IBM. It takes up the high QoS of TCP and combines it with the one to one and one to many device support of the publish subscribe architecture. According to this protocol any source of information can broadcast its information which can be received by the subscriber and all the information being transmitted is taken care by the broker which ensures quality of service of the data [48].

C. Lightweight Machine to Machine (LwM2M)

It provides easily deployable specifications for providing machine to machine services. LWM2M provides a reusable object model to manage constrained devices and service enablement. Often it is used simultaneously with CoAP to enable device management and run diagnostics in the IoT environment [49] the combination of LWM2M with CoAP allows the management of low power devices along with wireless firmware update. Not just the reduced power consumption but LWM2M is also an efficient protocol when it comes to data consumption.

D. Low Power Wireless Personal Area Network (LoWPAN)

This is a IPv6 transporting protocol that is employed in short range communication and its use has been expanding in the internet of things. It is based on IEEE802.15.4 standard and is deployed in the datalink and physical layers. The various forms of LoWPAN used in different types of networks are simple LoWPAN, extended LoWPAN and Ad Hoc LoWPAN [50] LoWPAN allows the nodes in WSN to communicate with each other over different protocols like Bluetooth and Wi-Fi.

E. Advanced Message Queuing Protcol (AMQP)

It is a binary protocol that supports publish/subscribe model and enhances reliable communication in a secured manner. Mostly used in application layer it allows communication in message-oriented environments of the IoT. The protocol has been designed to ease out the communication between the client and middleware servers. The protocol stack has two separate layers. The functional layer is responsible for handling the message capability and the transport layer is responsible for error handling, channel multiplexing and frame rate [51].

F. Extensible Messaging and Presence Protocol (XMPP)

It is a publish/subscribe based IETF standard that allow users to communicate over the internet. It is a messaging protocol that allows users to send and receive messages. It is based on M2M communication and allows the user to gain end-to-end encryption, authentication and access control. This protocol is used in multiple environments like single chat conversation or in multi-user chat groups. It a decentralised protocol that allows real-time communication between peers. It ensures the availability of users by using presence mechanisms before allowing exchange of messages [52].

G. ZigBee

This protocol is based on IEEE 802.15.4 standard which is designed for low power networks. ZigBee is used in in personal area networks based on low cost communication or low power systems that transmit over large distances. Furthermore, it has applications in systems with low data rate and longer duration sustainable devices. The protocol stack for ZigBee contains four layer :- Application, Network, MAC and Physical Layer [53].

Conclusion

In this paper we focused on analyzing the various services that are available or can be implemented to realise the concept of a smart city. Next, we have proposed an architecture to enable smooth functioning of these services. Finally, we have reviewed various protocols that support the proposed architecture. The world has begun a revolution which is based on the Internet of Things and with each passing day new adjustable protocols and robust architectures are being standardized. The vision of a smart city thus can be implemented by keeping in mind the overall layer-wise architecture and the functioning of various protocols to support the individual layers of the architecture. A robust architecture is imperative to support the necessary services of a smart city and industry 4.0.

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