A Framework based on the Smart City Vision through Internet of Things

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Abstract

Since, in the recent years, population density has been increasing quite steadily, there is a need to provide or set-up new services and infrastructure to meet the growing demands of the rising population. This leads to the opportunity to develop smart cities int the urban areas, where city management and infrastructure are real-time accessible by the citizens and hence, planning the future road to development of the city. To achieve the Smart City vision, there can be no better way than exploiting the Internet of Things utility for the above. The Internet of Things will be able to interconnect different and heterogeneous end systems[1]. By interconnecting these heterogeneous systems, we will be able to develop a real-time access network between each sectors. In this review, I aim to present the required framework for achieving a Smart City Vision through the use of Internet of Things.

Index Terms **- smart cities, Internet of Things, network architecture, information management, cloud computing.**

1 Introduction

According to [2], it is expected that 66% of the world's population will start living in the urban areas of the world. To ensure the well-being of the people in various areas such as economical, social, environmental etc. cities need to be smart. By smart, it is to say that cities need to enabled technologically. Smart City is that city which uses information and communication technologies (ICTs) to make city services and monitoring more aware, informative, interactive and efficient [3] [4]. The smartness of a city can be calibrated, controlled and enabled by the emergent Internet of Things [5]. Internet of Things (IoT) can be described as a radical evolution in the current Internet which changes it into an ubiquitous network of heterogeneous end systems, which can be used to harvest information by sensing processes and control/actuate/command the end systems of the physical world. It also provides services for information, transfer, analytics and application.

Various enabling systems have adapted in the society so well, that the IoT is in a very evolved stage. The whole IoT sensing paradigm can be seen as Wireless sensor networks (WSNs) seamlessly integrating into the urban structure. This information now can be shared across different heterogeneous platforms or end systems. This develops a common operating picture (COP) of the city.[4]

The urbanisation of the world is speeding fast (as seen in [2]), and there is an urgent need for understanding the importance of increasing the efficiency of city management systems. Currently, only a few municipalities have developed a system which allows real-time information handling. Normally, municipalities employ a common strategy - data collection, offline analysis and action [4]. This process has become a redundant one. The data collection process is very costly and difficult to do it time-to-time. This is where IoT can help. A large-scale, heterogeneous platform based IoT structure can reduce the time and cost factors significantly in data collection. Further, it could also analyze them for action. This will increase the efficiency of city management and will increase the social, economical, and environmental well-being of the citizens.

2 Motivation for a Smart City, from perspective of City Councils

World leading city councils have, until now, provided its citizens the best and efficient services to their citizens by the use of various technology systems. Usually, these systems employ sensors, data collection and a computer at a work station which analyzes the data. This method has been efficient only until now. Now, we need more efficient systems for city infrastructure monitoring. A fully integrated system of systems containing sensing, storage, analytics, and interpretation is required [4]. The new system requires to provide plug-and-play services, data collection in a safe and secure manner, quality of service (QoS), and flexibility to change the fundamentals of systems when needed. Software developers will have a task in hand to develop a management software to handle such a large data.

Various city councils manage large volumes of data collection even today. But mostly the process remains hidden from the third-party interest groups. So, it has now become increasingly important to develop a sharing platform, so that the data can be shared with different service providers in a city or an area. This is possible by a successful IoT urban infrastructure implementation. A smart city IoT capability includes the effect on citizens, transport and services. A number of areas can utilise the smart city IoT structure, such as, service operation in health services, city planning, traffic management, parking management, environment monitoring, etc. [4]

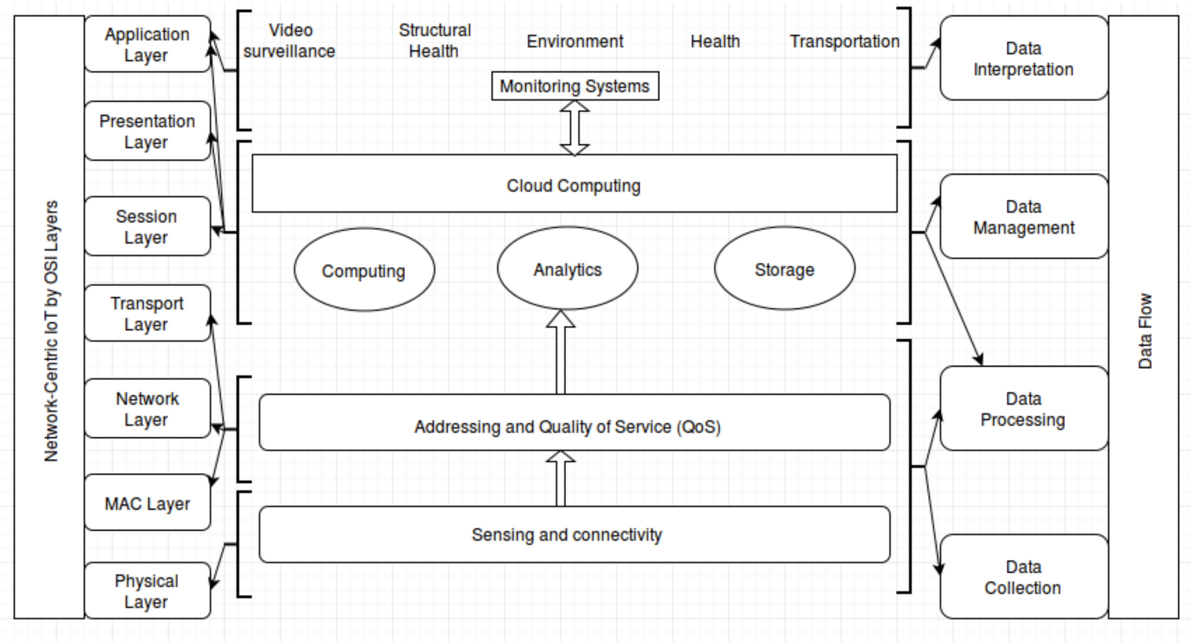

Figure 1: IoT infrastructure using the three domains - Communications, Management and Computations (adapted from [4]) (Image created using `http://draw.io`)

3 Discussing the IoT Infrastructure for the Smart City

There are three main requirements for smart city development and deployment - communications, management and computation. Corresponding to these requirements, we have three different IoT domains : Network-centric IoT, Cloud-centric IoT, and Data-centric IoT.

3.1 Network-Centric IoT

For the IoT vision to be successful, we will have to focus on the development of an infrastructure, which is based on both Internet and smart objects[6]. For this, the networking will be a fundamental issue. To find a solution for this issue, we move to the OSI or Open Systems Interconnection model of networking (see Fig 1). The above model partitions a communication system into abstraction layers. The original version of the model defined seven layers as shown in Fig 1.[7]

The seven layers of the OSI model are as follows : Physical, MAC (or Data Link), Network, Transport, Session, Presentation and Application - (order in increasing access of layers to the end-users). These layers are defined in such a way that a layer serves the layer above it and is served by the layer below it [7].

1. *Physical Layer*: In the OSI model, the physical layer (or layer 1) is the lowest layer. This layer consists of the elementary technologies and hardware re-

quired for the networking.

2. *Data Link Layer (the parent layer of MAC Layer)*: The data link layer controls the network gain access to medium and permissions to the network and regulates the networking model by following the pre-defined networking protocols. It detects and resolves the possible errors in the physical layer. When two or more devices simultaneously attempt to use a medium, frame-collision occur.The MAC layer resolves this by regulating the protocols. The MAC Layer has a similar sister layer within the Data Link Layer, known as LLC Layer. [8]

3. *Network Layer*: The Network Layer is responsible for designating the destination addresses to the packets which are passed on by the Data Link Layer. This also includes the addresses the intermediate routers. This layer is like the provider of the path-map to the network packets.

4. *Transport Layer*: The Transport Layer is responsible for delivering data packets to the appropriate addressed location or end-systems and also the appropriate application process on the host computers. This involves statistical multiplexing of data from different application processes, i.e. forming data packets, and adding source and destination port numbers in the header of each transport layer data packet. Together with the source and destination IP address, the port numbers constitutes a network socket, i.e. an identification address of the process-to-process communication.[8]

5. *Session Layer*: The session layers controls the connections between the end-users' application processes. It controls the time-window frame given to the application processes to interact between themselves.

6. *Presentation Layer*: The Presentation Layer ensures the readability of the information from one computer to another. It essentially acts as a translator for both the end-systems.

7. *Application Layer*: The application layer is basically the user interface. The OSI model defines the application layer as the user interface responsible for displaying received information to the user.[8]

To implement the OSI model's strategy, we need three fundamental mechanisms :

- *Sensing Paradigm*: In the current technological society, there are three sensing paradigms : RFID, WSN and crowd sourcing.
  RFID (or Radio Frequency Identification) uses electromagnetic signals to automatically identify objects to which tags are attached. [4] RFID systems have classifications according to their readers and tags. The best one for the IoT structure is the Active Reader Passive Tag (ARPT) system. In this system, the object has a passive RFID tag (not battery powered), which uses power from the active reader's interrogation signals. This way, it also communicates to the reader. This way,

Network Architecture.jpg

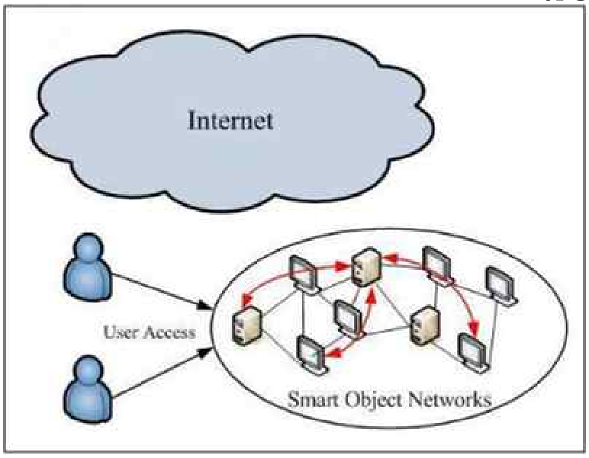

Figure 2: Autonomous Smart Object Network Architecture (adapted from [4]) (Image reference : `www.c-sharpcorner.com`)

Network Architecture.jpg

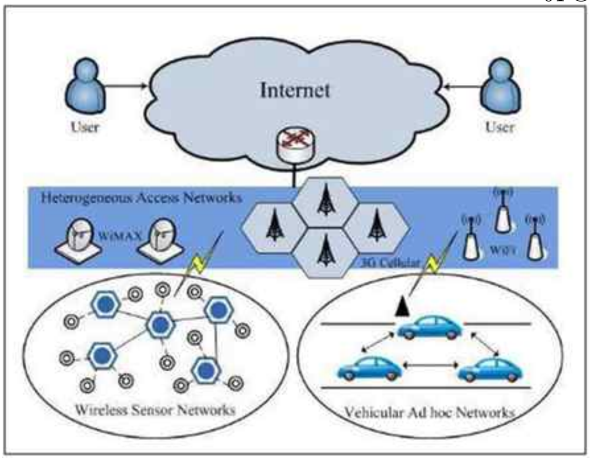

Figure 3: Ubiquitous Smart Object Network Architecture (adapted from [4]) (Image reference : `www.c-sharpcorner.com`)

the technology can be used in various supermarkets, transportation systems, etc.[4][9]
WSN (or Wireless sensor networks) are spatially distributed autonomous sensors which monitor constraints of physical and environmental kind, and cooperatively pass the data through a chain to the main network location (or control server). This enables the IoT devices to collect and analyze vital information.[4][10][11]

- *Addressing Scheme*: Uniqueness of a device is very essential in this IoT architecture. This helps in identifying and controlling the device remotely.[4] Currently, the addressing scheme used by the devices is IPv4. But IPv4 is going to get exhausted soon. We need another alternative. The option is provided the proposed IPv6. The increase in the address space in IPv6 ensures that every device is assigned an address. Also, its architecture is interoperable across devices and communication technologies, evolving and versatile while still stable, scalable, manageable, and simple enough that a resource-constrained smart object can easily run it.[12] Though, this system might provide the required addressing problem, we still face the difficulty of setting up the interface between Internet and the smart objects.

- *Connectivity Model*: The WSN community initially rejected the IP architecture systems[13], but then after seeing the benefits of the layered architecture's modularity and sepera-

tion of concerns, they finally accepted it.[14][15] Many IP-based systems have now emerged in the WSN category having the interoperability between the other end systems.[16]
There are two connectivity models, based on the IP architecture - autonomous (see Fig: 2) and ubiquitous (see Fig: 3) smart object networks.

3.2 Cloud-Centric IoT

As shown in Fig 1, we see the cloud as a central structure to the whole architecture. The vision in such a way that information is collected through the sensing paradigms and then stored into the cloud, where it can be universally accessed. Of course, there can be a few security measures to protect sensitive data. Also, the Cloud provides a unique low cost measure for an effective IoT business model. The sensing service providers will join the network by giving their data, analytics will provide their software tools. The Cloud integrates all facets of ubiquitous computing by providing scalable storage and computational resources to build new businesses.[17]

3.3 Data-Centric IoT

The IoT architecture will handle a huge amount of data in the process of analyzing and storing. Thus, we require a Data-Centric IoT, which will include collecton, storage, processing and visualisation of the data.

1. *Data Collection*: Data needs to be efficiently collected by sensing paradigms. It has various implications on different sectors, which accesses the data from the cloud. Thus, there is a need of generalised framework for data collection that could exploit the data whenever required. There are still a few issues, which needs to be resolved in the general framework of Data Collection. Sensing paradigms, like RFID and WSN, give data which can be accounted as true or authentic. But data from participatory sensing, which has been a novel start for data collection, still needs to be authenticated. This is where people needs to take the responsibility.[18]

2. *Data Processing and Management*: The data collected from the sensing paradigms is often in a raw form. Thus, there is a need of collecting the vital information from the raw data. Different development of algorithms need to take place, so that computers can extract the required information and provide it to the user. With this, also comes the responsibility to protect and manage the information. Algorithms will be needed to encrypt and decrypt information, so that the information does not go into the wrong hands. The information can be masked in such a way, that different encryption programmes can be used for different level of security of information. Information also needs to be stored systematically. A new address system needs development so that servers can be easily accessible by the address system.[19]

3. *Data Visualization*: The next step of

the data flow system is to visualize the information to the citizens of the smart city. This means, converting the information stored into a presentable form and display it to the viewers. Currently, there a many new technologies for this, for e.g., 3D viewer, AMOLED screens, LED, LCD, etc.

4 Design of Network Architecture

We will now design and construct different IoT structure for different application systems.
Generally, many city councils decide one of the two of the following approaches to set up a new system in their city - 1) an evolutionary approach and 2) a clean-slate approach.[20] The evolutionary approach corresponds to the actions taken to improve the existing architecture of the system, such that it meets the conditions of the new architecture system. On the other side, the clean slate approach corresponds to removing the old architecture, and setting up the new architecture. For many years, researchers, engineers, etc. have debated upon the two. Finally, it is the situations and circumstances which decides the approach to be taken.[21] For example, take the example of India. An evolutionary approach would be preferable in big metro cities like Delhi, Mumbai, Chennai, etc., but the clean-slate approach would be efficient and useful for mid-size cities.
There are four common network architectures that are applied to different smart city domains - autonomous network architecture, ubiquitous network architecture, application-layer overlay network, and service oriented network architecture.

1. **Autonomous Network Architecture**

   (a) *Architecture Description*: Autonomous Networks are isolated/semi-isolated (it depends on the system, whether the user wants access or not) from the Internet. If it is semi-isolated, the Internet connection is provided through a gateway, if required. As discussed earlier, the network uses the IP architecture for addressing issue. This provides the architecture more scalability and flexibility.[4] Figure 2 shows the architecture description.

   (b) *Application-Attendance system in any office, school, college*: RFID tags shall be provided to the employees/students for identification. As soon as the reader picks up the data from their tags, it sends the data into the local servers. The local servers can then send the data to the concerned official for analyzing the data. The readers can be placed at the gates of the offices/classrooms.

   (c) *QoS*: The QoS in this system is solely application-dependent and at a local reach. For the above example, network issues, authentication issues, sensor coverage might be the major concerns.

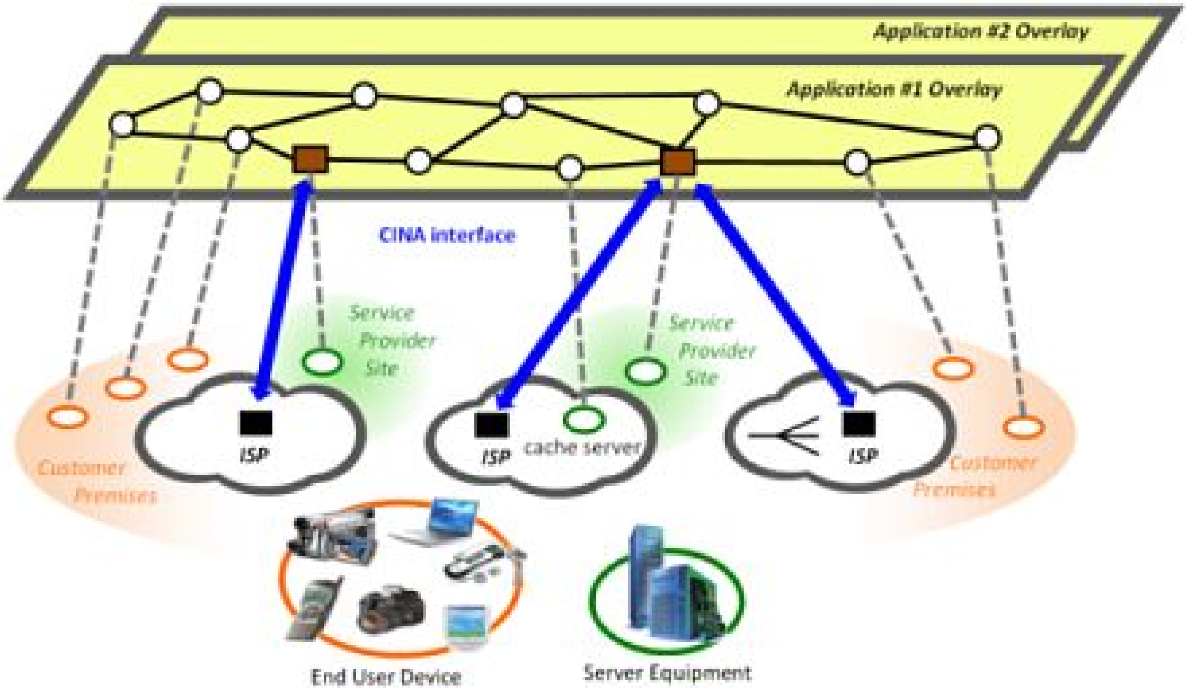

Figure 4: Application-Layer Overlay Network Structure (Image reference: `www.envision-project.org`

2. **Ubiquitous Network Architecture**

   (a) *Architecture Description*: The end systems/smart objects in this architecture have access to the Internet. Using an Internet gateway, setup by the service provider, authorized users have access to the information on the Internet either directly or by intermediate servers. There are main local servers in the architecture, which acts as a sink for the data collection from each smart object.[4] The features of the architecture are:

      i. *Multitier*: The network architecture is hierarchical, comprised of both multi-access networks and wireless multi-hop networks.[22]

      ii. *Multiradio*: The network architecture is mountable and integrable over different operator environment. These operator environment could be WLAN, WiMAX, macro-cellular, femto-cellular, or even ad-hoc. This architecture is versatile over all of them.

   (b) *Application-College Intranet and Internet System*: The college Intranet collects vital information on the college events and displays them onto a website which is linked to a server. The server has all the important information regarding the college forms, students' details, contacts, etc. It is important to give this information to the student. It will be given on a platform independent of the Internet. The end systems connect to the platform and share and access the information. The end systems can vary from a laptop to a smart phone, depending on the platform the college administration chosen. The most popular platform in this case is WLAN access, but it finally depends on the administration. This way, the college information is secured onto the platform and can be only viewed by the college students. Also, with this architecture, the data can also be restricted for user access. For example, the students can be restricted access to data corresponding to the administrative information, etc.

(c) *QoS*: The QoS part is a very stringent division in this architecture. The architecture demands a multi-hop access network. Thus, the difficulty of assuring QoS increases. There may be major concerns such as authentication issue, gateway issues, access rights issues, etc., but the most fundamental would be the Primary Layer issues like connectivity, coverage, etc.

3. **Application-Layer Overlay Network Architecture**

(a) *Architecture Description*: This architecture follows a structure in which many end systems are spread out and linked to one server or the sink of the information. Now, because of one main server architecture, there will be congestion near the sink. To resolve this congestion, we will be using the network visualization technology[24]. In this, the connections are divided into different overlay networks. Different segments of network are laid on top of one another. Nodes in this network are connected by virtual or logic links, each of which corresponds to a path.

(b) *Application-Environmental Monitoring*: For environmental monitoring, a large number of sensors would be required. The environmental sensors will need to be fitted everywhere in the environment to collect data such as weather, humidity levels, constituent gas levels (like nitrogen, oxygen, etc.). All this data will then be allocated in a chain of main and subordinate servers, where they will be analysed and passed on higher into the chain for the final reports. These analysis will be quite helpful in the society as this will include microclimate management, air quality sensing, environmental health and safety hazards, etc.

(c) *QoS*: The data traffic for environmental monitoring is elastic in

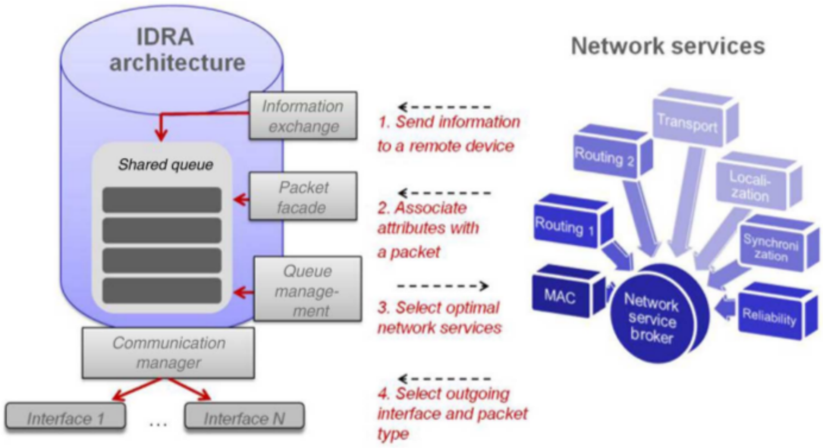

Figure 5: IDRA Architecture (Adapted from [4]) (Image Reference : [23])

nature. There might be delays and packet losses, which are tolerable to some extent. But there might also be fundamental Physical Layer issues which might hurt the working of the architecture.[4]

4. **Service-Oriented Network Architecture**

   (a) *Architecture Description*: We have been discussing all over the article about interconnecting heterogeneous end systems, which often contains a variety of sub-networks adopting different communication technologies[4]. In simple language, to achieve the above, we need to translate various languages of the sub-networks in the language of the other sub-network, so that they could communicate. And we have to do this process whenever any two different end systems try to connect each other. This would be physically impossible to do in the IoT architecture. To remedy this situation, we turn towards a new architecture named Information Driven Architecture or the IDRA.[23]
   The IDRA is actually a clean-slate approach, which aims to implement different sub-networks of end systems into a standardised technologically independent component called network service. It is simply creating an universal language which every end system will be able to understand. A special packet or metadata will be maintained by the IDRA system, which will contain the required information on the device. This could be then used to communicate with other device using it's metadata maintained by the same architecture.

(b) *Application-The Cisco®SONA Architecture*: Cisco has created an architecture which provides unified communication for IT managers to have their network work as a platform. It integrates all communication and collaboration tools as a new composite application providing the tools at their best advantage. More information : `www.cisco.com`.[25]

(c) *QoS*: The degradation in bandwidth may cause serious packet drop and severe performance degradation. To ensure the QoS of inelastic traffic, rate control and admission control is hence necessary to guarantee that they will receive sufficient bandwidth, at least greater than the threshold.[4]

As we have seen here, the four network architectures combine to form the whole Smart City IoT architecture. Different architectures can be used for different applications. And thus, these new way of implementing the applications give rise to the era of Smart City.

5 Conclusion

With the current pace of urbanisation, creating smart cities have become imperative. As seen, the IoT infrastructure makes the smart city more technology enabled and helps keep it's management, services, etc on track. With the architecture description in this paper, a plan can be surely created to develop a comprehensive Smart City. The discussed technologies are close to being standardised and companies are actively participating in production of devices compatible to the architectures (like, Cisco's SONA architecture and many more).

We must understand that the technologies of IoT have reached enough maturation level, that they can be exploited on a large scale project, such as building a Smart City. With the advent of IPv6, protocol issues of the existing IPv4 will be resolved.

Though the vision seems to be extraordinary, there are numerous hurdles like energy efficiency, QoS, security of information, connectivity and coverage issues, analysis methods and algorithms, etc. We must also take the role of civic bodies into this vision. Their role will be a pivotal one, that could change the architecture of the city. The first issue would be for them to choose the right approach - clean-slate or the evolutionary approach. they must choose the right option because it is a question of ensuring provision of essential services and quality of life for city inhabitants.

The results of Smart City vision would be glorious. The city's traffic management would be never haphazard or uncontrollable. The parking problem in the society would be resolved. The environment factors can be monitored and studied deeply. The health of important structures like bridges, monuments, etc. could be monitored and disasters could be avoided. Crime fighting would be easier with video surveillance around the city. Money transactions would be a lot easier with digital currency.

Though, we must not neglect the negative effects of Smart City vision. Since, these technologies are connected to the Internet (directly or indirectly), they can be exploited by hackers and cyber crime. Debates have been ensued over this topic for a very long time. We must try to resolve this quickly and get counter-measure for such activities.

Concluding, I would like to say that the Smart City vision is the next very important step for every country. If countries cannot implement these steps in the urban cities with an evolutionary approach, then they must try to implement it on rural areas with a clean-slate approach.

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