Smart WSN-based Ubiquitous Architecture for Smart Cities

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***Abstract*—In the quest for better quality of life and living standards, people living in rural areas are expected to move to urban locales. As this trend continues, more than half of world's population is expected to make cities their place of dwelling. To meet this massive influx of rural masses into urban areas, the cities world over need to equip themselves with robust infrastructure that provides necessary amenities like, adequate & clean power, hygienic water in sufficient quantities and accommodation that makes optimum use of resources in a sustainable manner. Based on these requirements, a host of applications like, smart power generation & distribution, smart traffic management, smart waste management & utilization, smart governance, etc., are being developed. The paper discusses few research issues and challenges related to the development of IT infrastructure for smart cities. Research efforts in this direction, however, appear to be application centric. Not much attention has been given to develop an IT based holistic infrastructural framework for smart cities. To this end, we develop a conceptual architecture: Smart WSN-based Infrastructural Framework for smart Transactions (SWIFT) that provides a ubiquitous platform for seamless interaction of various smart objects, devices and systems. In this paper, we introduce the SWIFT architecture and discuss issues related to its implementation.**

Keywords—architecture; pervasive; smart cities; ubiquitous computing

I. INTRODUCTION

Global smart city market is poised to grow at more than 14%, and is expected to reach over $1.3 trillion by 2019 [1]. The Indian government too has launched the National Smart Cities mission with an outlay of $160 billion in the next five years to develop 100 smart cities. Under this mission, the Indian government plans to enhance the living standards of urban populace by providing them smart, clean and sustainable environs. The prime focus of this initiative is on providing core infrastructure services like adequate and clean energy, water supply, sanitation, waste management, efficient urban mobility & public transportation and robust IT connectivity. The allocated outlay is aimed to promote the adoption of smart technologies and smart platform architectures for efficient use of resources, assets and infrastructure. Huge investment opportunities galore for R&D related to development of smart devices and architectures for establishing smart IT backbone to handle the infrastructural demand of smart cities. A comprehensive understanding of the infrastructural requirements, however, is necessary for the design of platform architecture to facilitate smart transactions. The paper discusses and analyses various requirements necessary for providing smart solutions to smart cities.

A city may be called 'smart' when investments in human & social capital and modern information & communication infrastructure, fuel sustainable economic growth for better quality of life, through smart management of natural resources and participatory governance [2]. Due to the overwhelming process of urbanisation, cities are expected to use most of the resources available like power, water and fuel, and also leave behind large carbon footprints and toxic wastes. Therefore, for sustainable urban development, a smart city needs to be designed with the objective of providing comfortable and livable conditions by inhibiting the generation of green house gases through *smart power* and *smart traffic* management; zero discharge of toxic waste through atom efficient, zero discharge processes; generation of *smart waste* that is either fully recycled or converted into smart energy generation in a sustained manner.

One of the foremost requirements is the participation of citizens in prioritising and planning urban interventions, *i.e.* smart people. In addition to their role as *nettizens*, smart people play a major role as human sensors, perceivers & interpreters, and act as smart data feeds to enable decision & control at the apex level. The paper highlights smart IT based interventions such as: smart infrastructure, smart security & surveillance, smart energy, smart waste, smart traffic, smart communities, smart commerce, smart people etc., and the underlying research challenges.

Central to the smart IT backbone to facilitate the above, is the architecture to support smart requirements of smart cities. To this end, we develop the conceptual architecture: **Smart WSN-based Infrastructural Framework for smart Transactions** (**SWIFT**) - a three-tier pyramidal architecture, which provides a ubiquitous platform to facilitate transactions across various smart objects. The bottom-most layer of SWIFT architecture is the Smart Wireless Sensor Networks (S-WSN) layer, which comprises various sensors to monitor environment, traffic, domestic utilities (power, water, LPG), security & surveillance etc. These sensors communicate their information to nearby smart cluster heads (SCH), which are usually at one-hop distance. The SCHs

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relay the information received from their cluster nodes to the next higher layer for further processing. The second layer, **Smart WIreless based Pervasive Edifice** (**SWIPE**) is the heart of **SWIFT** architecture, which comprises several Smart Fusion Nodes (SFN) that pervade the entire city, and acts as the edifice on which SWIFT architecture is built. SFNs act as data classifiers and perform data fusion to draw meaningful interpretation of the sensed data for query processing and other related services. They are strategically placed at various locations in the city to collect information from S-WSN layer to facilitate ubiquitous computing. Smart Decision & Control Enabler (SDCE) is the apex layer that provides a host of services to all smart objects in the city based on data provided by SWIPE. The paper introduces the proposed SWIFT architecture and describes its functions with illustrative examples.

The rest of the paper is organized as follows. Section II provides an overview of smart cities and a brief on related research. Few research issues and challenges specific to smart cities are covered in Section III. Section IV introduces the conceptual three-tier SWIFT architecture developed to handle challenges specific to smart cities. Section V describes conceptual implementation of SWIFT architecture with illustrative examples. Section VI discusses the adaptability of SWIFT architecture in meeting the triple bottom line requirement for sustainable development of smart cities. Sections VII concludes the paper.

II. Infrastructural Requirement for Smart Cities

A. An Overview of Smart Cities

With better employment opportunities and living conditions, urban locales have been attracting rural population to their fold. The clamor for living in cities is expected to grow at a rapid pace, and in the next ten years more than half of world population will be living in cities. To avoid congestion that could arise due to this massive influx of rural populace into urban areas, countries world over are devising innovative programs to develop infrastructure that makes optimum and smart use of scarce resources. However, to address the inherent challenges, a paradigm shift is necessary in the way the infrastructural requirements for smart cites are identified, designed, conceived and implemented. Foremost among the requirements for smart cities is the IT infrastructure that is *pervasive* to cover the entire city; *ubiquitous* to provide 24x7 services; *reliable* to tolerate faults and provide QoS; *flexible* to platform different types of devices & systems; *scalable* to accommodate city expansion; *adaptable* to embrace newer technologies, regulations and policies; and more importantly, *versatile* to handle the vagaries of human kind and their never ending quest for better living conditions.

Despite the euphoria being created about the emergence of smart cities, a unilateral definition of smart city is still on the anvil. While some definitions centre on information & communication technology (ICT) as the quintessential driver and enabler for smartness, others base their definition on socio-economic impact, good governance and multi-stakeholder partnership to enhance sustainability and quality of life in urban areas. However, in all discussions, debates and deliberations on objectives, functions and the values that smart cities bring forth to the public, there appears to be broad consensus on three key enablers, smart people, smart governance and smart infrastructure. Based on this premise, smart city may be defined as: 'a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership' [3]. In this context, Smart Cities emerge not just as an innovative modus operandi for future urban living, but as a key strategy element to address issues related to poverty and unemployment and provide clean and green environs to the city dwellers, who are the prime stake holders of smart cities. The three enablers are driven by human capital, social capital and public & private capital respectively. The functions of the three key enablers and the applications where they are utilized are summarized in Fig.1.

B. Background Literature

The concept of digital cities was in vogue in the mid nineties and several attempts were made to modernize the cities through digital infrastructure. However, these concepts and the subsequent developmental work could not take off, as the initiatives were mainly related to the physical capital. The role of *non-techie* citizens and the government as a facilitator for e-governance was largely disregarded.

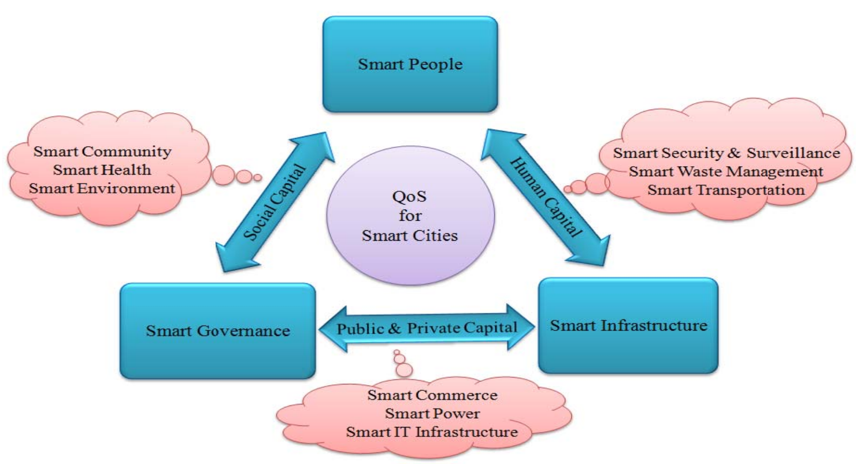

Fig. 1. Key enablers and drivers for providing QoS for Smart Cities.

Few such examples were analyzed and presented in [4]. The paper presents a case for developing new technological infrastructure in cities while advocating judicious investments in human and social capitals in addition to physical capital.

For making best use of limited resources like power and water, smart cities must be designed to conserve them. Smart buildings need to be designed that make that use of sunlight to offset a part of power load on the grid, and capture rainwater for harvesting. Intelligent monitoring and control systems must be designed to monitor buildings, power grids, traffic lighting, etc., to ensure optimum use of resources. However, ubiquitous sensing which is necessary to realize these objectives poses numerous challenges. An overview of the state of art in sensing mechanism to monitor smart cities along with few technological challenges is presented in [5].

Moving objects in a city, like humans and automobiles can provide trace data about their position and important information about their surroundings. The prevalence of GPS and such other devices on cell phones and vehicles makes it easier to trace the movement of these objects. A *trace*, which captures temporal sequence of spatial points with their timestamps, may be used to extract and mine information related to traffic, human activity, environment, etc. This information can be used for traffic management, transportation, urban planning, public health, public security, commerce, etc. A general framework for obtaining the trace data and mining information is presented in [4].

Collaborative innovation involving interactions within scientific communities across various knowledge fields, leads to new products. The role of communities and networks as fundamental conditions of innovation is discussed in [6]. The Internet of Things (IoT) is expected to substantially support the IT backbone and infrastructure of smart cities. A scheme that deploys several hundreds of sensors in a cloud to provide IoT services is presented in [7]. The work discusses various commercial cloud-assisted remote sensing (CARS) platforms and highlights their capabilities.

As the sensors keep generating huge amounts of data, the distribution of context in relation to sensor data for deriving coherent and cogent information, plays critical role. Context-aware computing has proven to be successful in understanding sensor data. A survey of various context aware approaches from an IoT perspective is discussed in [8]. Due to the deployment of myriad sensors along with various heterogeneous devices and systems, and due to the unreliable nature of some of the objects, the QoS rendered to the citizens may be severely hampered. To address this issue, cognitive management framework for IoT is proposed in [9]. Intelligent and autonomous executions of various applications are facilitated by mapping *cognition* and *proximity* with relevant objects for the application.

A case study on the success of first smart city in Greece is presented in [10]. The vision of involving local citizens in city development plans and motivating them to participate in decision making process has paid rich dividends, and the city of Trikalla consistently ranks among the top cities in the world. Realizing this, the Government of India plans to identify cities with a healthy percentage of net savvy people, and convert them into smart cities. The candidate cities also need to have a proven track record in terms better city planning, environment monitoring, transparency, social equity measures and financial stability to be considered for their upgradation as smart cities.

Further survey of literature on smart cites reveals that research towards the development of a ubiquitous IT infrastructure platform for smart cities is adhoc and still at a nascent stage. It can be observed that research on developing a comprehensive smart infrastructural IT framework that provides a platform for various sensing devices and smart objects to seamlessly interact is yet to be initiated. To this end, we introduce a conceptual architecture named SWIFT, a platform IT architecture for smart cities.

III. RESEARCH ISSUES AND CHALLENGES

Central to the concept of smart cities is the creation and connection of human & social capitals backed by good IT infrastructure, for generating sustainable economic development with better living standards to the people.To meet this, a smart city needs to possess smart homes, smart buildings, smart energy management, intelligent transportation, smart surveillance & security, etc. Based on this premise, the basic research issues and challenges are in creating enabling technologies for the following:

- Smart Economy & Commerce
- Smart Environment
- Smart People
- Smart Governance
- Smart Living and Smart Communities
- Smart Energy, Water and Amenities
- Smart Traffic & Transportation
- Smart Security & Surveillance
- Smart Waste Recycle & Management

Research is now centered on providing QoS for the above applications. One of the first steps towards becoming smart is to create a rich digital environment of broadband services. This involves establishment of hybrid broadband infrastructure with optical fiber for high bandwidth and wireless networks for pervasive internet services to support cloud computing, IoT, open data, future media and other emerging communication technologies. By bringing about standardization of applications, these technologies can assure economies of scale in infrastructure, which can significantly bring down the developmental costs, while accelerating the learning curve for operating smart cities.

To sustain the innovation ecosystem, the use of technologies, like content and context fusion, location-based content, multi-sensory environments, augmented reality applications, open and federated platforms for content storage and distribution, may be explored.

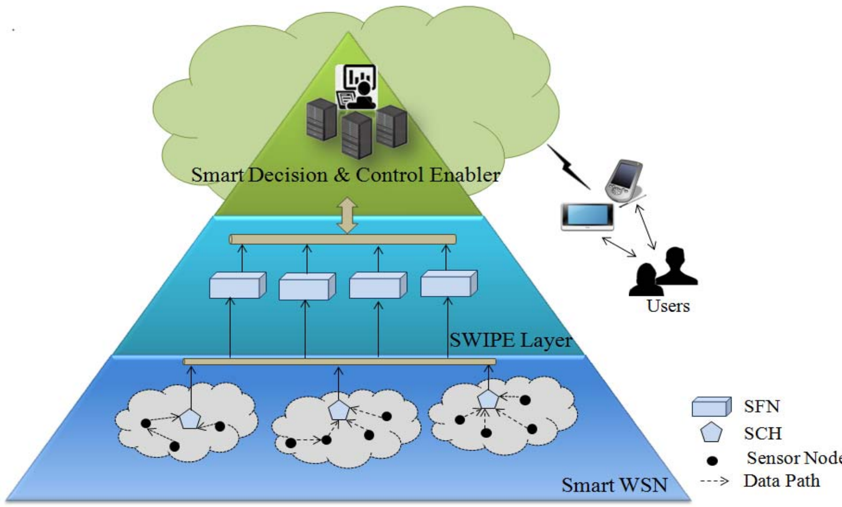

Fig. 2. SWIFT architecture.

IV. SWIFT Architecture

Research in smart city infrastructure has largely focused on providing quality service to a host of applications. The research in this direction is either, application specific or technology specific. Whilst it is important to focus on providing better applications and technologies, it is equally important to develop platform architectures where the advances in these technologies can freely interact. This is more so, in urban areas where the citizens use different types of devices in a market that thrives on heterogeneity. In order to provide a platform where different devices and objects can seamlessly interact for synergistic results, we introduce an infrastructural architecture named "**S**mart **W**SN-based **I**nfrastructural **F**ramework for smart **T**ransactions" (**SWIFT**) architecture for smart cities.

SWIFT is a three-tiered architecture, with Smart Wireless Sensor Network (S-WSN) layer forming the base. The second layer "**S**mart **Wi**reless-based **P**ervasive **E**difice" (SWIPE), resides on the S-WSN layer. The third is the apex layer, "**S**mart **D**ecision & **C**ontrol **E**nabler" (SDCE). A schematic of SWIFT architecture is shown in Fig. 2.

The S-WSN layer acts as the sensory organ of the SWIFT architecture. Wireless sensors nodes are deployed at various locations in the city, to monitor climatic conditions, environment, pollution, security, traffic, etc. The SWIPE layer is the heart and soul of SWIFT architecture, where bulk of the processing is performed by a host of Smart Fusion Nodes (SFNs). The SFNs are placed at strategic locations in the city to collect and process the data received from S-WSN layer. The data processed by the SWIPE layer is put on SDCE cloud, which provides a host of services to the smart city dwellers. Based on data generated by SWIPE layer, SDCE is empowered to actuate necessary controls related to smart services such as, security & surveillance, power & utilities, traffic management, etc. The citizens too can land on the cloud for various queries related to these services. The three layers of SWIFT are described in greater detail below.

A. Smart WSN Layer

The Smart WSN (S-WSN) layer consists of several hundreds of physically dispersed wireless sensor nodes that sense a phenomenon of interest and report the data for further analysis. The sensor nodes are usually low-cost stand-alone types, with limited battery power, and are not capable of transmitting the sensed data to long distances. To get over this limitation, Smart Cluster Heads (SCHs) are deployed at various locations in the city to collect and aggregate data from nearby sensor nodes. SCHs that pervade the city, are high-end sensor nodes with good Wi-Fi capability and battery back-up. The sensor nodes group themselves into clusters and relay their sensed data to a closely located SCH. In addition to sensed data, the nodes transmit their node ID and battery status to the SCH. The SCHs are capable of taking low-end, but nevertheless important decisions like raising an alarm, generating emergency actuation signals etc. After aggregating and processing the data, the SCHs transmit the information to nearby Smart Fusion Nodes (SFN) in the SWIPE layer. A schematic featuring the functional components of SCH is given in Fig. 3.

SCHs are conveniently located close to their cluster nodes, on light posts, nearby buildings, or any such location where they can be powered without much difficulty. Such deployment facilitates acquisition of real-time data related to various physical and social phenomena and paves a way to create contextual information. Contextual information helps in drawing locality-wise inferences, which can be used in applications where the systems need to adapt themselves to the changing environments.

The *Contextual Interpreter* in the SCH validates the context by collecting data (sensed and context information) from multiple sources and separates the composite signal

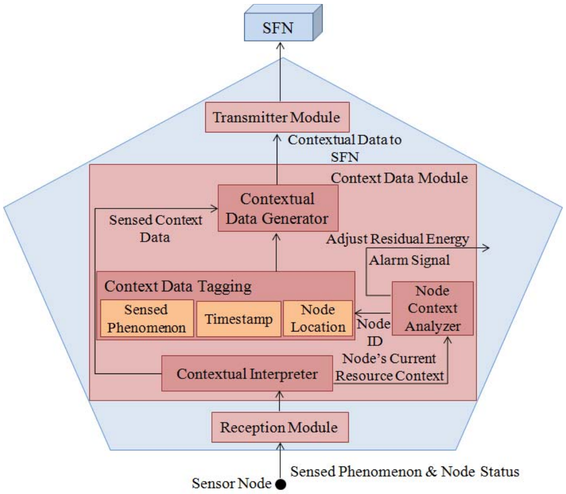

Fig. 3. Smart Cluster Head (SCH).

received into its constituent signals, viz., node ID and sensed data. Based on the node ID information supplied by the *Node Context Analyzer*, the *Context Data Tagging* unit prepares context tags: 'Sensed Phenomena', 'Timestamp', and 'Node Location', and passes these tags to the *Contextual Data Generator*. The *Node Context Analyzer* also analyzes node status (such as battery level), and if deemed necessary generates alert messages and alarms for troubleshooting. The *Contextual Data Generator*, on receiving the sensed data along with appropriate context data tags, generates primary context information which is then made available to SFNs in the SWIPE layer for further processing.

The wireless sensor nodes of the S-WSN layer, monitor temperature, humidity, rainfall, atmospheric pressure, wind velocity, etc., to capture the climatic behavior of the city. For example, to monitor pollution, sensor nodes that monitor CO_2, NO_x, SO_x, SPM and release of toxic gases are deployed at all vulnerable locations. Similarly, sensors are deployed at pertinent locations to monitor various phenomena for applications in smart traffic management, smart security & surveillance, smart power generation & distribution, smart waste management, etc.

B. *SWIPE Layer*

The **S**mart **Wi**reless-based **P**ervasive **E**difice (SWIPE) layer is the platform on which different objects and devices, whether smart, intelligent or dumb, can interact to process, share, or feed information. SWIPE layer is the edifice on which the entire SWIFT architecture is built. SWIPE being built as a platform architecture, has the potential to house any technology whether primitive or advanced in nature. It features a self evolving mechanism with good learning features to be adaptive and flexible to changes in applications and technology.

The SWIPE layer comprises several Smart Fusion Nodes (SFN) located strategically at various locations in the city. The SFNs have unlimited power, and may be conveniently placed on traffic signals, buildings, structures, etc. The SFNs may also be powered by solar panels or other such power supply units. The SFNs collect or elicit information from neighboring SCH, smart meters, and other smart devices. The devices and applications can communicate with SFNs through 802.11 or a wired Ethernet. The functional components of SFN are shown in Fig. 4.

The SFN has several processing elements (PEs) that have good processing capabilities. Each PE has *Data Fusion Engine* and *Decision Logic* unit to perform various process operations, and are particularly useful in performing data fusion operation. Data fusion operation involves processing of data received from multiple sensory data sources, to draw meaningful and accurate inferences about the phenomenon being monitored.

The SFN on receiving the primary context information from SCHs or any other smart devices, performs data classification. The *Intelligent Router* placed in the *Primary Context Data Classifier & Router* module of the SFN classifies the data and routes it to an appropriate PE for *dynamic* data fusion operation. For example, let an SFN placed at traffic signals be fed with tagged information related to traffic data from various SCHs. Based on the context derived, the *Intelligent Router* determines the nature of operation to be performed on data received from the SCHs (such as traffic density, direction, flow, etc.), and identifies a PE for performing data fusion operation. The *Intelligent Router* then routes all incoming data related to traffic to this PE. The *Data Fusion Engine* fuses this data to provide location-specific traffic information. The *Decision Logic* unit assists in taking appropriate decisions like traffic re-routing, etc., based on inferences drawn from fused traffic data.

While the prime objective of the *Intelligent Router* is to route the incoming data to facilitate data fusion operation, the router is also capable of performing operations related to equitable distribution of load amongst the PEs, if required. To enhance reliability, the *Intelligent Router* offers the following built-in fault-tolerance features in the event of failure of one of the PEs:

- PE Redundancy: Data fusion operation is performed on at least two PEs.
- Data Buffering: The incoming data is buffered till the successful completion of the data fusion operation. The buffered data is routed to a healthy PE in case of failure.
- Data Transfer: On detecting PE failure, the data fusion operation is suspended and all data pertaining to this operation is transferred to a healthy PE.

Due to these features, the SWIFT architecture is robust & reliable, can tolerate faults, and is capable of handling real-time data. The introduction of newer devices due advances in technology, the dynamic nature of the city and its people as it grows big, poses new challenges to the architecture in terms of its adaptability and scalability. To handle these challenges, the SFNs are endowed with *Knowledge Base* modules that help the SWIFT architecture to learn & evolve over time to meet future demands of the city and to embrace changes in technology.

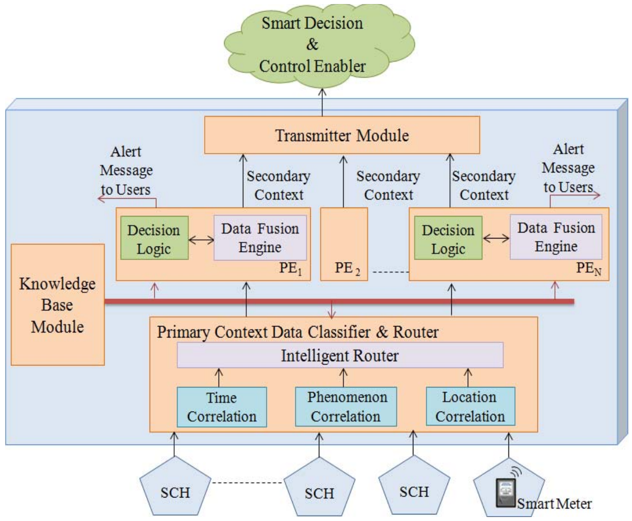

Fig. 4. Smart Fusion Node (SFN).

The modular nature of SWIPE layer, allows creation and extension of its functional components, and supports normalization of data collected from the participatory smart devices and sensor nodes. Therefore, additional number of SFNs can readily be deployed at newer locations in the city, without making much change in the architecture. This feature makes SWIFT a highly scalable architecture.

The transmitter module of SFN helps in transmitting the secondary context data generated by the *Data Fusion Engine* of a PE to other SFNs and thus facilitates seamless interactions between SFNs across the SWIPE layer. After processing the data, the SFNs place this information on the SDCE cloud. The solution provided by SFN is scalable and extensible, where functionalities can be added without much altering the existing components.

C. SDCE Layer

The Smart Decision & Control Enabler (SDCE) layer is the apex layer in the SWIFT architecture. The layer abstracts out the underlying components and presents a user friendly service domain. SDCE features a cloud environment and any citizen can land on to this cloud for queries. The SDCE layer comprises high-end computational hardware and software elements to facilitate information sharing across heterogeneous clouds belonging to different application domains. Data generated by the S-WSN and SWIPE layers are stored and processed by SDCE. It serves as data storehouse, where different types of data are archived. SDCE has powerful data mining tools and inference engines to provide *Google-type* services to the smart city dwellers and to satisfy their context-based service requests. The SDCE layer offers 'Sensing-as-a-Service' [11] to the smart users based on 'Everything-as-a-Service' [12] concept.

V. CONCEPTUAL IMPLEMENTATION OF SWIFT ARCHITECTURE

The functionality of the SWIFT architecture can be better described with an illustrative example of fire detection as shown in Fig. 5. Consider a group of sensors (GPS enabled temperature, optical and IR) distributed spatially to monitor the outbreak of fire and to determine its location and its severity.

When a fire breaks-out, the thermal/optical/infrared radiations trigger the sensors to signal the presence of fire and report their raw data to SCH. The *Context Data Tagging* and *Contextual Data Generator* modules of SCH act on this data to generate appropriate tags (time, location and type of sensor) and primary context information, and transmit the same to a nearby SFN. The *Knowledge Base* module of SFN determines the operations to be carried out by the PE to fuse the heterogeneous contextual information for validating and determining the severity of fire. Depending on the severity, the *Decision Logic* unit of the PE generates alert messages to fire brigade for rapid action. The fused data is then forwarded to SDCE for archiving and for further operations if any.

The conceptual implementation framework of SWIFT architecture for various operations like smart communities, smart power (generation & distribution), smart waste management, smart environmental monitoring, smart infrastructure, smart surveillance, vehicle & traffic management, smart people, and smart commerce, is illustrated in Fig. 6. The figure depicts the placement of different types of wireless sensors, the SCHs that collect information from their cluster nodes, the SFNs located at strategic locations to gather information from the SCHs, and the SDCE cloud that responds to queries from different sources.

To further understand the implementation issues, we elaborate the operation of SWIFT architecture with the help of two examples. The first is an example to illustrate the implementation in applications that basically generate trend analysis for corrective and punitive actions if required, and for archiving. The second example aims to illustrate the implementation of SWIFT architecture for applications that demand instantaneous query processing on real-time dynamic data.

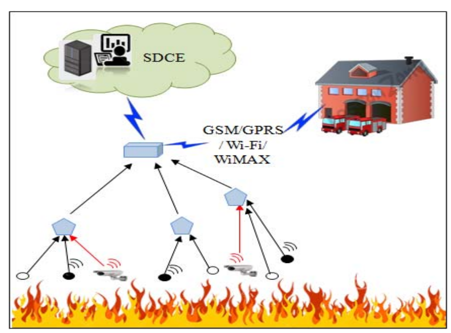

Fig. 5. Illustrative example.

A. Generation of Trend Analysis

Consider an application that needs to map the trend analysis of air quality in a city. Air quality depends on parameters like CO_x, NO_x, SO_x, hydrocarbons, SPM (PM_{10}, $PM_{2.5}$), temperature, RH, atmospheric pressure, etc.

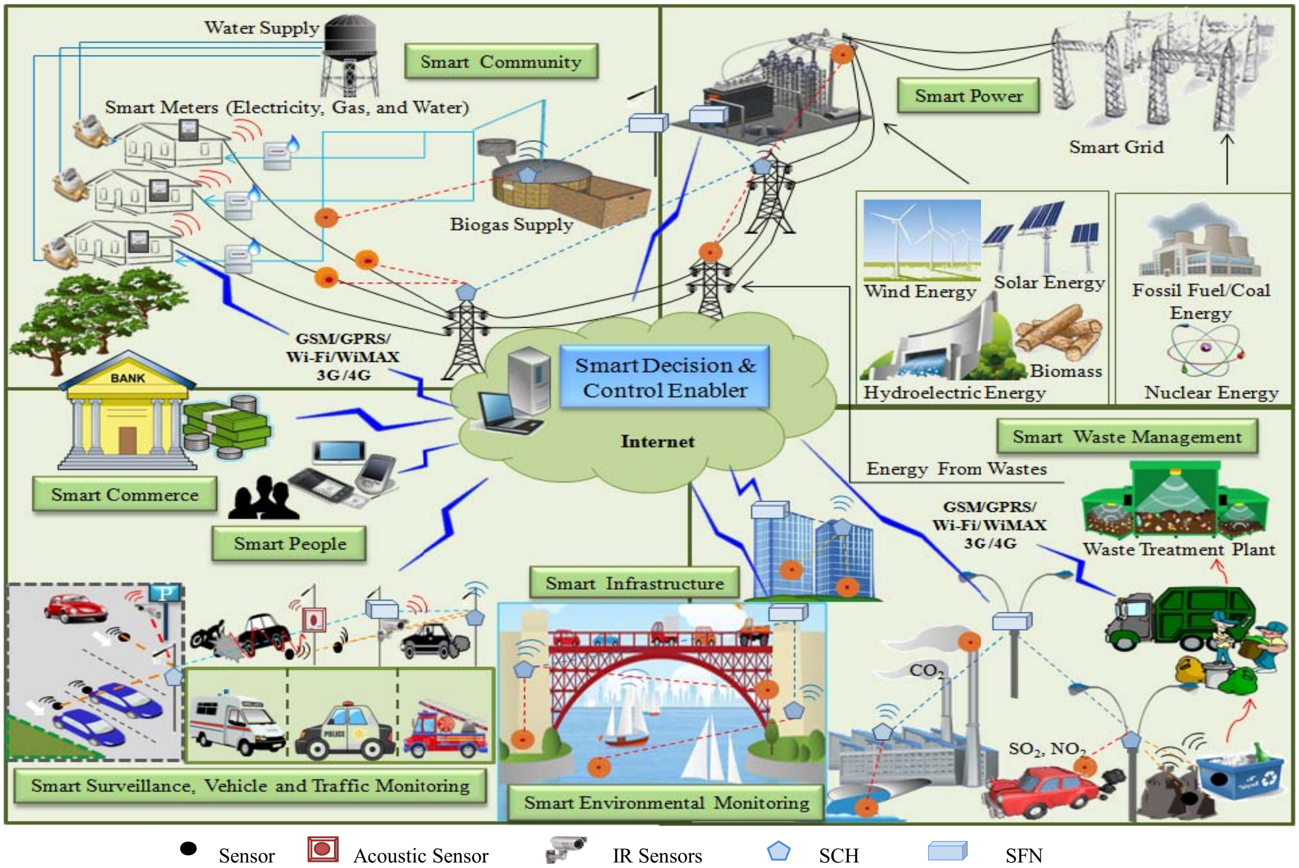

Fig. 6. A conceptual implementation of SWIFT architecture in Smart Cities.

ıir Quality Index (AQI) is usually employed to provide a epresentative indication of air quality. It is a number usually ı a scale of 1 to 500, with higher numbers representing poor ir quality. The AQI is statistically derived by determining ıe air quality parameters of interest for a particular locality, nd factoring their importance by assigning weights. Due to ifferent climatic, demographic, social and political nvironment, there may be a need to define different AQIs or different frames of reference. The SWIFT architecture ıonitors air quality parameters of interest, by placing sensor odes at locations where the impact of these parameters is elt the most. Accordingly, the S-WSN layer deploys sensor odes at industrial areas, traffic junctions, garbage dumps, vaste treatment plants, etc., as shown in Fig. 6. The sensor odes group themselves into clusters and periodically report ıeir measurements to the SCHs. As SCHs need good power ack up, they are installed on lamp posts, buildings, traffic quares, etc., where both power and Wi-FI access are readily vailable. The *Node Context Analyzer* extracts the unique ode ID and the *Context Data Tagging* unit prepares context ıgs that represent i) sensor type and the phenomenon being ıonitored, ii) node location, and iii) timestamp to indicate ime at which measurements are reported. The *Contextual Data Generator* generates primary contextual information iz., level of COx, NOx, SOx, SPM, etc., and transmits the ame to a nearby SFN for data fusion operations. The SFNs ıay be placed at locations where there is unlimited power nd ready access to Wi-FI/WiMAX services.

For determining AQI, data related to various air quality parameters needs to be monitored over a period of time. Some parameters like SPM demand information related to temperature, pressure, RH, etc., for accurate determination of the particulate matter. In such cases, the PEs need to perform data fusion operations on more than one parameter. The *Intelligent Router* is capable of understanding this requirement and routes the data received from various sensors to the appropriate PE for data fusion operation. The *Primary Context Data Classifier* categorizes the incoming data and routes it to one of the PEs. The *Knowledge Base* module of the SFN makes available, statistical, expert system and other such tools to PE for accurate determination of AQI for the zone in which the SFN is located.

The SDCE gathers the information from all SFNs to prepare a comprehensive AQI map (hourly/ half-hourly) for the entire city. After collecting the data for few months/ years, SDCE performs data mining operation to prepare trend analysis of air quality in different seasons and at different times of the day. This operation helps SDCE in carrying out further integration and analysis to respond to queries related to say, precautions to be taken during a particular season, predict the outbreak of air borne diseases, measures to be taken to improve air quality, etc. The people can have an access to this information by sending query to the SDCE through Internet using wired/ wireless technology on laptops, PDAs, or mobile phones.

B. Dynamic & Real-time Query Processing

Real-time query processing is required when the phenomenon being monitored is highly dynamic. In such cases, if a query is not served within a particular deadline the response loses its significance. As an illustration, consider a traffic monitoring system as shown in Fig. 6. Most queries on traffic are related to the determination of optimum route to a destination. In order to respond to such queries, SWIFT architecture gathers information related to parameters like traffic density, traffic flow, etc., by deploying sensors along the road, freeways, traffic junctions etc.

The *Contextual Interpreter* in the SCH processes data from different sensors by separating the context (time, location, etc.) and sensor information from the data received. The *Node Context Analyzer* and *Context Data Tagging* modules of the SCH extract *node ID* and generate 'location', 'time' and 'sensed phenomenon' tags. The context tags are then fed to *Contextual Data Generator* to generate primary contextual information, for example, location of a vehicle. The primary contextual information is delivered to the local SFN placed close by. The *Data Fusion Engine* performs data fusion operations to determine spatio-temporal relationship to obtain traffic flow and density information of the locality, and pushes this information to the SDCE cloud. Based on information received from various SFNs, the SDCE prepares dynamic traffic density maps for all routes in the city and charts out the optimal route to be taken by the vehicle to reach its destination. The data stored at SDCE can be used for predicting the traffic density at various times during the day and to provide directions to reroute the traffic.

VI. Addressing Triple Bottom Line Issues

The foremost criterion for sustainable development is to address issues related to the triple bottom line, *i.e.* economic prosperity, environment integrity and social equity. From a sustainable development perspective, economic prosperity cannot be achieved at the cost of abusing environment or encouraging disparities in social equity. But traditionally, most developmental works primarily focused on the first bottom line, while often relegating the other two to sidelines. The SWIFT architecture attempts to consciously deviate from this traditional line of action by developing SOPs that are tuned towards mutual co-existence and co-development of all three parameters.

Smart and optimal use of resources leads to substantial savings in power, water and transportation bills, besides leaving lesser carbon footprint. To this end, the SCHs in the S-WSN layer populate the SFNs from time-time, about the consumption pattern of various resources across different locations in the city. With the data so collected, the SDCE layer charts out a plan for equitable and optimal use of resources. For example, by analyzing the pattern of power consumption across the city, a smart power grid can maximize the utilization of solar power both during day and night times, and thereby reducing the environmental impact. The SWIFT architecture evolves appropriate SOPs to store power during the day and utilize the same at busy areas in the night. As a social equity measure, the less elite class who consume less power may charge their solar powered batteries during the day and sell the same back to the grid during peak hours at a premium. Through a similar approach, the SWIFT architecture can evolve mechanisms that encompass the triple bottom line for sustainable development.

VII. Conclusion

In this paper we have presented SWIFT, a conceptual architecture that is envisaged to serve as the IT backbone for smart cities. SWIFT is a platform architecture that can potentially accommodate the IT demands of all types of applications, technologies and services irrespective of the city demographics. The architecture is modeled to provide IT infrastructure that is *pervasive* to cover the entire city; *ubiquitous* to provide 24x7 services; *reliable* to tolerate faults and provide QoS; *flexible* to platform different types of devices & systems; *scalable* to accommodate city expansion; *adaptable* to embrace newer technologies, regulations and policies; and more importantly, *versatile* to handle the vagaries of human kind and their never ending quest for better living conditions. A conceptual implementation of SWIFT architecture has been discussed with the help of few illustrative examples. We plan to carryout simulation experiments related to the S-WSN layer in future.

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