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Smart City Architecture and its Applications based on IoT

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Abstract

Wireless sensor networks have increasingly become contributors of very large amounts of data. The recent deployment of wireless sensor networks in Smart City infrastructures has led to very large amounts of data being generated each day across a variety of domains, with applications including environmental monitoring, healthcare monitoring and transport monitoring. To take advantage of the increasing amounts of data there is a need for new methods and techniques for effective data management and analysis to generate information that can assist in managing the utilization of resources intelligently and dynamically. Through this research, a Multi-Level Smart City architecture is proposed based on semantic web technologies and Dempster-Shafer uncertainty theory. The proposed architecture is described and explained in terms of its functionality and some real-time context-aware scenarios.

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Keywords: Wireless sensor network; smart city; Dempster Shafer theory; context aware reasoning

1. Introduction

In recent years, there has been an increasing trend of large numbers of people moving towards urban living. As forecasted in[1] by 2030 more than 60 % of the population will live in an urban environment. Some of the systems that can address the challenges related to increased population will contribute to the development of the Smart City. The Smart City concept operates in a complex urban environment, incorporating several complex systems of infrastructure, human behaviour, technology, social and political structures and the economy. A Smart City provides an intelligent way to manage components such as transport, health, energy, homes and buildings and the environment. The data generated by these components are primarily by wireless sensor networks. Wireless sensor networks have been deployed in many industrial and consumer applications such as health monitoring, smart home applications, water monitoring and environment monitoring.

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Sensor nodes associated with different Smart City applications generate large amounts of data that are currently significantly under-used. Using existing ICT infrastructure, generated heterogeneous information can be brought together. Some of the existing wireless communication technologies that can be exploited to achieve this information aggregation are 3G, LTE and Wi-Fi. In the context of usage of embedded devices and existing internet infrastructure the Internet of things (IoT) encompasses PC's and other surrounding electronic devices. The Smart City vision is dependent on operating billions of IoT devices from a common place.

The recent emergence of low power wireless network standards for sensors and actuators has enabled administrators to manage and control wide ranges of sensor networks and actuators remotely. In order to facilitate the interaction between wireless sensor networks and information and communication technologies, a Smart City architecture is proposed in this paper. The proposal is to deploy the architecture on a service platform. Through this platform, sensor applications can be connected and utilized by different web applications for an intelligent operating condition.

The proposed architecture helps in exploiting very large volumes of data and information using semantic web technologies and uncertain reasoning rules. We use a reasoning approach for knowledge extraction and information combination from different Smart City domains such as vehicle, health, home and environment domain and knowledge extraction. For example, the use of Dempster-Shafer combination rules to combine sensor information from the home and environment domain can enable us to recognize activities of individuals or groups, or to recognize the development of scenarios that might require management or intervention.

The contributions of this paper include: 1) A Multi-Level Smart City architecture; and 2) some of the real-time context aware solutions associated with the Smart City architecture. In this paper, related work is described briefly in section 2. Section 3 describes the Multi-Level Smart City architecture. Section 4 concludes and describes future work.

2. Related Work

In a Smart City, wireless sensor networks are the major sources of heterogeneous information generation. The information generated by different sensors often overlaps and is partial in nature. Addressing the challenges related to fusion of partial data is a research challenge. The Dempster Shafer theory of evidence, originally proposed by Dempster[2] and then extended by Shafer[3] is an extension of traditional probability and can be used for uncertain reasoning under these circumstances. Similarly, Tazid et al[4] considers the merits and demerits of different combination rules (such as the Dempster rule, Yager rule, Sun rule) that are used in sensor data fusion. Yoon and Suh[5] and Javadi et al[6] use the Dempster-Shafer approach, or uncertain reasoning, for sensor data fusion in the environmental domain. The proposed data fusion approaches were limited to the devices and their functionality for a single Smart City domain only. Through this research, we aim to address multi-domain sensor data fusion.

Some existing Smart City projects, such as the IBM project SCRIBE[7], define the Smart City in term of semantic model based on data gathered from around the world. The SCRIBE ontology is defined using open standards such as Common Alerting Protocol and the National Information Exchange Model (NIEM) and addresses the heterogeneous data issue in different Smart City domains. Similarly, the Smart Santander project[8] aims to evaluate the key building blocks of the IoT, which are mainly the interaction and management protocol mechanisms. In the Smart Santander project, a large number of sensors will be deployed in different cities and exploited for different applications. The developed test bed will help in exploiting various Smart City domains such as environment monitoring, traffic intensity pattern monitoring and guidance for drivers on available parking spaces. The City Sense project[9] aimed to improve existing human infrastructure and thus help in providing better services to citizens by exploiting available resources (such as electricity, water, and traffic) in a more efficient manner. However, these Smart City projects do not provide detailed information about their implementation. In addition, their semantic models do not specify how they will incorporate uncertainty aspects.

Considering these aspects, our approach will use a multi-level system design, in which low-level raw information is semantically enriched and inferred by intelligent customized applications in a Smart City domain. Furthermore, our sensor fusion approach is based on domain expert knowledge and a reasoning process that uses the Dempster-Shafer theory of evidence. This approach is also well suited to dealing with uncertainty in heterogeneous data for the Smart City model.

3. Multi-level Smart City Architecture

With the aid of modern wireless technologies and wireless sensor networks, we envisage the future of the Smart City systems providing powerful, intelligent and flexible support for people living in urban societies. As shown in Figure 1 we propose a Smart City architecture that is an extension of[10], which was restricted to the vehicle domain only. By integrating wireless sensor networks and available wireless communication services, the following research aims are targeted: 1) real-time high-level context-aware customized services; 2) better living environments; 3) improved utilization of the available resources.

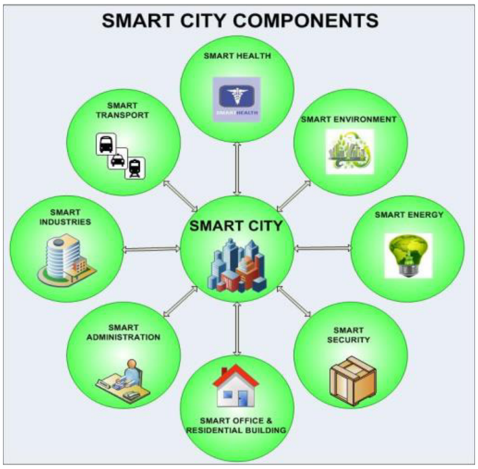

Fig. 1. Smart City Components

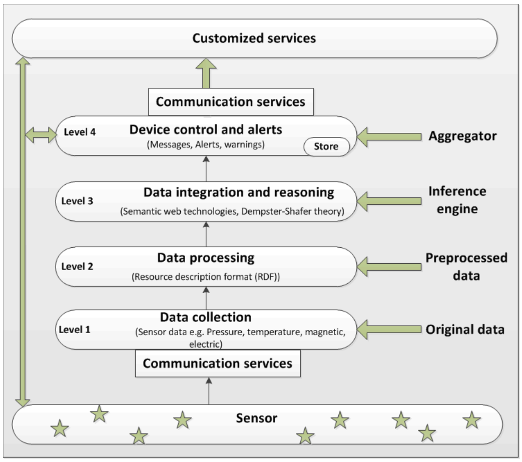

Fig. 2. Multi-Level Smart City Architecture

As shown in Figure 1, we envisage the main elements of the Smart City architecture to be smart health, smart environment, smart energy, smart security, smart office and residential buildings, smart administration, smart transport and smart industries. The sensor nodes deployed in each Smart City domain provide the primary data source for heterogeneous information generation. Information generated through the sensor nodes are collected using the existing communication services (see Section 3.2). For example, the use of satellite network for GPS devices, cellular services such as GSM/3G/4G for smart phones and the use of internet for PC's and other navigation devices for raw data collection. The collected data are then processed and analyzed using semantic web technologies and Dempster-Shafer combination rules. The focus is on deploying the architecture on a cloud platform for use as a software as a service (SaaS).

The proposed architecture can help Alzheimer's patients and elderly people with their daily living activities, for example, by sending alerts and warnings to end users if they forget, or are unable to complete, daily living activities. The system will also serve as an intelligent platform for people living in a Smart society. By combining data from different Smart City domains, this architecture will help in assisting people in an intelligent manner, for example, guiding a driver to take another route in case of road congestion, alerting heart patients in situations where their heart rate is exceeding a threshold limit while performing an activity, assisting people with alerts and warnings for their household items such as sending alerts for buying food items via a Smart fridge.

The implementation of the architecture will follow the steps outlined below. Firstly the raw data are collected and processed to make them web consumable. Once the data are converted into a common format they are then semantically enriched with OWL concepts based on the knowledge of domain experts. At the same level, the collected data are processed using the Dempster-Shafer rules to deal with the uncertainty aspects of the semantic model. The idea is to recognize activity and learn new rules that are governing an activity. The new rules learned at this level will be used in defining the knowledge of the semantic model. The same approach will be used in defining customized services that will provide feedback to the end users (citizens) in the form of alerts and warnings as mentioned in Level 4 of the Smart City architecture.

3.1 Multi-Level Smart City Architecture

As shown in Figure 2, sensors form the primary source of information generation. The raw data sensed by the sensor node are transferred to Level 1 of the Smart City architecture using communication services to perform further information processing. A detailed description of each Level is explained below.

3.1.1 Level 1: Data collection

In this level, raw information collected from sensors is stored for further processing. Some of the formats in which heterogeneous data are collected are csv, tweets, database schemas and text messages. The collected formats are then processed using semantic web technologies in order to convert them into a common format. The next level describes the steps used in conversion of data into a common format.

3.1.2 Level 2: Data processing

Information gathered from the data collection level is summarized prior to transmission, analysis and fusion in the further levels using semantic web technologies. The main objective of this level is to convert the collected heterogeneous information into a common format, e.g. Resource Description Framework (RDF). RDF[11] is the most common way to exchange information over the web and it facilitates heterogeneous data sharing and integration for different Smart City domains. RDF also helps in defining metadata about the resources on the web. Different software applications can then utilize RDF data for intelligent reasoning operations. Pre-processed RDF data generated at this level will be exploited using semantic knowledge and uncertain reasoning rules in the next level for high-level context-aware information retrieval.

3.1.3 Level 3: Data integration and reasoning

Semantic web technologies enable exploitation of domain specific data based on the concepts and relationships between those concepts. The techniques used in this level are summarised below.

Web ontology language (OWL)[12] is used for publishing the ontologies. OWL is an RDF graph that is built using the RDF and ontologies. It allows the classification of the individual/concepts based on the classes. It also provides two different types of properties, which can be used to form relationships between different classes, namely the Data property and Object property. Once data classification is done, knowledge can be further enriched with domain experts and uncertain reasoning.

Dempster-Shafer will be used here for activity recognition and learning new rules in a particular domain of discourse. In this paper the Dempster-Shafer approach is used for combining sensor data [6] from different Smart City domains. This approach will help in learning new knowledge through uncertain reasoning and thus assist in achieving an intelligent smart system.

SPARQL is an RDF query language[13] that is used to query, retrieve and manipulate data/records stored in the RDF format. Once the whole database is expressed in the form of RDF triples, SPARQL enables the query and retrieval of data in the same format. Therefore, this level motivates towards low-level information fusion. The new rules learned during the process of extraction of high-level context information from raw sensor data can then be stored and used for building up knowledge in the Smart City architecture.

3.1.4 Level 4: Device control and alerts

Data obtained from level 3 can be utilized by different web applications for intelligent operating conditions. The inferred data can be utilized in many ways such as input/output, messaging, alerts and warnings[14].

3.2 Communication Services

The communication medium plays an important role in achieving the Smart City concept. Figure 3 shows the existing communication services that are utilized in a Smart City infrastructure: 3G (3rd generation), LTE (Long-term evolution), Wi-Fi (Wireless fidelity), WiMAX (worldwide interoperability for microwave access), ZigBee, CATV (cable television) and satellite communication. The main aim is to connect all sorts of things (sensors and IoT's) that can help in making the life of citizens more comfortable and safer. An example is provided by communication services in the home domain for connecting telephone devices and PC through the internet. In the case of the Government sector, cloud and communication services are combined to obtain a better governance system. In the case of the health sector, communication technologies can be used to connect health statistics, medication and location of the patient from a remote location thus helps to achieve a Smart Health system. Hence, with Smart City and communication technologies we can provide a more secure and convenient infrastructure for better living.

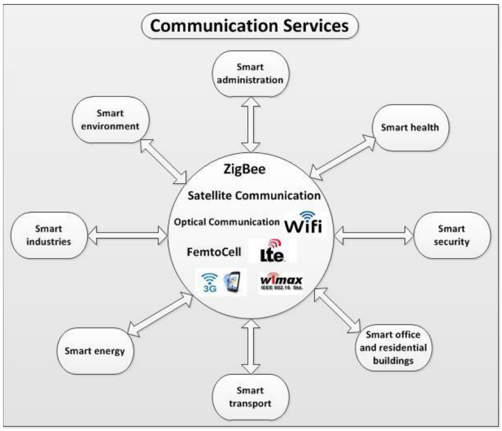

Fig. 3. Communication Services

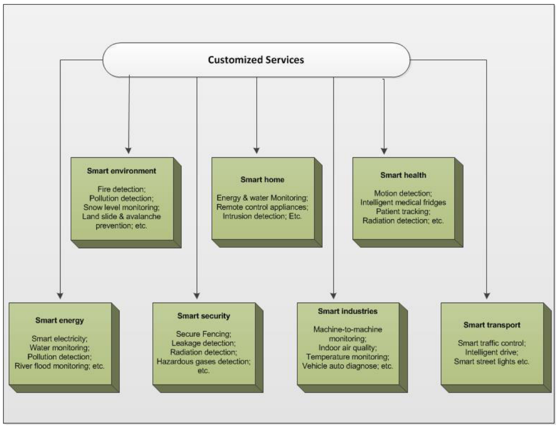

Fig. 4. Customized Services

3.3 Customized Services

Figure 4 lists some of the customized services in the Smart City environment. For example, in the case of the vehicle and health domains, by combining sensor data we can measure the impact of driver health parameters on driving conditions. Combining health parameters like blood pressure and heart rate with vehicle status can help the driver to measure their real-time health condition, which can help in creating a safe environment for drivers. Similarly using vehicle location, vehicle speed and volume of traffic approaching a junction, we can help in better monitoring of vehicle status. In the case of the healthcare domain, information collected through wireless sensor networks about patient health and activity can assist the disabled person. Similarly, by combining the home and environment domains data, the effect of temperature on home activities like eating, bathing, sleeping and cooking can be learned. This can help in recognizing correct activity status, which in turn can be a useful care tool for the elderly and people suffering from dementia.

In the case of the environment and administration domains, low-level information collected from the environment domain such as temperature and water level will help in deriving high-level customized information. When high-level customized information (such as flood, earthquake, forest fire, landslide and other natural calamities) is combined with city administration services, it could help in saving lives. Similarly, in the case of the industrial sector, context-aware services obtained through heterogeneous data fusion will help in creating a safe working environment for factory workers. By continuous monitoring, recording and exploiting the ambient sensor information from different domains (such as harmful gas detection, machine conditions and workers' health) in an industrial environment, a better, more productive and safer environment for workers can be created.

4. Discussion and Conclusion

The Smart City concept has been revolutionized and has evolved into a new era with recent developments in ICT that combine wireless sensor networks and computer networks. We aim to address some of the customized services in a Smart City environment by using semantic modeling and Dempster-Shafer theory. In addition, through the Dempster-Shafer approach in our Smart City architecture we aim to address the uncertainty aspect of our Smart City semantic model. Although it is very difficult to cover each and every aspect of the Smart City, through our architecture we aim to focus on the most important areas of the Smart City environment.

Future work is planned to perform experiments on the ideas discussed, which includes discovering real-time heterogeneous information, proposing a common semantic knowledge model, using Dempster-Shafer models for combining sensor data and for reasoning, and defining data interoperability and scalability aspects in our architecture.

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