Smart Beijing: Correlation of Urban Electrical Energy Consumption with Urban Environmental Sensing for Optimizing Distribution Planning

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***Abstract*—This paper focuses on consumer-side activities and investigates the environmental impact of the electrical energy consumer (transportation, buildings, street lighting, etc.), in order to improve the operational efficiency of the city as a whole. To achieve the goal we propose a two-layer approach which consists of a sensing layer and an application layer. To begin, circumstances within the city of Beijing are identified which have a large temporal impact on environmental conditions. A taxi-based vehicular ad hoc network is proposed as a low-cost and efficient approach for urban sensing using information collection methods of "Internet of Things" to capture various environmental parameters (air quality, noise pollution, traffic levels, water quality, etc.) in a distributed manner in real time. Using this data and correlation analysis techniques, global machine learning approaches will be trained to recognize important city events and dynamics which will affect electrical power consumption and create anomolies in pollution levels in specific locations, such as sporting events, rallies and fairs. This event-driven situational information could then indicate a predictive relationship with electrical energy consumption information, which can be exploited in the application layer. Besides, we introduce a middleware above the application layer to proactively plan a certain information management system around the Common Information Model and other information standards, in order to deal with lack of stable integration of the standards. Utilities could then get intelligence and values as expected from the data that will be collected from our system.**

Keywords-urban sensing; electrical energy consumption; two-layer approach; middleware; correlation analysis.

I. Introduction

Population growth, as well as a growing middle class, has caused an explosion in the number of vehicles on roads, resulting in traffic jams, environmental pollution and a series of other social problems. The urban electrical energy development has also been greatly impacted by these growth spurts as well [4], [6]. In the 21st century, development of low-carbon economy, construction of an ecological civilization and achievement of sustainable development are the general consensus of scientific community. Within the generalized Smart Grid concept, Smart City is in full swing in the development, especially for metropolises, megacities and cities in emerging economies. Though cities are major consumers of energy and generators of pollution, they can be active participants of Smart Grid and turning to be "prosumers" utilizing an urban environmental sensing network, which is a remote information sensing application in prospects of the entire city's resources.

The Internet of Things has the potential to broaden the Digital City concept [7] by adding more rich content, the result of which is a new concept called a Smart City. The Smart City concept emphasizes the inclusion of urban information for use in intelligent control and handling. If a Digital City is analogous to the information society which mainly relies on personal computing, a Smart City is then a reflection of a networked society which relies on pervasive computing with intelligent devices. Authors in [9] present a simulator based on software agents that attempts to create the dynamic behavior of a smart city, in order to analyze and investigate the system complexity of the future smart grid infrastructure. Through mobile cellular networks [2], a real-time urban monitoring system is constructed for evaluating the urban dynamics, and the visualizations of combined data realize several information layers on top of a map of Rome. Within the vision of smart cities, Copenhagen uses the Copenhagen Wheel [10] to achieve real-time environmental sensing and improve the cycling experience through the powers of crowd sourcing, Lisbon introduces a map-based service platform [11] that allows access to real-time information about the state of taxi transportation as well as predictions regarding its future state based on a naive Bayesian classifier.

Although several current Smart City activities have shown interdependencies between inter-personal interactions and their urban environment through a mobile platform [1], [3], such as the in daily life existing sensing infrastructure of mobile phones, they are still not directly involving some actuation technology in terms of energy reduction or efficiency. The presented work is going to investigate the impact of end-user behavior on the entire energy consumption, and the environmental impact of the urban energy consumer (transportation, buildings, street lighting, etc.), through

1) Developing complex machine learning approaches for

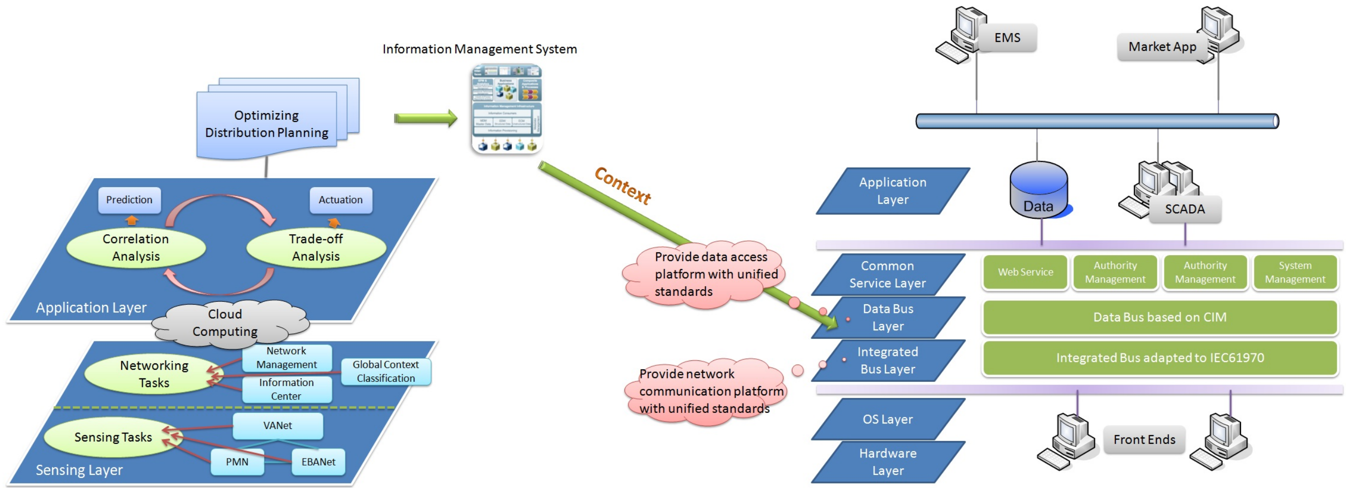

Figure 1. System architecture of two-layer approach with middleware to interface with CIM (Common Information Model)

distributed, city-wide situation recognition;

2) Defining abstraction levels of urban situational information;
3) Analyzing the influence of urban situational information on energy consumption and environmental quality levels.

Being able to recognize large-scale crowd and population level activities will enable prediction of the immediate future developments in energy consumption levels as well as active locations, which could be characterized as one proactive and interactive measure of electricity price reduction.

However, to achieve the goal of recognition of city events and dynamics, such as sporting events, rallies and fairs that will affect electrical power consumption and create new issues of pollution in specific locations, a dynamical, low-cost and energy efficient sensing platform is required. A taxi-based VANet (vehicular ad hoc network) as the main platform for a large city-scale sensing is to be presented, which is complemented with a PMN (Participatory Monitoring Network) using flash disks or mobile phones for a small-scale sensing with a finer granularity. Based on this metropolitan sensing network, an event-driven prediction process of the immediate future developments in energy consumption levels and highly active locations is then to be constructed in an application layer. Furthermore, a high level ODP (Optimizing Distribution Planning) is going to be introduced as a middleware over the application layer, which could give electric power industry standards such as CIM (Common Information Model) a proper context through an IMS (Information Management System), since today the UML-based CIM is broadly applied for system and business process integration by utilities worldwide (see Figure 1 right part), and related information exchange between systems.

II. System Architecture

As described in Section I, a two-layer approach presented in Figure 1 (left part) is employed to realize an application framework based on the urban sensing for supporting the optimization of the energy consumption.

- The metropolitan sensing network based mainly on VANet consisting of city taxis, collects and processes the urban sensing data in distributed manner. The integration of wireless environmental sensing terminals in city taxis realizes a unique information collection by incorporating these vehicles in the IoT (Internet of Things), capturing environmental and taxi-based information in real time.
- An application layer is established on the sensing layer as one framework, which combines the IoT technology with Smart City requirements. This will enable intelligent decision making, control and services based on a networked solution leveraging situational recognition technology, the IoT and distributed intelligent systems.

Through correlation analysis IV, such as a multivariate linear regression analysis [8], [13] among the non-urban structural factors, based on global situation recognition in the sensing layer, immediate future energy development is then predictable in the application layer. In electric power transmission and distribution, the CIM that is defined in UML, provides a common language to describe exactly what data is being exchanged among a utility's business systems. The major motivation for this exchange has been to support system planning functions including transmission planning, maintenance scheduling, and operations planning. So above this application layer, a local model of ODP is proposed as middleware to interface with CIM. The local ODP will give the CIM a proper context as input through a certain information management system, which could let the utility adjust the activated transmission planning in real-time in view of the predicted immediate future energy development, in order to optimize the urban electrical energy distribution in real-time, thereby reducing the electricity price.

III. Sensing Layer

For the purpose of a metropolitan sensing, a model of distributed urban sensing is proposed, in which each mobile sensor node is responsible for the distributed processing task with respect to the coverage zone of the neighboring nodes, including local recognition processing. This sensing layer enables besides the urban sensing and networking tasks, the global situation recognition for city events as well, which could alternatively accomplished through a social network service like Twitter or Facebook.

The main platform of this mobile sensing network, which has already been done, is a VANet that uses every participating taxi as a wireless node to gather and transmit data based on IEEE802.15.4c, because 802.11p that is the standardized MAC layer of VANet fails to provide reliable broadcast support in a congested highway.

Some units in a city are more important for energy consumption and must be monitored with a finer granularity than the rest of the system. Examples of these are government buildings, tourist attractions and university campuses. Therefore, a small-scale sensing is being developed, which will be accomplished with a PMN using flash disks or mobile phones.

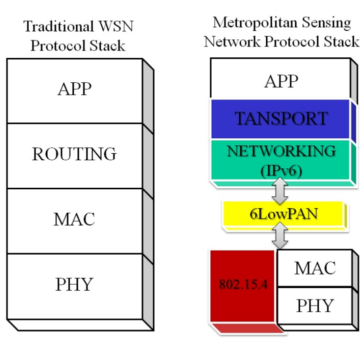

Figure 2. Comparison of protocol stack between traditional WSN and our metropolitan sensing network

A. Protocol Stack

This main metropolitan sensing network has a large number of sensor nodes which work in a distributed manner, so that the low cost design and energy efficiency protocols are the main features of this network. Differing from the conventional sensor networks whose protocol stack is composed of four layers, we designed a six-layer protocol stack, see Figure 2. The MAC and PHY layer are compliant to IEEE 802.15.4. We replace the ROUTE layer with IP layer which is running IPv6 protocol. Moreover, the node can be accessed via Internet directly from client computers. In order to transport IPv6 data packets over a low-power 802.15.4 radio, an adaptive layer is added between IP and MAC layer.

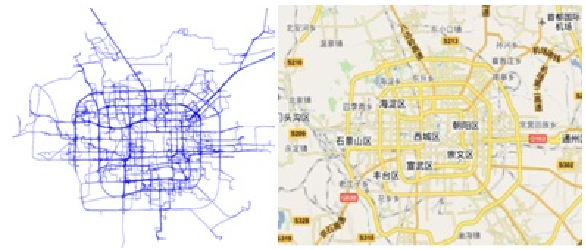

Figure 3. Coverage of the city by taxis; (left) the accumulated traces of ten taxis in one day (7 am - 9 pm)

B. First Dataset

Through analyzing the GPS traces of over 20,000 taxis of Beijing, an interesting fact is revealed that quite a few taxis could offer excellent spacial coverage of the city, at the cost of a long round trip time, see Figure 3. For the delay-tolerant applications, such as air quality monitoring, carbon emission surveillance etc. using taxis as data collector and data carrier will be a most low-cost and efficient way to get a better understanding of the dynamics of a city.

IV. Application Layer

Situation classification and prediction based on the urban sensing are proposed for detecting city events and dynamics, to improve prediction of temporal and spatial energy consumption characteristics. This situational information is event-driven, and cannot be statistical derived, as opposed to other information sources such as weather forecasting which currently factor into such models. In order to make this correlation clearly, we will proceed with the following three research topics:

- Developing machine learning approaches: for urban pattern (situation) recognition or classification, the sensing data is assumed to be temporally dynamical, so HMM (Hidden Markov Models) or other classification algorithms based on time series are going to be considered. Due to the complexity of the city scene, we are going to decompose the scene into many relatively homogenous objects. The various statistical characteristics of these homogenous objects in the scene are then subjected to an object-oriented classification, such as traditional statistical classification combined with fuzzy logic classification.
- Researching the optimal abstraction levels of situational information [12]: 1) raw sensor data of for instance, taxi-based sensor nodes; 2) low level contexts, such as states of taxis, like taxi location; 3) high level contexts, are the city activities and dynamics, such as infrastructure changes at the edge of Inner City,

waterfront development, household services activities, etc.

- Researching the influence of urban situational information on energy consumption: the benefits of context (situation) prediction for enabling spatially fine-grained evaluation and control of power consumption in an industrial application have been discussed in [5]. For the urban scenario, we will investigate the use of a multivariate linear regression analysis among the non-urban structural factors that have a significant impact on the power demand, such as the location of the residence relative to the city center, availability of private car in the household, etc.

Correlation Analysis: through the data of air quality (CO, CO_2, SO_2, NO_x ...), location data of taxis, etc. collected by the deployed urban sensing network, the global situation classification system will recognize important city events and dynamics which are energy relevant. For instance, during the Football World Cup, many fans will get off work earlier in order to drive home before the game start. This action will surely change the city's activities and dynamics, which leads directly to the immediate distribution change of urban energy consumption. However, this change could not be in view of the previous statistical consideration of the urban energy distribution. The sudden surge of air pollution which is transport-conditional and the trajectory of the taxis could become the crucial situation contexts that correlate directly with the urban energy consumption in residential areas. Therefore, here mentioned correlation should be actually deduced not directly from the sensed urban data, but from some extracted situational information of the sensed urban environment as described before.

V. Conclusion and Future Work

This work began by identifying the need for energy correlation analysis with urban environmental sensing. A two-layer architecture was proposed that comprises a sensing layer and an application layer. The already realized metropolitan sensing network based on VANet collects and processes the urban sensing data in a distributed manner, which not only enhances the information processing capacity, but also has the capability of network layer.

An application layer was introduced as one of the next research steps, which enables an application framework based on the urban sensing for support of intelligent decision making, control and services. Through the proposed middleware ODP, utilities could get more intelligence and value from the data that will be collected from existing USI (Urban Sensing Infrastructure) and other "smart grid" devices, like AMI (Advanced Metering Infrastructure). Although the main concepts have been presented here, a full evaluation of the system is yet to be completed. The main aspect which is being explored is the parameterization of the correlation between event-based situational information and electrical energy consumption data to introduce this as a metric for further optimizing urban energy distribution by means of non-statistical energy consumption prediction.

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