SMART 2016

The Fifth International Conference on Smart Systems, Devices and Technologies

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URBAN COMPUTING 2016

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SMART 2016 Editors

Lasse Berntzen, University College of Southeast, Norway
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SMART 2016

Foreword

The Fifth International Conference on Smart Systems, Devices and Technologies (SMART 2016), held between May 22-26, 2016, in Valencia, Spain, continues a series of events covering tendencies towards future smart cities, specialized technologies and devices, environmental sensing, energy optimization, pollution control and socio-cultural aspects.

Digital societies take rapid developments toward smart environments. More and more social services are digitally available to citizens. The concept of 'smart cities' including all devices, services, technologies and applications associated with the concept sees a large adoption. Ubiquity and mobility added new dimensions to smart environments. Adoption of smartphones and digital finder maps, and increasing budgets for technical support of services to citizens settled a new behavioral paradigm of city inhabitants.

The SMART 2016 conference also featured the following symposium:

- URBAN COMPUTING 2016- The International Symposium on Emerging Frontiers of Urban Computing and Smart Cities

We take here the opportunity to warmly thank all the members of the SMART 2016 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to SMART 2016. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the SMART 2016 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that SMART 2016 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of smart systems, devices and technologies.

We are convinced that the participants found the event useful and communications very open. We hope that Valencia provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

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Automated Categorization of Consumers Based on Consumption Forecast in Smart Grid

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***Abstract*—Deploying smart meters in Smart Grid systems entails that large amount of measurement data is acquired. By processing and analyzing the data, relevant information can be obtained about the power consumers. One of the most important tasks is determining the main characteristics of the consumer in order to find the best suitable category. This categorization may be essential i) to optimize and estimate the load of transportation grid; ii) to provide the best rate for the consumer as well as the supplier in case of free market of electricity; iii) to forecast and to plan correctly the required amount of energy from power-plants to minimize the difference between the demand and supply. In this paper, a categorization method based on forecasting consumption time series will be introduced to categorize consumers with different consumption patterns with good performance. The performance of the method was subject of analysis, and the new algorithm is proved to be usable in real applications.**

Keywords*— *Consumer categorization; Clustering methods; Classification methods; Time series forecast; Feedforward Neural Network.

I. Introduction

Smart power transmission grids are the future of the electricity distribution and transmission systems. In contrast to the present grids, a smart grid can efficiently and adaptively manage the balance between supply and demand in the network [1]. These capabilities root in the intelligent monitoring and measurement system which is an integrated part of the network.

Using smart meters either at the customer or in the power transmission network entails that a huge amount of measurement data is acquired. In order to obtain intrinsic information about the actual status of the network and the behavior of consumer the data have to be processed. As a result, it is required to have sophisticated and innovative algorithms [2]–[4] because of the complexity and the amount of data. The categorization of consumers in Smart Grid systems is an important task to i) optimize and estimate the load of transportation grid; ii) provide the best rate for the consumer as well as the supplier in case of free market of electricity [5]; iii) forecast and to plan correctly the required amount of energy from power-plants to minimize the difference between the demand and supply [1].

Currently the consumer categorization is done either manually or with supervised methods, as a result it requires time and continuous attention. Recently we have dealt with both the automated classification and clustering of consumers, and we have demonstrated that using nonlinear forecast [6] it is possible to i) classify the consumers to known classes; ii) determine correct clusters without any prior information. Nevertheless, the customer categorization still not fully automated as neither the changes of categorization nor the changes of proper classes can be detected.

In this paper, we introduce a new categorization method for automated categorization of the power consumers, and test results on measured power consumption data as well. The method is capable of distinguishing categories and detecting category changes of power consumers with different consumption patterns. The novelty of the method inheres in capability of categorizing several type of time series with high performance as well as it does not require any supervision. Furthermore, as this method is based on the analysis of error levels of time series forecast, in can be combined with existing forecast methods [7].

II. Related work

In this section existing methods will be briefly summarized.

A. *Classification methods*

The classifications methods can be distance based, feature based or model based methods. According to [8], in methods designed for classification of time series can be either i) modified or redesigned methods, which are capable of handling sequential data; or ii) extensions, which transforms the sequential data to fit to the existing methods.

The distance based methods provide decision based on the distance between the data elements, so for all new measurement the distance has to be calculated. The class assignment is made using the minimal distance. The performance of the method is highly influenced by the choice of the measure of the distance [9]. In general the Eucledian distance is applied, however special problem may require refined metrics [10]

Feature based methods transform the sequential data into a feature-set. The class assignment is based on the resemblances of the values of the feature-set. The performance of the method is determined by the method of election of the features [11]. In case of time series the most common transformation is wavelet decomposition. To reduce the number of features, kernel methods are also deployed, such as Support Vector Machines.

In case of model based approaches during a training phase for all classes a model is constructed. The new data is classified upon the best fitting model. The most commonly used statistical models are Gaussian, Poisson, Markovian Model, and Hidden Markovian Model [12].

Artificial neural networks do not require prior knowledge about the data. The main advantage of using these methods is that the input noise has less influence on the performance [13].

Forecast based classification method (Class-MBF) exploits the different statistical properties of the power consumption time series acquired from different classes of consumers [6]. The underlying idea of the Class-MBF has the following two components. When an approximator (with capability of estimating forthcoming values of time series using preceding, known values) is trained on time series of a specific class, then i) values of other time series of the same class can be forecasted with low error rate; and ii) values of time series of other class can be forecasted with significantly higher error. As a result, each of the classes can be described by the process in the background, thus an approximator can be trained for each class using representative time series. The resulting algorithmic flow of the scheme is depicted by Figure 1. After

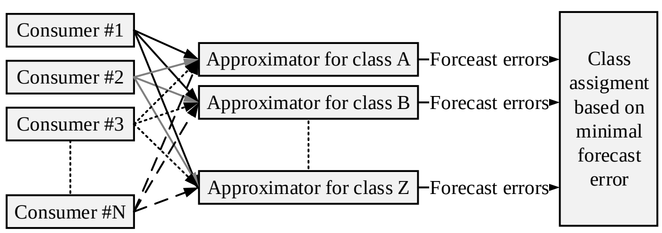

Figure 1. Algorithmic scheme of the classification method

the training phase finished for all approximators, the values of a new sequence with unknown class can be compared to their forecasted values (using each approximator) resulting forecast error sequences. The mean of the forecast error will be used as a decision variable to decide the class where the sequence belongs to. The decision is the result of seeking the approximator which minimizes the forecast error. A training set is used for each approximator to calculate its free parameters with learning algorithms.

B. Clustering methods

The clustering methods can be hierarchical, squared error based, graph theory based, fuzzy clustering, neural networks-based clustering methods [14], [15].

Hierarchical Clustering methods organize data into a hierarchical structure. This approach can be either agglomerative method or divisive method. The first one initializes clusters with one objects and merges clusters based on the distance between them. The latter one proceeds in an opposite way as all the objects belong to one cluster, and the existing clusters are divided into smaller groups [16].

In cases of squared error based methods the sub-optimal partition is found by heuristic algorithms. The k-means algorithm is the most widely used method [17].

Fuzzy Clustering relaxes the constraint which states that a data object belongs only to one cluster. These methods are capable of discovering more sophisticated relations between the clusters and objects [18].

Neural networks-based clustering methods are mainly the self-organizing map (SOM) clusters and adaptive resonance theory networks (ART). The data is represented by artificial neurons and the strengths of connections between the neurons represent the connections between the clusters [19].

The underlying idea of forecast based clustering method is similar to the Class-MBF method. In each iteration of the algorithm, for each existing cluster an approximator is trained using the time series of the cluster. The approximator is used as in the classification method, to estimate the forthcoming value of time series using past values. In each iteration the approximators are evaluated by all time series, as a result, a matrix of error values can be constructed. The values of forecast error matrix can be considered as the distance of a time series from clusters. Then the minimal forecast error value is sought to merge adjacent clusters. If a time series can be forecasted with two or more approximators with low error rate than it is presumed that the two or more clusters can be merged. After the merge is done a new iteration started with the reduced number of clusters. When minimal error rate exceeds any of intra-cluster forecast error rate then the iteration is terminated as the final result is available [20].

III. CONTINUOUS CATEGORIZATION OF POWER CONSUMERS BASED ON FORECAST

In this section the algorithm of the automated method for categorizing the power consumers is introduced. The algorithmic flow of the entire method is summarized by Figure 2, which components are detailed in the following subsections. The used notation is summarized by Table I.

TABLE I. Used notation

Notation	Description
N	Actual number of consumers
$\mathbf{x}^{(i)}, i = 1 \dots N$	Power consumption time series for consumer i
$n^{(i)}$	Length of $\mathbf{x}^{(i)}$ (number of values in time series i)
M	Actual number of categories
$\mathcal{C}^{(j)}, j = 1 \dots M$	Category j
$\Gamma^{(j)}()$	Approximator of $\mathcal{C}^{(j)}$
$\tau_{(j)}$	Training set of $\Gamma^{(j)}()$
L	Number of preceding values used by approximator
$\varepsilon_k^{(i)(j)}$	Forecast error value for $x_k^{(i)}$ with $\Gamma^{(j)}()$

A. Approximator

The performance of the method is mainly influenced by the approximator used. Our previous results [6], [20] indicated that the Feedforward Neural Network (FFNN) [21] has the required properties and can be used as approximator. However the clustering method is not restricted to the FFNN approximator, any method (e.g. methods introduced in [7], [22]) which is capable of forecasting power consumption time series can be deployed.

The structure and parameters of the FFNN were determined by experiments. It has been used three hidden layers where the first and second layer implemented with sigmoid non-linear activation function. The third hidden layer and output layer contained artificial neurons with linear function. The Levenberg-Marquardt [23] backpropagation learning function have been applied during training phases.

B. Initial categories

Initially, we suppose that the N consumers are not categorized, thus a clustering has to be executed. Each of the consumers are assigned to its own category as a result $M = N$. For each category the training set is assembled as follows:

$$\tau_{(j)} = \left\{ \left(x_m^{(i)} \dots x_{m+L}^{(i)}; x_{m+L+1}^{(i)} \right) \right\}$$
$$\forall i : \mathbf{x}^{(i)} \in \mathcal{C}^{(j)}, m = 1 \dots \left(n^{(i)} - L - 1 \right) \quad (1)$$

Using the training set, the free parameters ($\mathbf{W}^{(j)}$) of approximators are set by learning algorithms, as a result, an approximator can be used to forecast the forthcoming values based on L preceding values as follows:

$$\hat{x}_k^{(i)(j)} = \Gamma^{(j)} \left(\mathbf{W}^{(j)}, x_{k-1,\dots,k-L}^{(i)} \right). \quad (2)$$

The forecast error value $\varepsilon_k^{(i)(j)}$ is the absolute value of the difference of the estimated and concrete values of the time series i with $\Gamma^{(j)}$. The forecast error of entire time series $\varepsilon^{(i)(j)}$ is calculated as the root mean square error of the individual forecast error values. For every time series and category the forecast error values are also calculated to define the nearness between two categories as follows:

$$e^{(j_1)(j_2)} = \textbf{mean} \left(\varepsilon^{(i),(j_2)}, \forall i : \mathbf{x}^{(i)} \in \mathcal{C}^{(j_1)} \right) \quad (3)$$

where $e^{(j_1)(j_2)}$ denotes the average forecast error of time series of category j_1 with approximator $\Gamma^{(j_2)}()$. As a result, an $\mathbf{E} \in \mathbb{R}^{M \times M}$ matrix of error values can be constructed. Thus two j_1 and j_2 categories can be merged if

$$j_2 = \min_j \left(e^{(j_1)(j)}, j = 1 \dots M, j \neq j_1 \right) \quad (4)$$

and

$$j_1 = \min_j \left(e^{(j_2)(j)}, j = 1 \dots M, j \neq j_2 \right) \quad (5)$$

In order to exclude cases where a time series from a specific category can be forecasted at similar error level with several other approximators, a $\Delta^{(j)}$ threshold value is introduced for each category. The threshold value is calculated as the difference of the mean and deviation of the error values:

$$\Delta^{(j)} = \mu^{(j)} - \sqrt{\frac{1}{K} \sum_{k=1}^{K} \left(e^{(k)(j)} - \mu^{(j)} \right)^2} \quad (6)$$

where $\mu^{(j)}$ is the mean of the error values:

$$\mu^{(j)} = \frac{1}{K} \sum_{k=1}^{K} e^{(k)(j)} \quad (7)$$

We have obtained good performance using (6), however the calculation of threshold value should be fitted to the characteristics of times series of real applications.

After a successful merge the iteration starts over. This recursion is executed while there are categories which can be merged.

When initialization is done the algorithm forks as follows: i) previously not categorized new, upcoming consumers assigned to existing (or new) category; ii) existing category assignments revised periodically in order to follow the changes of consumer's behavior. In next sections the two blocks are discussed.

C. Assigning consumer to existing category

The categorization of time series of a new customer is based on seeking the approximator hich minimizes the forecast error of the values of the time series to be categorized. Formally the new customer with time series $\mathbf{x}^{(\cdot)}$ can be assigned to category j, where the $\varepsilon^{(\cdot)(j)}$ minimal $\forall j = 1 \dots K$. Similarly to (6) a threshold value is applied to consider only significantly low error values during the decision of assigning a consumer to any of existing category. The threshold value is calculated as in (6) with a minor change: instead of values of $\mathbf{E}$ the $\varepsilon^{(\cdot)(j)}$ forecast error values are used.

The case when the minimal $\varepsilon^{(\cdot)(j)}$ value does not significantly differs from the other error values indicates that the new consumer does not belong to any existing category, thus it has to be assigned to a new category $\mathcal{C}^{M+1}$. If a change occurs among the members of a category then the training set of the corresponding approximator is reconstructed and the training is carried out.

D. Category change of a consumer

It is possible that the power consumption behavior of a consumer changes in time. That event should be detected and the assigned category of a consumer should be changed. This can be done with generally two different ways: i) periodically the method is re-initialized; ii) periodically the free parameters of approximators are reset and time series of all categories are re-evaluated. As the execution time of the method is characterized by the number of training phases to be performed, the second method is preferred which has fewer training phases. Furthermore in order to reduce the execution time the training of approximators can be done parallel. Each member of $\mathcal{C}^i$ is evaluated by all $\Gamma^{(j)}()$ and the decision of category assignment is revised using the decision rule introduced previously. After the reassignments are done the approximator of altered (both the old and new) categories have to be adapted by running the learning algorithm. Furthermore, it also may happens that a category turns into empty. In that case the category and its approximator can be disposed.

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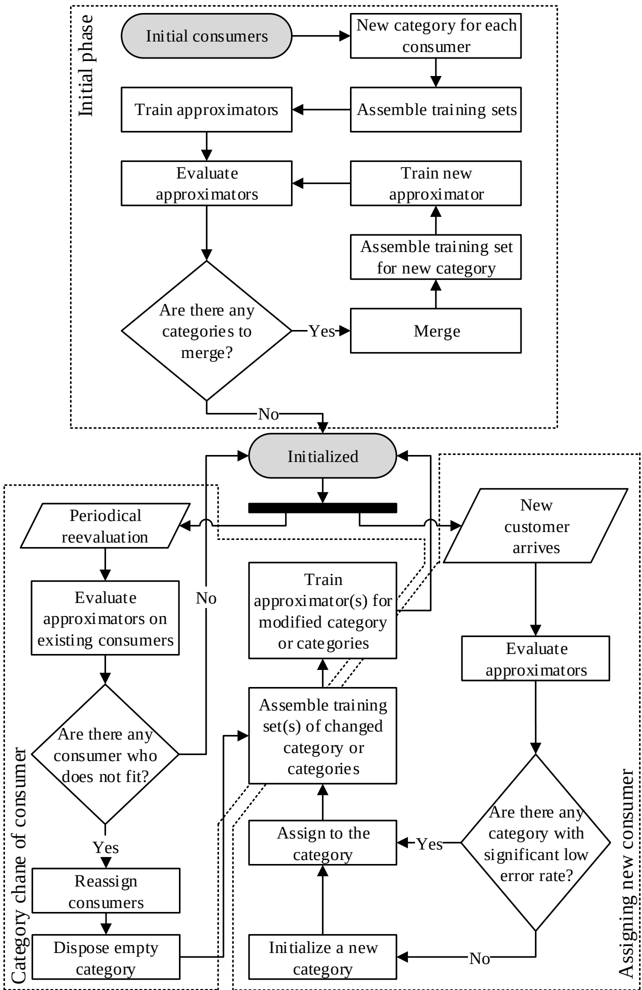

Figure 2. Algorithmic flow of consumer categorization

IV. PERFORMANCE ANALYSIS

In this section the data model, test environment and the performance of the proposed method is introduced. The categorization method were tested by artificially generated time series data and measured power consumption time series as well. The performance of the categorization method is evaluated as follows: for each time series the category which is considered as correct solution is known prior to the test (i.e. the parameters of the model which generated the time series is known, or manual categorization of real data is done). The desired category associations are compared to the results of the new categorization method and the ratio of correct and all decisions is used as performance metric.

A. Data models

Two approaches were used to generate time series: (i) autoregressive (AR) processes for testing and reference purpose only; (ii) a realistic bottom-up model, where the consumption data of consumers were constructed as the sum of statistically independent consumption data of electric appliances.

1) AR model for consumption time series: This model is used to produce time series to investigate the basic capabilities of the method. Exemplary parameters for AR processes (for different categories) are shown by Table II. Using these values, time series with different statistical properties can be artificially generated. The actual parameters for tests were fitted on measured power consumption time series.

TABLE II. Possible parameters for AR processes

	a_1	a_2	a_3	a_4	a_5
Category_1	0.3	0.7	0.3	-0.4	-0.2
Category_2	0.4	0.2	0.1	0.2	-0.1
Category_3	0.9	-0.8	0.5	-0.2	-0.1
Category_4	-0.4	0.8	0.3	-0.1	-0.1

2) Markovian model for consumption time series: Using the following model, we have generated close-to-real consumption time series. The consumption of individual appliances is described as a two-state Markovian process. Thus short term time dependencies of the time series are modeled. Formally, the power consumption of a single appliance is generated by a discrete random variable

$$X^{\text{Markovian}} \in \{0, h\}, \tag{8}$$

where the two states (On/Off) are the power off state and operational state where the actual power consumption is h. This model can be easily extended with additional power consumption levels.

The parameters of the Markovian model were fitted on real measurements, which are coming from the Reference Energy Disaggregation Data (REDD) set [24].

The total power consumption of a customer is modeled by the sum of individual Markovian processes. Each category of consumer contains different types of total power consumption data which are constructed from different types of appliances.

Figure 3 depicts the consumption of a single appliance, and also shows the time series generated by summing several independently generated Markovian On/Off processes.

As we have investigated the correctness of the model comparing the autocorrelation values of generated data and measured power consumption time series, we found that the generated values has similar long-term correlations, however the artificial data do not have the characteristics of daily periodicity.

B. Measured consumption data

The real consumption data used for the performance analysis were obtained from a large Central-European electricity distribution company. The measurements were acquired at 150 sites for one year in 2009. Each value in the time series represent aggregated power consumption for one hour. As the actual data is trade secret it has been normalized by the company and personal information was removed as well. The consumption data, for all consumer individually was categorized manually by technicians of the company. The differences of number of customers in categories are minimal. The proposed method was tested on the real data comparing the results of automated categorization to the manual categorization.

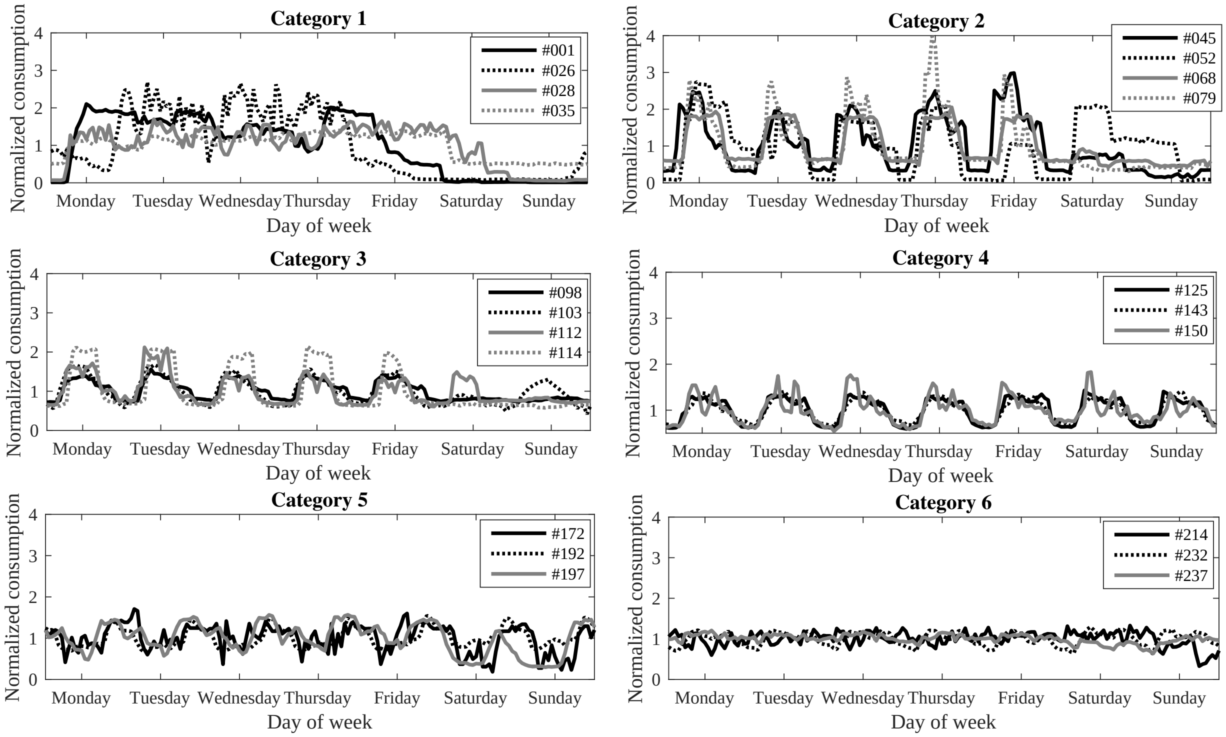

Figure 4. Exemplary power consumption time series from different categories

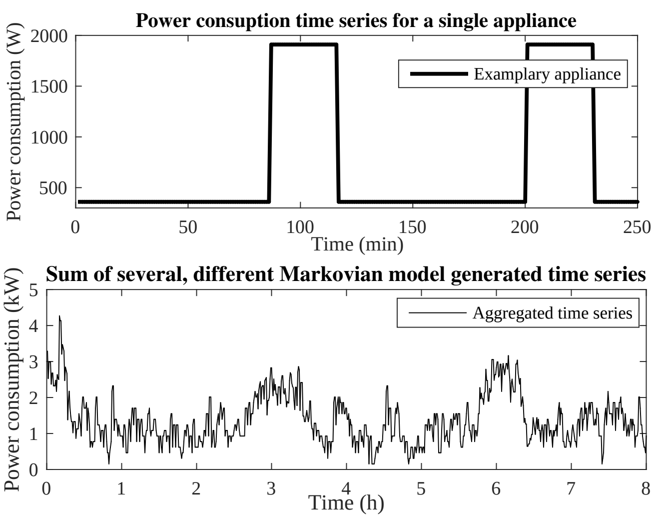

Figure 3. Demonstration of a) single Markovian On/Off model generated time series; and b) aggregated time series

Figure 4 demonstrate some of the different categories, with exemplary consumption time series. The figure also shows the differences of time series in a specific category as well. Category 1 contains power consumption of consumers who operate in weekdays continuously but not on weekends (first category). Consumers of second category have characteristics of repeating daily periods (both weekday only and all day as well), however the third category contains consumers with similar periodicity but the overnight consumption is significantly higher than the other consumers with periodical consumption pattern. Other categories either not have such regularities (e.g. sixth category) or the 'shape' of the daily periodicity differ from time series from other categories (e.g. fourth category). Also the degree of variance of the consumption time series can be the basis of dividing customer into different categories.

As a result, several aspects have to be taken into account, where some of them cannot be described in exact way. Thus the application of automated, self-learning methods are worthy in order to exploit information of hidden properties of time series.

C. *Performance results*

In this section, we introduce the results on performance analysis carried out on data models described previously. The simulations has been executed in Matlab environment [25]. We have repeated all test for several times to have averaged result in order to eliminate the preferential cases of FFNN.

1) Initial categorization: Figure 5 shows the performance results of initial categorization in case of different number of correct categories and of different data models. (Please note that in case of real consumption data only eight categories of data were available.) The evaluation of resuts is done as follows: the desired categories are matched with the resulted categories based on majority decision. In case of less or more categories, the members of missing or extra categories are considered as wrong category assignments.

For real consumption data the performance of detection capabilities are lower for eight categories than with less

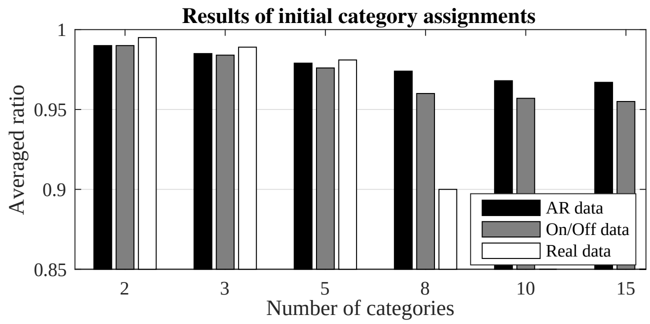

Figure 5. Results of performance test on initial categorization.

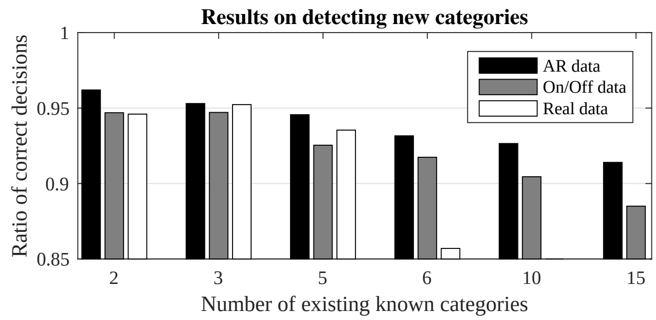

Figure 7. Results of performance test on detecting that for a new consumer a new category may be established

categories. Possible reasons are: i) some of the categories are overlapping; ii) the categorization made by the human experts are not only based on the consumption but some additional meta-information which are unavailable.

2) Category assignments of new consumers: There are two scenarios of category assignment of new consumers: i) the new consumer fits to any of existing categories; ii) new category is required for the new consumer. Both cases were investigated, but separately.

Figure 6 indicates the results, when no new category is required. The category assignment made by the method is considered correct, when the category assignment of new consumer matches to the desired category assignment. As can been seen, the method has high performance in case of each three data models, however in case of real consumption data the same characteristics can be observed as the performance of initial categorization.

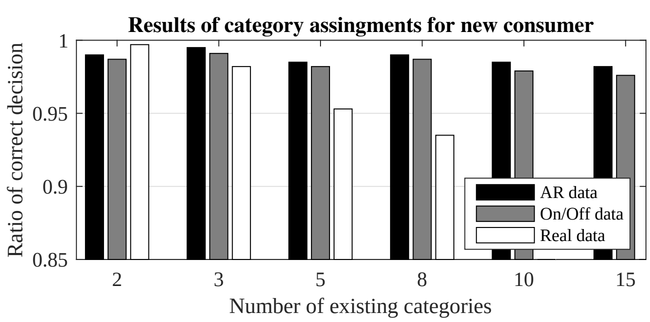

Figure 6. Results of performance test on assigning new consumers to existing categories.

Figure 7 shows the averaged correct decision ratios in case when new category have to be introduced for the new consumer as it does not fit to any of existing category. In case of this test the decision of the method correct, when a new category is introduced for the new consumer. The ratio of correct decision is defined as the proportion of cases when new category is created and number of all test cases. The ratio of correct decisions are generally lower, however it might be improved by introducing more sophisticated or adaptive threshold value (6).

3) Category changes: We have investigated the capabilities of change detection of our method, using hybrid time series which $1 \ldots M$ values are from different category from $M + 1 \ldots 2M$.

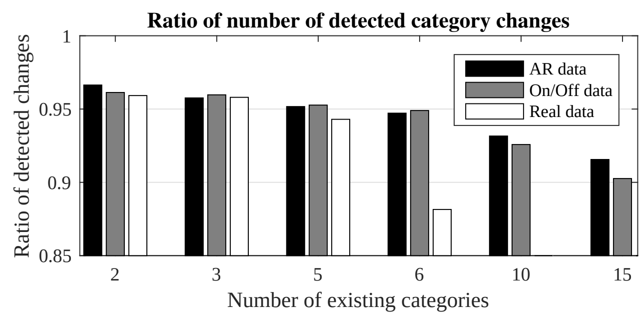

Figure 8. Results of performance test on detecting the consumer category changes

Figure 8 shows the results of correct detection of category change. During tests only the detected category changes were investigated, the false positive decisions were counted neither correct nor wrong decision. Results indicate that the performance is slightly better than in case of categorizing new consumers. This performance also may be improved by using more sophisticated threshold value.

V. Conclusion and Future Work

In this paper, we introduced a forecast based method to categorize different electricity consumers that have the same first and second order statistics but have different distributions and time dependencies. To forecast the values of time series a nonlinear approximator has been deployed.

The introduced method has been tested on different consumption models including realistic Markovian process based model. Furthermore, we have tested the method on measured power consumption data acquired by a Central European power distribution company. As a final result, it has been shown that feedforward neural network based method is capable of low error rate categorization in real applications on real data.

The performance of the method can be further improved by applying adaptive decision threshold value, or deploying other forecast methods and category decision algorithms as well, such as Radial Basis Function Networks, Deep Learning methods. These possibilities are considered as future work. Also our goal is to extend the method to handle medium term and long term periodicity of the time series.

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Smart Sustainable Cities: A New Perspective on Transformation, Roadmap and Framework Concepts

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Abstract—**The unprecedented rapid urbanization will affect the sustainability of cities around the globe. City leaders are currently seeking to transform their cities into Smart Sustainable Cities to face this global urbanization trend and its related challenges. To ensure the effectiveness and efficiency of a transformation process, current city needs, future trends, readiness of a city for the change, quality of life of citizens, and the set of smart and sustainable initiatives and solutions should be considered. The latter could be achieved through a comprehensive roadmap and framework to guide the transformation process. Developing such a roadmap and framework require a deep understanding of the concepts of transformation, roadmap, and framework in the context of Smart Sustainable Cities. Definitions that currently exist in the literature do not take into consideration the different objectives of a Smart Sustainable City. This constitutes a gap in knowledge. This research paper bridges this gap by highlighting the weaknesses and deficiencies in existing definitions and introduce new definitions for the three concepts, taking into account the specificity of a Smart Sustainable City as a solution for the rapid urbanization while maintaining the sustainability of a city and ensuring a high quality of life for its citizens. The proposed comprehensive definitions of these three concepts namely transformation, roadmap, and framework aim at guiding city planners, policy makers, and key stakeholders in developing and designing Smart Sustainable City initiatives and programs.**

Keywords-Smart Sustainable Cities; Transformation; Roadmap; Framework; Innovative Solutions.

I. INTRODUCTION

The world is experiencing the largest wave of urban growth in the history. Over half of the world's population is now living in cities. According to the United Nations estimates, by 2050, 66% of the total world's population is expected to be urban. With this rapid urbanization, cities will face sustainability challenges especially in the lower-middle-income countries where the urbanization speed is fast [1]. The challenges include (but not limited to) the social stress, poverty expansion, spatial dynamics, natural resources shortage, and urban pollution with its effects on the climate change [2].

Given this unprecedented global urbanization growth and the need for sustainability at all aspects of a city, the concept of "Smart Sustainable Cities" (SSCs) emerged as a desired goal for future urban development and attracted the attention of many researchers and practitioners in the field [3]. Their challenge is to ensure that cities are offering improved living conditions for their citizens by solving a set of sustainability challenges at the economic, environmental, and social levels. The Information and Communication Technologies (ICTs) offer high potential for solutions to many of these challenges while ensuring that they are environmentally friendly and viable [4].

The International Telecommunication Union Focus Group on Smart Sustainable Cities (ITU-T FG-SSC) analyzed nearly one hundred definitions of smart cities, sustainable cities, and SSCs to introduce a new definition for a SSC. This new definition refers to a SSC as "an innovative city that uses ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects".

Additionally, as illustrated in Fig. 1, a SSC is defined along six dimensions named: Smart Economy (competitiveness), Smart Environment (natural resources), Smart Governance (participation), Smart Living (quality of life), Smart Mobility (transport and ICT), and Smart People (social and human capital). Each dimension is described by a set of factors, used to identify where the smart and sustainable initiatives are needed under that dimension. Table 1 [6] lists these factors.

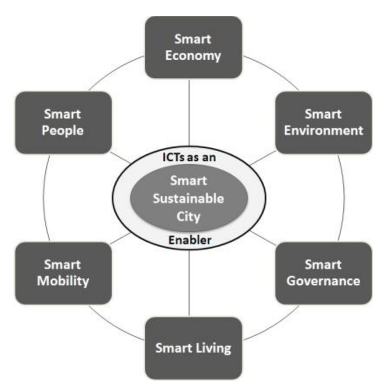

Figure 1. A SSC, its six dimensions, and the role of ICTs

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TABLE I. DIMENSIONS AND FACTORS OF A SSC

Dimension	Related Factors
Smart Economy	Innovative spirit Entrepreneurship Economic image and trademarks Productivity Flexibility of labour market International embeddings Ability to transform
Smart Environment	Attractive natural conditions Pollution Environmental protection Sustainable resource management
Smart Governance	Participation in decision-making Public and social services Transport governance Political strategies and perspective
Smart Living	Cultural facilities Health conditions Individual safety Housing quality Education facilities Touristic attractivity Social cohesion
Smart Mobility	Local accessibility (Inter)-national accessibility Availability of ICT infrastructure Sustainable, innovative, and safe transport systems
Smart People	Level of qualification Affinity for life-long learning Social and ethic plurality Creativity Flexibility Cosmopolitanism/open-mindedness Participation in public life

The main objectives of a SSC are to improve the quality of life of citizens, urban efficiency, and competitiveness, while taking into account the sustainability aspects of a city at all levels. The latter could be achieved through the use of ICTs and other means (e.g., policies) across various and interrelated systems, such as the provision and access to energy, education, transportation and mobility, water resources, waste management, housing and livelihoods (e.g., jobs), environment, local economic, and others [7].

To face the rapid urbanization and its related challenges, city leaders are currently seeking to transform their cities into SSCs. To ensure effective and efficient transformation process, the current city needs, future trends, readiness of a city for the change, quality of life of citizens, and the set of smart and sustainable initiatives and solutions should be considered [8] [9].

A transformation process, as illustrated in Fig. 2, consists of a high-level view roadmap that is used to identify the transformation process activities [30] (e.g., outline the need for defining a transformation plan). The roadmap, in turn, provides a framework(s) for strategic creation and turning strategy into actions [31] [32]. A framework often has a layered structure indicating what kind of initiatives can or should be developed and how they would interrelate. It provides the needed solutions to achieve the transformation activities (e.g., a recommendation to hospitals to develop online applications that allow patients to track their illness at any time). Developing such a roadmap and framework requires a comprehensive definition of a SSC transformation and a full understanding of the concepts of roadmaps and frameworks in the context of SSCs.

Different definitions of the concepts of SSC transformation, SSC roadmap, and SSC framework exist in the literature. The majority of these definitions do not take into consideration the specificity of a SSC as a solution that ensures the sustainability of a city at all levels while providing a high quality of life for its citizens through the use of ICTs and other means.

Using definitions that do not take into account all aspects of a SSC leads to an incomplete city transformation from one state to another. Without clear definitions of a SSC transformation, SSC roadmap, and SSC framework, city planners, policy makers, and key stakeholders will not have a concrete base to follow in designing their transformation roadmaps and frameworks. Consequently, the possibility of neglecting essential aspects while transforming a city into a SSC becomes high. Therefore a comprehensive definition for each of these three concepts is needed.

The aim of this research paper is to study and analyze existing definitions of SSC transformation, SSC roadmap, and SSC framework in the literature, highlight their weaknesses and deficiencies, and introduce new comprehensive definitions for these concepts. The proposed definitions could assist city policy makers and key stakeholders in developing and designing smart and sustainable initiatives that meet the objectives of a SSC. The research follows the literature based research methodology through which a gap in knowledge in relation to defining the concepts of transformation, roadmap, and framework in the contexts of SSCs is identified.

In what follows, a literature review on existing definitions of SSC transformation, SSC roadmap and SSC framework concepts is highlighted in Section 2. Section 3 provides a discussion on existing definitions of the three concepts and introduces new ones. The paper concludes with Section 4.

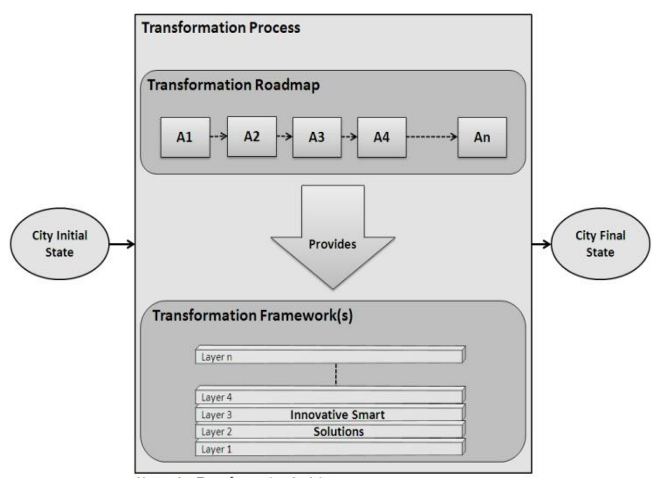

Figure 2. Concepts of a SSC Transformation, Roadmap, and Framework

II. LITERATURE REVIEW

Understanding the concepts of transformation, roadmap, and framework in the context of SSC is essential and dependent on their definitions. More clear definitions are used; more comprehensive transformation roadmap and framework could be developed and designed. However, the existing definitions of these concepts in the literature do not consider all objectives of a SSC.

The aim of this Section is to highlight the existing literature on a SSC transformation, SSC roadmap and SSC framework definitions.

A. *Transformation Concept in SSCs*

The rapid urbanization is a significant challenge facing cities around the globe. City leaders need to address this phenomenon by increasing the efficiency of existing city's systems, services and infrastructures to a level that have never been achieved before. The latter would be realized through a holistic transformation process to enhance the sustainability of a city at all levels and improve the high quality of life of citizens, such as the case of the transformation towards SSCs. For this transformation to be consistent with the objectives of a SSC, a comprehensive definition of a transformation concept is needed.

Generally, various definitions of the transformational change exit in the literature with no agreement yet about what could be and what could not be considered as a transformation [28]. The "Transformation Theory", proposed by Daszko and Sheinberg [18], defines a transformation as a "change" to create something new that has never been existed before. This change could not be predicted from the past and it leads to a change in the whole system structure, function and/ or form. Geels and Kemp [10] define a transformation as a continuous process (i.e., it is difficult to tell when a transformation process will end) that leads to changes in a direction of trajectories. During this process, a new system may be created from the old one, through changes that are being taken in a new direction.

For Satterthwaite and Dodman [25], a transformation is used to represent both the substantial activities and fundamental changes that affect economic, political, and social systems. The latter requires adaptation of policies and investments and integrates them with the development process of a city to meet its needs and to address the massive ecological footprint. A transformation in Harrington et al. [12] helps to divide the scope of change into manageable segments. It assists in identifying the key behaviors that are necessary to sustain the change and modifying and reinforcing positive behaviors through changing the structure of the system while measuring progress toward the previously identified goals.

Last but not least, a transformational change from the United Nations Development Program (UNDP) perspective [29] is a process by which positive development results are achieved and sustained over time through institutionalizing projects, policies, and programs within national strategies. It ensures the consistency of achievements over time, and does not include short-term transitory impacts.

In the context of SSCs, a transformation occurs at every level of a city, ranging from economic, social and environmental structures to the ways that form citizens' everyday lives. It is a long term process that cannot be achieved overnight. The Department of Business, Innovation and Skills (BIS) [24] does not provide a clear definition for a SSC transformation process; however, it shows a lack of absolute definition for a SSC that could be seen as a series of steps through which cities will be able to become more resilient and livable, hence, being able to respond quicker to new challenges.

A SSC Transformation in De Santis et al. [14] is a complex multidimensional process that changes over time as all involved stakeholders will work to achieve more and better results. The transformation will affect many aspects of city operations including government, mobility, energy, services, buildings, and environment. The ITU-T FG-SSC [19] defines a SSC transformation as a long-term process that consists of a series of generic steps. These steps are defined to allow compatibility and promote sustainability of a city as time passes.

Finally, Smart Dubai [23] defines a transformation as a process that focuses on four main issues: (1) efficiency through optimizing the use of city resources; (2) safety through protection of information and people and anticipating risks; (3) seamlessness through integrating daily services of life; and (4) impact through enriching business and life experiences.

B. *Roadmap Concept in SSCs*

Generally, a transformation roadmap is a high-level view of key activities that are required to change a situation from one state to another through defining a set of milestones that are needed to close a gap between the current and desired future situation [30]. A transformation roadmap in SSCs has almost the same meaning; with some specificity related to the nature and complexity of a transformation process in the context of SSCs.

In Schaffers [27], a transformation roadmap is required to realize the aspiration of SSCs as innovation ecosystems. It presents the state of the art, trends, and developments, as well as identifies challenges, obstacles, and gaps related to the transformation towards SSC. It reflects the vision of a SSC's socio-economic and cultural development.

Komninos et al. [21], define a SSC transformation roadmap as a blueprint that provides recommendations for urban development by using of future technologies. It allows formulating of some policy recommendations to city authorities for mastering the new interdisciplinary planning for SSCs. A transformation roadmap main purpose is to show how to control the interlinked city layers of infrastructure, digital technology, people-driven innovations ecosystems, and urban activities.

For the European Platform for Intelligent Cities [15], a transformation roadmap supports cities in their transformation towards SSCs operating environments. It includes various aspects of the transformation process including strategy development, program management, business case creation, and implementing and operating SSC

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services. The British Standards Institution [13] does not provide a specific definition for a transformation roadmap. It indicates that a SSC roadmap could be seen as a realistic framework that aims to deliver clearly identified results in achievable stages. From their point of view, each city in the United Kingdom (UK) should develop its own transformation roadmap based on its vision and goals. A roadmap is not a master plan and it should be deliverable. To be effective, a roadmap should take a phased and incremental approach and there is no need to over-plan at the beginning but instead provides a framework to support the transformation process to deliver the city vision over time.

For the ITU-T FG-SSC [20], a SSC roadmap is a process that can be followed by city leaders and managers to transform their city into a SSC. It provides a framework to guide the transformation process, identify a set of SSC services, and focus on different ICT infrastructures. It also consists of a security framework to protect citizens, and provides monitoring techniques and ways to include citizens in the transformation process.

Finally, the Smart Cities Council [26] defines a transformation roadmap as a bridge between ideas and actions. It is linked directly to the city vision document and/or development plan; therefore; it is neither a vision document nor a master plan. A transformation roadmap is a simplified outline that shows the major steps of how to become a SSC and could overcome the obstacles to a SSC transformation. The benefits of a SSC transformation roadmap include identifying the best place to start from, enabling cities to build in stages, maximizing synergies and minimizing cost, increasing public support, and attracting talent and businesses.

C. Framework Concept in SSCs

Transforming a city into a SSC requires a comprehensive framework to guide the transformation process. While a transformation roadmap provides a high-level view of changes that are needed to shift a situation from one state to another, a framework provides a set of tools that can be used to get there [30]. A transformation framework, in general, is a structure that can be used as a guide to build systems from scratch or modify existing ones into something useful.

Although there is frequent use of the term “Smart Sustainable City” in the literature recently, there are still few attempts to provide a definition for its framework concept. To start with, a SSC framework has been defined by CISCO [11] as a process that helps city key stakeholders and participants to understand how cities operate, define city objectives, understand the role of ICTs within the city physical assets, and define the role of stakeholders within a city. It is a step-by-step process of how to implement SSC initiatives. It allows cities to create a standard index system to record, collect, and measure city data that could be used to manage and implement SSC solutions for the purpose of economic, social, and environmental gains.

Chourabi et al. [17], define a SSC framework as an integrative framework that can be used to assist government professionals on how to establish SSC initiatives. From their point of view, a SSC framework should be based on eight critical factors that are: economy, governance, policy context, technology, built infrastructure, management and organization, natural environment, and people and communities. A SSC framework should clarify the influences and relationships between any suggested SSC initiative and these eight factors. Lee and Hancock [22], define a SSC framework as a conceptual framework that provides a holistic view of a SSC development. It is a tool that can be used to classify different initiatives and implementation practices.

The British Standards Institute [13] defines a SSC framework as a guide used by UK city leaders of SSC programs, at all levels and from all sectors. The focus of a SSC framework is to enable processes by which new smart technologies could be coupled with organizational change to help deliver the different visions of UK future cities efficiently, effectively, and sustainably. The framework captures the current good practices and provides “how-to” advices to help city leaders in developing and delivering their own SSC strategies.

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (*IEC*) indicates that a SSC framework could be seen as a layered structure that captures different cross-city governance processes aiming to deliver benefits based on core guiding principles while taking into account the critical success factors. It provides a valuable set of tools for scenario-building to guide the transformation process through participative decision making [16].

Last but not least, the Smart Cities Council [26] defines a SSC framework as a guide through which cities can plan and implement their SSCs. It captures the relationship between city responsibilities (i.e., what should be accomplished for citizens) and its enablers (i.e., the use of smart technologies to make these tasks easier). A SSC framework could transform a city into a SSC while ensuring that individual projects are compatible with each other even if they have been developed separately and at different times.

III. DESCUSSION AND NEWLY INRODUCED DEFINITIONS

The objectives of a SSC are to improve the quality of life of citizens, urban efficiency, and competitiveness, while ensuring the sustainability aspects of a city at the economic, social (i.e., including cultural aspects), and environmental levels [5]. This could be achieved through providing innovative solutions, using ICTs and other means, on the dimensions of Smart Economy, Smart Environment, Smart, Governance, Smart Living, Smart Mobility, and Smart People [6], as illustrated in Fig. 3.

Any attempt to design and develop a transformation process towards SSCs should take into consideration the objectives of a SSC and explicitly reflected in the definitions of a SSC transformation, SSC roadmap, and SSC framework concepts. In the following sub-section, new comprehensive definitions for these concepts capturing the objectives of SSC are introduced.

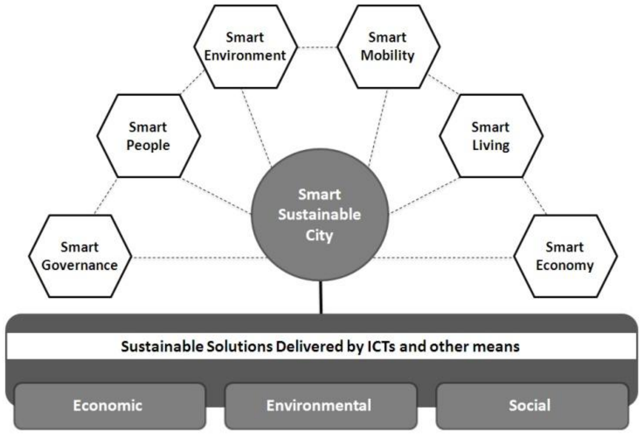

Figure 3. Overview of relationship between a SSC and City's Sustainability

A. *SSC Transformation Definition*

The analysis of existing definitions of a SSC transformation concept in the literature shows that there is no standardized, commonly accepted set of terminologies to describe and define a SSC transformation. Depending upon the lens with which it is viewed, there are different definitions of the concept in the literature. None of the studied definitions take into account all aspects of a SSC. For example, some of the listed definitions consider the quality of life as important objective of a SSC while others do not. Some definitions indicate the significance of improving the sustainability of a city while others neglect this issue. Also, as shown through the analysis of the listed definitions and keywords used, the use of ICTs as an enabler to reach the SSC objectives is not highlighted.

The list of extracted keywords used to define or describe a SSC transformation in the studied definitions is as below:

- Process
- Series of steps
- Series of generic steps
- Complex
- Multidimensional
- Change over time
- Compatibility
- Sustainability
- Resilient
- Livable
- Efficiency
- City resources
- Safety
- Seamlessness

Analyzing the above listed definitions shows that the objectives of a SSC are not properly considered. The role of ICTs, as an enabler to SSC, is also not highlighted. Therefore, believing in the need to highlight these elements, this research defines transformation towards a SSC as "*a complex multidimensional process through which changes are applied at all city levels; aiming to enhance the sustainability of a city and provide a high quality of life for its citizens through the use of ICTs and other means*".

B. *SSC Roadmap Definition*

The existing definitions available in the literature of a SSC roadmap have been studied and analyzed. As in the case of a SSC transformation, the results show that there are no common set of terminologies to describe and define a SSC roadmap. Each definition defines the concept from its point of view. None of the studied definitions take into account the objectives of a SSC. For instance, the sustainability of a city, which is one of the important objectives of the transformation towards SSCs, is not considered in any of the studied definitions.

The list of keywords used to define or describe a SSC roadmap in the studied definitions is as below:

- Outline
- Process
- Blueprint
- Phased and incremental
- Realistic framework
- Show how
- Support transformation
- Provide recommendations
- Technology
- Not a vision
- Not a master plan
- City layers
- Urban development
- Cultural development
- Socio-economic development

Given the analysis mentioned above, this research paper introduces a new definition for the concept of a SSC roadmap in line with its main objective, which reads as follows: "*A SSC roadmap provides a high-level view of the objectives and goals of the transformation process and identifies the transformation activities and milestones in order to realize the city's vision for being smart and sustainable".*

C. *SSC Framework Definition*

The studied definitions of a SSC framework concept in the literature do not follow a standardized, commonly accepted set of terminologies to define and describe the concept. Each study defines a SSC framework from its perspective or depending on the needs of a city over which a framework will be applied. None of the listed definition takes into account all aspects of the objectives of a SSC. For example, the quality of life of citizens is not highlighted in any of the listed definitions.

The list of extracted keywords used to define or describe a SSC framework in the studied definitions is as below:

- Process
- Integrated
- Conceptual
- Layered structure
- Provide tools
- How-to
- Plan and implement
- Government professionals
- Stakeholders
- Change
- Services
- Deliver vision
- Strategies
- Initiatives
- Sustainability
- ICTs

Examining the readiness of a city for a change is essential before starting a transformation process. Any change programs or initiatives are likely to lead to only failure if they start before ensuring the readiness of a city for a change [33]. According to the Community Tool Box of the University of Kansas, the readiness for change differs from one city to another depending on its context and varies across city levels as well [34]. Some cities may be more than ready for the desired change while others being at a very earliest stages of readiness for that change. Therefore, any transformation process should take into consideration the

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city capabilities and adapt the transformation framework accordingly.

The analysis of studied definitions of a SSC framework shows that the readiness of a city for a transformation process, which is assessed using tools identified by a transformation framework, is not taken into account in any of the listed definitions.

Accordingly, a new comprehensive definition of a SSC framework that takes into account all aspects of a SSC and the need for assessing the readiness of a city for a transformation process is introduced. This research considers a SSC framework as "*a layered structure that leads city planners and relevant stakeholders throughout a transformation process by providing guidance on city readiness for change and the innovative solutions needed to grant urban sustainability and high quality of life for citizens*".

IV. CONCLUSION AND FUTURE WORK

To face the rapid urbanization and its related challenges, city leaders are currently seeking to transform their cities into SSCs. The latter could be achieved through a comprehensive transformation process and its related transformation roadmap and framework. Developing such a roadmap and framework requires complete definitions of the concepts of transformation, roadmap, and framework in the context of SSCs. The main objectives of a SSC should be explicitly reflected in these definitions to avoid neglecting any essential aspects while transforming a city into a SSC. Studying and analyzing existing definitions of these three concepts in the literature shows that some of the important objectives of a SSC are not considered which constitutes a knowledge gap. This research bridges this gap by introducing new comprehensive definitions for the concepts of SSC transformation, SSC roadmap, and SSC framework, while ensuring that they are consistent with the main objectives of a SSC. The proposed definitions of these three concepts aim at guiding city planners, policy makers, and key stakeholders in developing and designing SSC initiatives. In the future, this work will be used as a base for developing and designing a conceptual framework that assist in the transformation towards SSCs.

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Smartness of Smart Sustainable Cities: a Multidimensional Dynamic Process Fostering Sustainable Development

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***Abstract* — Smart Sustainable Cities are gaining global attention rapidly. They are becoming a reality and hundreds of related initiatives around the world are taking place. Accordingly, cities are claiming to be smart and even smarter than others. However, smartness, as a concept, still has no standardized definition noting that it does not exist until it is defined and measured. For selected researchers and practitioners, it is assessed through the city's participatory governance, economy, mobility, environmental strategy and management of natural resources, and the presence of aware citizens. Others focus on the advancement of technologies and the infrastructure needed to introduce smart solutions. For smartness to be properly assessed, its boundaries should be clearly set. By setting these boundaries through a comprehensive definition, it becomes possible to build an assessment model that methodologically monitors smartness of cities. In this research, a literature review on existing interpretations of smartness is presented and followed by an analysis of the goals of a Smart Sustainable City with lights shed on the quest of sustainable development. Through an analytical discussion, smartness is proved to be a dynamic process enabling change. It uses technologies to infuse innovation thereby achieving multidimensional urban efficiency. Also, a mutually reinforcing relationship between smartness and sustainable development is shown. The research paper concludes with introducing a holistic definition of smartness which contributes to clarifying the concept and constitutes a cornerstone in assessing the performance of Smart Sustainable Cities. It also provides the grounds for supporting or defying self proclamation of a city for being smart and/ or smarter than others.**

Keywords- Smart Sustainable City; Smartness; Development; Information and communication Technology; Innovation.

I. Introduction

With the transition from the 20th to the 21st century, overpopulation became one of the core concerns in relation to urban growth and sustainability of cities. Today, 54% of the world's population lives in urban areas, a proportion that is estimated to reach 66% by 2050 [1]. Urban growth is expected to continue and this requires a major change in the approaches of urban planners. Cities should be turned into safe, healthy, efficient and attractive places for people to live in. Attention should be attributed to different variables constituting the base for a Smart Sustainable City (SSC) [2]. Though advanced, SSCs are becoming a reality and hundreds of related initiatives around the world are taking place [3]. Currently, there exists a competition on how to interpret the concept of a SSC. It has become a notion with a relatively positive connotation [4]. Many cities around the world embarked on the SSCs bandwagon labeling themselves as "smart" believing that it is a sign of development [5] whereas smartness does not exist until it is properly defined and measured [6].

Smartness, used to assess the performance of a SSC, is still not a well rooted concept in the literature. It is regarded differently by different researchers and practitioners. One group of countries claims to be smart by associating smartness to the development of the technical infrastructure needed for a SSC. Another group refers to smartness as the improvement of e-government services considered to be a prerequisite for the development of a SSC [7]. The variance in the interpretation of the concept makes it difficult to set the boundaries for assessing and reviewing the performance of a SSC and to overcome self proclamations of cities for being smart and sustainable. Therefore, this research aims at filling this gap in knowledge.

The main driving question to identify smartness is "What could be the main elements that make a city smartly sustainable"? Is it governance, technology, communication, transport, infrastructure, people, economy, culture, environment, natural resources, innovation, quality of living or something else? By answering this question, we would be identifying the main elements and potential cross cutting issues in a SSC that city planners and decision makers should consider when assessing the performance of a selected city. Therefore, identifying, through a critical analysis, the boundaries of smartness either by adopting an existing definition or by putting forward a new one that captures the elements needed to be present for a city to be smart and sustainable is needed. By bridging this gap in knowledge, this paper aims at providing guidance on the main issues to look at when assessing smartness and explaining what it really means for a city to be smarter than another in the urban sphere. In addition to framing the core elements constituting smartness of SSCs, the introduced definition is anticipated to provide basis for building a comprehensive model to monitor smartness on one hand and to assist policy and decision makers in urban planning for the betterment of their cities on another hand [8]. Also, this paper links smartness to the quest of sustainable development, a concept that is widespread at the global level.

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Section 2 of this paper explores the concept of smartness and its exiting definitions. Section 3 critically analyzes the definitions of smartness and sheds light on its alignment to the principles of sustainable development. Section 4 highlights enablers and cross cutting issues affecting smartness and proves it to be a dynamic process. Section 5 overviews the expected outcomes of the research. The paper concludes with Section 6.

II. SMARTNESS: CONCEPT AND DEFINITION

This section sheds light on the definitions of a SSC and smartness as available in the litterature and touches on different related concepts.

A. Definition of a SSC

The definitions of a SSC are numerous and so is the interpretation of smartness. The concept is getting popular around the world but it is being referred to in different names and in varied contexts which makes it fuzzy. There is neither a single template for framing this concept nor a unique definition [9]. In order to address this gap in knowledge, the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), responsible for standardizing telecommunications related issues at the global level, formed a technical focus group named the ITU-T Focus Group on Smart Sustainable Cities (FG-SSC). The latter, after an extensive participatory effort, standardized the definition of a SSC as follows: “A smart sustainable city is an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects" [10].

Variance in relation to the dimensions of a SSC also exists in the literature [11], but the majority of the approaches agree on six dimensions, namely smart economy, smart environment, smart governance, smart living, smart mobility and smart people [12] as depicted in Fig. 1. The ITU through its ITU-T/FG-SSC referred to these dimensions as the primary indicators for a SSC. Given the adoption of these six dimensions by the international community and their strong academic foundation, they are used in this research to represent the dimensions of a SSC. The integration of these dimensions among others will constitute the main blocks of smartness.

B. Definition of Smartness

Tracing the roots of the term “smartness” in the context of cities can contribute to a better understanding of what this term denotes and connotes in the urban sphere. In the marketing language, smartness is centered on a user perspective [13]. In the urban planning field, it refers to the intelligent use of ICTs to improve the productivity and efficiency of a city’s infrastructure and services [14]. In the technology context, smartness implies the automatic computing principle such as self-configuration, self-healing, self-protection, and self-optimization [15]. In the urban growth context, smartness is treated as a normative claim and ideological dimension. Being smarter entails strategic directions and adaptation to user needs [16]. Nowadays, governments and public agencies at all levels are embracing the notion of smartness to distinguish their new policies, strategies, and programs for targeting development, economic growth, and better quality of life for their citizens [17].

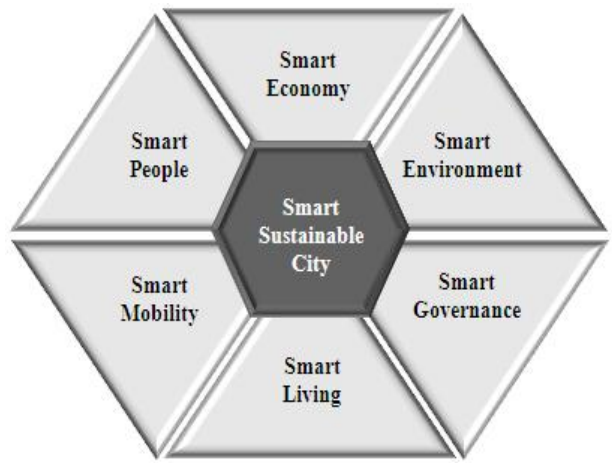

Figure 1. Dimensions of a Smart Sustainable City

Academics, professionals, private sector and governments, despite few commonalities, refer to smartness differently. “Smartness” of a city describes its ability to bring together all its resources to effectively and seamlessly achieve the goals and the targets it has set to itself [18]. Thus, smartness is mainly linked to seamless integration and interoperability. In some instances, smartness is interpreted as being strictly linked to urban efficiency at the level of economic development, environment, human capital, culture and leisure, and e-governance [19]. It is also regarded as urban efficiency along the six dimensions previously mentioned and considered intelligence as the use of ICTs infrastructure as the "glue" which integrates all the other elements of the smartness of the city [20]. Another approach groups the core factors leading to smartness into three categories, namely technology, people and institution and refers to smartness, in this case, as the urban efficiency reached via the intersection of these three groups [21]. Also, literature research shows that core smartness factors are also focused on sustainability and livability [22]. The latter lists internal and external factors grouped into eight clusters, namely management and organization, technology, governance, policy, people and communities, economy, built infrastructure and the natural environment. Therefore, smartness is the result of the achievement of these factors all together aiming at achieving urban efficiency. According to the European Union, smartness is a concept associated with the model of a technologically advanced, green and economically attractive city [23]. The ITU-T/FG-SSC considers smartness as an attribute of the SSC along the six different dimensions shown in Fig. 1. It also looks at smartness in terms of finding smart solutions instead of conventional ones to address the needs of citizens. Therefore, smartness refers to addressing the needs of citizens via innovative technologically oriented solutions. In-line with this focus on innovation, selected researchers and practitioners interpret smartness as innovativeness [24].

Different approaches highlighted the role of technology and mainly ICTs as crucial to smartness since it transforms life and work within a city in significant and fundamental ways [25]. However, researchers argue that without the real engagement and willingness to collaborate and cooperate between public institutions, private sector, voluntary organizations, schools and citizens, smartness will not be reached [26]. Therefore, ICTs are essential for smartness but collaboration and partnerships amongst the different elements of the city is a must.

The list of definitions is long which clearly shows that the concept is still vague. No effort was so far conducted to come up with a synthesized definition capturing the main elements of smartness in the context of SSCs. In what follows, a discussion of the aforementioned definitions is presented and a holistic definition of smartness framing its related elements is introduced.

III. Smartness of a SSC: Towards a Holistic Definition

This section discusses the above mentioned definitions of smartness and shows that smartness is a multidimensional dynamic process fostering the principles of sustainable development.

A. *Discussion of Definitions*

The presented definitions of smartness show the variance in interpreting the concept amongst governments, international organizations, academia, private sector, civil society organizations and others. They focus on innovation and technology as being important elements of a SSC and the majority considers ICTs and other means as enablers for city's advancement and sustainability. They also consider it as a facilitator for ensuring integration and interoperability amongst the different systems of the city. Moreover, the approaches either consider smartness as the process of achieving urban efficiency at the aforementioned six different dimensions or along a subset of these dimensions.

In addition to achieving urban integration and interoperability, thus efficiency through innovative use of technologies and other means, several points are important to note. These are the adaptation to citizens' needs and their quality of life. Also, different definitions shed light on the role of citizen engagement and on selected means of implementation of a SSC like partnerships between the different stakeholders in a city as a mean for advancing the realization of a SSC. Accordingly, smartness could be associated to the use of ICTs and other means to advance innovation throughout the different dimensions of a city to achieve urban efficiency. Smartness necessitates undertaking a series of actions to achieve urban efficiency; In other words, smartness is a process aimed at achieving urban efficiency. The latter is achieved by following an integrated approach which addresses the citizens' needs while advancing economic growth and being environmentally friendly. This lies at the core of the concept of Sustainable Development and its principles which commit to equality, inclusion and justice, the precautionary principle, and the integration of the complex interconnections that exist between the environment, economy, and society. Therefore, smartness of a city is related to the quest of sustainable development. In the following section, we will explore in more details the concept of sustainable development, its pillars and relation to the objectives of a SSC, thus its role in identifying the smartness of a selected SSC.

B. *Alignment with the Principles of Sustainable Development*

This section highlights the alignment existing between the goals of a SSC and the core principles of sustainable development. Thus, it justifies the mutually reinforcing linkage we create between smartness and sustainable development.

To start with, the concept of sustainable development became well known after the launch of "Our Common Future", a report published by the World Commission on Environment and Development in 1987. This report, also known as the Brundtland report, refers to sustainable development as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs." The concept received global support after its acceptance by the United Nations General Assembly. In 1992, leaders of states around the world set out the principles of sustainable development at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil [27]. These principles focused among others on social equality and inclusion which is in itself challenging as it requires moving beyond meeting immediate needs and investing in solutions that lead, in the long term, to sustainable and resilient outcomes in the lives and livelihoods of populations [28]. The key principle of sustainable development underlying all others is the integration of environmental, social, and economic concerns into all aspects of decision making and governance systems. This integrated rather than fragmented approach is essential to urban efficiency in the context of SSCs and they are explicitly mentioned in the ITU definition of a SSC. Therefore, a relationship between the smartness and sustainable development is identified.

Since the Brundtland report and the Rio Summit, sustainable development has transitioned from being a debatable concept, to one that has widespread endorsement by international institutions, governments, businesses, and civil society. It recognizes that growth must be inclusive and environmentally sound to reduce poverty and build shared prosperity for today's population and to continue to meet the needs of future generations. It focuses on carefully planning to deliver both immediate and long-term benefits for people, planet, and prosperity [29]. Also, sustainable and resilient livelihoods denote granting sustainable and resilient good quality of life which is an objective of a SSC.

The concept supports economic and social development, in particular for people with a low standard of living and in parallel highlights the need for protecting natural resources and the environment [19]. It has generally been recognized for main aspects, namely Economic, Environmental and Social along with synergies amongst them and implications on governance systems. The economic aspect focuses on the ability to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme imbalances. The environmental aspect maintains a stable resource base. The social aspect focuses on achieving distributional equity, adequate provision of social services including health and education, gender, and political accountability and participation. Fig. 2 shows the synergies between these aspects.

Given the above, sustainable development is considered as a process and sustainability is the state where the key goals of sustainable development are addressed: a high quality of life is achieved and the environment is preserved [30]. To attain an improved quality of life, which is one of the main goals of SSC, the city should be people-centered. It should address the needs of its citizens especially those of the poor to which main priority should be given as it constitutes the greatest challenge and indispensable requirement for achieving sustainable development [28].

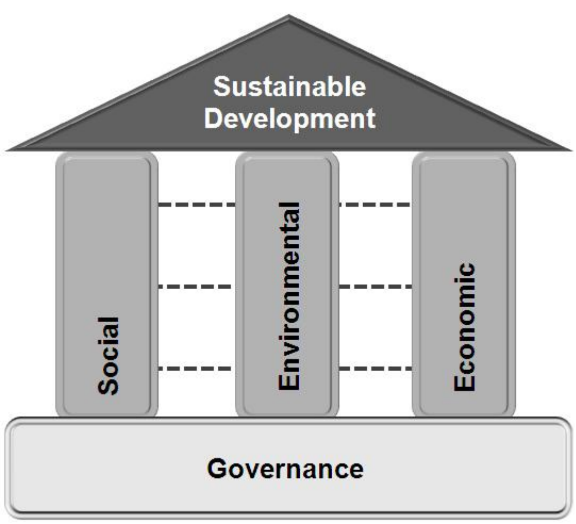

Figure 2. Aspects of Sustainable Development

Also, attaining a high quality of life requires reducing inequalities, considered to be a core driver for advancing sustainable development. Therefore, contributing to the process of sustainable development results in a contribution to smartness in the context of cities and vice versa, thus the relationship identified above could be regarded as mutual in nature.

It is important to note that culture can be a powerful driver for development, with social, economic and environmental impacts at the community level [30]. Development approaches that are responsive to the cultural context and the specificities of a place and community, and advance a human-centered approach to development, are most effective, and likely to yield sustainable, inclusive and equitable outcomes [28]. Acknowledging and promoting respect for cultural diversity can facilitate achieving development goals and improving quality of life. Culture, understood this way, makes, development more sustainable, urban efficiency higher and cities smarter. Therefore culture further strengthens the linkage between smartness and the alignment with sustainable development

Last but not least, in September 2015, during the United Nations Summit, the Sustainable Development Goals were announced and adopted by the world governments. They replace the Millennium Development Goals (MDGs) to present a holistic approach to development by embracing integrated economic, social and environmental dimensions. They constitute a set of 17 goals and 169 global development targets defining the global sustainable development agenda [31]. Goal 11 is dedicated to SSCs and communities which further supports our approach in linking smartness to sustainable development.

This alignment is of upmost importance since, if properly implemented, it addresses many of the criticisms facing SSCs. For instance, one of the reported criticisms of SSCs is the possibility of widening digital gap and the alienation of a big portion of the society, namely the technology illiterate. Following this example, when measuring smartness bearing in mind the principles of sustainable development, we would not only measure availability of services but also equal accessibility. Therefore, smartness, when linked to sustainable development, will advance concepts of equality and inclusion and respond to comparable criticisms. It will also highlight the integration needed to be present among the different aspects of a city. Up to this point, smartness in addition to being associated to the use of ICTs and other means to advance innovation at the different dimensions of the city to achieve urban efficiency, it is proved to be a process that enjoys a mutually reinforcing relationship with sustainable development.

C. *Smartness: a Multidimensional Dynamic Process*

In what follows, a discussion highlighting cross cutting issues and enablers of SSCs and which affect smartness of cities is provided. The dynamicity of the smartness process is also underlined.

1) Smartness Cross cutting Issues and Enablers

As mentioned previously, the integration of environmental, social, and economic concerns into all aspects of decision making and governance systems are essential to sustainable urban efficiency [32]. Recalling the SSC definition of ITU, we note that not only integration is needed but also innovation. ITU refers to a SSC as an innovative city. Therefore, innovation lies at the core of SSCs and relates to the different dimensions of a city. Also, ICTs and other means are considered as the nerve connecting all dimensions of a city to grant efficiency.

The main challenge towards the transition to a more equitable and environmentally aware growth is to address the innovation issue not only from an economic, but also from social and environmental dimensions [30]. Also, for sustainable development, the challenge for innovation does not rest solely on economic benefits and opportunities, but also in the societal changes induced by innovative capacity and the consequences of this for the environmental and social sustainability. Innovation can lead to the transformation of systems, values and culture as well as the production of new and/or improved products or processes [33]. Innovation serves as a crucial driver of rising prosperity and improved national competitiveness [34]. It fosters the wheel of sustainable development [35], thus fosters the realization of SSCs and affects their smartness.

In addition to innovation, we regard ICTs as an enabler for achieving urban efficiency and improving quality of life of citizens. ICTs alone are rarely the key to unlocking economic value, but it induces real wealth creation when it is combined with new ways of doing business and provides an important opportunity for technological leapfrogging, in particular through mobile telephony [36]. ICTs allow the production of better statistics leading to better decision making, deployment of an intelligent infrastructure, advancement of social inclusiveness and citizens' engagement, enhancement of economic competitiveness, establishment of low carbon businesses and promotion of sustainability [37]. In addition, the fragmented approach to development resulted in having applications that live in silos. Business as usual cannot continue when implementing SSCs and trying to monitor smartness. Integration between the different dimensions of a city should be promoted to grant sustainability. This technical integration amongst different platforms constitutes one of the main roles that ICTs can play in a SSC, thus smartness.

Researchers refer to technology differently. Some of them consider technology as a crucial dimension of a SSC [21] while others believe that it is an indispensable ingredient of the SSC that acts as glue connecting different everyday living services to public infrastructures thus ensuring integration and interoperability. It is the orchestrator of the various elements of the SSC which should coexist [3]. The ITU-T/FG-SSC highlights the crucial existence of technologies due to their ability to act as a digital platform from which an information and knowledge network can be created [5]. Such a network allows for the aggregation of information and data not only for the purpose of data analysis, but also towards an improved understanding on how the city is functioning in terms of resource consumption, services, and lifestyles. Information made available by these digital platforms would serve as a reference for stakeholders to take action and create policy directions that would eventually improve the quality of life for the citizens and the society as a whole. Therefore, ICTs constitute an enabler for SSCs and a tool to be harnessed for ensuring sustainable development. Therefore, ICTs provide opportunities for increasing integration among the different dimensions thereby attaining urban efficiency. Harnessing ICTs for realizing sustainable development enforces the importance of highlighting it in the definition of smartness as a tool to achieve urban efficiency. Therefore, smartness, up to this point, denotes the use of ICTs and other means to infuse innovation at all dimensions of a city thereby advancing urban efficiency.

2) Smartness: a Dynamic Process

Having defined the main elements of smartness, its enablers and the mutually reinforcing relationship with sustainable development, it is important to show whether it is a snapshot or a process and whether it is of dynamic or static nature. So far, we clearly see that there have been three distinct phases of how cities transformed from being technology driven to city government driven and lately to be citizens driven. The first phase of SSCs is characterized by technology providers encouraging the adoption of their solutions to cities without taking into consideration their impact on citizens and their quality of life. Thus, smartness is solely connoting the adoption of advanced technical solutions. A shift in the manifestation of SSCs occurred thus a new phase of cities with a different interpretation of smartness took place. This phase was led by city planners instead of technology providers and they focused on technology solutions aimed at improving the quality of life of citizens. In this case, the concept of smartness changed to include the impact of the adopted solutions on people. Lately, leading SSCs started to embrace citizen co-creation models for helping to drive the next generation of smarter cities where the engagement of citizens lie at the core of the advancement of cities. Smartness, in this case, focuses on citizen's engagement and social inclusion, a core principle in the sphere of sustainable development. These different phases or manifestations of SSCs denote the dynamicity of the concept of smartness. Also, it sheds the light on the need for technology to provide services and ensure coherence amongst the city's systems and governments to properly adopt technology enabled solution for the betterment of the city and the lives of its citizens. These objectives lie at the core of the philosophy of sustainable development. These concepts of equality added to the elements previously mentioned constitute the basis for sustainable development which is on its own a process, not an end in itself. [38].

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Having discussed the dynamicity of smartness as a process, the dimensions to consider for urban efficiency, the cross-cutting issues and enablers, and the need for alignment with the principles of sustainable development principles, it becomes possible to introduce a new holistic definition which reads as follows: *"Smartness is a dynamic process through which ICTs and other means are used to advance innovative multidimensional urban efficiency in line with the principles of sustainable development"***.** Each city is unique with distinctive economic, environmental and social contexts and will have to determine its own path to becoming smart and sustainable while benefiting from available and related good practices. Becoming a SSC is not an end goal but rather a process enabling change. Fig. 3 depicts the result of analyzing the concept of smartness.

IV. EXPECTED OUTCOME

The discussion above clearly indicates the lack of a clear harmonized and holistic definition of smartness in the context of SSCs. By following a hybrid approach, this research puts forward a definition for smartness. It highlights the importance of ICTs and other means as enablers to advance innovative multidimensional urban efficiency while ensuring alignment with sustainable development principles. This introduced concept is expected to constitute the foundation of a methodological model aimed at assessing the performance of a SSC, thus monitoring its smartness. This is important given the inexistence of such a model and its importance in assisting policy and decision makers in urban planning in the prioritization of efforts for the betterment of their cities [8] [39].

By observing smartness and the quest of sustainable development, we highlight a mutually reinforcing relationship among them. Both, to be achieved, for instance,

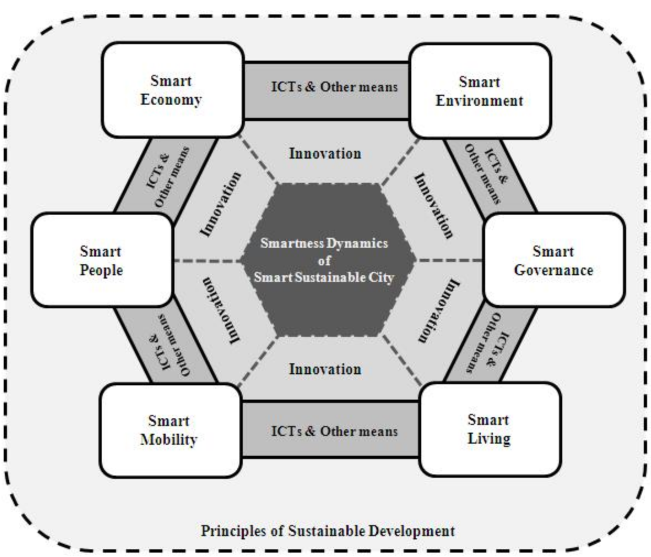

Figure 3. Smartness Dynamics of a Smart Sustainable City

should be people centered and should grant people a high quality of life. By linking both processes, we note that smartness is not only about technologies and use of smart solutions but rather about achieving economic development with environmental ceiling and social foundation touching on, just to name few, social equity, gender equality, health, jobs, education and others.

V. CONCLUSION

There exists a theoretical debate as to what smartness means for cities in different contexts. In this research, we showed that smartness is a dynamic process enabling change. It uses technologies to infuse innovation in the systems of the city and achieve urban efficiency at different dimensions while being aligned with the principles of sustainable development which is in itself a process rather than an end.

Cities continue to develop and refine their environmentally friendly economic and social goals and the strategies to achieve them. To take advantage of how smarter city approaches can help advance those strategies, city authorities and stakeholders need to understand how their city is performing today and where progress is being achieved in infusing smartness into their systems. Defining smartness and setting its boundaries contribute to assessing the performance of a SSC. Such an assessment can identify emerging strengths and weaknesses and highlight where real progress is occurring and inform a plan for future improvements. It will assist city managers and policy makers in monitoring the complexity of the factors that make up a city smart and sustainable noting the uniqueness of each city in terms of its economic, environmental and social contexts.

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Smart Environments & The Convergence of the Veillances

Privacy violations to consider

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***Abstract*— As a vast array of embedded smart devices will connect to the IoT (Internet of Things), society is rapidly moving into the unchartered territory of Pervasive Technology. Networks of devices will be unobtrusive; thereby freeing humans from the effort of human-to-machine (H2M) interactions, as well as elements of everyday decision-making. Technology will be far more intelligent and ubiquitous, thinking and acting for us behind the lines of visibility. The purpose of this paper is to probe the attributes of pervasive technologies (e.g. smart environments) within the context of the rapidly converging four veillances (i.e. surveillance, dataveillance, sousveillance, and uberveillance), so as to critically identify potential risk events of these processes. The authors utilized a philosophical research approach with intellectual analysis taking into account a framework of privacy border crossings violations for humans so as to yield value judgments and thereby generate discussion in the technology community.**

Keywords- pervasive technology, privacy, smart environments, uberveillance, veillances

I. INTRODUCTION

The authors of this presentation propose risk events and consequences influencing the sociocultural realm when considering the rapidly changing landscape of emerging pervasive technologies. Through the use of a broad and generic, yet internationally recognized, risk assessment framework (ISO 31000:2009), the authors defined the risk category as emerging pervasive technologies (e.g. IoT) and the cause of risk as the converging of the veillances. Using a philosophical research approach with intellectual analysis, the authors adjusted and expanded risk events from previous research [1]. In conclusion, the authors present privacy border violations. In closing, we invite dialogue to ensure robust review in the risk identification process.

II. RISK CATEGORY: PERVASIVE TECHNOLOGY

Society is rapidly entering the unchartered and precarious terrain of an interconnected world of pervasive technology. Machines will continue to be far more intelligent and ubiquitous, thinking and acting for us behind the lines of visibility. An amalgamation of networks of devices will be unobtrusive. Humans will be increasingly freed from the effort of human-to-machine (H2M) interactions. Machines will act autonomously and make decisions for the human [1].

III. RISK CAUSE: THE CONVERGING VEILLANCES

As depicted in Figure 1, the interconnection and reach of the veillances is extensive, and especially in the context of emerging pervasive environments (e.g. smart environments). Veillance, watching or being watched, now extends from the sky (surveillance) to the street (dataveillance) to the person around you (sousveillance) to within you (überveillance) and then ripples out and back to the sky. Physical distance from the human is denoted. The circles have been adapted from previous iterations to appear with dotted lines, representing more permeable boundaries relative to the interrelationships between the veillances. The four veillances are as follows.

A. Surveillance (e.g. satellite view)

Surveillance was first recognized in the early 19th century from the French sur meaning “over” and veiller meaning “watch”. This is the veillance of authority; the powerful monitoring the less powerful. Examples include satellites, municipal cameras in streetlights or on/within buildings, or the interception of data for intelligence gathering by a government.

B. Dataveillance (e.g. street view)

Dataveillance is the methodical and organized collection or use of digital personal data in the investigation or monitoring of one or more persons [2]. This veillance extends from a veillance of authority to also one of non-authority. Examples include systematic digital monitoring of

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people as they use the internet, or commercial data mining practices by a company with advanced capabilities in analytics to understand consumer behavior.

C. Sousveillance (e.g. person view)

Sousveillance [3] is the capturing of activities from the perspective of one participant in a shared activity with other participants. This is a veillance happening from the person view to other people in the vicinity. Examples include a lifelogger capturing images of others attending an event, or peer-to-peer social media in which your posts are viewed.

D. Überveillance (e.g. sensor view)

Überveillance [4] is electronic surveillance within the human body. Some contend it is analogous to big brother on the inside looking out. This veillance has to do with the watching of the fundamental who (ID), where (location), and when (time) of the human. There is the potential for deriving the why (motivation), the what (result), and the how (methods/thoughts) of the human [4]. Examples include medical and non-medical implants (e.g. contact lens "glass" with internet access or iPlants within the human body), or wearables collecting health and sleep data (e.g. heartrate, perspiration, pulse, activity, and temperature).

E. The Convergence Intensifies

With pervasive technologies, the veillances are rapidly converging. Information exchanges can now move seamlessly and automatically in and through the human, and out across multiple platforms in each of the veillances. With pervasive technologies, we have more interoperable veillance networks that connect buildings to vehicles to other vehicles to wearables to spatio-temporal tracking bearables, to biosensor data from inside us and back out to be analyzed through advanced algorithms. Pervasive technologies create the methodology for the intensification of convergence.

Überveillance is positioned central because it can uniquely bring together all forms of watching from above, below, beside, and from within by involuntarily or voluntarily using obtrusive or unobtrusive devices. As pervasive environments develop, internal data gleaned from the human can be ever more combined and synthesized with data from across the spectrum of veillances. The consequence is rich, broad, deep, sensitive, and highly private personal data mining. The data can be analyzed relative to the current physiological and/or psychological state; predictive analytics can increasingly forecast the future state of the human.

IV. Risks Events in Synthesized Environments

When synthesizing the environments of pervasive technology (risk category) and the converging veillances (risk cause), we propose six risks (risk events), as follows.

A. Insightfulness

With context-awareness and context-adaption, ubiquitous devices will be continuously "on" and autonomously learning behaviors. With data gleaned across all veillances, devices will assess humans in multiple contexts, capacities, and over time. This is likely to lead to a capability for the system to have rich insightfulness, or a precise and profound understanding of humans in the current, but also future, state.

B. Imperceptible

As networks are operating behind the line of visibility, humans are not likely to comprehend the scope, or reach, or even timing of data practices. The processes and procedures are likely to be imperceptible. Users could be blinded to what is collected, by whom, for how long, how it is synthesized with other data, and who owns the data.

C. Incomprehensibility

Terms and conditions are often murky and/or mutable. Additionally, the average human is not likely to comprehend the wide-ranging system, nor the risks associated across multiple organizations sharing data. The system is likely to be incomprehensible for the consumer. Simpler technologies have already proven to be complex and convoluted to the average consumer.

D. Indelibility

Data may become ineradicable – somewhere within the veillances. Our digital footprints are likely to leave an indelible history of analyzable behaviors, especially if we do not own our data, or if data were shared and stored elsewhere in the veillances.

E. Invasiveness

As we allow devices to listen inside of us and communicate back and forth between the veillances, we are likely to create systems in which not only our behaviors are predicted, but even our intent. Dignity could be at risk – even if unintended.

F. Involuntariness

Opting-in to technology is becoming a requirement to participate in society. It is evermore compulsory for an individual to subscribe to cloud-based email to be gainfully employed or to receive extensive services across disciplines at a hospital. More often, individuals are pressured to opt-in to belong and benefit socially, or to benefit financially (e.g. discounts offered by an insurance company).

V. Conclusion: Socio-cultural Consequences to Consider

When considering the risk events, the authors suggest there are likely to be socio-cultural consequences relative to autonomy and privacy.

A. Autonomy: Participation in Society

With greater pressure on individuals to opt-in to participate in society, and less control over processes and ownership of our personal data, we may be increasingly forced into tolerating these risks. Examples may include opting-in to wearables that collect biosensor data to receive

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lower insurance premiums, or agreeing to cloud-based storage of sensitive data to remain gainfully employed.

B. *Privacy: Probably Border Violations*

To mine out privacy issues, the authors chose to examine the four borders of privacy as defined by Marx [5], a leading figure in surveillances studies. Marx proposed four borders as follows. Natural Borders are privacy boundaries relative to such elements as those that are materially observable such as walls, doors, clothing, facial expressions, and verbal conversations. Social Borders are privacy boundaries relative an individual's expectations such as confidentiality with professionals or family/friends, freedom from invasion of privacy by others in the social system. Spatial or Temporal Borders are privacy boundaries relative to an individual's expectations such as the right to establish delineation between various areas of an individual's life (work, personal, religious spheres) or at various points in time; rights to maintain decoupled spheres. Borders due to Ephemeral or Transitory Effects are privacy boundaries relative to an individual's expectations such as the right to have information forgotten, or to delete permanently a past extemporaneous or regrettable action [5].

When weighing the aforementioned proposed risks (events) against the four borders of privacy to yield consequences, we concluded that pervasive technologies are likely to violate all four privacy borders in the current societal context.

VI. Discussion

In closing, we invite consultation relative to the risks identified and the conclusions presented so as to purposefully anticipate the risk events leading to socio-cultural impacts of pervasive technology fueling veillance capability. We do not want to unnecessarily obstruct progress to commercialize products. We contend that a collaborative risk identification process will allow for a more robust anticipatory approach to ensure that sociocultural issues are identified well and earlier in the process. Perhaps this will stimulate efforts to apply approaches such as Anticipatory Ethics, Privacy by Design (PbD), and/or the International Associations of Impact Assessments' (IAIA) Social Impact Assessment (SIA)/Privacy Impact Assessment (PIA).

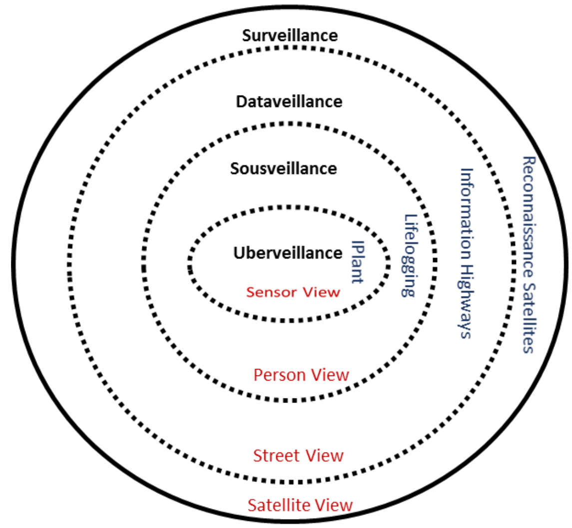

Figure 1 The Veillances Original diagram Michael, Michael, & Abbas, 2009; Adapted by Michael, Michael, & Perakslis, 2013

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Multiradio Sensing Systems for Home Area Networking and Building Management

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***Abstract*—Many WSN systems use proprietary systems so interoperability between different devices and systems can be at best difficult with various protocols (standards based and non-standards based) used (ZigBee, EnOcean, MODBUS, KNEX, DALI, Powerline, etc.). This work describes the development of a novel low power consumption multiradio system incorporating 32-bit ARM-Cortex microcontroller and multiple radio interfaces - ZigBee/6LoWPAN/Bluetooth LE (Low Energy)/868MHz platform. The multiradio sensing system lends itself to interoperability and standardization between the different technologies which typically make up a heterogeneous network of sensors for both standards based and non-standards based systems. The configurability of the system enables energy savings, and increases the range between single points enabling the implementation of adaptive networking architectures of different configurations. The system described provides a future-proof wireless platform for Home Automation Networks with regards to the network heterogeneity in terms of hardware and protocols defined as being critical for use in the built environment. This system is the first to provide the capability to communicate in the 2.4GHz band as well as the 868MHz band as well as the feature of multiboot capability.**

Keywords - Smart Sensing; Home Area Networks; Energy Management; Multiradio Systems.

I. Introduction

Wireless Sensor Network (WSN) systems have the potential to be ubiquitous in today's society in a myriad of applications such as Smart Homes, Building Energy Management (BEM), micro grid management, environmental monitoring and smart cities. New architectures are required to offer improved inter-operability, to improve reliability of data communications and to address the spread spectrum requirements associated with next generation sensor systems through the development of smart radio systems. Currently available platforms exist that have multiple radios but these tend to operate in a single Industrial, Scientific and Medical (ISM) band (typically 2.4GHz) – and not in combination with the 868MHz ISM Band which is ideal for the built environment due to its long range, low data rate properties.

The value of WSNs as a sensing system is clear - typically wired sensor systems are expensive to install with 70-90% of the cost of a sensor system installation relating to labor and wiring – which ranges from 40 to $2000 per linear foot of wiring [1]. A number of challenges still need to be addressed to ensure WSN technology achieves its' full potential across all application areas. An abundance of communications technologies persist within the Home Area Networking (HAN) domain, with no single technology identifying itself as the "one size fits all" solution.

The *AUT*onomic *H*om*E* area *N*e*T*work *I*nfrastru*C*ture (AUTHENTIC) project [2][3] funded by the International Energy Research Centre (IERC) [4] seeks to explore, the design and delivery of a HAN infrastructure capable of supporting opportunistic decision making pertaining to effective energy management within the home. This requires the integration of key enabling heterogeneous technologies including a variety of physical sensors within the home (temperature, contact sensors, passive infra-red), cyber sensor sources (services) outside of the home (e.g., meteorological data, energy providers dynamic pricing sites) together with effective interfacing with the smart grid beyond the home. Section I of this paper introduces the subject matter and application space associated with wireless sensing solutions for the built environment. Section II reviews some of the state of the art in current wireless sensing system technologies, with emphasis on multiradio systems. Section III describes the "Authentic Board" developed within the project. Section IV describes the multiradio functionality and Section V examines the results of initial trials and tests carried out using the system.

II. Previous Works

There are a variety of standards available (proprietary and non-proprietary), which are widely used within the many deployments of HAN which exist. ZigBee, Bluetooth, IEEE 802.11x (Wi-Fi) are globally recognized as references in wireless communications and go far beyond the scope of WSN. Those technologies have been developed using the license-free ISM band of 2.4-2.5GHz, although ZigBee has an implementation for the 868MHz and the latest 802.11.n standard used by Wi-Fi offers support for both 2.4 and 5GHz. Indoor range above the GHz frequency is quite limited especially for indoor applications with dense obstacles. The Wi-Fi technology surpasses those issues with higher transmission power (up to 100 times higher than ZigBee/802.15.4), which is of course not suitable for battery powered systems in low power WSN systems.

Although some manufacturers provide WSN systems using 868MHz or even 433MHz, it is more common to see them designed around proprietary technologies such as ZigBee. An interesting trade off investigated in this paper is the development of a system with the ability to adapt its

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communications channel to use the best radio link depending on the throughput and range requirements in any configuration.

Multiradio platforms are a subject of research for WSN as they offer some attractive characteristics and improvements over single radio WSN platforms. Multiradio systems with radios covering Wi-Fi, Bluetooth and 6LoWPAN (IPv6 over Low power Wireless Personal Area Networks) operating at the 2.45 GHz ISM band have reported to achieve enhanced robustness, latency and energy characteristics [5]. In different implementations, multiradio systems operating at the 433MHz and 2.45 GHz ISM bands were reported [6] using a preamble sampling technique in a wakeup radio implementation showing experimental performance evaluation of a developed protocol in terms of power consumption and latency over different duty cycle values and under various amounts of traffic loads. A multiradio platform for on the body WSN applications operating in 433MHz and 868Mz is reported in [7] with focus on the platform architecture. More consideration on the issues of antenna design for such devices is found in [8] [9].

The OPAL is an example of a multiradio platform where increased performance in terms of the network realization, latency, data throughput and power consumption were achieved compared to single radio platforms [10]. The OPAL platform is a high throughput sensing module that includes two onboard 802.15.4 radios operating in the 900 MHz and 2.4GHz bands to provide communication diversity and an aggregate transfer rate of 3 Mbps. It embeds a 96 MHz Cortex SAM3U processor with dynamic core frequency scaling, a feature that can be used to fine-tune processing speed with the higher communication rates while minimizing energy consumption.

The platform described in the following sections of this paper is a novel low power consumption multiradio system incorporating 32-bit ARM-Cortex microcontroller and multiple radio interfaces - ZigBee/6LoWPAN/Bluetooth LE/868MHz platform, which features autonomous behavior to enable interoperability between systems utilizing different radio front ends. It provides a solution for network congestion in environments such as HAN and Commercial Buildings in a credit card sized form factor (see Figure 1 below). It also provides better interoperability than the usual wireless sensor devices approach, enhancing the communicability between different network entities (sensor nodes, smart meters, media, smartphones), and driving the wireless sensor networks to the smart cities application space.

III. System Implementation

The aim of this system development is to provide a future-proof wireless platform for HAN with regards to the network heterogeneity in terms of hardware and protocols currently in use and under development.

A specification process was undertaken with industry partners and service providers in the area of building management – to identify the core requirements associated with a wireless system for deployment in homes and offices.

Figure 1. AUTHENTIC Credit Card Form Factor Platform.

The four main issues that need to be considered prior to selecting any unit or design approaches are: over all power consumption, cost, complete module size and user friendliness. Technical features assessed and considered included: functionality requirements as regards, actuation and control, quality of service, latency, number and types of sensors/meters and interfaces, programming methods (wireless/non wireless), power supplies/energy harvesting compatibility, radio frequency band, standards/non standards communications and data transmission range.

In conjunction with these end users, as part of our system specification, three communication standards were identified as being needed within the home area network environment: ZigBee – 2.4GHz, 6LoWPan – 2.4GHz, Bluetooth Low Energy – 2.4GHz, as well as a non-standards based ISM band 868MHz transceiver as a response to the 2.4GHz limitations identified - bandwidth congestion and data loss associated with non line of sight (NLOS) effects of the building structure limited RF range. The board has been designed around the standard ARM CORTEX-M3 based microcontroller, which offers a good trade-off between power consumption and performance. See Figure 2 for an overview of features and functionalities.

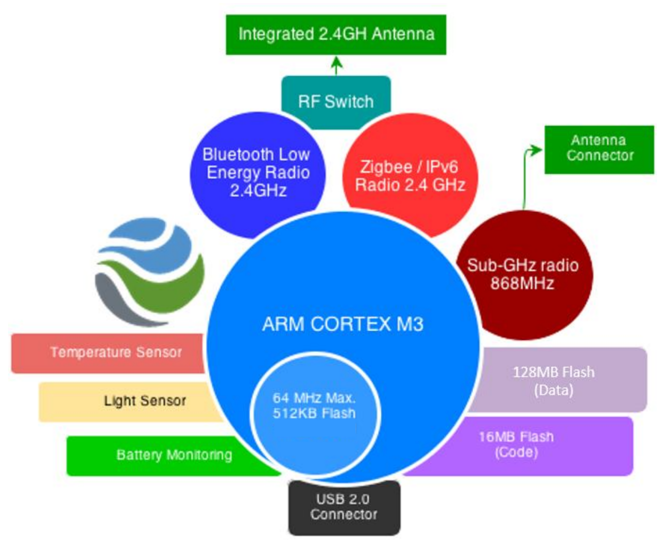

Figure 2. Block diagram of AUTHENTIC Platform functionality.

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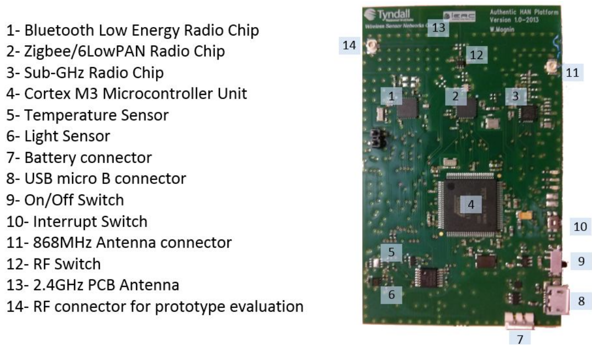

Figure 3. AUTHENTIC multiradio embedded system.

The final embedded system was designed around a credit card form factor (Figure 3) and deployed in offices and homes for preliminary tests and characterization

Microcontroller: The heart of the system is the ATMEL SAM3S8C microcontroller, a 32-bit ARM Cortex M3 Core. - 64MHz Maximum, 512KB flash, 64KB RAM, USB 2.0.

External Flash Memories: Two external flash memories: 128MB NAND flash for data logging, 16MB NOR-flash for code execution. The two memories are connected to the microcontroller External Bus Interface (EBI).

Radio Communication: The platform integrates three radio chips: Bluetooth Low Energy radio chip, (manufacturer: NORDIC, model: NRF8001), ZigBee/6LoWPAN radio chip, (manufacturer: ATMEL, model: AT86RF231), Sub-GHz radio chip (868MHz), (manufacturer: ST Microelectronics, model: SPIRIT1).

Sensors: Two sensors were interface via an I^2C interface: temperature sensor, accuracy: ±0.5°C, (manufacturer: MAXIM, model: MAX31725MTA+), light sensor, range: 0.045 Lux to 188,000 Lux, (manufacturer: MAXIM, model: MAX44009EDT+T). These are used for detecting in home activity monitoring occupancy through lighting usage.

Battery: The battery used is a lithium prismatic battery with a capacity of 1.3mAh which is recharged through the USB port or through the use of energy harvesting systems compatible with the built environment [11].

IV. MULTIRADIO FUNCTIONALITY

A. *Communication Architectures using Multiradio systems*

In the context of "crowded radio frequency spectrum", a wireless sensor network composed with a number of the proposed devices' architectures can automatically adapt to the most reliable frequency communication channel based on the local interferences. This type of architecture has some interesting commercial applications for interoperable networks, HAN's, commercial buildings and smart cities. Compared to single-end radio devices, it has the potential to provide increased connectivity in deployment, and can potentially reduce the interference impact on the network as the system can hop from ISM band to ISM band in an autonomous and opportunistic manner.

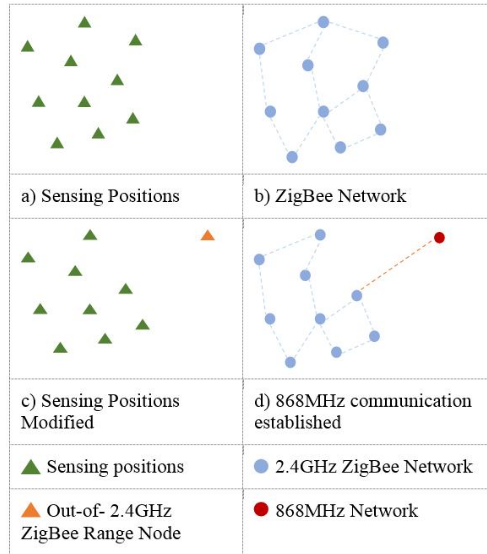

Figure 4. AUTHENTIC multiradio system in operation

By developing smart mechanisms for multi-protocol routing between the different radios, this architecture can potentially reduce the number of repeaters (and thus the infrastructure cost) compared to a standard single ended radio platform. In addition, multiradio systems provide better interoperability with Off-The-Shelf wireless devices, many of which operate on a variety of different standards and which may constitute a typical smart home deployment.

From a research point of view, such a platform can be used to develop and evaluate firmware/wireless protocols using different frequency bands.

The multiradio concept is illustrated in Figure 4 and shows how, by jumping between the 2.4GHz and 868MHzfrequency bands, a connection can be made between remote clusters of ZigBee nodes which are in different locations or separated by a congested spectrum making communication at 2.4GHz difficult.

Thus the network automatically switches to the 868MHz frequency in order to maintain communication with the out of range node. In that case, one node from the first cluster will act as a virtual "dual sensing" node, providing two inputs to the ZigBee Network.

B. *Multiradio Aspect*

The Bluetooth and 868MHz multiradio functionality has been tested as a proof of concept in a HAN as part of the AUTHENTIC deployment in office environments and in homes (for open field testing, the system was deployed temporarily outside).

To evaluate the capabilities of the multiradio functionality, the remote node sends data (light, temperature or other peripheral sensor) to the base station using the 868MHz radio or the 2.4GHz ZigBee network. The base station then sends the received data to a Smart Phone/HAN gateway using the Bluetooth interface that displays the data stream (in this case, temperature and light level from the remote sensor) as shown in Figure 5.

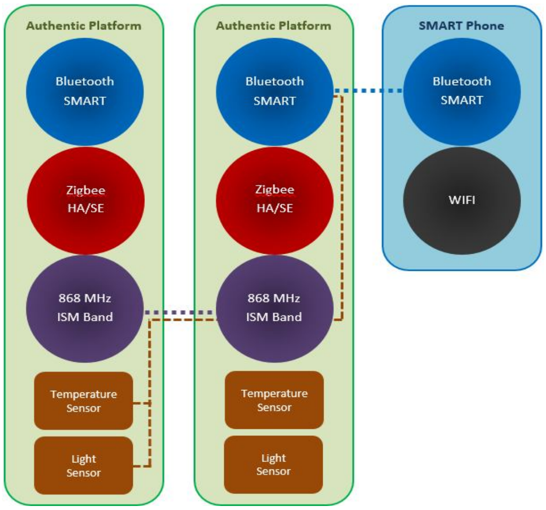

Figure 5. AUTHENTIC multiradio system

C. *Multiboot - Autonomous system Implementation*

Multiboot capability enables the system to boot up and run according to various boot images [12] [13] which are stored in various sectors (region) of memory see Figure 6.

To facilitate energy savings at an embedded system level, the multiboot configuration of the system will allow the platform to host two different applications and jump between them (via a boot loader). The applications can and will use different radios in future deployments, which will be useful for overcoming transmission issues in a congested/noisy environment. The targeted example is the mote running a ZigBee 2.4GHz application and an 868MHz application. Failing to transmit data at 2.4GHz due to electromagnetic effects or long range requirements, the node would switch to the 868MHz application to operate in a less congested ISM band. This behavior would be coordinated among the network nodes in protocols under development. In this case, the idea is to allocate memory regions to specific applications.

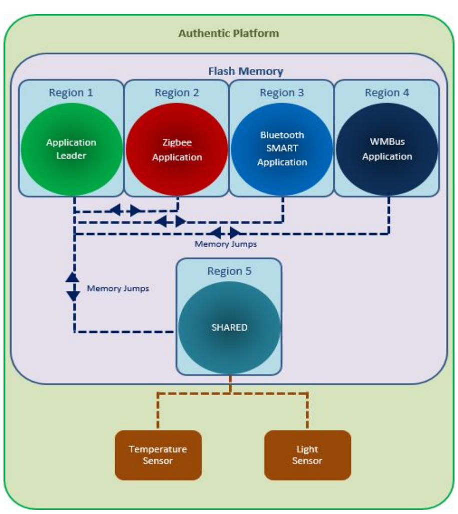

Figure 6. AUTHENTIC Multiboot reconfigurability

The **Multi-Application Software Management** tool acts as a main application that we will call "**Leader**". The **Leader** is programmed in a specific area of the memory and will act as what is commonly known as a Bootstrap Loader. The particular boot state functionality can be associated with a range of communications modalities say ZigBee, Bluetooth or Wireless Modbus according to application requirements associated with energy consumption, latency or Quality of Service.

The **Leader** can access any location of the memory. The applications that will contain the required functionalities of the system (e.g., sensing, communication) will be described as "**Users**". The **Leader** can then grant the leadership to the different **Users** that will need to return the leadership to the **Leader** (different solutions are possible for the latter).

The **Leader** will provide API (Application Programming Interface) in order to modify intrinsic parameters of the system (e.g., system clock frequency, timers etc.). Thus, this functionality will considerably reduce the complexity of the development from the user developer's point of view.

From a smart home/building management system deployment perspective, it will provide an essential software management tool for multiradio platforms.

V. RESULTS

A. *AUTHENTIC Board Power Characterization*

To carry out theses energy consumption tests the following modalities were implemented as shown in Table I.

TABLE I. SYSTEM POWER CONSUMPTION IN DIFFERENT MODES

Symbol	Operational Mode Measured	Value	Unit
ITX868	Current consumption in TX mode 868MHzmodule, POUT = +12 dBm, all components on	43.98	mA
Isb868	Current consumption in standby mode 868MHzmodule, all components on	28.24	mA
ITXBLE, 0dBm	Current consumption in TX mode BLE module, POUT = 0 dBm, all components on	24.80	mA
IsbBLE	Current consumption in standby mode (between 2 transmissions) BLE module, all components on	17.29	mA
ITX, ZigBee1	Current consumption in TX mode ZigBee module, POUT = +3 dBm, all components on, 1 led on	64.07	mA
ITX, ZigBee2	Current consumption in TX mode ZigBee module, POUT = +3 dBm, all components on, 1 led off	71.12	mA
Isleep1	Current consumption in sleep mode (microcontroller) and all the other components on	15.73	mA
Isleep2	Current consumption in sleep mode (microcontroller) and all the other components off	3.18	mA
Isleep3	Current consumption in deepest sleep mode (microcontroller) and all the other components on	3.1	mA
Isleep4	Current consumption in deepest sleep mode and components off / removed	3.5	µA

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The MCU is programmed to turn on all the devices, setting the output power of the module to (+12 dBm for 868 MHz module, 0 dBm for BLE, +3 dBm for ZigBee), start the transmission of a single packet (1 byte length) and then put it in standby mode. Sleep mode tests include the MCU turning on all the devices before going into sleep mode, turning off all the devices and entering sleep mode, turning on all the devices and entering deepest sleep mode and turning off all the devices and goes into deepest sleep mode.

For the 868 MHz tests, GFSK (Gaussian frequency-shift keying) modulation with the Gaussian filter "BT Product" set to 1 was used. For the Bluetooth LE modules the default Gaussian filter used is 0.5. For the ZigBee module quadrature phase-shift keying (QPSK) modulation was used. Table I shows the results of all tests in different modes. These provide the building blocks for developing low-power networking algorithims for optimising the lifetime of the WSN systems and QoS parameters.

B. *Multiradio Range Test Comparison*

1) Indoor Non Line of Sight (NLOS) range testing

This section focuses on the NLOS testing of the 868 MHz, Bluetooth and ZigBee radio modules on the AUTHENTIC Board. Two boards are used: one acts as a sensing node and one as a Base Station. The node reads data from the temperature sensor as well as received signal strength indication (RSSI) values. This is then sent to the Base Station where it is converted into a value expressed in °C (minimizing energy consumption associated with processing on the node), which is in turn sent to our visual interface (a smartphone connected via Bluetooth). The test took place in an office environment consisting of open plan cubicles, closed offices, coffee dock facilities and meeting rooms in a simulated "home environment". The node (represented by the star) was kept stationary while the base station and the smartphone moved around the entire area for data gathering at the different frequencies under test. In Figures 7, 8, 9, the areas where the data is received perfectly are reported in green, in orange the areas where the signal is poor and the data is received intermittently, in red the areas where there is no signal and data is not received.

Figure 7. 868MHzrange test

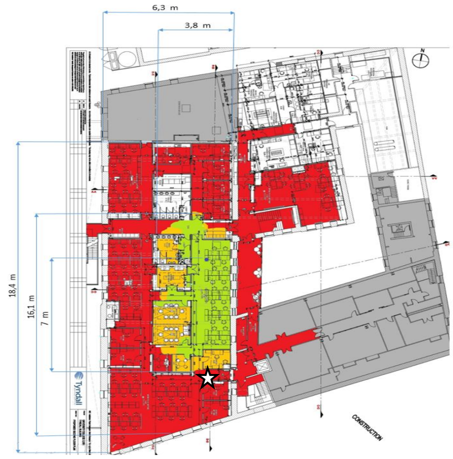

Figure 8. Bluetooth range test

Figure 9. ZigBee 2.4GHz range test

Theory would suggest that the range associated with lower frequency (868MHz) ISM bands would significantly outperform higher frequency ISM bands (2.4GHz). In this experiment, the difference is little more than a 10% improvement see Table II. We expected 868MHz to be much better than ZigBee, a possible reason (under investigation) is that the 868MHz data rate (500 kbps) is higher than the ZigBee one (250 kbps) and there is a tradeoff between the range and the data rate. Moreover, the modulation used by the modules are different: the value of Eb/N0 (noise power per unit bandwidth) of the offset-QPSK is less than that of the GFSK; this means that the bit error rate is better for the ZigBee module operating at 2.4GHz. To improve the 868MHz range, it is possible to increase the power of the module (it can reach +16 dB) and reduce the data rate. Further experiments are under way to validate this.

TABLE II. COMPARISON OF RANGE FOR INDOOR NLOS TESTS

Radio	Appoximate Area Covered	Max. distance (Line of sight)
868 MHz	130.4 m^2	11.4 m
Bluetooth LE	60.04 m^2	7 m
ZigBee	108.6 m^2	10.6 m

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2) Outdoor Line of Sight (LOS) range testing

An open field is one of the simplest and most commonly used environments to do RF range tests. In this section tests for the three modules on the AUTHENTIC Board (868 MHz, Bluetooth, and ZigBee) are reported. The tests took place in a sports field in University College Cork, which offered a long range LOS measurement

868 MHz: To test the Sub-GHz module, two AUTHENTIC boards were used, one as Node Remote and one as Base Station. The first reads data every four seconds from the temperature sensor and sends it to the Base Station. The maximum range measured was 193m.

Bluetooth: For this test two devices were used: one AUTHENTIC Board and a smartphone. The board was left stationary and the smartphone was moved around the area checking if the connection was still available or not. The maximum LOS distance measured was 18.4m.

ZigBee: To test the ZigBee module, two AUTHENTIC boards (one as Trust Center and one as Occupancy Sensor) were used along with a RF231USB-RD USB Stick (as Remote Control) were used. The Trust Center creates the network and the other two devices join it. After this, the Occupancy Sensor reads the value of the LED (on/off) and sends it every four seconds to the Remote Control that moves around the area. The maximum range measured was 193m.

The maximum distance measured in Line of Sight for both the ZigBee and 868MHz system was 193m, but this value could be greater and additional tests need to be carried out to establish the maximum range for each. The maximum range achieved was due to the presence of physical obstacles (walls/buildings, which would have interfered with the LOS measurements at the maximum extremity of the test location. The results are tabulated in Table III.

TABLE III. COMPARISON OF RANGE FOR OUTDOOR LOS TESTS

Radio	Max. distance (Line of Sight)
868MHz	193m *
Bluetooth LE	18.4m
ZigBee	193m *

* Limit of the field measurement not the technology

VI. CONCLUSIONS & FUTURE WORK

This work describes the development and preliminary characterization of a novel low power consumption multiradio system incorporating multiple radio interfaces - ZigBee/6LoWPAN/Bluetooth LE/868MHz platform. It provides a solution for network congestion in environment such as Home Area Network and Commercial Buildings in a credit card sized form factor. The multiradio sensing system shows the potential for such systems to improve interoperability between the different wireless technologies enhancing the communications between heterogeneous network entities (Sensor Nodes, Smart Meters, Media, Smart Phones), and driving the Wireless Sensor Networks use case in the built environment The configurability of the system can increase the range between single sensor points and can enable the implementation of adaptive networking architectures of different configurations.

Additional characterization and optimization of the system in a variety of environments is underway and development of frequency hopping protocols to maximize the potential of the multiradio system and its possibilities to maximize system lifetime of a WSN in a Smart Home or office environment through the development of networking protocols leveraging off the platforms capabilities.

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Sensors and the Smart City

Creating a Research Design for Sensor-based Smart City Projects

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Abstract—**In this paper, we present a proposal for a research design, based on the argument that there is a connection between smart cities and the concepts of "smart buildings" and "smart users". Smart cities refer to "places where information technology is combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental problems". Smart buildings refer to ICT-enabled and networked constructions such as traffic cameras and lights, buildings and other man-made structures. With inexpensive hardware such as the Raspberry Pi, Edison, Arduino, and their ecosystems of sensors, we can equip these structures with sensors. Smart users refer to the high level of education in western societies, which allows us to utilize technology such as smart phones to create better cities. Citizens can provide data through their smart phones, and these data can, together with sensor data from buildings, be used to analyze and visualize a range of different variables aimed at creating smarter cities. We propose that a first step of smart city research should be a thorough process of identifying and collecting input from relevant stakeholders in order to find the most relevant objectives for research.**

Keywords- smart cities; smart buildings, smart citizens; sensors; research design.

I. Introduction

As of 2009, more than 50 percent of the world's population lives in urban areas [1], and this number is forecasted to increase in the coming years. Cities occupy only 2 percent of the planet, but account for 60-80 percent of energy consumption [2]. As the sizes of cities grow, so do the challenges facing cities [3]. These challenges include issues related to public health and socio-economic factors [4], energy consumption, transport planning and environmental issues [5]. Air pollution caused by traffic jams is but one concrete example of the many challenges facing growing cities [6]. In order to reduce traffic and environmental impact it is necessary to implement safe, reliable, rapid and inexpensive public transport. Therefore, it is an obvious need for cities to be smart. Dameri and Coccia [7] summarize the major objectives of smart cities:

- Improve environmental quality in urban space, reducing CO_2 emissions, traffic and waste;
- Optimize energy consumption, by making buildings, household appliances and electronic devices more energy efficient, supplemented by recycling energy and use of renewable energy;
- Increase quality of life, delivering better public and private services, such as local public transport, health services, and so on.

In this paper, we argue for the application of sensors and data analytics for resolving some of the challenges facing cities. There is a connection between smart cities and the concepts of smart buildings and smart users. Smart cities refer to places where information technology is combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental problems [8]. Examining how to achieve this connection between ICTs and the world around us is the focus of our paper.

Smart buildings and *smart homes* refer to the use of built-in infrastructure to provide safety and security, entertainment, improved energy management, and health monitoring [9]. A smart building or a smart home relies on the use of sensor technologies to achieve this. The data collected by such sensors can also be aggregated and used by the city for various purposes. Sensors can provide information to law enforcement, emergency response, power management, home care services, environmental protection, city planning, and intelligent transport systems.

The *Internet-of-Things* (IoT) refers to devices connected to the Internet that can exchange data with external computerized systems. In the context of smart cities, such devices can monitor traffic, pollution, noise level, use of electrical power, etc.

Inexpensive hardware such as the Raspberry Pi, Edison, Arduino, and their ecosystems of sensors, enables us to deploy sensor technology on a large scale. Such low cost devices can provide valuable information for optimizing energy use, infrastructure and public transport planning, as well as emergency response and other vital services. Applying sensors is just the first step towards smarter cities. The next step involves smart users.

Smart users refer to the high level of education in western societies, which allows us to utilize technology such as smart phones to create better cities. Cities in and of themselves are not smart, nor is a smart phone or computer smart unless the person using it does so with a specific purpose in mind. Actually, the apparent intelligence of the computing systems comes from the amount of human

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intelligence that was invested in it. Citizen participation is seen as an important element in smart cities [10]. Studies show a causal relation between high levels of education and growth in the number of available jobs [11]. In our context, we see citizens both as providing input through traditional participation projects, but also as providers of data for analysis. Citizens can provide data through their smart phones, either actively or passively (with consent), and these data can, together with sensor data from buildings, be used to analyze and visualize traffic patterns, movement through the city and between cities, environmental factors etc.

We apply these concepts to the framework for smart city planning [10], in order to present an experimental research design for the application of sensors and analytics in Smart City planning. This approach is in part the result of an ongoing collaboration with regional analytics businesses. The rest of the paper is structured as follows: Section 2 discusses the use of sensors for data collection. Section 3 discusses how analytics can be applied as input for participatory planning, and section 4 presents the outline of a research design, using the Smart City framework of [10]. Section 5 presents a brief overview of a possible case where this design will be applied.

II. A World of Sensors

A sensor is a component able to detect a change in its environment and convert this change into an electrical signal. The signal returned by a sensor may be binary (on/off), a value within a range, e.g., temperature, light, wind, humidity, precipitation, position, and acceleration. Camera sensors return images or even image streams. Since sensors are operating in real time, they can produce large amounts of information. Therefore, sensors are normally connected to some kind of unit that monitors changes, and forwards information at regular intervals, or when the change is big enough. The left part of Figure 1 shows how sensors are connected to an aggregation and preprocessing unit.

Many mobile devices have built in sensors, e.g., a GPS sensor, camera or accelerometer. The number of built-in sensors is expected to increase with new versions. Newer cars also have built-in computers handling sensor input, local processing and communications [12]. According to Abdelhamid et al. [13] a 2013 model car has on average 70 sensors, while luxury models may have more than 100 sensors. The number of sensors is expected to grow.

Typical applications for hand-held or car mounted devices are traffic monitoring and prediction. The devices send their coordinates, and the server software receiving this information decides if a specific traffic route is clogged or not.

Another application is environmental monitoring. One example is the Green Watch project [14]. The project distributed 200 smart devices to citizens of Paris. The devices sensed ozone and noise levels as the citizens lived their normal lives, and the results where shared through a mapping engine. The project showed how a grassroots-sensing network could reduce costs dramatically, and also engage citizens in environmental monitoring and regulation.

Bröring et al. [15], used the built-in diagnostic interface of cars (OBD-II) to obtain sensor data used to estimate current fuel consumption, CO_2 emission, noise, standing time and slow moving traffic.

Citizens can also act as sensors themselves, by reporting what they observe. One example is FixMyStreet.com, a web application that enables citizens to report problems with roads and other infrastructure.

Today, low cost devices (e.g., Raspberry Pi, Edison and Arduino), have both processing and communication capabilities. Such devices can easily be connected to different types of sensors [16] [17], and can do local processing of data, before packing the results and sending it to a central processing facility for further processing, analytics and visualization. Raspberry Pi 3 and Edison have built-in wireless communication capabilities, which make connection to city-wide WiFi networks even easier. Separate components are available to connect such devices to mobile networks.

A. Applications

Sensor networks may have a wide range of applications. The most obvious examples can be found within the following fields:

- Safety and security
- Energy monitoring and control: Smart power meters
- Environmental protection
- Health

B. Safety and Security

An important aspect of smart cities and smart buildings is to make people feel safe and secure. Sensors can be used for a multitude of application, both to secure property and to keep citizens safe. This includes intrusion alarms, surveillance cameras, fire detection and flood alarms. Such alarms can connect to law enforcement and emergency response, but also to private operators and trusted neighbors.

C. Energy Monitoring and Control

Sensors can be used to monitor temperature and lights. Detection of movements can turn lights on, and heating and air-conditioning can be optimized to not spill unnecessary energy. Smart meters can provide information useful for energy planning, and also prevent blackouts and brownouts by adjusting the price of electrical power.

D. Environmental Monitoring and Protection

By collecting environmental data, the building itself and the city can get early warnings on pollution levels and other environmental problems, and initiate necessary actions.

E. Health

Old people want to live in their homes as long as they feel safe. Sensors can be used for daily health monitoring, where data are sent to medical professionals, but also detect medical emergencies, like fall detection.

F. Privacy Issues

Deploying large networks of sensors (proximity sensors, presence sensors, surveillance cameras, gas and smoke sensors), and in particular the data collection from personal devices raise some concerns related to privacy of the individual. Therefore, it is necessary to implement legal mechanisms to regulate how information can be obtained, what information can be obtained, and for what purpose the information can be used. The public must be informed and give their consent of use of the information.

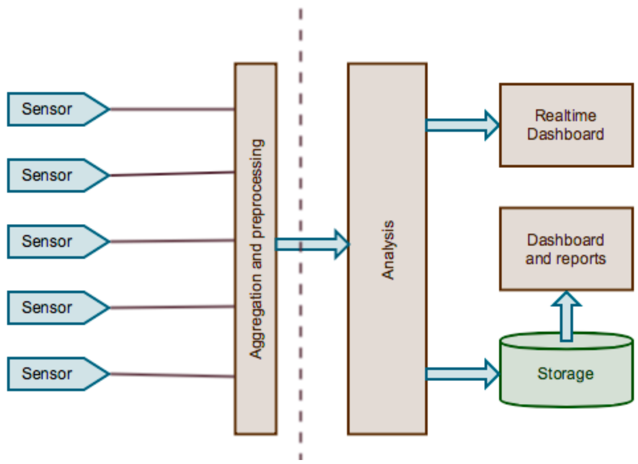

Figure 1. Sensor network, analyzing and visualization architecture

III. APPLYING ANALYTICS AND VISALIZATION IN PARTICIPATORY PLANNING

Mining and analyzing data has been on the agenda of researchers since the 1960's. However, the period from ca. 2000 to present is the most interesting one in the history of data mining, because of the emergence of the Web and the large amounts of data generated from the web [18]. A review of data mining literature between 2000 and 2011 reveals that a number of different areas have been developed, all of which can be used for various types of analysis [18]:

- Neural Networks - For classification, time series prediction, pattern recognition
- Algorithm architecture - For calculation, data processing, clustering
- Dynamic prediction - For prediction, forecasting and tracking
- System architecture - For association, decision making and Consumer behavior
- Intelligent agent systems - For autonomous observation and acting on external input
- Data modeling - For representation or acquisition of expert knowledge
- Knowledge-based systems - For knowledge discovery and representation

Most of these can be applied in collecting data from sensors, and there are many examples from literature. One study shows how data mining and predictive analytical techniques can be applied to predict the number of vacant properties in a city [19]. Geographic information can be combined with a plethora of different data to provide valuable information for decision makers. Massa and Campagna show how geographic data extracted from social media can improve urban planning in a smart city context, and present a methodology for social media geographic information analytics [20]. A similar study mines data from the location-based social network FourSquare to identify under-developed neighborhoods [21].

De Amicis et al. [22] have developed a geo-visual analytics platform for land planning and urban design, and argue for the importance of visual, 3D analytics. Another system, STAR CITY, uses sensor data from both machine and human-operated sensors to analyze traffic patterns in cities. The prototype has been tested in Dublin, Bologna, Miami and Rio de Janeiro [23]. Another study uses sensor data to model traffic noise and predict which areas were most likely to experience noise on a given day [24].

Energy monitoring for the purpose of reducing the city's carbon footprint is another area made possible by analytics. Researchers are working on a framework, which would allow for integration of energy monitoring in entire neighborhoods [25].

Visualization of the results produced by the analytics, can help decision-making. Information can be presented real time through the use of dashboards, using different types of graphical visualizations show issues that need to be dealt with. The combination of analytics and visualization is shown in the right portion of Figure 1.

This section has provided a brief overview of analytics and its coupling to visualization, and also given examples of existing systems that at various levels and from several perspectives provide decision makers with important input. The combination of sensors, geographic information and user-generated data can, especially when coupled with some form of visualization, be a powerful instrument for decision makers. Coupled with citizen participation [26] projects, this can be a great resource for the development of smart cities. In the next section we provide a brief outline of a possible research design for participatory- and sensor-based smart city projects.

IV. TOWARDS A RESEARCH DESIGN FOR PARTICIPATORY PLANNING OF SMART CITIES

Chourabi et al. [10] presents a framework for smart city initiatives, which is separated into internal and external factors (Figure 2). These factors influence each other, and depending on the type of project, some are more important than others. The framework can be applied as a tool for planning smart city initiatives, and we will in this section discuss how it can be applied as the foundation for a research design.

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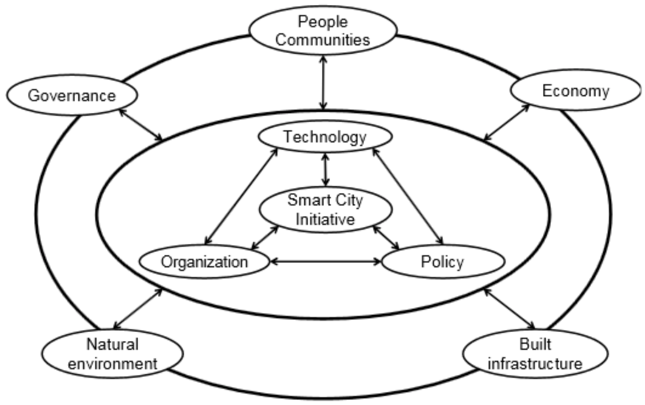

Figure 2. The Smart City Initiatives framework [10].

Our objective is to create a research projects where sensor data from buildings, cars and people are collected, analyzed and visualized, so that decision makers have access to data about issues related to transport and movement, pollution and city planning. With this in mind, the framework of Chourabi et al. [10] can be used for the initial project planning:

The *Smart City Initiative* is as described above. In our home regions, there are several smaller cities in close distance to each other, and we are working to set up a case study of how sensor technologies can help these cities become even more integrated as one single job and housing region. The approach may be influenced by urban congestion and by city topographic classes: compact, river and seaside.

The *Technology* consists of sensors, software and hardware for data mining and analytics. Using existing technologies such as the Raspberry Pi, Edison, Arduino and smart phones would be a natural first step of such projects. A second step could be to evaluate the use of existing technology in order to examine if there is a need for further custom development. We have already developed a unit for environmental monitoring based on the Edison platform and one Arduino-based unit for detecting physical proximity, e.g., to detect if a parking spot is occupied or not.

Technological challenges include IT skills of the end users, and issues related to organizational culture [27]. One of our projects partners is a company specializing in analytics, and the population generally has good IT skills, so this challenge is not a major one. The bigger challenge would be to overcome organizational barriers. We propose that the cities involved in the project be responsible for setting goals and objectives, recruiting participants and for procurement of necessary hardware and software, as well as placement of sensors. Local media could also be a partner in recruiting participants. The analytics companies would implement the software solution (collecting, analyzing and visualizing data) and we, as researchers would be responsible for the overall project organization and coordination between other actors.

For the *Organization* and *Policy* factors, there are some challenges to be addressed. Organizational issues include alignment of goals and turf wars, and both formal (legal) and informal(normative) challenges as issues to consider when making new policy [10]. The region in which our project will take place already has a formalized collaboration on a range of different issues. This means that most of the factors related to governance and policy have already been addressed in previous collaborations. The major challenge will be to get the different cities to agree on a set of goals, as well as what these goals mean in practice.

The external factors of our projects will also have implications. The framework lists collaboration, leadership, participation, communication, data-exchange, integration, accountability and transparency as typical *Governance* issues. Again, the established collaboration between the project partners should help alleviate these challenges.

The *People and Communities* factor involves issues such as accessibility, quality of life, education, communication and participation. Citizen participation through the use of smart phone sensors will be a key factor in our project, so recruiting participants is a major issue. As the objective of the project ultimately is to create regions that are better to live and work in, and to travel between, we will need to be very clear about the potential benefits of participation. Communicating these through traditional and new media will most likely be essential. We address this factor in more detail below.

Economy and Built infrastructure: Smart city initiatives are easier to implement in areas with high levels of education, entrepreneurial businesses and a good ICT infrastructure [10]. The cities we are trying to set up our project with all have challenges related to growth, but there are several innovative businesses and industries in the region. A challenge often facing these businesses is how to attract the right employees, so it is likely that they will be positive towards any initiative where this could be an outcome. The IT infrastructure in the region is good, but there will likely be some challenges in more remote parts. For example, there are still areas without 3G or 4G mobile data coverage, and some of these areas could be in places where it would be useful to place sensors.

The final factor, *Natural environment*, addresses the need for more sustainable and greener cities. Therefore, placing sensors that monitor traffic patterns, building usage and learning more about how and where the people in the region travel, are objectives in our proposed study. Knowing more about travel patterns allows for optimal use of available public transport, and could also facilitate the creation of apps for carpooling. Another use of sensors could be to scan cars passing tollbooths, and to impose higher tolls on vehicles with higher CO_2 and NOX emissions.

A. Recruitment and Participation

We would argue that the people and communities factor is essential in our proposed project. Close collaboration with the people who would be affected by any policy changes that might come from the project might help alleviate some of the resistance that could otherwise arise. As the brief overview of sensor technology and existing research projects show, there are so many possibilities that some kind of process is needed to narrow the scope of the project. Because cities and regions have different challenges, we propose to gather relevant stakeholders in a planning workshop, where the objective is a) to identify the most pressing objectives for the region in question, and b) to figure out the technical, legal and organizational challenges facing each individual objective. Identifying relevant stakeholders can be done for example through the stakeholder framework of Podnar and Jankic [28].

Participation and collaboration between government, citizens and organizations is seen as essential in the development of smart communities [29]. Many of the activities (parks and recreation, planning and community development) typically involved in smart city projects can benefit greatly from citizen participation [26], and there is a clear correlation between cities' adoption and implementation of sustainability policies and public participation in policy formulation [30].

The EU-supported NET-EUCEN thematic network has proposed a framework for measuring user involvement, with indicators for how well users are involved in defining, developing and assessing digital government [31]. While this framework was developed for eGovernment in general, the principles of involvement can be transferred to the Smart City context. The individual indicators for the three dimensions are presented in Table I.

Our goal is to involve users and stakeholders in all phases of the project. In the definition phase, the users and stakeholders will discuss and decide on issues where senor input, analytics and visualization will be of most value. In the development phase, the users and stakeholders will be involved in the design and development process to make sure that both technology and visual output is useful to handle the issues found during the definition phase. In the assessment phase, the users and stakeholders will be asked to provide feedback on possible modification or extensions.

TABLE I. DIMENSIONS AND INDICATORS OF USER INVOLVEMENT [31].

Dimension 1: Definition		**Dimension 2: Development**		**Dimension 3: Assessment**	
Engagement of citizens/users in elicitation of needs	Yes:0.25 No : 0.00	Involvement of users/testers in common shared environment	Yes: 0.20 No: 0.00	Involvement of ALL user categories in the assessment	Yes: 0.33 No: 0.00
Involvement of users in the service definition	Yes:0.25 No : 0.00	Involvement of user in interface test and refining	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: phone calls	Yes: 0.0825 No: 0.00
Involvement of users in functionalities definition	Yes:0.25 No: 0.00	Involvement of user in functionalities test and refining	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: web modules	Yes: 0.0825 No: 0.00
Involvement of users in the complete interaction definition	Yes:0.25 No : 0.00	Involvement of user in check of documentation / guidelines	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: consultations	Yes: 0.0825 No: 0.00
		Involvement of ALL user categories in the tests	Yes: 0.20 No: 0.00	Instrument used gather the users' feedback: workshops	Yes: 0.0825 No: 0.00
				Scope: improvement of the service usability	Yes: 0.165 No: 0.00
				Scope: definition of new features	Yes: 0.165 No: 0.00
I1	**Max score 1.0**	**I2**	**Max score 1.0**	**I3**	**Max score1.0**
Total score: I1/3 + I2/3 + I3/3					

V. CONCLUSION

In this paper, we propose a research design for smart city projects where sensors are used to collect data on a range of variables related to transport, energy use, safety, health and the environment. The sensors may be stationary (., fixed to buildings), mobile (e.g., mounted in cars) or part of smartphones and their ecosystem (e.g., smart watches containing sensors).

The collected data can be analyzed and visualized so that decision makers are able to make better informed decisions related to day to day management of cities. The collected data can also be used for prediction of what will happen in the future.

We apply the smart city framework of Chourabi et al. [10] to address the potential issues involved in such projects. In addition, we argue that it is essential for smart city projects to find ways of involving key stakeholders, as different cities and regions are faced with different challenges. Key stakeholders should be involved in both project definition, project development and project assessment.

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Approach for Finding Ridesharing Paths in Spatiotemporal Space

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***Abstract*—Ridesharing recommendation is an important application in urban computing. The existing grid map method is a popular method but may overlook many possible ridesharing opportunities. In this paper, we proposed an algorithm to find ridesharing paths that consist of two stages. In the first stage, GPS tracjectoreis are segmented and represented as cubes, and in the second stage, those cubes serve as landmarks for identifying possible ridesharing paths. We used the GeoLife GPS trajectories dataset to evaluate this approach and compared our algorithm with the grid map method. The results show that the number of possible ridesharing paths identified by our approach is six times that of the grid map method.**

Keywords–Urban computing; similar trajectories; ridesharing paths; GeoLife GPS Trajectories.

I. INTRODUCTION

"Ridesharing is the sharing of vehicles by passengers to reduce vehicle trips, traffic congestion and automobile emissions.", according to Wikipedia [1]. Many studies in urban computing use GPS trajectories to analyze ridesharing problems [2][3][4][5] in spatial or spatiotemporal space. These methods can find the sub-trajectories where only partial paths have ridesharing possibility while the origins and destinations of two paths are not always the same. Some methods can further find proximate trajectories where two parallel paths are not exactly on the same road but can have ridesharing relation. Most methods require the information of road network to compute ridesharing paths [5][6][7][8][9] , while another popular method proposed in [3][4] works without road network information (termed as the grid map method here) by partitioning a map into numerous blocks and identifying overlapping blocks for potential ridesharing paths. Figure 1 shows a simple example of the grid map method. The data shown in Figure 1 are the GPS temporal traces (trajectories) extracted from GeoLife dataset (from 9 am to 10 am in the downtown area of Beijing). The whole map is divided into tiny rectangular grids according to the x and y coordinates, and the number of traces passing through each grid is calculated. Any grid that has less than 10 passes is not shown on this map. While this method is effective and can successfully identify ridesharing paths without road network information, one caveate of the grid map method is that only the paths in the same block are considered as a candidate of possible ridesharing paths but the paths in the adjacent blocks were not even if the gap between two paths in adjacent blocks is just a few centimeters. Therefore, the grid map method may overlook possible candidates.

In this paper, we proposed yet another approach that does not require road network information either, with the aims to improve the searching ability by solving the abovementioned caveate in the grip map method. Our approach can find proximate sub-trajectories, includes partial ridesharing paths and the parallel paths. Inspired by computational geometry [10], our approach segments and expands trajectories into numerous cubes. Our approach finds ridesharing paths between one target trajectory and all other trajectories on both spatial and temporal space once. The evaluation was carried out by feeding the GeoLife GPS trajectories dataset into our approach as well as the grid map method. The results show that our method outperformed the grid map method in terms of the number of identified ridesharing path candidates.

Figure 1. An example of the grid map method. We used the GeoLife GPS trajectories dataset to evaluate this approach.

The rest of the paper is organized as follows. Section II gives an example of ridesharing paths. Our approach is described in Section III. The experimental evaluation to show the accuracy and compared results are in Section IV. Section V gives an example to apply our approach. Related works are explained in section VI. Finally, we conclude our study and the future works in Section VII.

II. RIDESHARING PATHS

Figure 2 shows an example of ridesharing paths and each symbol represents a GPS point. The averaged distance (spatial gap) between the two paths within the range of the red circle in Figure 2 is about 20 meters. Figure 3 shows the same trajectories as in Figure 2 but further including the temporal data as the third dimension. Figure 3 shows that the temporal gap between the two paths is about 1800 seconds and they have ridesharing relation.

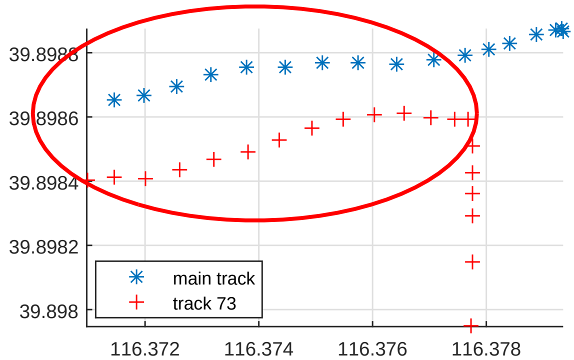

Figure 2. An example of ridesharing paths. X-axis denotes the longitude and Y-axis the latitude. The two paths (main track and track 73) are identified as having a ridesharing relationship within the range of the red circle.

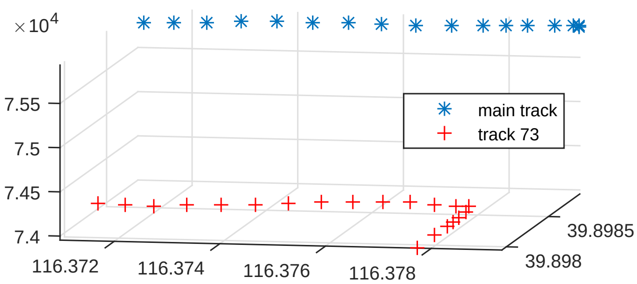

Figure 3. The same tracjectories as in Figure 2 represented in a three-dimensional plot. X-axis denotes the longitude, Y-axis the latitude, and Z-axis the temporal dimension (sec). The total time duration is 86400 seconds(24 hours).

III. Proposed Approach

This section presents our algorithm for finding the ridesharing paths, includes an algorithm for preprocessing raw data, an algorithm for cube-intersection, and a heuristic for finding the multiple ridesharing paths.

A. Preprocessing

The GPS trajectories are segmented and expanded into a series of cubes objects in this step before inputted to our cubes-intersection method. This step makes it feasible to get ridesharing paths and reduce the computational cost while a cube includes many GPS points. In Algorithm 1, the input T is a GPS trajectory, where each point $p_i = \{x_i, y_i, t_i\}$ is characterized by the longitude, latitude and timestamp. The sequence of T is in temporal order. The two parameters, ϵ and τ, are the size of a cube in the x-y plane and time domain respectively. In the beginning, a new cube object c is initiated for inserting GPS points later. Next, each GPS point of T is scanned to check whether the size of a cube c_j is bigger than the parameters, ϵ and τ when a new GPS point p_i have been inserted to c_j. The checking is conducted by (1), (2) and (3). $dist()$ converts the distance of two coordinates to meters. The new GPS point p_i will be removed from c_j if p_i lead c_j to out of the threshold ϵ and τ, and the p_i will be inserted to new c_{j+1}. The center position of the cube c_j is computed by (4) and stored as part of cube attribute. The direction of the route in a cube is computed by (5). In the final step, cubes series C will be outputted when every GPS point of T is scanned. Figure 4 shows the concept of the $cubes$ visually.

$$\begin{aligned} lng\_range\left(c\right) &= dist\left(\left(lat1, b1\right), \left(lat1, b2\right)\right) \\ lat1 &= Latitude\left(first\_point\left(c\right)\right) \\ b1 = min\_Longitude\left(c\right), b2 &= max\_Longitude\left(c\right) \end{aligned} \quad (1)$$

$$\begin{aligned} lat\_range\left(c\right) &= dist\left(\left(lng1, d1\right), \left(lng1, d2\right)\right) \\ lng1 &= Longitude\left(first\_point\left(c\right)\right) \\ d1 = min\_Latitude\left(c\right), d2 &= max\_Latitude\left(c\right) \end{aligned} \quad (2)$$

$$\begin{aligned} time\_range\left(c\right) &= \\ max\_Timestamp\left(c\right) &- min\_Timestamp\left(c\right) \end{aligned} \quad (3)$$

$$\begin{aligned} center(c) &= (x_c, y_c, z_c) \\ x_c &= \frac{max\_Longitude\left(c\right) + min\_Longitude\left(c\right)}{2} \\ y_c &= \frac{max\_Latitude\left(c\right) + min\_Latitude\left(c\right)}{2} \\ z_c &= \frac{max\_Timestamp\left(c\right) + min\_Timestamp\left(c\right)}{2} \end{aligned} \quad (4)$$

$$\begin{aligned} direction\left(c\right) &= arctan(\\ Latitude\left(last\_point\left(c\right)\right) &- Latitude\left(first\_point\left(c\right)\right), \\ Longitude\left(last\_point\left(c\right)\right) &- Longitude\left(first\_point\left(c\right)\right)) \end{aligned} \quad (5)$$

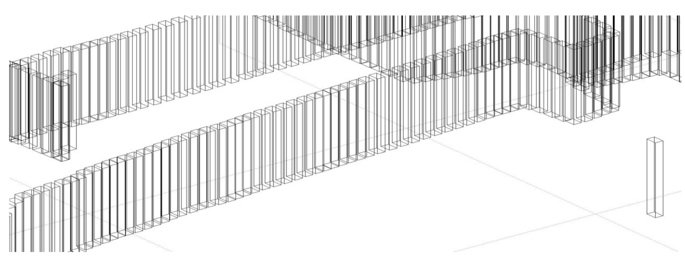

Figure 4. A conceptual plot of the cube series after Preprocessing algorithm.

B. Cubes intersection

This part is to check the intersection between any two cubes in a three dimensional space to find ridesharing paths. In the algorithm 2, the cube series C_1 represents a target trajectory and C_2 represents a combination of all other trajectories. We used a simple all pair checking between the cubes of C_1 and the cubes of C_2. Equation (6) defines a function to check the intersection. After (6), two cubes will be further checked that the direction of two cubes are similar by comparing with

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Algorithm 1 Preprocessing

Input: Trajectory $T = \{p_1, p_2, \dots, p_m\}$. Size threshold ϵ. Time threshold τ.
Output: Cubes series C

initial a cube c_1
let j = 1
for $i = 1, 2, \dots, m$ **do**
  add p_i into c_j
  if lng_range(c_j) $>$ ϵ **or** lat_range(c_j) $>$ ϵ **or** time_range(c_j) $> \tau$ **then**
    Remove p_i from c_j
    compute center position and direction of c_j.
    insert c_j into C
    j = j + 1
    initial a new cube c_j
    insert p_i into c_j
  end if
end for
compute center position and direction of c_j.
insert c_j into C
return C

the input parameter δ, an angle threshold. In other words, two trajectories have no ridesharing possibility if they have opposite directions. Two cubes have ridesharing relation if they had a intersection. The information of ridesharing paths will be recorded in L. The cube ID j that intersects with the cube of C_1 will be added to L where the row number is the cube ID i and the column number is the trajectory ID of c_j. The output L is a sparse matrix, whose number of rows is the number of cubes in C_1 and the number of columns is the number of trajectories in C_2.

$$isIntersect(c_i, c_j) = \begin{cases} true, & \text{if } dist((y_{c_i}, x_{c_i}), (y_{c_i}, x_{c_j})) < \epsilon \\ & \text{and } dist((y_{c_i}, x_{c_i}), (y_{c_j}, x_{c_i})) < \epsilon \\ & \text{and } |z_{c_i} - z_{c_j}| < \tau \\ false, & otherwise \end{cases} \quad (6)$$

Algorithm 2 Cubes-Intersection method

Input: cube series $C_1, C_2 = \{c_1, c_2, \dots, c_m\}$. angle threshold δ
Output: sparse matrix L: each element can store more than one number.

for all $c_i \in C_1$ **do**
  for all $c_j \in C_2$ **do**
    $\theta_{i,j} \leftarrow$ get angle difference between $direction(c_i)$ and $direction(c_j)$.
    if $isIntersect(c_i, c_j)$ **and** $\theta_{i,j} < \delta$ **then**
      add j into L(i, track_ID(c_j)).
    end if
  end for
end for
return L

C. Multiple ridesharing paths

The matrix L is already a database of multiple ridesharing paths. L contains every ridesharing path and can be seen as a one-dimensional table where each column represents one trajectory from a three-dimensional space. Each row represents a ridesharing relation between the target and other trajectories. Below is a heuristic to find the multiple ridesharing paths from L.

1) In L, the columns with the number of non-zero elements less than β shall be deleted, where β is a user-defined parameter.
2) In L, rows with only zero shall be deleted.
3) Compute Φ vector from L, whose definition is

$$\begin{aligned} L &= [r_1, r_2, \cdots, r_n]^T \\ \Phi &= [\phi(r_1), \phi(r_2), \cdots, \phi(r_n)] \\ \phi(r_x) &= \#NonZeroElements(r_x) \end{aligned} \quad (7)$$

   Simply said, Φ is a vector that each element is the number of non-zero elements in row r of L.
4) Choose a range in Φ, in which the elements are large enough.
5) Recover the GPS points from those cubes correspond to the range of rows in L, to show the real paths with ridesharing relation.

In L, We want as many non-zero columns as possible because the columns represent the trajectories have ridesharing relation; we want as long non-zero continuing rows as possible because the rows represent a long ridesharing path. A user can retrieve a short range of rows that have many columns with non-zero elements, or just one column that have the longest ridesharing path. However, it is difficult to have both at the same time. Step 1∼4 can be repeated until the range of rows and columns is small enough to find ridesharing paths. In section V, we will show an example to explain this idea.

IV. EXPERIMENTAL EVALUATION

This section shows our experimental design to investigate the questions of the performance. The structure of this section begins with the experimental purposes, followed by the overall experimental design and the experimental results.

A. Experimental Purposes

Some questions related to our approach were explored. The intention was to examine the accuracy and the ability to search ridesharing paths. Those questions were examined with Geolife dataset. The questions we explored were:

1) Will the gap between two ridesharing paths be like the ϵ we set?
2) Can our approach find more ridesharing paths than the grid map method?

Question 1 is to find out the distribution of GPS points in two intersected cubes. GPS points are possible in any position in a cube, and some GPS points may be in the corners of a cube which may lead a gap space of two ridesharing paths more than ϵ meters. Question 2 is to find out the ability of our approach to search ridesharing paths is better than the grid map method.

B. Experimental Design

This experiments use the Geolife dataset[11] as the test data. The dataset contains 17,621 GPS trajectories with a total distance of 1,292,951 kilometers and a total duration of 50,176 hours by 182 users. Those trajectories were recorded by various GPS loggers and GPS-phones with various sampling rates. 91.5% of the trajectories are logged in a dense sampling rate, e.g. every 1∼5 seconds or every 5∼10 meters per GPS point. Each record in the dataset contains the information of latitude, longitude, altitude and time-stamp. This dataset recorded a broad range of user movements, including life routines like go home, go to work, and some entertainments and sports activities such as shopping, sightseeing, dining, hiking, and cycling. The majority of this dataset is in Beijing, China, few data is in other countries.

To reduce the variation, we only use the GPS points in Beijing city that inside 6th Ring Rd, from coordinate (39.688403, 116.091945) to (40.179632, 116.714733). The experiments were carried out on the mainframe with the specification below:

- CPU: Intel Core i7-4790 3.6GHz
- Memory: DDR3-1600 16GB Non-ECC
- OS: Windows 7 64bits
- Programming Language: C++ on Visual Studio 2013

The experiment design for question 1, Figure 5, uses two different cube sizes, (ϵ=20,τ=600) and (ϵ=100,τ=3600), to show the distribution in all pairs of intersected cubes. To check any pairs of ridesharing paths which found by our approach have a gap distance as we expect, DTW(Dynamic Time Warping) [12][13] was used to verify the gap distance between two ridesharing paths. The DTW method can find the pairwise GPS points on two trajectories. The DTW in this experiment is the dynamic programming edition, whose computational speed is much faster than the recursive edition.

The experiment design of question 2 is shown in Figure 6. To evaluate the ability of our approach to search ridesharing paths, we compare results of our approach with the grid map method. The outputs of either approach are the ridesharing information and the length of each ridesharing path was accumulated. The larger accumulated result, the better ability to find ridesharing paths. Both the block size of grid method and the cube size of our approach are 100 meters width and 3600 seconds height.

C. Experimental Results

Will the gap between two ridesharing paths be like the ϵ we set? Figure 7 shows a statistic result when ϵ=20 meters. The figure shows that 92% pair-points have a gap distance less than 20 meters. The Figure 8 shows a statistic result when ϵ=100 meters. The result shows that 95% pair-points have a gap distance less than 100 meters. Both results show that the distribution in most intersected cubes is in our expectation. Most of the ridesharing paths have a gap distance less than ϵ.

Can our approach find more ridesharing paths than the grid map method?

The result in Figure 9 shows that the accumulated ridesharing path of our approach is six times that of the grid map method. The finding ridesharing ability of our approach is significantly better than the grid map method. The possible

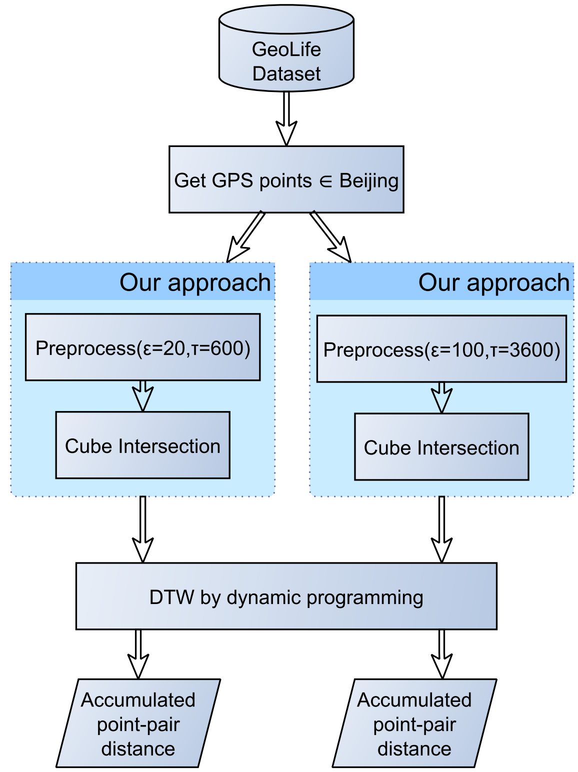

Figure 5. The design of experiment 1

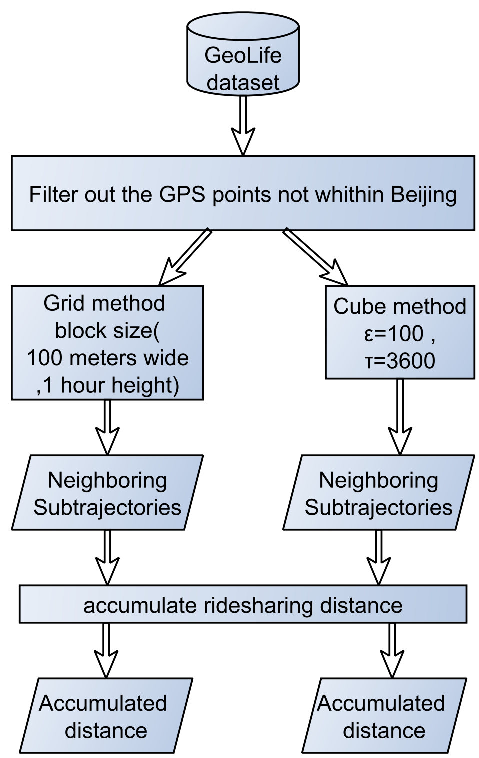

Figure 6. The design of experiment 2

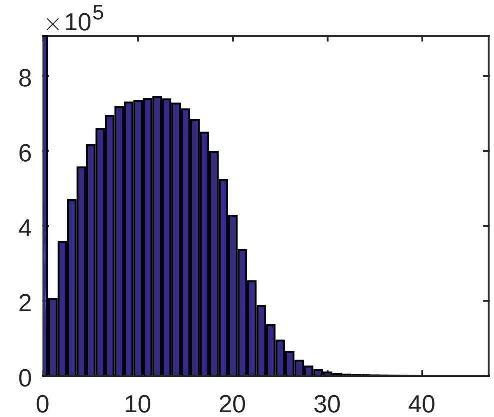

Figure 7. Accumulated results of cube size ϵ=20 and τ=600. X-axis represents the distance between the two corresponding GPS points (in meter), and the. Y-axis dentoes the counts GPS point-pairs within each bin in the X-axis.

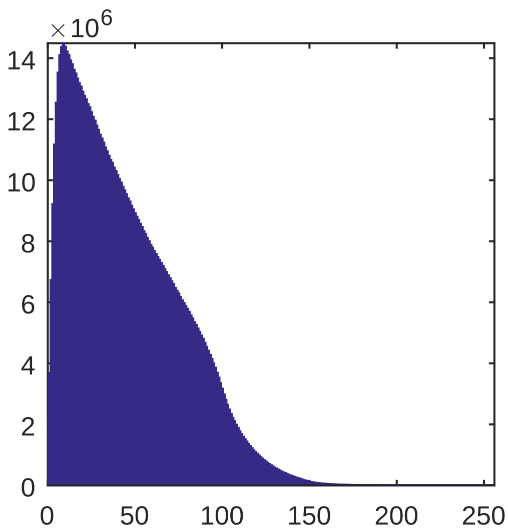

Figure 8. Accumulated results of cube size ϵ=100 and τ=3600. X-axis represents the distance between the two corresponding GPS points (in meter), and the. Y-axis dentoes the counts GPS point-pairs within each bin in the X-axis.

reason is that in the grid map method, only the paths in the same block are considered as a ridesharing path while the path in the next block will not be considered even if there is only a few centimeters gap between them. Our approach can find every ridesharing paths while the gap between two paths is smaller than ϵ. However, the computational time of the cube method is 1960 seconds, which is larger than the grid method, 152 seconds. The possible reason is that our approach needs more time to search wider range and more ridesharing distance. On the other hand, we use a huge array to represent a grid space in the grid map method for random access ability, which any pair of paths can be checked whether they are in the same block in a constant time.

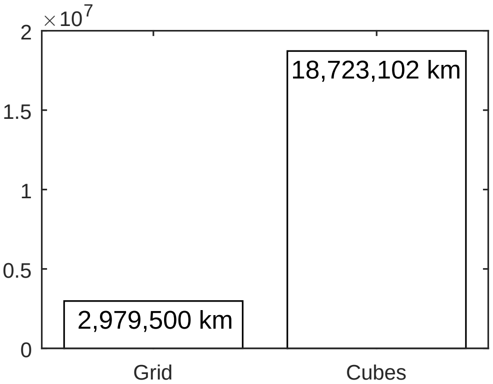

Figure 9. The accumulated ridesharing path distance

V. Application

Our approach can find ridesharing paths by comparing multiple candidate trajectories with one target trajectory. Here we demostrate an application of the proposed method, by using the trajectories data of User 0 and User 2 (about 170 trajectories for each user) in the Geo-life dataset. The task was set as a query “Compare each trajectory of User 0 to all the trajectories of User 2, and find the trajectory from User 0 that has the most ridesharing paths with User 2”. Because our approach is comparing each trajectory to multiple trajectories at once, our approach is performed 170 times if there were 170 trajectories in User 0. The parameters in this example are $\beta = 10$, $\tau = 3600$ seconds, $\epsilon = 100$ meters. For example, by setting $\beta = 10$ and $\epsilon = 100$, the ridesharing paths in L with the length less than 1000 ($\beta \times \epsilon$) meters will be excluded. The results are shown on Figure 10 and Figure 11, the symbols in the graph are original GPS points with timestamps. We set the cube segments from 782 to 816 based on the values of Φ in Figure 12. These segments have most continuous ridesharing paths than other ranges of segments. The main track on the graph represents a target trajectory of User 0. Other tracks on the graph are the trajectories of User 2. Figure 10 is a two-dimensional graph showing the geographical path. Figure 11 is a three-dimensional space with temporal space, shows that there are four paths overlapped in terms of spatial distance but not in terms of temporal gap. Table I demonstrates the one-dimensional trajectories table extracted from L for the application. We found that User 0 has a GPS trajectory on 2009-04-03 that significantly overlapped with the trajectories of User 2 on 2008-11-19, 2008-12-05 and 2009-03-09.

VI. Related Works

This section introduces some works which are related to our study.

A. Computational Geometry

The rectangles intersection problem has been thoroughly investigated in computational geometry [10] . One research which uses computational geometry to find similar parts of trajectories is Buchin et al. [14] , which also takes temporal data into account. However, the method can become inefficient in practice for large sets of trajectories with many vertices.

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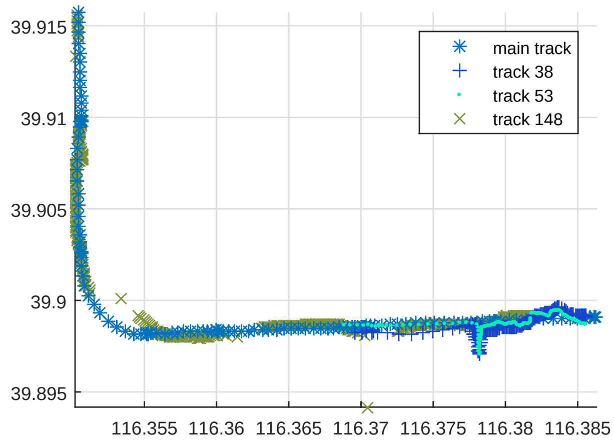

Figure 10. The application in two-dimensional plot. X-axis denotes the longitude, Y-axis the latitude.

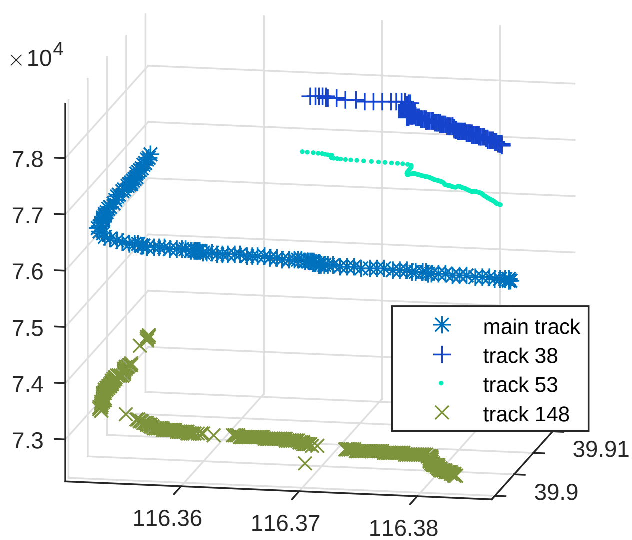

Figure 11. The application in three-dimensional plot. The total time duration is 86400 seconds(24 hours).

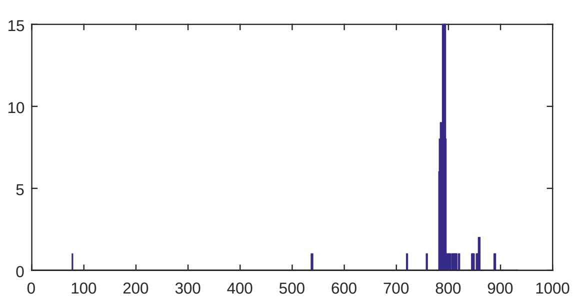

Figure 12. The values in Φ of this application. X-axis denotes the cube ID number. Y-axis denotes how many trajectories intersect with this cube.

TABLE I. ONE-DIMENSIONAL TRAJECTORIES TABLE FROM THE MATRIX L IN THIS APPLICATION.

main track	**track 38**	**track 53**	**track 148**
782	52	1	0
783	52,53	1,2	0
784	53,54	2,3	0
785	54,55	3,4	7
786	55,56	4,5	7,8
787	57	6	8,9
⋮	⋮	⋮	⋮
792	63,64	13	14
793	64,65	14	16
794	65	15	16,17
795	0	0	17,18
796	0	0	18,19
⋮	⋮	⋮	⋮
816	0	0	38

B. *Methods of finding similar trajectories*

The methods based on curve similarities, such as Longest Common Sub-Sequence LCSS [15], Edit Distance on Real sequence(EDR) [16], Hausdorff distance [17] and Dynamic Time Warping(DTW) [12][13] , are essentially not designed for ridesharing. These methods can get a value of similarity of two trajectories. However, they can find only one common sub-trajectory from two trajectories while there are multiple separated common parts. These methods also measure the similarity of the shape of two trajectories which is not required in our approach. The computational cost is high while the methods directly process GPS points without any points reduction methods. Usually, these methods only consider spatial data but spatiotemporal data [18].

C. *Graph-based methods*

Graph-based methods, such as Network Hausdorff Distance(NHD) [6][7], temporal graph-based method [8], grid with road network information method [5][9][19], the 2 synchronization points shortest paths problem [20][21], use road network information to simplify the analysis of trajectories. The road network information is like the nodes and the edges in Traveling Salesman Problem(TSP). The major issue of these methods is they will be useless while there is no road network information. Our approach processes GPS points directly but not mapping the points into POI.

D. *Ridesharing system*

The studies of the ridesharing system, such as taxi ridesharing [5], salient traffic problem [22] and the system of [3][4], show effective results. However, the taxi ridesharing and the salient traffic problem also need road network information. The system of [3][4] uses no road network information but splits user trajectories into a number of segments according to temporal distance and match the segments into grid space. The issue of the system is it may overlook possible candidates in adjacent grids as we explained in the introduction of this paper.

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VII. Conclusion and Future Works

In this study, we designed a different approach to identify possible ridesharing paths for the ridesharing recommendation. The proposed approach can find ridesharing paths between one target trajectory and all other candidate trajectories in spatiotemporal space. The experimental results show that more than 92% ridesharing paths have a gap distance less than ϵ, which represents our cube intersection approach function well. The ability of searching ridesharing paths is significantly better than the grid map method. However, the time cost of our cube method is higher than the grid map method. The possible reason is that our searching program is not yet optimized. We expect to reduce the time cost of this method by incorporating some optimization techniques from computational geometry in future works. Based on the classification of ridesharing system in a previous study [23], our proposed method is categorized as "routing and time" class, which focuses on matching passengers and drivers by checking the pick-up and drop-off locations on the same path and the same time. Other classes such as "Origin-Destination pair" and "Keyword/List" consider only the starting and ending points but ignore the route between the two points, which is also an effective way for a ridesharing system. We leave this issue to future studies.

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Greening the Scientific Conferences

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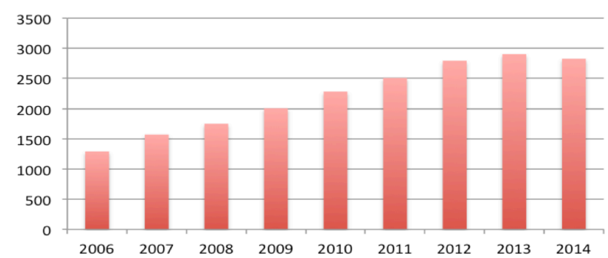
***Abstract*—Today we are facing an increasing number of scientific conferences that play an important role in the exchange of information for academia and researchers. In order to attend a conference, attendees travel to the conference city from all over the world and for bigger meetings this will produce a significant amount of carbon dioxide and other greenhouse gasses. In sustainable urban environments, various mobility solutions such as public transport, car sharing, and ride sharing are offered to enable seamless multimodality and reducing the urban pollution. However, the urban impact of the academic events needs to be addressed on a larger spatial scale. In scientific conferences, the conference location is decided during the early stages of conference planning and is announced by way of a Call For Papers. To this end, the conference location is merely decided based on economic, political, or city-attractiveness concerns. In this paper, we will first articulate the importance of the conference location by analyzing the real world data of some past conferences. Next, we show that there is a strong correlation between the emission rate per capita of the contributing authors and the final attendees of the conference. Based on this finding, we will then propose the idea of variable conference location that suggests deferring the selection of conference city to the paper submission deadline. As a result, it would be possible to make an informed and environmental-friendly decision about the conference location.**

Keywords - greenhouse gasses; emission; conference management; green events

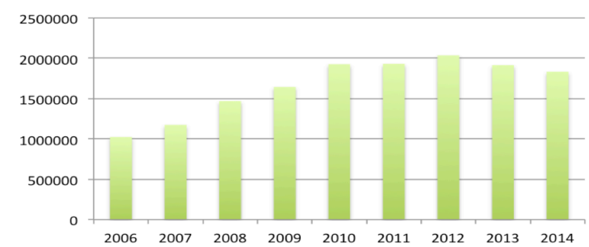
I. INTRODUCTION

Scientific conferences are an integral part of the science and academic life. Every year millions of scientists and researchers around the world attend a meeting or conference for presenting their works, receiving feedback, and doing face-to-face interaction and networking. The meetings have also emerged as a significant contributor to national economies. According to a 2009 UNEP green meeting guideline, every year over 80 million people around the world attend a meeting or conference and even more attend trade shows or exhibitions [1][2]. Another study states that in 2012, there have been 284,600 conventions/conferences/trade shows in the US alone, with a total of 87 million attendees [3]. Also, according to the U.S. Bureau of Labor Statistics, conventions and events sector is the fastest growing occupation and is expected to expand by 43.7 percent from 2010 to 2020 [4].

Over the past several years, the number of conferences and scientific papers has increased significantly. For instance, according to one of the proceedings databases [5], which contain listings of thousands of conference



(a)



(b)

Figure 1. Number of conferences (a) and procedings' pages (b) between 2006 and 2014

publications, the number of conferences, as well as the proceedings' volumes, are two-folded. Figure 1 shows the increasing rate of scientific conferences and their proceedings volume between 2006 and 2014.

There are a number of arguments that might explain this phenomenon. One reason could be the broad acceptance of academic publications and citations as the evidence of research impact of scientists. This puts much pressure on scientific communities to sustain their career and academic promotion via publishing more papers and attending many scientific conferences. Besides, the recent advances in virtual meetings, digital communication, and webinars have not impacted the value of face-to-face communication and in-person meetings. Accordingly, it seems that the widespread adoption of such technologies may be years away [6][7].

This global rise of conferences and meetings imposes a bigger number of travels and consequently causes a significant amount of carbon dioxide (CO2) and other greenhouse gasses. The transportation and especially the long-haul travels of attendees are the major source of conference-related emissions. So, minimizing the travel path to the attendees' home country and city would significantly reduce the carbon footprint of the conference.

In order to reduce the contribution of transportation to urban pollution, the city designers try to shorten the paths to daily living destinations and make them accessible within a walkable distance. In the case of academic events, we are dealing with the same optimization problem on a larger spatial scale. However, neither the conference location nor the attendee location is flexible which hinders the optimization of the traveling distances and reduction of the urban pollution. Consequently, little attention is paid to the environmental impact of the conference location. The conference location is usually decided based on administrative or city-attractiveness factors. As such, the conference location is predetermined and the volume of emissions can be calculated only after the conference registration phase when the participation list is completed. Supposing that the conference location could be variable, it would be possible to calculate the optimal conference location based on the participants' list and their travel path to the conference location. Although the post-determination of conference city may reduce the emission, but in practice, this does not seem to be feasible. One of the major problems of this approach is the narrow timeframe for the participants and the conference organizers. This issue will not allow participants to plan the travel and address the formal requirements such as submitting the travel request to their organization or applying for the visa of the target country. Also, the conference organizers will not have enough time to plan the conference tasks and organize the local chairs and local staff competently.

In the present work, we first articulate the importance of the conference location by analyzing the real world data of some past conferences. Next, we show that there is a strong correlation between the emission rate per capita of the contributing authors and the final attendees of the conference. Finally, as depicted in Figure 2, we suggest a data-driven approach for selecting an environmental-friendly conference location.

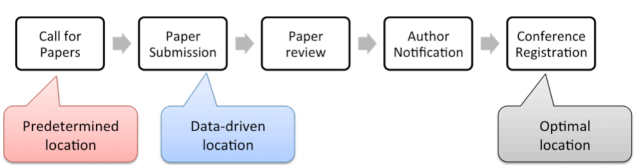


Figure 2. Determining the conference location at various phases of a scientific conference

The major contribution of this paper is to establish a data-driven approach to approximate the emission per capita of conferences based on the submitted papers and their prospective presenters. As such, the conference location can be determined as early as the paper submission phase. This will give enough time to the conference organizers to plan the logistic and organizational tasks, as well as attendees to plan their travel accordingly.

The rest of this paper is organized as follows. Section 2 reviews the state of the art. Section 3 introduces the data resources and the semantic data integration process for enriching the data and filling the missing values. Section 4 presents the emission calculation method for determining the emission per capita of conference participants. The proposed approach of this work is presented and discussed in Sections 5 and 6. Finally, Section 7 describes the future work and concludes the paper.

II. STATE OF THE ART

According to United Nations Environment Programme (UNEP), "a meeting or conference can be considered climate neutral when all possible efforts have been made to reduce the greenhouse gas (GHG) emissions arising from the organization of the meeting and when carbon offsets have been purchased to compensate for the unavoidable emissions" [1]. Since a significant part of the conferences' emission is associated with participants' travel activities, the conference location plays a significant role. There are a few guidelines for greening the meetings and the most common recommendation about the location of meetings is to minimize the local and long distance transportation needs for participants and products. However, in the specific case of scientific conferences attendees and their origin countries are unknown at the early stages of the conference planning and as a result optimizing the distances for long-haul travels is not possible.

Another proposed option for reducing the emission is to restrict meetings to major cities because holding them in outlying areas will require more connecting flights and subsequently more emissions [8]. There are also a few other proposals that suggest organizing fewer meetings or restricting the number of attendees but as discussed in the previous section, these suggestions are already neglected and overridden by the scientific community.

Other options are the virtual meetings [8] and the amplified conferences [9] that use ICT and networked technologies in order to extend the reach of the conference and liberate the participants from traveling to the conference location [10]. Although the virtual meetings are a great alternative to physical conferences in order to reduce emissions, but the trade-off is the limitation in social and networking activities.

III. DATA RESOURCES

The dataset of this study is taken from an integrated conference management system that offers various modules for paper management and conference registration. The selected dataset contains the paper submission and registration records of seven international conferences between 2010 and 2015. Each conference comprises a collection of co-located conferences and workshops. The attendees of these conferences range between 300 to 600 and the conferences have various acceptance rates. Figure 3 shows conference cities as well as the number of paper contributors, accepted authors, and attendees of these conferences.

Selection of paper contributors and accepted authors is based on the contact author of submitted papers during the paper submission phase. Each contact author may contribute one or more papers and will be considered as accepted author if at least one of the submissions is accepted.

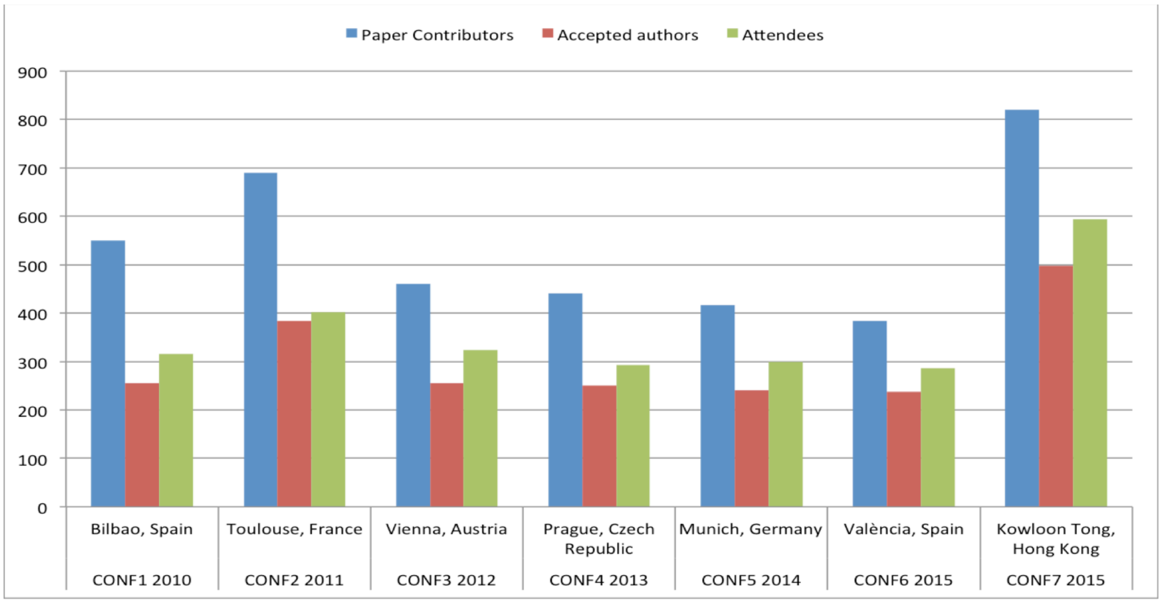


Figure 3. number of paper contributors, accepted authors, and attendees of selected conferences

Usually, conference organizers require at least one registration per accepted paper in order to include the papers in the conference proceedings and urge the authors of accepted papers to register and present their work in person.

In order to calculate the emission rates, we would need to identify the city and country of the contributing authors. Since the dataset of conference management system contains only the author's affiliation, we used the open data to acquire their city and country names. To this end, we first used the DBPedia lookup service [11] to disambiguate the affiliations and match them with the DBpedia resources. To increase the precision of results, the queries were limited to the "Organization" class of DBPedia ontology and the affiliations were annotated with their DBPedia URIs. For instance, the lookup service assigns the DBPedia resource [12] to the affiliations containing text "MIT" or "Massachusetts Institute of technology".

After this step, we used the DBPedia SPARQL endpoint to extract the city and country name of each affiliation by using the specific property names of DBPedia ontology as shown in Figure 4.

We used the OpenRefine tool [13] to automate the above-mentioned steps and could disambiguate and reconcile a big portion of the data. For the remaining part, which was not recognized by the DBPedia, we made an intensive data cleaning and manual matching to create a complete and concise dataset for our analysis. As the final step, we used an online API [14] to calculate the distance between the conference location and the corresponding cities of the contributors and participants.

```
SELECT str(?city_name) str(?country_name) WHERE
{
  OPTIONAL {
<http://dbpedia.org/page/Massachusetts_Institute_of_Tech
nology> dbp:city ?city
<http://dbpedia.org/page/Massachusetts_Institute_of_Tech
nology> dbo:city ?city }

   ?city rdfs:label ?city_name .
   ?city dbo:country ?country .
   ?country rdfs:label ?country_name

   FILTER (lang(?city_name) = 'en')
   FILTER (lang(?country_name) = 'en')
}
```

Figure 4. SPARQL query for extracting city and country names based on affiliation

IV. EMISSION CALCULATION

For estimation of CO_2 and other greenhouse gasses, we have used an adapted version of the emission factor calculation proposed by UK Department for Environment Food & Rural Affairs [15]. This method uses a simple model

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to calculate the carbon dioxide equivalent (CO2e) of the travel emissions, which includes CO2, CH4, and N2O weighted according to their global warming potentials.

For specifying the emission conversion factor, we suppose that all participants within a reasonable short distance to the conference location use train and others with longer distances take a flight. To this end, we define three distance categories for domestic rail transport, short-haul flight, and long-haul flight as shown in Table I.

TABLE I. DISTANCE CATEGORIES AND THEIR EMISSION FACTORS

Transportation Type	Distance Range	Emission Factor (kg CO2/pkm)
Domestic (rail)	Less than 785km	0.01205
Short-haul flight	Between 785km and 3,700km	0.0831
Long-haul flight	Greater than 3,700km	0.097

The amount of carbon dioxide equivalent for each conference participant, is then calculated as follows:

Emission = Round-trip Distance * Emission Factor * Uplift Factor

where the emission factor for each transportation type comes from the recent report of [16] and the uplift factor is an adjustment factor to consider non-direct routes, delays, and circling of flights. For rail transport, it will be set to one and for flights, it comes from the IPCC Aviation and the global Atmosphere 8.2.2.3 [17]. Although the uplift factors for short-haul and long-haul distances are different (higher for short-haul flights and lower for long-haul flights), but currently only a uniform value of 1.09 is used by the airline industry which seems to be good enough for the purposes of this paper.

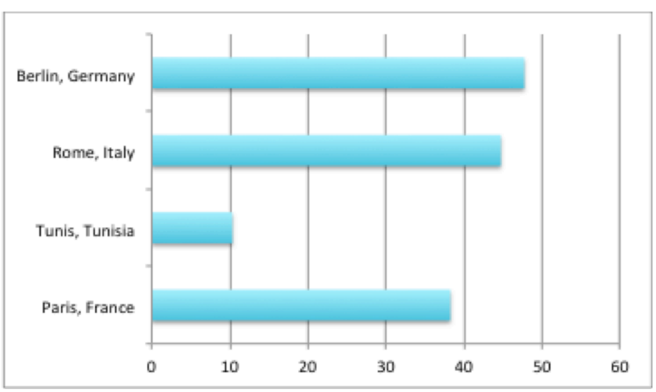

Figure 5. Emission saving per person for Conf 6 in Valencia Spain (kg CO2e)

V. APPROACH

Using the dataset of the conference management system and the above-mentioned emission calculation method, we have assessed the emission per capita for registered participants, contributing authors, and the accepted authors.

The registration dataset includes city and country information of each participant, which makes it possible to make a near-real calculation of conference emission caused by participant's travel. It is important to note that this value could be calculated only after the finalization of the registration process. Therefore, it can be only considered as an informative/evaluation indicator and cannot be used in a proactive way to reduce the conference emissions. In order to highlight the decisive role of conference location in causing emissions and as a demonstrative example, consider the case of CONF-6, which took place in Valencia, Spain. The calculation of carbon emissions shows that by relocating the conference to other cities, a reasonable fraction of the carbon emission will be reduced. Figure 6 shows the amount of emission savings per capita by relocating the CONF-6 to Berlin, Rome, Tunis, or Paris.

If we consider the number of submitted papers per country and compare it with the emission savings (Table II), we find that the host countries with a higher number of submissions do not necessarily provide a higher rate of emission saving. For instance, in the case of the CONF-6, the top three countries namely France, Tunisia, and Italy are not the optimal location for organizing the conference. Furthermore, a country like Brazil with a high number of submissions will cause a huge amount of emission per capita.

TABLE II. SUBMITTED PAPERS VS. EMISSION SAVING

City, Country	Submitted Papers	Emission Saving
Paris, France	31	38.26
Tunis, Tunisia	31	10.33
Rome, Italy	29	44.72
Berlin, Germany	21	47.72
Brasília, Brazil	20	-1262.77

We now extended the emission calculations to the other two groups namely the contributing and accepted authors. In the dataset of conference management system, each submitted paper has a contact author who upon acceptance of the paper, will register for the paper and attend the conference. Each contact author might have also multiple paper submissions but will be counted only once in the emission calculation lists. This is in line with the economic and budget considerations of the participating organizations that usually prefer to reduce the size of their delegates to the conferences and ask a single author to present multiple papers.

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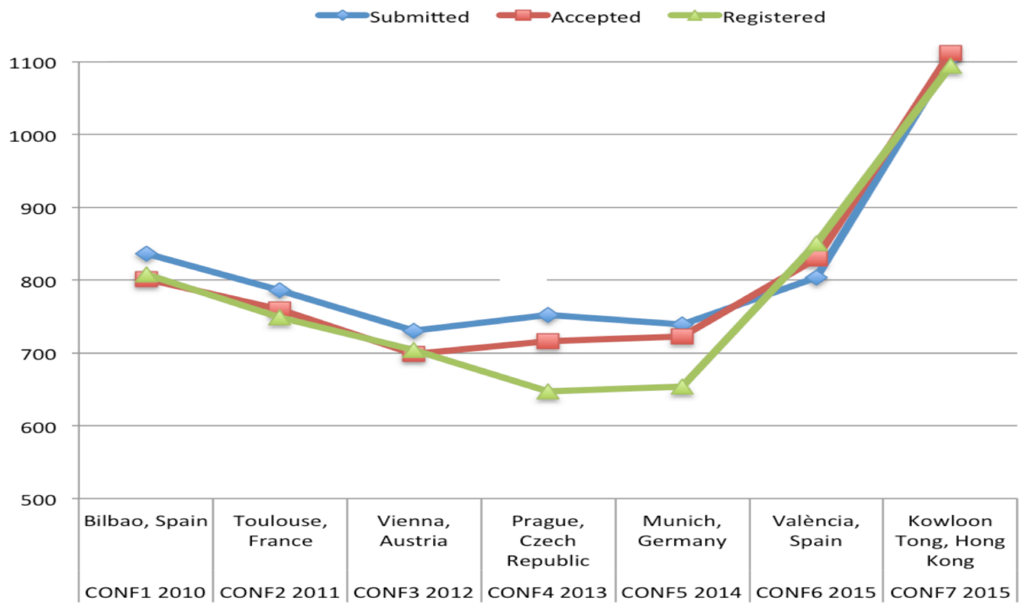

Figure 6. Emission per capita for selected groups and cities (kg CO2e)

In the case of contributing authors, the dataset does not contain the city information of authors and instead we used the distance between the conference location and centroid of author's country for calculating the emissions.

Figure 6 shows the emission per capita for the selected target groups and cities. This empirical result shows a correlation of 0.97 between accepted-registered authors and a correlation of 0.95 between submitted-registered authors. The latter correlation is especially interesting because the list of contributing authors is typically known at the early stages of the conference lifecycle. So, independent of the review and evaluation processes, it can be used as an effective indicator to decide about conference locations.

VI. DISCUSSION

With the current trend in the scientific conferences, it seems to be improbable that the alternative communication models such as virtual conferences replace the physical conferences. So, it makes sense to make the conferences as green as possible.

The preliminary results of this research show that at the early phases of conferences and with a rather good accuracy, the carbon emission of a conference can be estimated. As such, the conference-positioning problem will turn into a well-known 1-center problem [18], where the cost between nodes will be the carbon emission of travel between those nodes. This process will result in a short list of candidate nodes (cities) that produce a lower amount of CO2 emission. As such, the conference organizers will be able to consider the candidate cities as well as other organizational policies to make a data-driven and environmental-friendly decision about the conference location.

Due to the absence of some required data in our dataset, we have made some simplifications to our emission calculation method. These include restricting the transportation vehicle to the railway for short distances (less than 785 km) and considering the country centroids for distance calculation. But, comparing the emission of registered participant and contributing authors shows that these simplifications do not have significant impacts on the estimation of travels' emission. Furthermore, the data preparation for the simplified model requires less effort and as a result, it would be more convenient for the conference organizers to apply it in practice.

Despite proof of feasibility and environmental benefits of the proposed approach, acceptance of variable conference location by the academic community might need a longer time. Nevertheless, compared to other proposed options such as virtual meetings, less frequent meetings, or limiting number of attendance, the proposed solution does not restrain the quality of participants' communication and networking activities.

VII. CONCLUSION AND FUTURE WORK

Our analysis shows that there is a big potential for emission reduction of scientific conferences. The existing options for emission reduction are typically decreasing the quality of social interaction and face-to-face.

The proposed idea of "*variable conference location*" suggests deferring the selection of conference city to the paper submission deadline. The empirical results show a rather strong correlation between the emission per capita of contributing authors and the conference attendees. As a result, it would be possible to make an informed and environmental-friendly decision about the conference location when the paper submission is over. This will give enough time to both attendees and organizers to accomplish the conference preparation tasks.

In order to realize the concept of variable conference location, we would need datasets and services that take the

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environmental concerns into account. For instance, instead of restricting the transportation method to railway or flight, we may be able to plan multimodal trips that consider the environmental concerns provided that the required datasets and services are available. Currently, there are a growing number of cities that promote the multimodality transportation at the urban level. As such, people will be able to plan their transport based on a network of transit option or even combine them to address the individual needs. Unfortunately, the multimodality concept is not yet well established for the case of international trips and the existing trip planning services usually support only a single mode of transportation. This problem is mainly because of the disconnected information resources in transportation domain and lack of standards for data exchange between them. Furthermore, we would need information services that are capable of examining the alternative travel itineraries in order to identify the environmental-friendly variant. So, future work should aim to refine the proposed approach by considering various factors, such as alternative modes of transportation, multi-stop flights, and multimodal trips.

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