Smart Communities and Mobile WSN: a New Approach to a Preventive Healthcare System

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ABSTRACT: *Smart Community is a geographical area that can cover neighborhood, urban, regional, national area whose residents, organizations, and governing institutions are using Information and Communications Technologies (ICT) to transform their region, life and work in significant and fundamental ways. Its aim is to facilitate the construction of a pervasive, high speed communications system and information services that will benefit all sectors of the community: education, healthcare, local government and business. Processing and receiving in real-time information by all the other community members, citizens themselves become distributed intelligent probe and actors on the Community area to make better decisions and enhance the quality of life and improve local economy producing enduring benefits. This work shows how Smart Communities and Mobile Wireless Sensor Networks (MWSN) can play an increasingly vital role in a healthcare system, improving citizens' health, reducing mobility costs and user's carbon footprint. The system architecture and the visual interface prototype of a Collaborative Health Navigation System, will be discussed.*

Keywords: Smart Communities, Distributed Data Sensing, Mobility, Ubiquitous Computing, Android

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1. Introduction

The ubiquity and pervasively of smart phones in every socioeconomic classes, allow not only to communicate with each other but also to create huge cooperative community sensing networks that can cover neighborhood, urban, regional, national area and the whole globe too. The synergy between human interaction and Information and Communications Technologies (ICT) can provide benefits unimagined before and transform life and work to meet the challenge of the new millennium.

Cooperation among government, industry, educators, and the citizenry, instead of individual groups acting in isolation, can be used to promote job creation, economic development, and to produce an improved quality of life in communities. For these reasons several Smart Communities Projects have been proposed. The Italian Ministry of Education published a notice on "*Smart Cities and Communities*" and "*Social Innovation Projects*" on March 12, 2012 to promote ideas that can use the most advanced technologies to directly impact areas of public interest and to solve urban problems such as mobility, security, education, energy conservation and environment. In USA the SMART Technologies for Communities Act (112th Congress, 2011–2012) has been introduced to provide communities with the resources necessary to implement intelligent transportation systems (ITS) to reduce congestion, improve safety and improve the air quality by reducing air pollution. In this pilot program communities would be eligible for funding to integrate the latest information and communications technologies into their transportation system in order to: reduce collisions and increase driver and pedestrian safety, measure and improve the operational performance of their transportation network, deliver environmental and economic benefits by reducing congestion, streamlining traffic flow, and improving access to multimodal transportation alternatives, improve incident and emergency response, enhance personal mobility and convenience, including through real-time traffic, transit, and multimodal traveler information.

The basic idea in smart communities is that members of local government, business, education, healthcare institutions and the citizens themselves work together to use technology to transform their community in significant and positive ways, increasing convenience and control for people in the community as they live, work, travel, govern, shop, educate and entertain themselves.

Processing and receiving in real-time information by every community members, citizens themselves can become distributed intelligent probe and actors on the urban scene to make better decisions about sustainable development. Nowadays a truly sustainable development must be the guiding principle for the communities well-being, because it improves and protects the quality of the environment, enhances the quality of life, improve local economy, produces enduring benefits, not just today, but for our children and their children as well.

Transportation identifies the main area of research and development referred to the concept of the city as a widespread and intelligent community in which environmental and social issues are addressed jointly, such as mobility, security, education, energy conservation and environment. Transportation accounts for over a quarter of the energy consumed in the United States annually, and actually produces one-third of total US carbon dioxide emissions, more than industrial, residential, and commercial sectors, largely due to private automobile use. A real time cooperating travel planning, that run on a smartphone, can make the data on transportation choices and availability more comprehensible providing easy access to travelers' community through social networking. This enhances traveling experience and by calculating the user's carbon footprint in real-time users would recognize the large disparity in carbon dioxide generated by driving private vehicles, instead of using bus or rail. With this heightened awareness users would then opt for more sustainable transportation choices.

This work shows how smart communities and Mobile Wireless Sensor Networks (MWSN) can play an increasingly vital role in a healthcare system, improving citizens' health, reducing mobility costs and user's carbon footprint. The system architecture and the visual interface prototype of a Collaborative Health Navigation System, developed under the project "*Ecourb: Analysing and Modelling Air and Thermo Pollution for Urban Ecolabelling Systems*" Progetto Strategico Regione Puglia, will be discussed in the following of this paper.

Human health and Community prosperity and well-being are directly dependent upon a real pollution reduction, with this aim the municipality of several cities have realized projects for bike sharing (i.e. project "*Bari in bici*" www.comune.bari.it/portal/page/portal/bari). Bike sharing reduces urban traffic and pollution, and can also be used successfully to achieve affordable and accurate real time representation of micro scale environmental conditions and accurate pollution analysis.

Currently, in Italian cities, networks of very accurate stations for the measure of some atmospheric parameters and pollution concentration values, are present for law (D.M. 2 April 2002 n. 60).

Due to the very complex 3D structure of urban area, its very complicated fluid dynamic behavior, and the reduced number of stations, this kind of monitoring network provides very accurate measures but it has the disadvantage of being very punctual with few sampling on the territory, therefore scarcely indicative to extend information for the characterization of entire city areas and to correlate to real observed health effects or to obtain accurate pollution trend analysis.

High resolution pollution monitoring in Metropolitan area requires high density sensor grid impossible to implement due to the cost and management complexity. Several approaches based on Vehicular sensor networks have been proposed in literature to reduce the number of sensing devices, balancing the communication cost and the pollution measurement accuracy.

The proposed prototype integrates the in situ data from the systems already installed for the urban environment monitoring (expensive and therefore in a small number), with other data from mobile low cost systems, in order to analyze urban processes at different scales (macro, meso, micro) significant for urban environments (from regions and metropolitan areas to urban centers, areas, neighborhoods, up to building blocks) and to provide a Collaborative Health Navigation System able to suggest ideal paths for different types of diseases. Users can define a destination, the amount of time to reach it or his cycling capability, the type of pollution to avoid (i.e. powders, gas, noise) and the navigation application automatically suggests the route with the lower pollution level.

Our prototype is based on simple low cost sensing platform embedded in the bike frame, that by bluetooth connection sends acquired data to an application running on the cyclist smartphone. Data collected in the smartphone are compressed and transmitted to a Monitoring Server by specific wifi access point available at bike sharing racks.

The Monitoring Server collects, validate data and produce high resolution pollutant concentration contour map that can be graphically visualized by users on their smart phone or can be used by the proposed Collaborative Health Navigation System application to choose the healthiest route.

Our mobile sensor prototype include a CO electrochemical sensor, a non dispersive infrared CO2 sensor, an "*Arduino*" based transponder, and an Android application for sensor-monitoring server connection and navigation.

This paper is structured as follows: after a related works section we describe the system architecture and the prototype of the low cost, high precision, miniaturized mobile monitoring station. In section 4 we show the pollution map generation, while the Collaborative Health Navigation System application will be described in section 5. We conclude with some considerations on preliminary results on data integration, processing and visual representation on the Collaborative Health Navigation System application.

2. Related Works

Smart communities provide a perfect platform for innovation on pervasive healthcare, in [1] is defined and discussed a smart community architecture to realize secure and robust networking among individual for pervasive healthcare. Authors refer to a paradigmatic class of cyber-physical systems with cooperating objects (networked smart homes). In [2] a consumer-community paradigm is introduced, investment in health information exchange and the creation of Smart Health Communities by shifting the focus of exchange from public servant to value-added service provider, can serve as a platform for a wider array of wellness services from consumer care, traditional health care, and research.

WSN have been proposed in several researches to study urban micro scale phenomena and investigate urban micro-climate, pollution and air quality conditions and citizen health correlations. CitySense [3] describes the design of a wireless urban meteorological sensor network testbed, deployed in Cambridge, MA. Sensor nodes proposed in CitySense use powerful CPU with large storage capacity and high bandwidth radio link whose performance are deeply analyzed. In [4] micro scale environmental parameters is observed by WSN in order to measure the comfort of outdoor spaces. Temperature, humidity and light are measured by a set of services provided by Environmental Monitoring Services and correlated with the comfort level in urban area. [5] describes the UScan system architecture, a fine-grained sensor network to investigate the complex temperature distribution in urban area. About 200 sensor nodes have been deployed in a 250m by 430m area in downtown Tokyo (approximately 1800 nodes/km2) and a lightweight clustering methodology has been proposed to correlate environmental parameters and temperature pattern. These fine-grained WSN could provide very useful high spatial resolution environmental data, but require huge number of sensor nodes to cover the whole urban area. To overcame this problem participatory, people centric and opportunistic mobile WSN have been proposed. For example [6] is a project developed to demonstrate the potential of low cost mobile sensors to provide data for the control of the environmental impacts of transport activity at urban, regional and national level. Vehicles and people act as sensor carriers, probes, and an eScience and distributed grid computing infrastructure is proposed to support data processing. The project identify several application scenarios i.e. pollution maps evaluation and pollution aware journey planner. [7] presents the implementation and the performance evaluation of the ConceMe application which uses sensors (gps, microphone, camera, etc) and mobile phone to share information by social network. [8] analyzes the balancing between the CO2 measurement quality and the transmission cost of vehicular WSN. [9] presents a WSN to monitoring pollutants by sensors on the car exhaust system manifold. Motes, sensors and transponder, collect and transmit data to a GIS to represent pollution information in a meaningful way. In [10] a prototype of a opportunistic sensor network, transported by public transportation system, is proposed and the network connectivity variability problem is analyzed. In [11] a mobile sensor computing system, CarTel, collects, processes, delivers to a portal and visualize data. The system has been deployed on some cars in several urban areas collecting data about traffic speed, images from a camera and automotive diagnostic. The BikeNet project, presented in [12], is a mobile sensing system suited for cyclists. Cyclist performance and environmental values are measured and uploaded in a remote repository. Stored data can be shared promoting social networking.

Participatory WSN could extend the monitored area, but because human/sensors are free to move, the network topology is highly dynamic and produces a non uniform time and spatial sampling and it is not possible to assure data availability in every point of the observed area at the same time. However environmental data acquired in urban area are highly correlated in the time and space domains [13 - 15] and Compressive Sensing (CS) techniques [17 - 21] can be used to reconstruct environmental data with good precision [13].

3. System Architecture

Aim of this project is to create a Collaborative Health Navigation System application for smart phone based on a simple low cost sensing platform. Sensors by bluetooth connection send acquired data to an application running on the cyclist smartphone, data collected in the smartphone are compressed and transmitted to a Monitoring Server by specific wifi access point available at bike sharing racks. The Monitoring Server validates and interpolates data acquired by bikers and produces urban pollution level maps.

The Health Navigation System app, running on the biker's smartphone, receives these pollution level maps by wifi or cellular network connection and compute the healthiest routing.

Figure 1 shows the main components of the proposed system architecture and its temporal diagram.

The sensors/transponder, deployed in our prototype [22], acquires periodic CO and CO2 measurements and sends values to the smartphone data logger app. In our evaluation we used the following sensors: a Figaro TGS 5042 electrochemical sensor and an ultra low power non dispersive Infrared Cozir CO2 Sensor Module. Sensors output values are sampled every second by an Arduino wearables microcontroller board [23] and uploaded to data logger by a bluetooth BlueSmirf Gold device.

The Android data logger app receives acquired data and executes the following activities:

• Computes the ppm values by sensor sensitivity characteristic curves;

• Associates each measured values with the location of the sensors, latitude and longitude are obtained by the GPS device embedded on the smart phone;

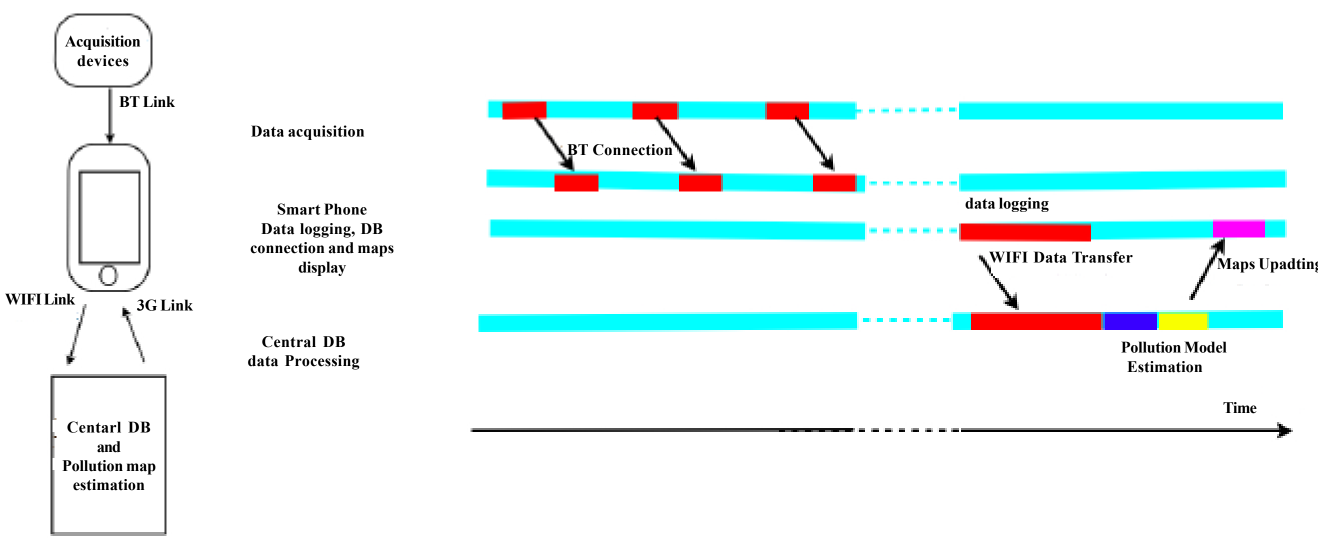

Figure 1. The system architecture and its temporal interaction diagram

• Associates each measured values with the acquisition time obtained by the GPS device;

• Write data in local text files;

• Write data in a local SQLite database;

• Searches for specific wifi access point to upload on the Monitoring Server the data text files;

• Shows the acquisition history on the smart phone display, it depicts the map with the bike route and the acquired pollution data along the path.

Figure 2 shows an example of a real CO2 acquisition history along a bike route. The data logger app reads the local SQLite database, computes a moving spatial average of the sensor measured values, classifies data in four classes of values associated to different pollution risk and reports them graphically in different color on the smart phone display along the ridden path.

4. Pollutant Map Generation

The data logger app executes a polled search for a specific wifi access point, when the bike is in proximity of the AP, for example in the bike sharing racks area, it uploads the collected data to a Monitoring Server.

The Monitoring Server executes the following activities:

• Collects data from all the shared bikes and from the fixed high precision systems already installed for the urban environment monitoring;

• Executes a detailed inspection of every dataset received by mobile systems and erases spikes or data without associated position information;

• Computes a moving spatial average of the sensor measured values;

• Validate dataset by spatial correlation between mobile sensors and fixed systems measurements. Data too discrepant or incongruous compared to the nearest calibration stations or other calibrated mobile systems, are flagged and not used for map pollution generation;

• Interpolates scattered data to produce a contour map that represents the pollutant concentration in the urban area;

• Sends on demand the pollutant concentration contour map to the Health Navigation System app running on the bikers smartphone, to compute off line the healthiest route;

• Sends the pollutant concentration contour map to a routing application running on a web server to generate on line the healthiest route;

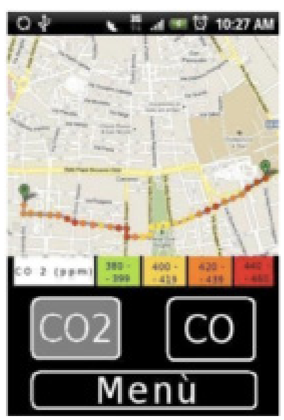

Figure 2. An example of a real acquisition history along a bike route

The definition of a continuous function and its gradient from scattered data is the main problem to resolve to produce high resolution pollutant concentration maps in urban area by Mobile Sensor.

Mobile sensors routing is very unforeseeable and acquired datasets result formed by non uniform, unorganized scattered data. However urban environmental data are highly correlated in space and time domains [13-15], and adopting adequate city map model and mobility model [25, 26] (the city of Bari, our test city, match very well the Manhattan Grid Map and the Manhattan

Mobility model) a flexible not uniform data sampling may be adequate to achieve a micro-scale accurate urban monitoring. In prior recent works on Mobile Wireless Sensor Networks, Compressive Sensing (CS) [13,17-21] based techniques have been proposed to reconstruct data from a small collection of random linear projections. These techniques, making use of the high correlation of pollution data in space and time domains property, provide efficient data compression and good reconstruction error compared to conventional sampling and bilinear interpolation techniques.

For our project two mobile wireless sensor devices have been built and dataset acquired by only two devices cannot be used to compute a real high definition pollutant concentration contour map of all the urban area because the values measured are not enough correlated in time and space, two bike need too much time to ride and to acquire data along a sufficient number of path. For this reason we used real pollutant data to test the data logger application, thermal data from Lansat Thematic Mapper (ETM+) to test the CS based interpolation technique [13] and simulated data to generate the pollutant concentration contour map of the urban area.

5. The Collaborative Health Navigation System Application

Traffic, gas and powders emissions are in continuous increment in our cities and every year several million of people die from the direct impact of air pollution [33], for this reason a Collaborative Health Navigation System ables to suggest paths with the lowest pollutant exposure, could be an important application for the health of the citizens. In our prototype the users can define the starting point and the destination point of the path, the amount of time to reach it or his cycling capability, the type of pollution to avoid and the navigation application automatically suggests the route with the lowest pollution level.

Usually navigators take advantage of graph theory to determine the route, in fact, in our project, the graph represents the map of the city, each node is a road intersection and each branch is the segment that connects two intersections. Each branch has a cost that depends on the length, on the pollution average value and on the average slope of the associated road. The routing path is determined using Dijkstra's algorithm [34] that allows to establish the best path solving the single-source shortest-path problem when all edges have non-negative weights. The algorithm starts at the source node, S ,and grows a tree, T, adding nodes to the tree in order of distance. It marks all nodes as unvisited and sets to zero the initial distance values for the starting node and infinity for all other. Iteratively it considers all unvisited neighbor of the current node and calculates their provisional distances adding the length of their connections to the value of the current node, i.e. if the value of the current node is 10 and the connection with a neighbor N has length 2, then the provisional distance from the starting node to node N will be 10 + 2 = 12. If this distance is less than every previously computed distance between the starting node and N, then this value is the real distance and is associate with that node. When all of the neighbors of the current node have been considered, the current node is marked as visited and will never be checked again and its associated distance is the minimal distance. The algorithm finishes when the destination node has been marked as visited.

Figure 3. A graph associated to a selected area of the city, each node is a road intersection and each branch is the segment that connects two intersections

Figure 3 shows the graph of a selected urban area.

The interface of the Health Navigation System, shown in figure 4, allows the user to choice the routing engine: routing based on pollution level or standard on line routing by Cloudmade [35] or OsmAnd [36]. Figure 5 shows the shortest route, the white path, and the healthiest route, the green path. The starting point is represented by the green marker and the destination point is represented by the red marker. It is easy to perceive that the path proposed by the routing engine based on the pollution level is not the shortest path but it includes the streets closer to the sea where the sea breeze dissolves the air pollutants. The cost of the green route depends on the dynamic range of the pollutant measures and on the path length:

$$Cost = k_1 * \left(\frac{PollutionLevel - MinPollution}{MaxPollution - MinPollution} \right) + k_2 * \left(\frac{Length - MinLength}{MaxLength - MinLength} \right)$$

the weights are set according to the importance of the attribute in the route calculation and to avoid that the healthiest path results too long compared to the shortest route. The green path shown in figure 6 has been calculated using a ratio k1/k2 equal to 0.05.

An online web version of the Health Navigation System is available at http://aqgis.services.joinet.it.

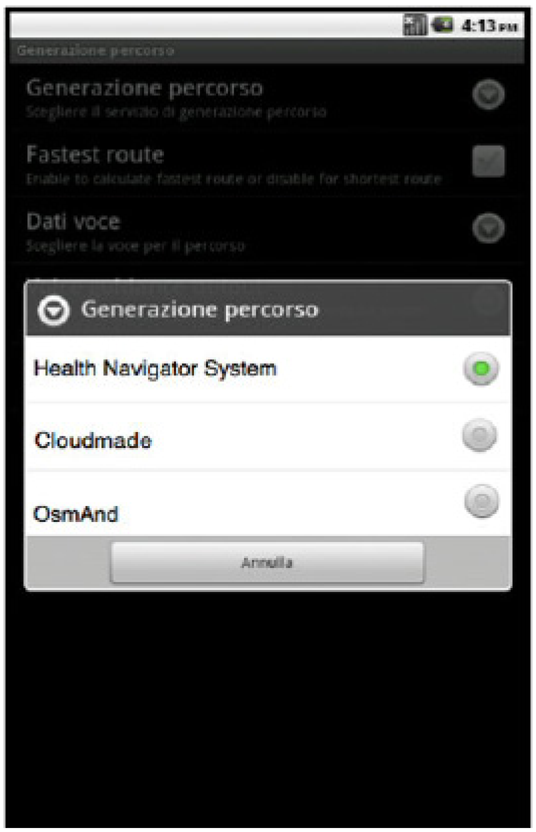

Figure 4. The interface of the Health Navigation System that allows the choice of the routing engine

Figure 5. The interface that shows the shortest route, the white path, and the healthiest route, the green path

6. Conclusion

Smart communities leverage ICT to improve the quality of life of their residents, in this paper a Collaborative Health Navigation System for smart phone, based on low cost, high precision, miniaturized mobile WSN has been presented. The system is based on a large number of mobile wireless sensors and on a small number of fixed accurate measurement stations. Data collected by mobile WSN and validated by a Monitoring Server are interpolated and used to produce maps of pollutant concentration in urban area. The navigation application, running on the user's smart phone, proposes the healthiest route avoiding the streets with high pollutant concentration. Considering that every year several million of people die from the direct impact of air pollution, the proposed system could results important for the health of the citizens. The system could be improved integrating other function i.e. information about connection with public buses or trains, offering localized advertisements and sharing information on ocial networks and communities, reducing mobility costs and user's carbon footprint.

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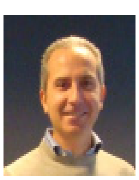
Biographies

Andrea Guerriero, received the degree in electronic engineering from the University of Bari in 1990. In 1991 he joined the Electric and Electronic Department of Politecnico di Bari where he works as Associate Professor . His main scientific activities include HPC and Grid Computing for Earth observations Application Development, Data mining, segmentation and indexing techniques, on remotely sensed data for environmental monitoring by satellite and in particular for "Early Warning" systems, WSN applications for environmental monitoring, handwritten character recognition and distance learning and teleworking.



Cataldo Guaragnella was born in Italy in 1964. He graduated in electronic engineering in 1990 at University degli Studi di Bari, Italy, and rece ived the Ph . D . deg ree in Telecommunications by the Politecnico di Bari in 1994. In 1996 he joined the Electrics and Electronics Department of Politecnico di Bari as assistant professor in telecommunications. Author of about 60 international papers, his main research interests include signal, image and video processing/coding, motion estimation in video sequences, video surveillance and multidimensional signal processing.

Claudio Martines was born in Taranto (Italy). He graduated in Information engineering at the Polytechnic of Bari. Claudio Martines is one of those people, and 'getting things done' and driving results—through collaboration, partnerships, and relationships. In 2009 with a group of colleagues and friends founded the Joinet srl company which is currently CEO also work in research and development group. From several years dealing with computational intelligence and in particular of: Holonic system, data analysis and human-machine interaction.

Alessandro Castellaneta was born in Taranto, Italy in 1984. After graduating with a specialization in computer science, continuing their studies in information engineering at the Polytechnic of Bari, Italy. After graduating as a junior engineer with a thesis devoted to embedded devices, decides to start a company to get her with other engineers. The core business is the design and implementation of information systems and consulting in information technology. To date, continues to deal with consulting, design and development of special information systems and advanced software for data analysis.