Smart City Vehicular Mobile Sensor Network

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Abstract. Smart City concept comprises numerous technologies and heavily depends on sensors to be aware of its environment in order to adapt and to evolve. Wireless sensors networks thrive on the latest development of sensor technologies where sensors dynamically connect and rely on wireless networks which might not be available all the time or their geographical coverage can change depending on various circumstances. Special challenge are mobile wireless sensors where data transmission can be significantly obstructed. Therefore in a Smart City environment sensor data can be gathered by using powerful sensors on mobile devices(smart-phones), static sensors or vehicular sensors that rely on heterogeneous and changing network infrastructure. This paper presents one possible approach to build such network infrastructure where vehicular networks, augmented with existing city's WiFi network, can be used to transmit (relay) and gather sensor data.

Keywords: Smart city · Sensor network · WiFi sensor

1 Introduction

One way to cope with challenges of modern urban environment (increasing population, pollution, energy consumption, etc.) and to introduce city to a next century is by making it smart. Smart cites leverage the benefits gained from using modern technologies to improve life of citizens and city integration into natural and eco-friendly environment. Governance of the city may benefit of modern technologies by properly responding to incidents, reallocating resources based on new environment conditions or any unnatural issues like accidents or disasters. Cities are highly integrated with traffic infrastructure meaning networks of roads and vehicles them-self. Therefore, along with standard infrastructure facilities such as water supply or electricity, smart city development is highly dependent on development of traffic infrastructure i.e. roads and streets because they are potential location of sensors and data transfer paths. Also, road infrastructure is used by modern vehicles that are becoming increasingly smart and heavily equipped with sensors and actuators. These, already existing, vehicular functionalities can be further enhanced by making vehicles capable of gathering more general sensor data and also become data transfer points of such heterogeneous mobile sensor network. Combining stationary and mobile sensors and network

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technologies into agile, error prone, modern and powerful network can prove to be valuable data infrastructure of smart cities. However, such network faces it's own challenges in which some points are stationary and some are mobile and there is constant need to determine best possible path for data transfer. What we want to achieve is constant presence of sensors in all parts of the city and their interconnection without heavy investment into stationary network infrastructure. To achieve this we should use heterogeneous approach that will utilize all possible network access points and achieve dynamic interconnection of all possible smart devices and sensors. By such approach we can develop robust information nervous system capable of functioning in various circumstances.

2 Related Work

Next section reviews state of the art and some of the major research directions in modern vehicular sensor networks.

2.1 Smart Cities

In the future, cities will account for nearly 90 % of global population growth, 80 % of wealth creation, and 60 % of total energy consumption. Developing better strategies for the creation of new cities, is therefore, a global imperative [1]. Besides global world initiative, according to [2] EU has intensive strategy to increase Competitiveness and Innovation, promote development of Smart Cities and Future Internet. Important part of this strategy are smart cities. EU strategy related to smart cities is shown on Fig. 1 as a roadmap towards year 2020. EU Smart city strategy contains four main directions:

- Building
- Heating & Cooling
- Electricity
- Transport

A city is considered smart when investments in human and social capital align with development of traditional (transport) and modern (ICT) communication infrastructure to fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance [4]. It is noticeable that beside utilizing technological development, making a city smart requires a lot of government agility and political will to change and adapt. Many initiatives and definitions of a Smart City recognize transportation as notable element that makes the backbone of Smart City infrastructure. Across Europe there are many attempts and examples of Smart Cities, Centre of Regional Science [5] has created the list of smart cities in Europe according to several criteria, top 10 cities on the list are:

1. Luxembourg (LU)
2. Aarhus (DK)

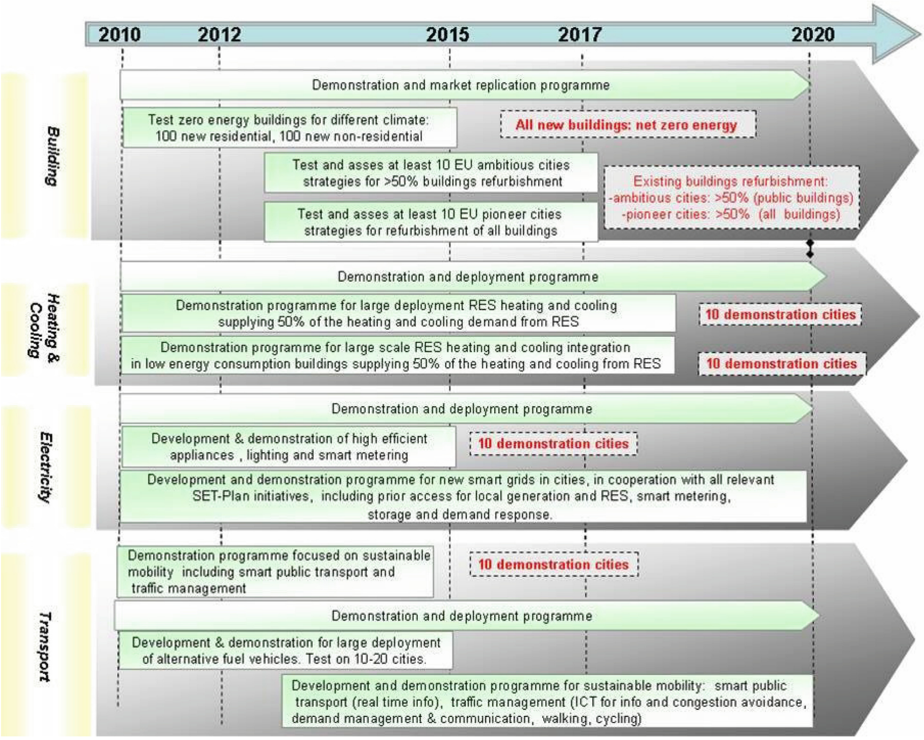

Fig. 1. EU Smart cities roadmap [3]

3. Turku (FI)
4. Aalborg (DK)
5. Odense (DK)
6. Tampere (FI)
7. Oulu (FI)
8. Eindhoven (NL)
9. Linz (AT)
10. Salzburg (AT)

Complete study considered 70 cities across Europe.

Future Cities Project. One, recent (2013) and notable project gathers a lot of attention and is supported by EU funds (2.5 million EUR). Purpose of this Future Cities Project[1] is to transform city of Porto into a living laboratory, currently more than 900 sensors have been installed around the city of Porto [6]. Project is coordinated by Competence Centre for the Cities of the Future at Faculty of Engineering of University of Porto. Along with several European universities, project partners are notable USA universities: MIT and Carnegie Mellon University, which makes this project worldwide.

[1] futurecities.up.pt.

2.2 Wireless Sensor Networks

A wireless sensor network is distributed network of independent sensors that monitor environmental conditions like: temperature, pollution, traffic, noise, air pressure,... Data gathered by one node is propagated throughout entire network, usually towards consuming nodes. Figure 2 shows sample wireless sensor network. According to [7] it is usual for a sensor nodes to communicate using wireless radio technology e.g. WiFi. However we must note that standard WiFi might not be always available and there must be alternative approach to transfer data. One of such alternatives is using vehicles as sensors and data transfer points at the same time. Vehicles are ideal because they move along entire city and can gather various data and provide strong alternative to standard network infrastructure. Vehicular ad-hoc networks (VANET) [8] provide new and integrated approach toward sensor networks. In urban environments it is convenient to have existing infrastructure restructured for a new use, thus: instead of making a new infrastructure and construction endeavors, authors suggest using vehicular networks for sensor communication.

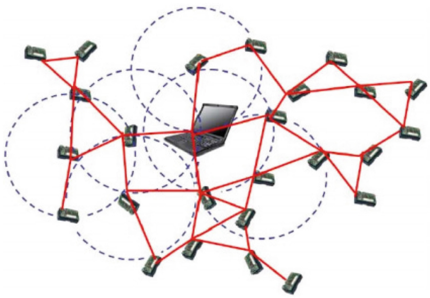

Fig. 2. Example of a wireless sensor network based on the Berkeley mote platform. The circles represent the transmission range of each node, which are connected by radio links (represented by edges) to all other nodes within range. [source: [7]]

2.3 Modern Vehicle as Sensor

Traffic networks in the city connect every essential entity (location) in the city. In essence traffic networks make the city. Using traffic, people and goods move inside and outside the city. Because of this mobility and omnipresence traffic networks and vehicles are perfect medium for deploying city-wide wireless sensor networks. With current advances in technology, improvements are made in vehicle infrastructure design: both sensors and actuators. Modern vehicle is highly equipped with sensors that improve driver experience and safety.
Some of modern vehicle sensors include:

- speed
- throttle

- acceleration
- fuel consumption
- OBD[2] data
- weight (passenger count)
- camera and optical recognition systems
- temperature and humidity sensor
- gyroscope*
- ambient light detector
- impact detector (airbag)
- GPS location,
- radar/lidar*
- ultrasound distance detector
- wifi*

Many of sensors* are currently being used and tested by Google Driverless Car[3] Issue with vehicular sensors is that they are not standardized and interconnected and most of them are private (used only by vehicle systems). Further step is vehicular interconectivity which depends on cooperation of vehicle manufacturers and development of appropriate standards. Smart Cities and smart traffic could benefit from exposing vehicle sensor data, at least for temperature measurements.

3 WiFi Urban Sensor Scanner

In described architecture, mobile object (vehicle) equiped with sensors, during movement in the urban sensor environment, require stable and constant internet access using existing WiFi infrastructure and all possible network alternatives [9]. Urban multi-sensor networks (UMN) like one described in [10] are implemented in the city environments that do have many WiFi hotspots deployed around the city area.

Static WiFi access points are positioned in the living spaces of city inhabitants and can form large scope WiFi network that can serve as information backbone of a Smart City. Along with static WiFi access points, there can be mobile access points like mobile hotspots or any other mobile device.

WiFi urban sensor scanner (WUSS) is usually an integrated solution that is made of:

- hardware: wifi network controller. like one used in smartphone devices and a GPS device.
- software: operating system like android, arduino, or raspberryPi

Purpose of (WUSS) would be to scan and monitor WiFi environment. WUSS can be implemented as an android application like one presented at SenseMyCity project[4]

[2] On Board Diagnostic.
[3] en.wikipedia.org/wiki/Google_driverless_car/.
[4] http://cloud.futurecities.up.pt/sensemycity.

Simplest form of WUSC would be to map state of WiFi networks in the city along with GPS location from where sensor measurement was taken. Measurements can be made by users (citizens) using private smartphones or system can be implemented as dedicated hardware equipment that is positioned on board of public transportation vehicles. For a successful Wireless Sensor Network (WSN) operation, reliable data exchange platform would be necessary, WUSS can be used to identify and map appropriate WiFi access points that can be used for WSN to transmit and/or exchange sensor data. Research that is carried out at University of Zagreb, Faculty of Organization and Informatics uses trillateration algorithm using free space pathloss model to localize WiFi access point position [9]. Each moving object scans its surroundings for the existing WiFi networks. Procedure follows the case shown on Fig. 3 where for each scan circle the coverage area is calculated. Assume that A, B and C are GPS location of the moving object. Radius represents the distance to the probable WiFi location. Radius(r) is calculated using *free-space path loss* formula:

$$r = 10^{\frac{\ln(10)(T-R-K-20\log(f))}{10n}} \tag{1}$$

where:

- R - receive power level, this value is being gathered using WiFi scanning equipment.
- T - transmit signal power strength is 17 dBm. According to IEEE 802.11b standard[5] the maximum power output level is 20 dBm and the minimum gives 13 dBm, this gives average of 17 dBm.
- K - path loss constant, value is -147.55,
- f - the WiFi frequency and is set to 2450 Mhz.
- n - the path loss exponent, it is set to 3 because we are measuring distances in the highly urban environment.
- r - is the distance (radius), the result in meters.

After the radius has been calculated circle around each moving object can be created. This circle represents "how well does an object hear an WiFi AP" not the location estimation of a WiFi AP. To determine the AP location it would be necessary to undertake the trilateration procedure. Figure 3 shows a case with 3 scan points from a moving object, each with its own radius. Trilateration procedures starts with selected starting circle: one with the strongest signal strength. After that, procedure calculates the intersection with all the other circles like this: for each circle, intersection is calculated between the circle and the current intersection area derived by previous round of intersection calculation. Each iteration makes intersection (polygon) smaller because it shrinks with every circle considered(intersected).

Radius of WiFi AP coverage estimation is calculated using the same pathloss formula (1) Input signal strength is the lowest signal strength of scan circle that contributed in the forming of final intersection.

[5] http://www.cisco.com/en/US/docs/optical/15000r7_0/15327/reference/guide/2770spcx.html.

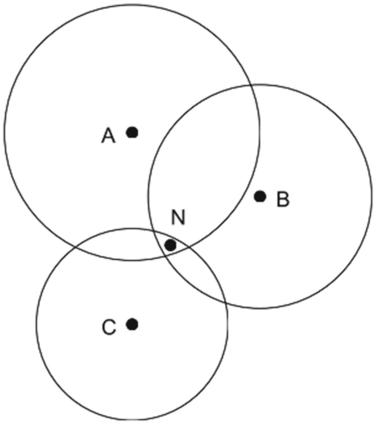

Fig. 3. Circle intersections with clustering [11]

4 Conclusion

Smart city can be observed as a living entity, it has all of vital functions like power supply, water, governance, inhabitants, traffic, etc. that can be augmented by information technologies and make the city smarter. By such approach we can make it self aware, not in a sense of artificial intelligence, but to be able to measure and record data about its current states. Traffic and vehicular networks provide mean to exchange dynamic data and information. By augmenting vehicular networks with sensor data, and network location technologies city becomes more self aware where each vehicle behaves as a mobile remote probe that gathers data. Wireless networks (if known) provide stable backbone for the data transmission. This paper addressed one challenge of smart cities - composition of heterogeneous sensor and network infrastructure by using vehicles as remote sensors, data transfer points and network location devices. Described combination of technologies enables integration of various networks and propagation of sensor data with higher reliability.

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