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A University E-Bike Sharing System used as a Real-Time Monitoring emissions tool under a smart city concept

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Short Abstract

This work intents to describe a new approach that would be able to combine the positive effects from the use of an E-Bike sharing system in a medium-large population urban city of Belgium demonstrated initially in case of the local University Campuses along with the use of the E-Bikes as environmental mobile sensing units.

1 Introduction

Over 300 bike sharing systems have been deployed around the world, with a higher concentration in Europe (78% of the systems) and mainly owned by municipalities (72%) [1]. While the use of conventional bicycles in an urban context has been promoted with significant success in several cities, namely Paris and London with 25,000 and 8000 deployed bicycles respectively, they still have several problems that make their widespread use difficult. Some of the drawbacks associated with conventional bicycles include the difficulty to travel for long distances and in hilly conditions, the possibility of arriving sweaty or fatigued to the final destination, such as the work place [2], and being exposed to extreme cold or hot climates, among others.

Several of these problems can be solved through the use of Electric Bicycles. E-Bikes reduce the trip effort required and the travel time [3], though at a higher cost due to the additional requirement of electricity. Despite the high expectations for E-Bikes, few studies have tried to understand the real world benefits that they convey in an urban environment. Furthermore, while previous studies addressed their estimated environmental impacts compared to other transportation modes and the users' characterization and acceptance of this alternative technology in China [4] and United States the experimental monitoring of bicycles focused mostly on conventional bicycles [5].

E-bikes are more energy efficient and produce fewer greenhouse gas (GHG) emissions per person compared to other transport modes such as car, bus, and motorcycle. E-bikes may reduce energy use, air pollution and noise for private transportation through a modal shift from fossil-fuel powered vehicles to e-bikes on short distance trips. However, designing effective promotion campaigns for the adoption of e-bikes require detailed knowledge on user characteristics and motivations. In order to explain e-bike use on University Campuses, the present study combines concepts from technology adoption with factors derived from research on mobility behavior related with the academic community.

In this work, it is proposed and further developed a fully automated E-bike sharing system with its operational concepts and system requirements of a demonstrated pilot case in Mons, at the University Campus (UMONS, Belgium). This service intents to serve as part of a movement to develop a sustainable transportation system in any size city while could also serve as a green initiatives on University campuses.

The basic concept is a combination of the use of the E-Bike sharing system and its sensing unit capturing information about the surroundings, including road conditions, carbon monoxide, noise, ambient temperature and relative humidity. Accessing this data through a smartphone or the web and use it afterwards (part of Big data analysis) to plan healthier bike routes with cloud computing, by achieving better exercise goals for the user and a database of environmental information from which the city can benefit are the major objectives. When users adopt this E-bike sharing system, the city profits to a new scale of fine-grained environmental information on a scale that has never been achieved before. As a consequence, this leads to a more detailed comprehension of the transportation impacts or even more on how the city could allocates its resources and corresponds to environmental conditions in real-time or how it structures and implements environmental and transportation policies.

2 Information Communication Technologies and Smart Cities Concept

The world population has been progressively concentrating in the cities. Problems associated with urban agglomerations have usually been solved by means of creativity, through infrastructure investments and information technology to support ‘smart’ solutions. The label ‘smart city’ points to ‘intelligent’ solutions allowing modern cities to thrive, through quantitative and qualitative improvement in productivity. The concept has been quite fashionable in the political arena in recent years [6]. Its main focus seems to be on the role of ICT (Information and Communication Technologies) infrastructure, although much research has also been carried out on the role of human capital/education, social and relational capital, and environmental interest, as important drivers of urban growth (Fig. 1). The European Union (EU), in particular, has devoted constant efforts to devising a strategy for achieving urban growth in a ‘smart’ sense on metropolitan areas. Not only the EU, but also other international institutions, believes in a wired ICT driven form of development.

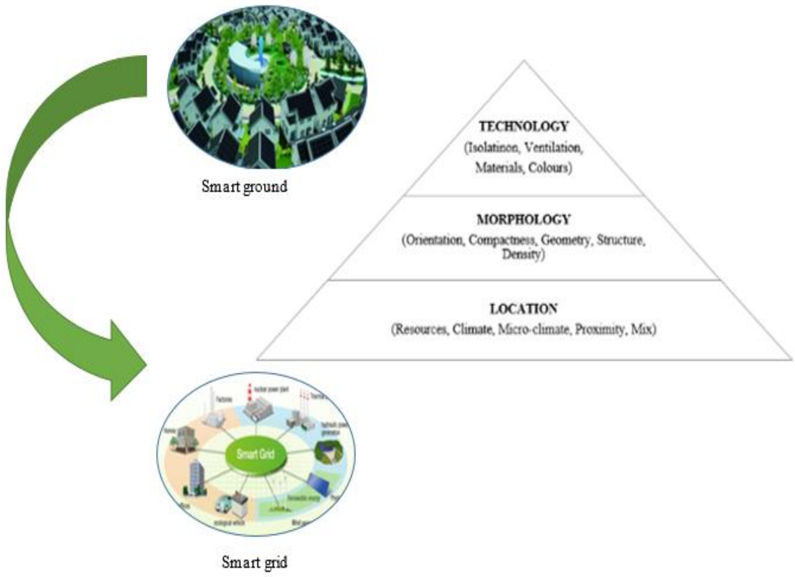

Figure 1: From the ‘smart ground’ to the ‘smart grid’

Connected to this new reality, new paradigms are emerging, like the Electric Vehicle (EV), the Smart Grids (SG) [7-9], the Vehicle-to-Grid (V2G) [10-13], and the Electrical Markets (EM) [14] as a consequence of the deregulation of electricity production and use. EVs’ integration on current electrical distribution network, without violating the electrical system’s technical restrictions, requires data on energy consumption analysis and smart charging approaches, where batteries charging or discharging processes need to be coordinated among the several users and the producers. In this complex scenario, information knowledge related with charging periods, prices, decision of charging or discharging EV batteries, need assistance before taking actions.

The aim of the proposed system is to improve the transit experience of commuters while giving them access to transportation information via a hardware device. At the same time, collected data serve as a tool towards the urban monitoring of a city, while measuring the effects of other transportation modes in the city and evaluating the ambient conditions. Transport information includes data about the most economical trip plan, minimizing the time of the journey, and Real Time Router which allows the users to optimize their trip, as and when external conditions change (eg: weather). The research proposal presented in this paper focuses on the creation of a mobile application to help the users to deal with this new reality.

This paper shows as mentioned in the beginning paragraphs results of a future application as ‘Smart Mobil Urban Monitoring System’, via the use of an E-Bike sharing scheme and as part of the RE-SIZED project that is related with the Integrated Community Energy and Transport Systems or otherwise called the concept of Smart Districts/Cities [15-16] (Fig. 2).

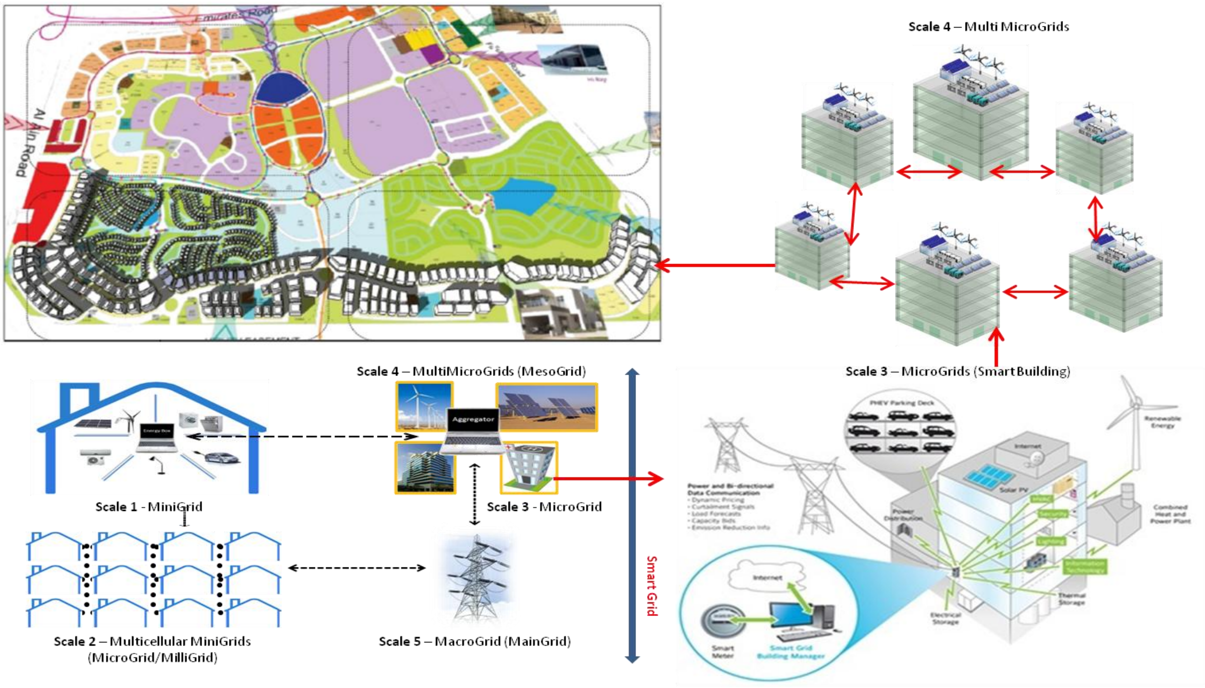

Figure 2: Schematic System Architecture of different levels towards the Smart District/City concept proposed by [17]

3 The case study of the city and University of Mons (UMONS), Belgium

Mons (in French, in Dutch *Bergen* meaning ‘mountains’ from the French word *Mont*) is a Belgian city and municipality, and the capital of the province of Hainaut. Mons is located along the N56 road. It is also accessed via European route E42, which is a continuation of French Autoroute A2, linking the British WW1 battlefields of Mons with the Somme Battlefields.

The University of Mons (French: *Université de Mons, UMONS*) is a Belgian university located in the city of Mons created by a merging of the engineering school (FPM, first University engineering school in Belgium in 1837) and the University of Mons-Hainaut in 2009. The University of Mons is the fourth (and smallest) university of the French community of Belgium with about 5,700 students. This section includes the data analysis of the survey conducted at the University of Mons, Mons, Belgium (Fig. 3).

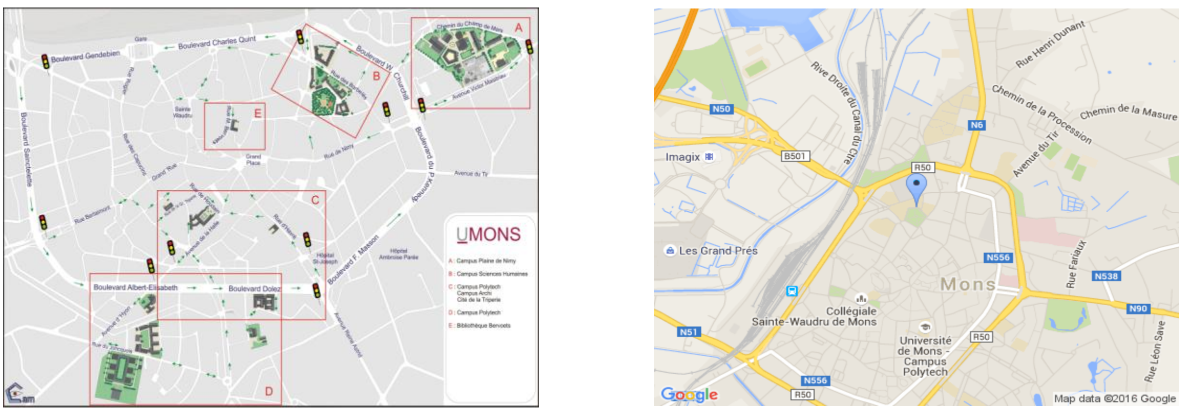

Figure 3: Location of the city of Mons and UMONS

The survey was carried out at the UMONS campus during the period of 17/06/2015 to 30/07/2015 on a sample of 74 students. The purpose of this work is to collect information on the preferences and analyse the attitude of the respondents towards the use of e-bikes in the form of a vehicle sharing system [17].

4 Wireless Sensor Technology (WST)

Wireless Sensor Technology includes a collection of sensor nodes with the goal to monitor the conditions of the built environment. Wireless Sensor Technology can be used in a particular region in the form of an integrated network, which is scalable, reliable and easily deployed. Sensor networks are currently employed in various applications (i.e. military purposes, biomedical monitoring, Building Energy Management System, etc.). Wireless Technology is considered as the bridge between the real and the physical world connecting hardware and software standards with the ability to be applied in large territorial units (i.e. district, industry, transportation, etc.).

The hardware and software standards of the Technology is outlined in IEEE 802.15.4 and the ZigBee Alliance. An IEEE 802.15.4 wireless mesh technology (via the ZigBee) meets the application requirements for commercial and other uses offering a low cost, low power and low data rate wireless technology. Its specifics of implementation remain variable and the standard on which it is based does not specify the details of the cluster-tree construction algorithm. IEEE 802.15.4 allows the use of multiple channels available at the physical layer, however, its protocol is designed for a single channel, which is operated effectively in a multi-channel environment as well [18].

The principle benefit of wireless data communication (sensor and viewing or storage) ensures a wide range of opportunities for future applications. The authors in [19] propose the application of the WST in case of buildings using related data communication and measuring quantities (i.e. temperature, humidity, energy consumption, etc.) that are useful in case of a transportation system, too within an E-Bike sharing system for monitoring in terms of a city and its strategic ‘smart’ planning.

4.1 The ZigBee alliance

The ZigBee is established as an alliance in 2002 [20] as an open and non-profit association of members and it concerns an IEEE 802.15.4 physical radio suitable for high-level communication protocols to create personal area networks with a physical range of approximately 10 to 20 meters and in unlicensed radio frequency bands, including data rates from 20kbits/s (868 MHz, Europe) up to 250 kbits/s (2.4 GHz), including 915 MHz (USA). It uses the common 2.4GHz band, referred to as the unlicensed industrial, scientific and medical band already used with wireless LANs (specified in IEEE 802.11 standard), which have been introduced into ‘intelligent’ buildings and electrical devices [19].

Under its specifications, ZigBee can be delivered an optimal balance of scale, performance and reliability for an extensive range of sensing and control applications. Generally speaking, ZigBee is a mesh network architecture (a Wireless Local Area Network-WLAN), where decentralised topology arrangements can be held and can be automatically be adjusted on network topology changes that theoretically support more than 60,000 devices on a single network within the possibility of its expansion as a future important part in the Internet of Things (IoT) designed to connect a wide range of devices in the industrial sector [18] (Fig. 4):

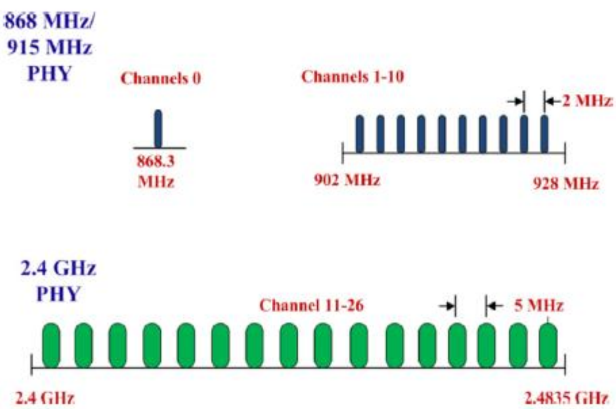

Figure 4: ZigBee channel allocation by [18]

4.2 Previous implementations

Kintner-Meyer and Brambley [21] discussed the benefits and the drawbacks of the wireless technology in an office building application and recommend to consider in its construction design wireless systems, such as: extendibility of the network, battery life and sensors mounted using Velcro or double sided tape that can be moved by occupants.

A ZigBee based application was presented, also by [22] for the development of a monitoring and protection system for building electrical safety. In the study electrical outlets were able to be turned on and off with the radios. This enabled the capability of applying energy conservation strategies in smart buildings.

5 Related Work on E-Bikes

E-Bikes are equipped with a power source and therefore offer possibilities for monitoring and interaction with the urban environment with potential benefits for its users. A detailed comprehension of the e-bikes use in specific urban scale communicates in an optimal way the benefits for sustainable transportation and beyond [24]. Moving objects (including E-Bikes) require battery power – typically vehicles with motors such as cars, lorries, boats or trains. This challenge focused on devices used by the rider (e.g. smartphone) or on attaching devices with a long battery life to bikes. E-bikes have an on-board battery that can be connected to a monitoring system that tracks the bike (rather than the rider via their phone) while not compromising data quality for battery life (as is often the case in cycling research) [23].

Related work on E-Bikes and wireless technology methods demonstrates its value for 'smart transportation'. Dill and Gliebe [24] proposed a GPS device for each 'bike trip', while data was dowloaded by a device after a cycling period (at least 7 days in total). Their application included 164 participants with the goal to map their commuting in Portland Oregon to assess the effect of different types of infrastructure, such as bicycle lanes or paths, on bicycling. The use of Androids has been also another application in presence of E-bikes. Thus interesting are also the results from BikeNet project which monitored a variety of sensors (including video and pollution monitors, via a mobile phone, and sent data via mobile network and WIFI). Paefgen's Picotrack monitor show the role of the monitor as an independent device using power from the e-bike battery, however, these modules are limited to GPS sensing only. BikeNet project consist a good practice of using smartphone and wireless technology as the central part of a monitoring and control system (a small Android touch screen computer and GPS module are used for this application) [25]. The Copenhagen Wheel [26-27] took this further, by connecting the riders' phones with Bluetooth sensors mounted on the bike.

Other interesting results derive from public bike schemes and applications from a real-time data collection and applied in European cities. Typical examples consist the case of Germany [28] and the Netherlands [29], which use log data when bikes move in and out the parking stations but most do not collect data about the actual journey between stations. When analyzing the movement of bikes in public hire schemes, the trip data uses the location and time of the station at the beginning and end of each trip rather than a GPS data. Other schemes include pilots ones integrated with a car sharing company in the San Francisco Bay Area or institution-based system such as the one at the University of Tennessee-Knoxville [30–32].

The authors of this paper have been working in the field of electromobility (and lately more specific that of E-bikes) for some years now and under different case studies [33-34]. Thus initially they have started working in case of an electric car-sharing approach and the required software to be used for the communication of the clients while optimizing their routing towards the University Campus [35]. Since this was based on the density of the people picking up the required service then there was an optimum parking allocations scheme that could facilitate the transportation of the students towards the University [36]. The use of a Smart Phone with the required Android application was a prerequisite for the best communication for the students [37] while further research included the use of V2V algorithms that could make easier this communication [38]. Since this scheme was considered a sustainable mobility part of the further Smart campus application then the last included work related with the electromobility connected within a Smart Grid either in the form of an electric car sharing [39] or even more under the mobility scheme of E-Bikes sharing scheme [40]. When the last was combined with the Unit's work in Smart Buildings – Districts [19] then it was created the idea of the 'Smart Urban Box' that has as a scope to monitor a city's environment under an E-Bike sharing scheme while giving some extra applications to the users of the E-Bikes. The design and installation of the E-Bike and 'Smart Urban Box' has been completely done by the authors as is further suggested and seen in Fig. 5.

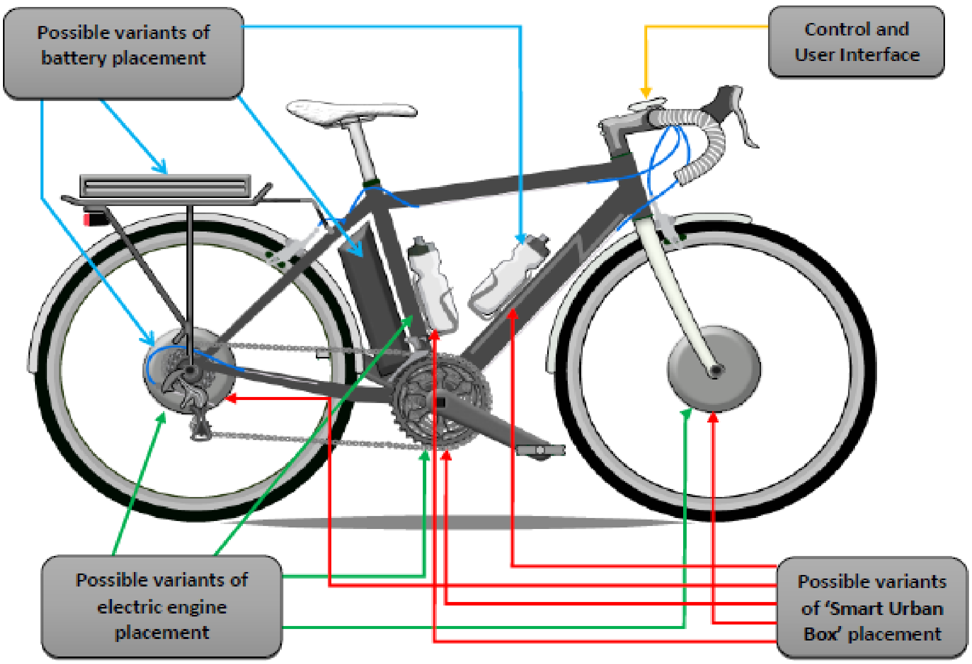

Figure 5: Sketch of the proposed design electric vehicle with its installed 'Smart Urban Box'

6 System Requirements

Exploring the options for monitoring key parameters (such as CO_2, CO, SO_2, SO, PM, GPS, temperature and humidity among others) of a demonstration project of urban transportation using a University E-Bike sharing scheme in Belgium, the use of wireless sensor network technologies is chosen. Further details of some of the components mentioned before are seen in Fig. 6. ZigBee solution is proved to be more cost-effective and since the E-bikes are located continuously away from the university buildings, an internet connection is needed in order to access the recorded data. The temperature and relative humidity data is required with a precision of 0.1°C and 0.1% (minimum accuracy of ±1°C). The temperature and relative humidity reading are suggested to be taken at least every 10 minutes. To be able to program the MCU the open source Arduino environment was chosen due to its popularity and documentation.

Figure 6: Various Components of the suggested 'Smart Urban Box'

One of the main benefits of a design including wireless technology sensor is the low energy consumption but also the total cost. The selected ZigBee radio in this case is the XBee S2 developed by [41], which have an indoor range up to 40m and outdoor RF line of sight up to 120m (Fig. 7). Scalability, replicability and modularity are overached concerns for the system desing allowing future applications and the collection of comparative data with low costs implemented within the combination of software and hardware.

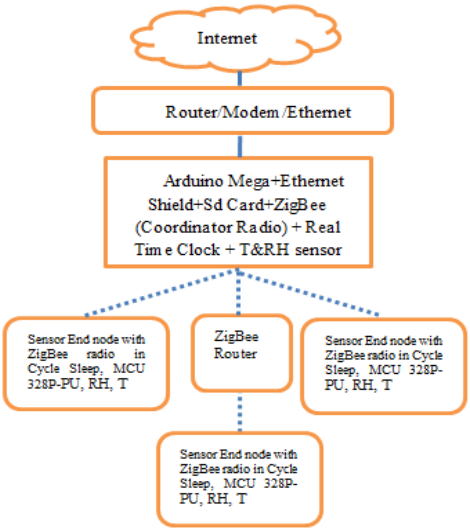

Figure 7: Sketch of the wireless sensor network connected to the internet [20]

6.1 Sensor End Node Description and Operation

The wireless sensor technologies transmit the key data of temperature and humidity to a coordinator radio in a direct way or through a router node (Fig.8). The routers are used to extend the range and the amount of end-sensors node that can be connected to the wireless sensor network (WSN).

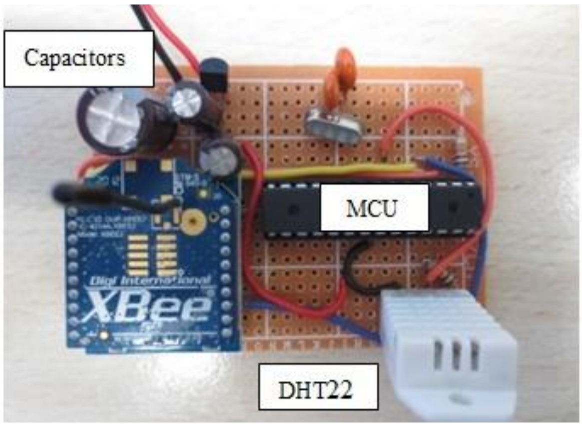

Figure 8: Photograph of sensor node built on stripboard. The MCU, the sensor and other electronics components can be appreciated in the picture [20]

The radios need a supply voltage between (2.1 to 3.6 V) for operation. In power down mode the current consumed by the radio is less than 1 µA at 25°C. The employed Xbee radio is the wire whip type. For this type of antenna, the recommendation is that it should be bent so that the antenna is away from metal (tall electrolytic capacitors and batteries for example). The radios use decoupling capacitors to filter out the noise.

When programing both the X-Bee and the microcontroller it is important to make sure to include a time before sleep (ST command) long enough to allow to read the measurement done by the MCU but not too long in order to save battery power. At the same time, the microcontroller needs to have a delay long enough before going to sleep in order not to maintain always the X-Bee radio on. This can happen because the sensor end node can fall indefinitely in a wake up and sleep cycle loop. The counter for the time before sleep is reset each time there is a serial communication signal to the X-Bee radio pins. For the Sensor nodes, the X-Bee radios operate in transparent mode. In this operation mode, all the serial data arriving to the radios serial pins are transmitted. For the sensor nodes, the settings have been programmed using the radios manufacturers free software utility X-CTU [42].

A low cost, low power, pre-calibrated digital temperature and relative humidity sensor was chosen (DHT22). For the humidity measurement, the sensor employs a capacity technology. After waking up the

MCU, it takes about 0.5s to read the temperature and the relative humidity. After two samples have been taken and sent through the serial connections of the MCU, a delay of 1300ms is employed before setting the MCU to sleep mode. To power the sensor end node circuit, a low dropout voltage regulator with very low quiescent current has been selected. The selected voltage regulator is the MCP1702. This low dropout (LDO) voltage regulator can deliver up to 250 mA of current while consuming typically 2.0 μA of quiescent current.

The coordinator radio is installed on an Arduino Mega (Fig. 9), using the microcontroller ATmega1280. The Arduino Mega was chosen because of its larger flash memory (128 Kb). For comparison, the Arduino Uno has a 32 kb flash memory. The Arduino Mega is complemented with an Arduino Ethernet shield to allow for internet connection. The coordinator setup also includes a real time clock (RTC) to be able to assign a time stamp to the arriving data from the end nodes. This can be done since the delay time to reception is basically negligible.

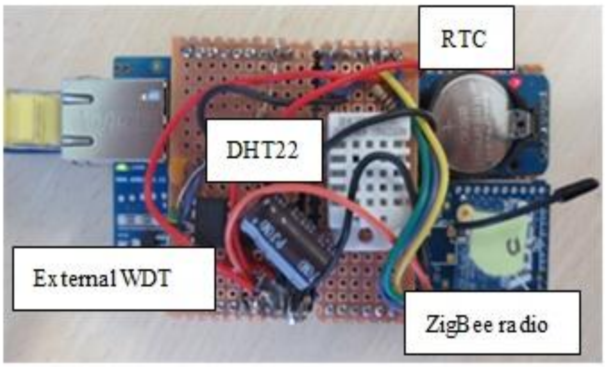

Figure 9: Coordinator photograph. An external Watch Dog Timer (WDT) circuit has been added to allow for reset of the microcontroller in case of malfunction. The Real Time clock, the Zigbee radio and the DHT22 sensors are clearly visible in the image [20].

7 Conclusions

This work has presented a new way of making use of electromobility and its vehicles for environmental and other purposes. Thus the design of the ‘Smart Urban Box’, a portable device that can capture information about the environment and the road conditions including carbon monoxide, sulphur dioxide, particulates, ambient temperature, relative humidity and other is proposed in combination with an E-Bike sharing scheme. This proposed design, development and implementation of this device and the whole system and its future use via an E-Bike sharing scheme is a new way of monitoring the urban mobility and environment of a city of any kind of size since the ‘portability’ of the system itself helps to collect important information related with the ambient characteristics and in real time. Accessing this data through a smartphone or the web and use it afterwards (part of Big data analysis) to plan healthier bike routes with cloud computing, by achieving better exercise goals for the user and a database of environmental information from which the city can benefit are the major objectives. When users adopt this E-bike sharing system, the city profits to a new scale of fine-grained environmental information on a scale that has never been achieved before. As a consequence, this leads to a more detailed comprehension of the transportation impacts or even more on how the city could allocates its resources and corresponds to environmental conditions in real-time or how it structures and implements environmental and transportation policies. Further development includes the completion of the proposed ‘Smart Urban Box’ device integrated with the new E-Bike design and installed in such a way so that this system could bring the best possible results related with the environmental and physical parameters and would be applicable in any city and road conditions globally.

Acknowledgments

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