Deployment of a partial mesh network for adaption of district level energy optimization schemes

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***Abstract*— The Building sector is a major contributor to Green House Gas (GHG) emissions as more than 40% of the total energy consumed in the EU is used to cover the needs for heating, cooling and electricity of buildings [1]. Taking into account the unprecedented pace of urbanization, it becomes more than clear that cities now hold a pivotal role in the efforts of securing a more sustainable future. In this context, the scientific community has enhanced its efforts on the development of innovative district level energy management systems. This paper presents the results of the deployment of a partial mesh network in Lavrion Technological and Cultural Park (Greece) in order to facilitate the adaption of district level energy optimization schemes. It highlights crucial points for the design, installation and commission of an effective communication infrastructure and it also describes the testing activities that were performed in order to ensure the Quality of Service (QoS) of the system. The results showed that the implemented partial mesh network achieves stable routes with low packet loss rates, minor delays and more than adequate network throughput for the successful adaption of district level energy optimization schemes.**

Keywords—energy, management, district, WLAN, mesh, network

I. INTRODUCTION

Cities are facing unprecedented challenges as the pace of urbanization is increasing exponentially. By 2050 the world's urban population is projected to rise by 72 % (i.e. from 3.6 billion to 6.3 billion) and the population share in urban areas from 52 % in 2011 to 67 % in 2050 [2]. Taking into account the cities cover today approximately 2% of the earth surface, but consumes almost 75% of global energy use and create 80% of the global CO_2 emissions it becomes more than evident that managing energy consumption both at building and district level as much as possible is a key challenge for the coming years to successfully accomplish a sustainable urbanization.

Currently lots of efforts are put on research and technical development related to improving energy efficiency, increasing the share of renewable energy and lowering the energy costs of buildings and districts. While most of the required technologies exist already and there are experiences about integrating them together still a wide-scale roll-out of more sustainable district level energy systems has not yet occur.

In addition, in 1996, the European Parliament and Council implemented the first directives for a competitive internal market for electricity and gas throughout the European Union [3]. Parliament's intended result of liberalized electricity and gas market is to give the European consumer the right to choose their energy supplier. Almost 30 years later, the electricity distribution business across Europe remains very diverse. It varies in the number and size of operational areas, the number of customers, network characteristics as well as ownership structure. However, it converse on the emerging trend of the establishment and operation of new energy distribution companies. Currently, there are more than 2400 energy distribution companies in Europe.

In this context, it becomes more than essential to develop and experiment with a novel district management and information system that apart from the environmental objectives of minimizing the energy usage in terms of kWh consumed; increasing the share of renewables and mitigating the CO_2 emissions, will also aim at taking advantage of the different electricity tariffs of the multiple energy providers and consequently minimize the energy cost of the district.

II. DISTRICT ENERGY MANAGEMENT TOOL

In the framework of the European project AMBASSADOR a new system is under development which aims at reducing the energy consumed within the perimeter of district, mitigate the CO_2 emissions and minimize the cost of energy within a district. The pivotal element of the AMBASSADOR system is the District Energy Management and Information System (DEMIS). DEMIS, based on consumers priorities, monitors and controls the energy flows between the end nodes both at building and district level. This is accomplished by collecting the consumption data of all the buildings of a district then utilizes real-time adaptive and predictive behavioral models of buildings and energy generation & storage sub-systems - exposed to weather conditions – and finally runs the optimization algorithms so as to master the energy flows within the district in the optimum way.

This holistic district energy optimization system takes advantage of the possible shared usage of the local energy production and storage and the complementarity of energy consumption profiles; develops management system functionalities to optimize building energy consumption; validate through a number of selected scenarios some functions and services proposed by the system on the three validation sites and finally studies different business models that can be successfully implemented.

Critical prerequisite for the successful operation of DEMIS is the consistent and reliable collection of a vast number of values. These values include energy consumption & production measurements as well as physical magnitudes such temperature, humidity etc. Therefore, it becomes apparent that the successful operation of this district energy management tool is massively dependent on effective information flow from the sensors to DEMIS. This requires the deployment of a reliable, secure and transparent communication system which will enable the bilateral communication between DEMIS and the smart energy systems. The next chapter describes the communication infrastructure as deployed at the demonstration site of Lavrion Technological and Cultural Park (LTCP) in order to serve DEMIS purposes.

III. COMMUNICATION INFRASTRACTURE

A. *Demostration site*

Lavrion Technological and Cultural Park (LTCP) is located in Lavrion, in South-eastern Attica, Greece, approximately 50 km from the center of Athens. The LTCP covers about 250000 m^2 in which 3 distinct building complexes exist. About 18 buildings have been restored and are now operated with a total area of 13000 m^2. The total area allocated to the housing of businesses is about 10000 m^2, while 3000 m^2 support the administrative and cultural uses of the Park. The Park mainly hosts RTD activities including both private and public sectors.

LTCP consists an excellent use case for the experiment on communication infrastructure strategies at district level as it has an extensive area that needed to be covered and also has a very demanding topology (steep slopes, long cliffs).

For the purposes of AMBASSADOR project, the LTCP demonstration site contains 5 buildings as well as the public lighting inside LTCP. These buildings account for different types of uses, different surface areas and employ a variety of systems for energy production, storage and consumption therefore providing a suitable basis for the deployment of the DEMIS. These buildings are:

- The administration building (hosts the LTCP managing authority and administrative services)
- The H2SusBuild building (research installation of NTUA's Laboratory of Metallurgy)
- A building hosting a data center
- A building hosting a small industrial company
- A building hosting a small cafeteria/restaurant

B. *Monitoring requirements*

The required monitored values as defined by DEMIS objectives have led to an extensive installation of power meters and sensors. A total of 34 smart power metering devices have been installed within the Park. These devices do not only offer a wide range of metering parameters but they are also equipped with advanced functionalities such as alarming, trending, forecasting, waveform capturing, compliance with international standards, on board gateways and other.
The electrical supplies that are measured are:

- Total electrical consumption of each building
- Renewable Energy Sources (PV, WT systems and Micro-CHP Fuel Cell separately)
- Electrical consumption of each building load (lighting, HVAC and other loads separately)
- Electrical consumption of electrolyser and H_2 compressor

In addition a total of 62 different sensors/actuators were installed in the five buildings which are measuring:

- Indoor temperature
- Relative humidity
- CO_2 concertation
- Occupancy
- Light level
- Movement sensors
- Hot & cold water thermostats
- Meteorological conditions (outdoor air temperature, solar radiation, humidity, barometric pressure, wind speed)

Significant consideration was given on the location of the sensor nodes and their physical distribution as some measurement processes and physical magnitudes require concrete specifications about the location of the sensor element in order to obtain a valid (or standard) measure respecting all the physical, RF distortion and legal constraints. E.g. The CO_2 sensors were mounted at 2 meters height over the floor which complies with the current European regulation locates the CO sensors between 1.5 and 4 meters (breathing range).

The great number of power meters, sensors and actuators that were deployed on the demonstration site created the need for a communication network with substantial capacity so to overcome any congestion issues.

C. *The solution*

A dedicated Wireless Local Area Network (WLAN) was designed, installed and commissioned in the perimeter of the park. While wired LANs are considered more reliable and have - in principal - superior performance, in the case of LTCP a wireless solution was preferred instead, mainly for three reasons:

- Considerable cost of Ethernet cabling
- Unreachable areas for cabling routing
- Visual impact of cabling
- Experiment on cases where wired lines are not an option

As the points of interest were identified it was essential to define the topological structure of the network. As it is described thorough in the literature [4],[5],[6] the topological structure of a network (physical or logical) influence on the definition of distances between nodes, physical interconnections, transmission rates, signal types, etc. and is defined (in general aspects) by:

- The area to be covered (extension, orography, transmission issues –noise, interferences-, etc.).
- The pursued reliability and robustness, expressed by load balance mechanism implementations for data links and routes reconfiguration, due to broken links.
- The bandwidth needed for expected data traffic.
- The maximum data delay allowed.
- The data transmission protocols planned to be used.

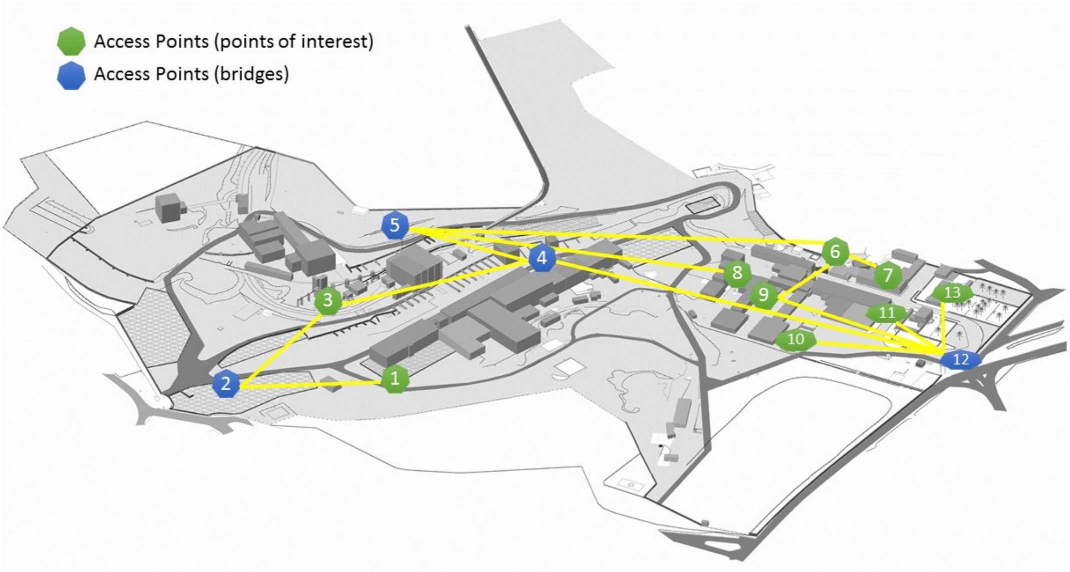

Fig. 1 LTCP access points

Based on the above a partial mesh topology was selected. In mesh network topology every node works as information sources or actuator and routers, implementing different paths to communicate the source node and the destination. This characteristic allows communication technologies and protocols to perform different routing mechanisms. The initial approach of following a star network topology was early discarded as it was critical not to rely on a central device that would disturb the network in case of a device failure.

A total of thirteen (13) access points were installed in order to establish a wireless communication network that will cover almost entirely the perimeter of the park. The coordinates of these access points are shown in the following Table 1 while Fig. 1 depicts the topographic location of these access points. It should be mentioned that nine access points (Green polygons) are installed in points of interest (power meters, sensors etc.) while the remaining four (blue polygons) serve as bridges for reliable signal transmission

TABLE I

No	Name	Coordinates
1	H2Susbuild	37.722088, 24.048016
2	Park Gate B	37.720710, 24.047051
3	Switchboard A	37.722326, 24.046878
4	Environmental Lab	37.723779, 24.047883
5	Tunnel	37.723767, 24.046658
6	Datacenter B	37.725240, 24.049649
7	Datacenter A	37.725374, 24.050142
8	Chemical company B	37.724743, 24.049723
9	Chemical company A	37.724896, 24.049840
10	Café B	37.724587, 24.050220
11	Café A	37.724950, 24.050583
12	Park gate A	37.724842, 24.051452
13	Admin building	37.725511, 24.050831

The distance between two access points varies according to location of the routers. The following TABLE II presents the distances between the different access points.

TABLE II

Access points	Distance (meters)
1→2	175
2→3	186
3→4	174
4→12	334
4→5	114
5→8	268
5→6	312
6→7	42
6→9	68
9→12	175
10→12	115
11→12	81
12→13	95

Fig. 2 provides a schematic representation of the partial mesh network as deployed in Lavrion Technological and Cultural Park. The communication infrastructure was designed so as to facilitate the transmission of all the monitored data to the H2Susbuild network. As it can be seen from the figure, the monitored values follow a number of possible routes until reaching the H2Susbuild network offering flexibility that can be proved very useful in cases of node failures.

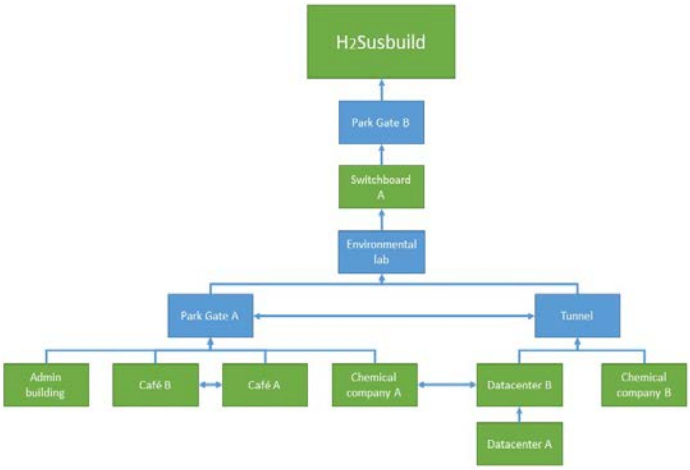

Fig. 2 Schematic of Lavrion partial mesh network

D. *Equipment specifications*

Each installed access point include a fully featured wireless RouterBOARD and a 5dbi (or 9dbi) 2.4GHz antenna. At the access point located in the H2SusBuild a Panel 10dbi 2.4GHz was used instead.

The RouterBOARD is a durable and waterproof device, it has one 10/100 Ethernet port with PoE (Power over Ethernet) support and a built-in wireless radio. It has software selectable at 2 or 5GHz wireless mode, and high 500mW output power. With the Nv2 TDMA technology, it can achieve up to 125Mbit aggregate throughput. It has a built-in N-male connector, and pole attachment points, so an antenna can be directly attached to it.

TABLE III presents the model specifications of the installed access points.

TABLE III

Model	Specifications
CPU	AR9342 600Mhz
Memory	64MB
Ethernet	One 10/100 Mbit/s Fast Ethernet port with Auto-MDI/X, L2MTU up to 2030
Wireless	5 or 2GHz (software selectable)
Extras	Reset switch, Beeper, Voltage monitor, Temperature monitor
Power	Passive 9-30V PoE only. 16KV ESD protection on RF port. Up to 0,19A at 24V (4.56W)
Operating temperature	. -30C to +70C
RouterOS	Level3 license (station or ptp)

E. *WLAN management*

The WLAN management system is performed through a software platform which has an easy to use and secure GUI/ Graphical Client and provides the following technical services:

- Automated discovery of network devices
- Status reporting of each connected device

- Logging information of device’s operation
- Accessible through web browser (HTTP or HTTPS)

F. Standards and operating requirements

The implementation of the wireless network was based on the standard 802.11a/b/g/n 2.4GHz which is part of the 802.11 set of IEEE standards that govern wireless networking transmission methods. Under the framework of the National Frequency Allocation Regulations a WLAN that operates in the frequency range of 2,4GHz and 5GHz does not require license. The equipment operates in the frequency range of 2.4 GHz and therefore complies completely with the ETSI EN 300 328 standard. The maximum antenna gain does not exceed 20dBm (100mW)

The network was implemented in 2,4GHz according to WiFi IEEE 802.11n standard achieving a maximum throughput of 150Mbps per link. All wireless communication equipment complies with the IEEE 802.11b/g standard. The system also incorporates an access control system through a scheme of Authentication – Authorization.

G. WLAN Testing

After the completion of the installation and commissioning activities, a series of tests were conducted in order to evaluate the performance of the network and to estimate its reliability. The tests were made using the software WinBox. Test results showed that the implemented mesh network achieves stable routes with low packet loss rates, minor delays and more than adequate network throughput

Bandwidth tests & Tx/Rx rates

Fig. 3 presents the results of the bandwidth test as performed betweeen Location (1) and Location (12).

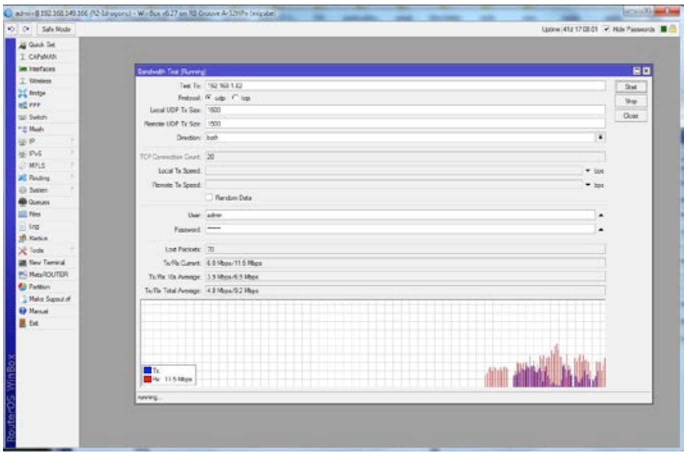

Fig. 3 Bandwidth test Location (1) and Location (12)

As illustrated in Fig. 3 for an uninterrupted operation of 41 days 17 hours 8 minutes and 1 second, only 70 packets were lost while the Transmitted and Received rate had an total average of 4.8 Mbps and 9.2 Mbps respectively.

Fig. 4 shows the transmitted and received rates as appeared in Lavrion site on heavily rainy day. Transmitted rate (Tx) varied from 50kbps to 1.34Mbps while Received rate (Rx) from 471kbps to 1.04Mbps which are both more than enough to serve DEMIS purposes.

Fig. 4 Tx/Rx rates

Traffic measurements (Total, daily)

As the most crucial factor affecting the Quality of Service (QoS) of a netwrok is when data trafic exceeds the capacity of the network, NTUA research team proceeded to the dimensioning of the system, using as data traffic measurement the projected peak traffic and not any mean or average. Fig. 5 presents indicative results of the traffic measurements as performed on the installed access point in Location (1) and it shows that data traffic reaches up to 60% network’s theoritical capacity eliminating therefore the possibility of QoS degradation due to congection.

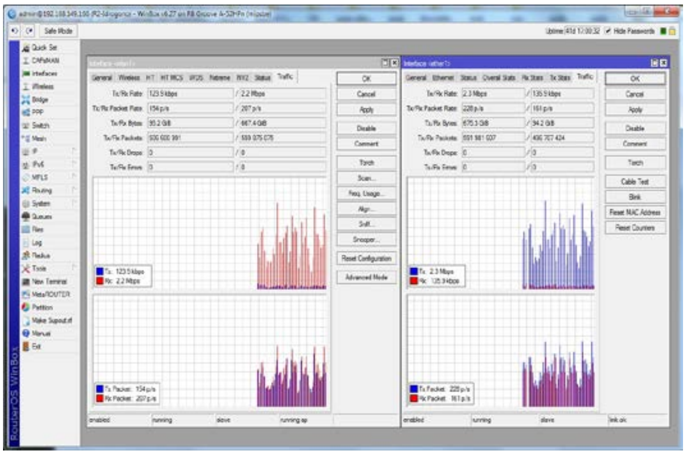

Fig. 5 Location (1) traffic test results

Lastly, TABLE IV summarizes the total and daily traffic of each access point as measured and analyzed on 02/04/2015

TABLE IV

Access point	Total traffic	Daily traffic
Park Gate A	458,10 GB	17,52 MB
Tunnel	24,80 GB	0,58 GB
H2Susbuild	762,60 GB	18,28 MB
Environmental Lab	17,00 GB	38,07 MB
Park Gate B	988,60 GB	40,02 MB
Cafeteria 1	3,13 GB	75,01 MB

IV. DATA MANAGEMENT

Once the sensors capture the data related to the pursued magnitudes, these information must be delivered to a data center (real or virtual) to be stored and processed. In the case of LTCP the sensors record the selected values with a 15 minutes interval and they direct these information to a local SQL database though an automation server. Afterwards, web services are used in order to route this data to a Cloud Data Storage where are available for processing and analysis.

The way the data pathway is set allows the bilateral flow of information from the sensors/actuators to the Cloud Data Storage and via versa so as to provide to the district energy management system the ability not only to collect data from the sensors/actuators but also control them (where applicable).

V. CONCLUSIONS

The purpose of the implemented wireless telecommunications network was to establish a system for secure, reliable and efficient communication between the actors of LTCP district in order to fulfil the network requirements for DEMIS deployment. This was successfully achieved by implementing a partial MESH system which addressed completely the difficult topology and other site-specific constraints of Lavrion Park. The developed system is a low cost integrated solution with specialized hardware and software for intelligent building systems management which provide reliable, dynamic mesh communication network. The technical specifications of the communication system were assessed for monitoring and control, components selection and implementation. In addition, the structure of the deployed system was designed so as to allow the easy expansion of the network in order to include more areas of the park, a parameter that can be proved very useful for future district site expansion.

A series of tests were performed after installation in order to verify that the implemented network is adequate for covering DEMIS network requirements. The testing results showed that implemented partial mesh network achieves stable routes, it has very low packet loss rates, minor delays and more than adequate network throughput. In fact, the excess of bandwidth offered by the network, as observed during the testing activities, can be employed for distribution of internet access to the residents of the district or for the use of surveillance systems.

As the trend of smart cities with advanced interconnection requirements is likely to increase even more in the following years, the case of LTCP partial mesh network can be used as an excellent example of a low cost, fully configurable and reliable solution that can be successfully implemented isolated areas with demanding topographies.

ACKNOWLEDGMENT

The AMBASSADOR project has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement No. 314175

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