Defining a Convergence Network Platform Framework for Smart Grid and Intelligent Transport Systems

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Abstract.

The challenges faced by electricity grids suggest smart grids will have to coordinate its operation with other important initiatives in areas such as transportation. The smart grid relies on the use of network platforms where meter readings and data can be transmitted. On the other hand, concerning transportation systems the need to achieve a reduction of road congestion and traffic accidents among the increasing use of electric vehicles has consolidated the importance of intelligent transport systems (ITS). Given the magnitude of the challenges faced by both the smart grid and ITS, the aim of this work is to identify the elements comprising a convergence platform capable of supporting future services for data traffic associated to smart grid operations as well as ITS-related commercial service applications and road traffic safety messaging. A seaport terminal scenario is used to present a convergence network platform incorporating wireless sensor network (WSN) theory. The results of the simulation of the proposed network confirms the suitability of WSN to be used in the transmission of data traffic associated to meter readings which is required for effective energy consumption and management policies in industrial environments comprising equipment with high energy demands.

Keywords: smart grid, intelligent transport systems, wireless sensor network, low-energy adaptive clustering, Vehicle Adhoc Networks (VANETs)

1. Introduction

The continuous challenges faced by electricity grids including the continuous rise in electricity consumption, the need for renewable generation of electricity, the need for efficient transmission and distribution, the need to recover quickly from natural disasters and more recently the increase in the use of electric vehicles suggest the smart grid will continue to receive substantial attention in the future. The smart grid relies on the use of network platforms where meter readings and data can be transmitted. The smart grid has been defined as an 'electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety' [1]. The U.S. Department of Energy defines the smart grid as 'a fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between' [2]. The definition found in [2] also adds that 'the smart grid's distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network'.

The European Commission in its European Energy Strategy 2020 has acknowledged the need to work towards the deployment of the future European electricity networks using the latest technology [3]. In the view of the European Commission electricity will be delivered where and when needed, and consumers will be able to monitor their electricity consumption in real time.

In Europe, over €5.5 billion has been invested in about 300 Smart Grid projects since the year 2001 [3] and of all that amount of money spent around €300 million has come from the EU budget. At present current EU-funded smart grid projects cover wind and other renewable electricity sources, infrastructure to support the achievement of a reliable, competitive and sustainable electricity supply and guidelines for more efficient integration of renewable energy into future infrastructures among others. The European Commission is careful to highlight that the EU is still in the early stages of the actual deployment of smart grids and that today, only around 10% of EU households have some sort of smart meter installed, although most do not necessarily provide the full scale of services to consumers [3]. However, the European Commission points out that those consumers with smart meters have reduced their energy consumption by as much as 10%. Furthermore, the adoption of the smart grid relies heavily on information and communication technology (ICT) developments. Indeed, the importance of ICT is evident as research work on smart grid has concentrated on customer involvement including areas such as technical operation systems, economic incentives to facilitate flexible demands including the development and design of proper information and communication systems and electric vehicles [4]. Figure 1 depicts a smart grid architecture with various elements comprising: power generation like thermoelectric and nuclear plants and renewable sources like wind, power transmission, power distribution and smart grid IP backbone/smart grid data management processing where meter readings and data can be transmitted. Users include electric/plug-in hybrid vehicles from private and freight/cargo transport, residential, offices, factories and warehouses. The size of power generators found may include domestic ones at kilowatt levels to large hydroelectric plants with capacity of several megawatts.

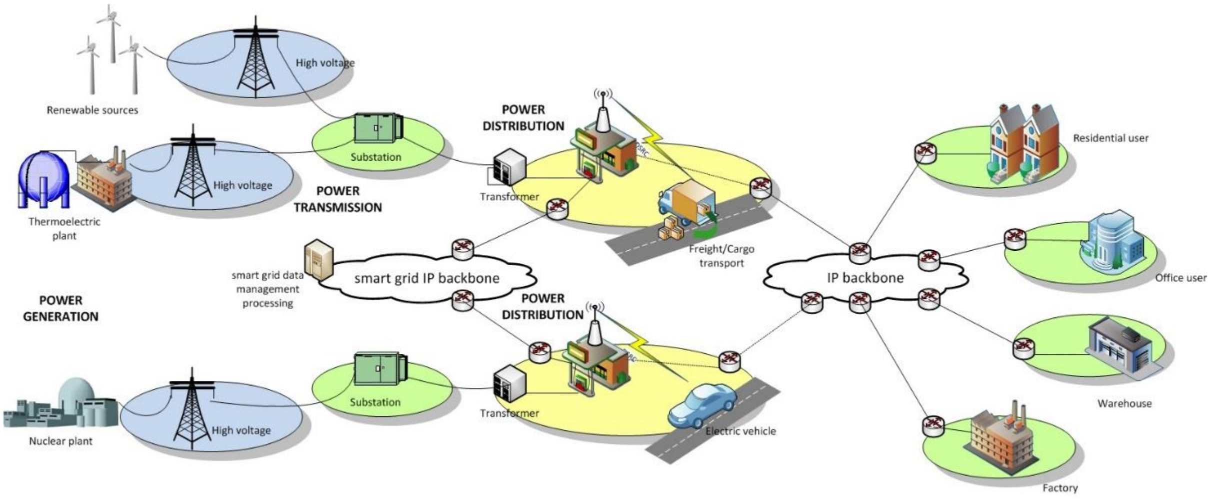

Figure 1. The smart grid configuration

Recent developments in smart grid research have anticipated the connection of electric vehicles into the power network and the myriad of technical challenges that need to be addressed properly [5]. Nonetheless, it has been recognized that electric vehicles with vehicle-to-grid capabilities can reduce emission from the transportation industry [5]. Furthermore, transportation systems need to achieve a reduction of road congestion and traffic accidents and make transport networks more secure and resilient has consolidated the importance of intelligent transport systems (ITS). ITS is based on the use of advanced information and communication technology to achieve a reduction of congestion and accidents while making transport networks more secure by reducing their impact on the environment [6]. The European Union has supported ITS research with the purpose of improving the efficiency of the road network comprising coordinated traffic control ramp metering, variable message signs, and traffic and incident detection systems which have been implemented across places in Europe to monitor road conditions and provide quick and smooth journeys [7].

Both the smart grid and intelligent transport systems (ITS) represent a unique challenge in terms of the convergence of network platforms to be used in the deployment of future services. The urge for convergence can be seen in the increase in the use of electric and plug-in hybrid vehicles which need public and private remotely metered recharging stations to recharge their batteries. The ability to monitor the energy state of vehicles in real time can help future energy management to mitigate the negative effect of vehicle charging such as variable electricity costs and battery degradation among others. On the other hand electric and plug-in hybrid vehicles meter readings can be transmitted using an ITS platform based on vehicle ad-hoc networks (VANETs) in addition to the use of available technologies such as cellular networks, Wi-Fi or 3G. Moreover, ITS applications supported by VANETs are expected to grow and evolve with the ultimate goal of achieving an accident-free driving environment [8]. VANETs can handle different types of service applications, including the transmission of both safety and non-safety messages into two modalities: vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). In the near future the importance of the convergence platform is expected to grow as new technological developments continue to take place. For example, the next generation of grid-based electric vehicles will be characterized for not only drawing energy from the smart grid, but also the storage of energy to the grid and allowing various data communication [8].

The next sections provide a review of the elements comprising the smart grid and VANET-based ITS which is followed by a framework that addresses the need for a convergence network platform based on commonalities such as systems security and electrification of the transport infrastructure. A seaport terminal scenario is used to discuss the characteristics of a convergence network platform followed by a model based on wireless sensor network (WSN) theory to simulate the operation of a common network platform for the smart grid and ITS. Future work opportunities are also discussed.

2. A Review of Smart Grid and VANET-based ITS elements

The European Commission Task Force for the Implementation of Smart Grid into the European internal market highlights that existing grids and related infrastructure have already elements of intelligence or smartness [9]. Furthermore, the European Commission also emphasizes that the smart grid of the future will rely on innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies. According to the European Commission [9] the use of the smart grid will make possible to:

- Allow consumers to play a part in optimizing the operation of the system
- Provide energy suppliers and their customers with greater information and options for how they use their supply
- Better facilitate the connection and operation of generators of all sizes and technologies, in particular, the transition towards large-scale integration of distributed energy resources
- Accommodate renewable energy peaks in the grid and allow for load management
- Significantly reduce the environmental impact of the whole electricity supply system
- Contain costs of the transition to a low-emission supply, by investing in intelligent planning and operations rather than in grid reinforcement only
- Maintain or even improve the existing high levels of system reliability, quality and security of supply
- Maintain and improve the existing services efficiently an allowing the development of new services and options
- Allow demand response programs, services and products for all consumer segments
- Foster market integration towards an integrated European market

The European Commission [10] has been working on the definition of the policies that will address future transport requirements. For example, it has set up the Strategic Transport Technology Plan (STTP) where the views from different stakeholders have been collected for the purpose of focusing efforts on aspects that include: transport management and information systems; smart systems/infrastructure; safety and security for all transport modes; alternative fuels; sustainable urban mobility, clean, safe and silent vehicles for all modes and also exploratory and strategic issues.

VANETs have the potential to cover both the needs of ITS and the smart grid. To make VANETs work for ITS and consequently the smart grid, VANETs require efficient wireless intra- and inter-vehicle communications mechanisms to collect data and exchange data among the driver, car, and roadside infrastructure [8]. Dedicated Short Range Communication (DSRC) is a next generation wireless vehicle network technology with an increasing role in ITS and with the potential to also meet the needs of the smart grid. One of the particularities of DSRC is its expected capability to operate at 33 dBm and provide coverage over a range of up to 1000 m with a data rate up to 27 Mbps [11] per channel (including two control channels and seven service channels).

The smart grid and VANET-based ITS can benefit from the use of a common ICT convergence platform. Figure 2 depicts the layers that comprise the common ICT platform for the smart grid and DSRC-based VANETs for ITS.

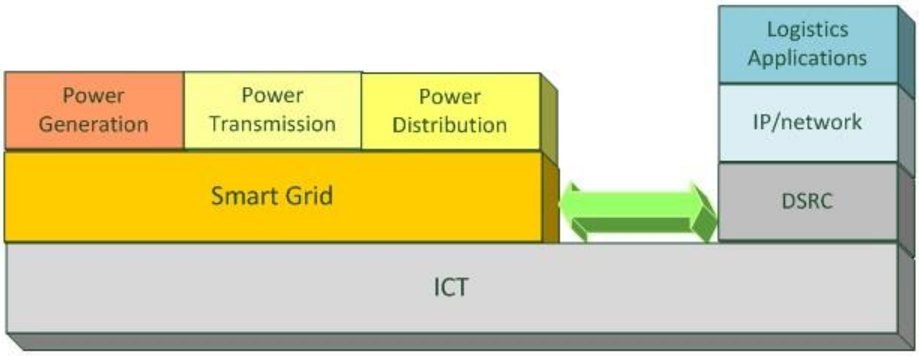

Figure 2. ICT is the common layer to support the smart grid and ITS using DSRC-based VANETs

In figure 2 the proposed use of ITS is represented by a DSRC-based VANET. The smart grid comprises three key elements: power generation, power transmission and power distribution. In the case of the DSCR-based VANET the upper layers comprise a layer for IP/networks and on top a layer for applications which include logistics and supply chain management. Important components to DSRC are roadside units (RSUs) which are normally associated to roadway, toll collection and parking management. In an ITS-enabled highway it would be possible to find RSUs used to transmit and receive messages from emergency vehicles, private electric vehicle, haulage trucks, delivery vans all of which are fitted with on-board units (OBUs). An OBU comprises a hardware module installed within the vehicle which includes a 5.9 GHz DSRC transceiver; a GPS location system; a processor for application services; and a human machine interface (HMI). DSRC technology operates in the Super High Frequency (SHF) Band at 5.9 GHz, where radio waves propagate mainly in the Line-of-Sight as well as due to multipath propagation [12]. Furthermore VANETs can be used to support applications for logistics services in multimodal environments as these are capable of supporting communication accessibility and reliability [13].

Wireless sensor networks (WSNs) have several common aspects with wireless ad hoc networks as in a WSN the data is forwarded, possibly via multiple hops, to a *sink* (sometimes denoted as *controller* or *monitor*) that can use it locally or is connected to other networks (e.g., the Internet) through a gateway/base station [14]. A WSN can be generally described as a network of nodes that cooperatively sense and may control the environment enabling interaction between persons or computers and the surrounding environment [15]. In a WSN, the activity of sensing, processing, and communication under limited amount of energy, ignites a cross-layer design approach typically requiring the joint consideration of distributed signal/data processing, medium access control, and communication protocols [16]. The theory of WSN offers significant advantages in the context of a common network platform for the smart grid and ITS and these are discussed in the next sections.

2.1 Justification for a convergence network platform for the smart grid and ITS

There are several instances that support the need for a convergence network platform between the smart grid and ITS, for example, the continuous growth of vehicles with electric and plug-in hybrid power trains. This means the recharging stations need to be connected as they are served by electric grid operators which have to apply advanced energy management methods [17]. Moreover, it has been recognized the need to accelerate work with a view to adopting technical standards for electric vehicle charging systems and for smart grids and meters [3]. Over the long term, the Commission's report on a roadmap for moving to a competitive low-carbon economy in 2050 [3] identifies smart grids as a key enabler for a future low-carbon electricity system, facilitating demand-side efficiency, increasing the shares of renewables and distributed generation and enabling the electrification of transport.

Communications capability is an important component that can determine the performance of the smart grid, as this is required to intelligently and automatically perform control and optimization operations as well as manage the rapid dynamic reconfiguration of system parameters to handle distributed and volatile energy requirements and loads [18, 19]. Furthermore energy management architectures address communications in order to perform operations concerning smart-control and communications including automated meter readings, communication with other grid appliances, control of domestic appliances and intelligent demand-side load management [19].

The economic impact of a convergence network platform capable of giving support to the smart grid and ITS can be significant as networks are required to support major economic activities such as logistics and transportation. A growing empirical literature has already documented the effects of network structure on behavior and choices in a wide variety of environments that include systems compatibility [20], airline route design [21] and among other applications that include matching markets, bargaining, friendship and job search and labor market. Furthermore in the management of the electric grid, since the electricity supply chain incorporates the processes from the primary fuel sourcing to electricity consumption, network planning is used to determine how much electricity to generate in which generation facilities and in which time periods by including elements such as fuel sources, transmission and distribution [22].

The importance of a convergence network platform for the smart grid and ITS will have immediate impact on enabling tracking and tracing. These two concepts complement each other as they contribute to increased security, streamline and optimize production planning and distribution and processes, locate sources of quality issues and manage recalls when needed [23].

3. Case of a seaport location

Several locations and facilities configurations can come to mind about the joint interaction between the smart grid and ITS, from airports to motorways to urban downtowns/city centers. A location where it is possible to associate the unique challenges in terms of the convergence of network platforms and the need for the deployment of future services mentioned in previous paragraphs is the seaport terminal, thus, though invisible to many, constitutes a fundamental element of global supply chains and logistics. A seaport has been defined as an interface between a sea transportation system on one side, and, on the other side, a land transport network [24].

Modern seaport container terminals operate several units of equipment for handling material which are electric-powered and require connection to the grid. These might include container quay cranes, rail mounted gantry cranes and hybrid yard hostlers. Container quay cranes are used for unloading/loading containers from/to a vessel. Operators of the cranes are given instructions on the sequence and sections of the vessel they have to unload/load. Yard hostlers or internal tractors are used to move the containers handled by the quay cranes to designated areas within the yards of the terminal. Electric-powered rail mounted gantry cranes handle and stack the containers transported by the yard hostlers. This type of gantry crane has become a common sight in many container terminals around the world. Yard hostlers are mostly diesel-powered but recent developments in powertrain technology has seen the adoption of hybrid propulsion, hence reducing CO_2 emissions. Figure 3 depicts a modern seaport container scenario comprising of container quay cranes indicated with letter *a*, rail mounted gantry cranes indicated with letter *b* and hybrid yard hostlers represented with letter *c*.

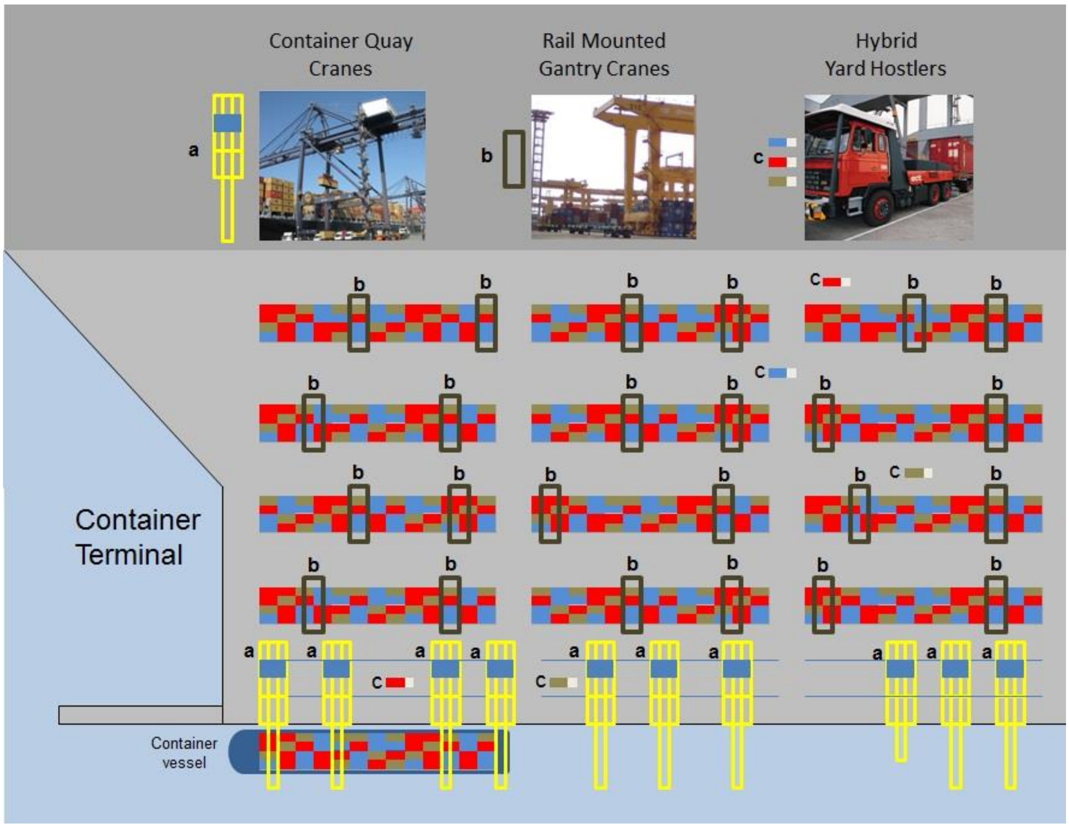

Figure 3. Seaport container terminal comprising of electric-powered material handling equipment for the movement of containers

One fundamental aspect of modern logistics operations like those taking place in seaport terminals is multi-modality or co-modality, which is about the efficient use of different modes on their own and in combination, resulting in a sustainable and optimal utilization of resources [6]. Complex logistics arrangements can result from the combination of different modes of transportation like road, sea and air. Multi-modality has become now an inherent characteristic of complex logistics operations and that has become evident in port operations. The need for multi-modal capabilities is driving seaports to adopt ICT solutions for the achievement of substantial efficiencies at the operational level through better energy utilization. In many port terminals it is possible to see sea, road and rail modes.

In order to cope with multi-modality DSRC-based VANET in a seaport container terminal needs to support the transmission of two types of messages: Wireless Access for Vehicular Environment (WAVE) Short Messages (WSM) and IPv6 traffic [11]. WSM messages involve low latency and critical safety-related messages assuming a real-time propagation (can be associated to emergencies/accidents). Within the seaport container terminal IPv6 traffic is related to commercial services involving download or streaming of data related to metered readings, instructions to operators and jobs/tasks update to mention just a few. The IEEE 1609 (.3) standard as required for smart grid and ITS applications describes the transport and network layer services including addressing and routing in support of reliable WAVE data transfer. The IEEE 1609.3 standard specifies the Transmission Control Protocol (TCP) in the transport layer which relies on sequence numbers and acknowledgement to provide a best effort service for end system data transfer.

A DSRC-based VANET platform for the smart grid and ITS will have to meet key requirements of modern seaport container terminals such as: real time track and trace capabilities to respond to customer enquiries about container handling; transmission of metered readings of electric power consumption; accurate register of yard hostlers traffic moving within the port premises; elimination of delays to vessel departures because of inaccurate loading and unloading operations and accurate billing to customers.

4. Simulation environment of the smart grid and ITS in a seaport container terminal

The diagram in figure 4 depicts a seaport container terminal network that consists of a local area network with Road Side Unit (RSU) access points connected to core network routers in a star configuration. In figure 4 the core routers are connected in a fully meshed or semi-meshed network configuration with a maximum number of core connections. Mobile switching centres depict the ability of the core routers to manage data transfers from several access points and the channelling of this information to the network routers.

The network architecture supports reliable data transfer between materials handling equipment including container quay cranes, rail mounted gantry gates and hybrid (plug-in) yard hostlers (all of these deploying onboard units – OBU) and the centralized data repository where applications are stored (reliable data transfer between a remote workstation and the centralized data repository) and reliable data from the remote workstation to the centralized repository. The diagram shown in figure 4 contemplates external trucks having OBUs, so they can be connected to the network. The internet cloud shown in the diagram represents the data transfers to or from the centralized workstation.

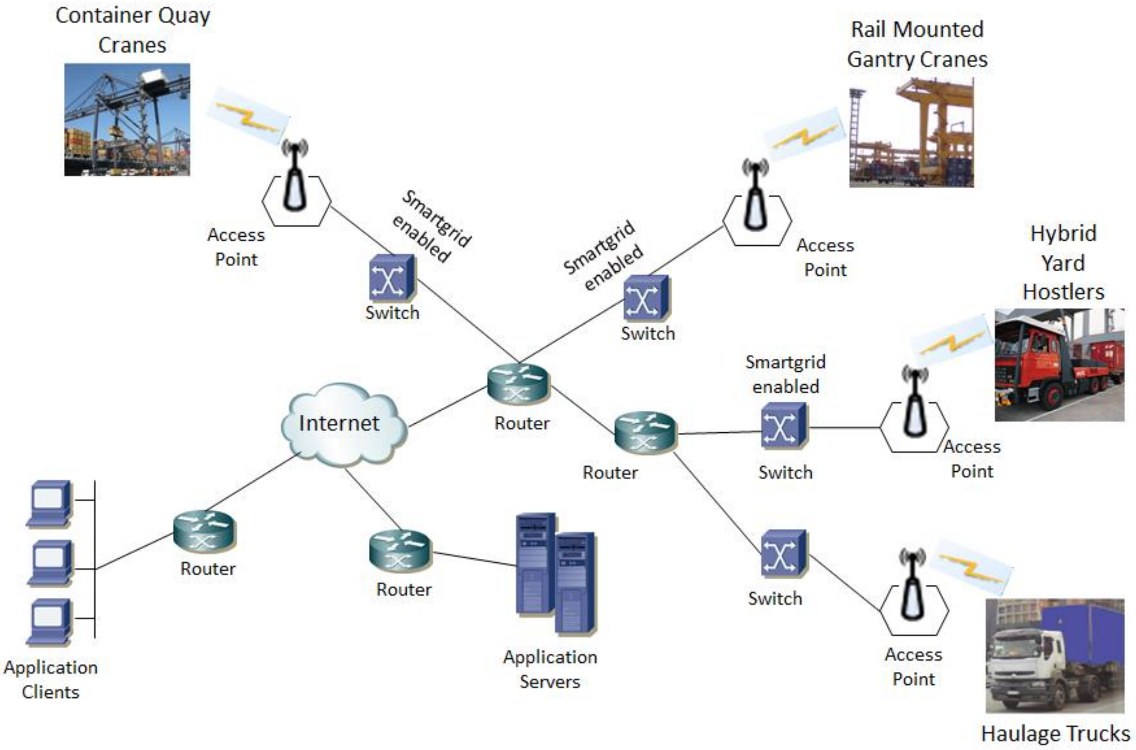

Figure 4. Architecture for a DSRC-based VANET platform for smart grid and ITS in a seaport container terminal

In the above scenario, WSN can be used to transmit information about the current consumption of energy. Battery charge information of plug-in vehicles can be transmitted along the cluster network to the smart grid network in real time. Furthermore, data can be used for more efficient distribution of energy in the power grid.

Success in the deployment of service provisioning models for highly mobile environments such as those found in seaport container terminals depends on the implementation of robust architectures capable of maintaining their overall performance when facing hostile environments [25]. Also the complexity of logistics operations in seaports reflects the importance of having an infrastructure that supports communication accessibility and reliability [26]. Perhaps one of the greatest challenges for the deployment of services for both the smart grid and ITS (on-demand services) is that the exchange of information between users and service providers must be kept reliable and secure, when sensitive information is transferred such as metered readings, customer billing or disclosure of sensitive information among others.

4.1 Use of wireless sensor networks (WSNs) for a common network platform

Wireless sensor network (WSN) theory can be used to simulate the operation of a common network platform for the smart grid and ITS. In WSNs the nodes can be stationary or moving, they can be aware of their location or not and they can be homogeneous or not and alternatively, it is possible to have a scenario with multiple sinks in the network [14]. In a WSN a *sink* is commonly known as *cluster head*. Given a certain level of node density, a larger number of sinks will decrease the probability of isolated clusters of nodes that cannot deliver their data owing to unfortunate signal propagation conditions [14]. Figure 5 depicts a WSN scenario comprising a base station, cluster heads and sensors applicable to the smart grid and ITS. The use of clustering offers several advantages including bandwidth reuse, better resource allocation and better energy management/power control [27].

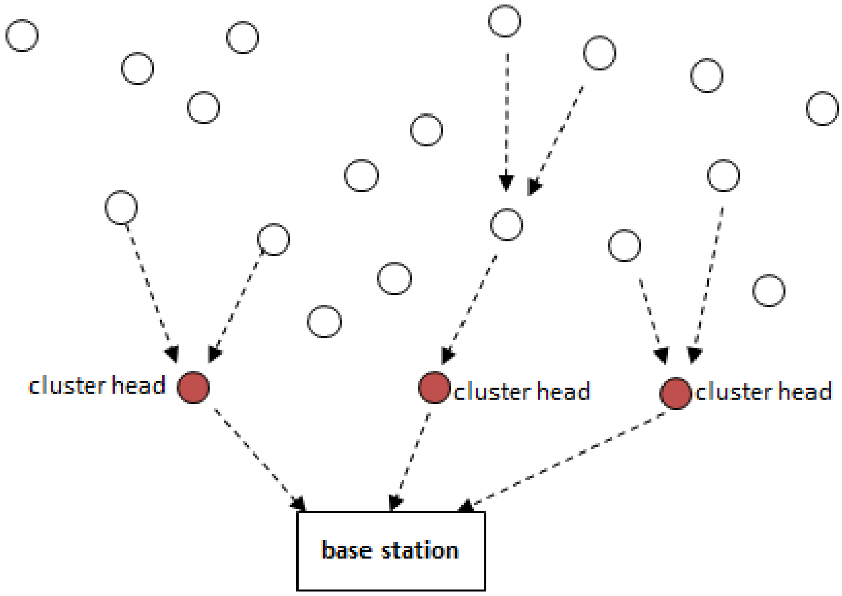

Figure 5. Representation of a base station and cluster heads commonly found in WSN configurations

In a common network platform for the smart grid and ITS and based on WSN theory, sensors are present in the meters that transmit readings for power consumption or communicate data about energy storage to the grid. Also sensors are present in the vehicle on-board units that receive traffic and non-safety commercial information and transmit vehicle-status information and in the roadside units that transmit and receive safety and non-safety/commercial information to/from vehicles in the area. The representation shown in figure 5 must meet good protocols for wireless micro sensors. According to [28] a sensor network protocol may include metrics such as ease of deployment (nodes being able to communicate with each other even in the absence of an established network infrastructure and predefined node locations); system lifetime (all aspect of nodes designed to be extremely energy efficient); latency (reception of data in a timely manner) and quality (protocols designed to optimize for the unique, application-specific quality of a sensor network).

In order to test the suitability of WSN for the common network platform requirements of the smart grid and ITS, the low-energy adaptive clustering hierarchy (LEACH) algorithm was selected. The algorithm is a protocol architecture for micro-sensor networks that combines the ideas of energy-efficient cluster-based routing and media access together with application-specific data aggregation to achieve good performance in terms of system lifetime, latency, and application-perceived quality [26]. LEACH is characterized for using [28]: a) randomized, adaptive, self-configuring cluster formation; b) localized control for data transfers, c) low-energy media access control (MAC) and d) application specific data processing. Based on WSN theory, in the LEACH algorithm the cluster head node receives data from all the cluster members, performs signal processing functions on the data (e.g., data aggregation), and transmits data to the remote base station and all non-cluster head nodes transmit their data to the cluster head [28].

The use of the LEACH algorithm makes a number of assumptions including [28]: all nodes can transmit with enough power to transmit to reach the base station, power control to vary the amount of transmit power, computational power to support different MAC protocols, nodes always have data to send to the end user and nodes located close to each other have correlated data.

The assumptions listed in the previous paragraph are suitable for the requirements of a WSN-based common platform to support the exchange of messages for the smart grid and ITS. The use of the LEACH algorithm enables to test the reliability of the packets sent from sensors to the base station and also test energy management/power control through randomized rotation that prevents draining the battery of any one sensor in the network.

The use of a WSN-based common platform to support the exchange of messages for the smart grid and ITS can be part of a demand response management system. This type of system is important due to the energy price variability that affects major electricity consumers such as seaports and other transportation hubs. For example, the rapid response of a WSN-based platform can be helpful in situations where energy price updates take place in short periods of time. In fact, energy consumers using smart meters and distributed renewable energy generators with stores of energy can respond to energy price updates with a period of less than 5 minutes [29].

4.2 Results of simulation trials for WSN

A Matlab implementation of the LEACH algorithm was used in this work. The results shown in figure 6 considered an area of 800 m X 800 m, a space representative of conditions seen in industrial environments such as port locations. The LEACH algorithm places nodes randomly throughout the designated area which can represent vehicles found in seaport operations such as yard hostlers, straddle carriers, haulage vehicles, gantry and quay cranes. The LEACH model parameters include the initial energy supplied to each node (E_0) equal to 0.5 J. For each one the energy required to transmit/received a message over the designated distance (E_{elec}) is equal to 50 nJ/bit. The energy used for data aggregation (E_{DA}) is equal to 5 nJ/bit/signal. The bandwidth of the channel was set to 1 Mb/s and each data message was 500 bytes long [28].

The simulations comprise three cases of 20, 60 and 100 nodes randomly distributed with the probability of a sensor to become a sink/cluster head rated at 0.1. The distance between the cluster and the base station is 400 m. The number of iterations simulated was 200.

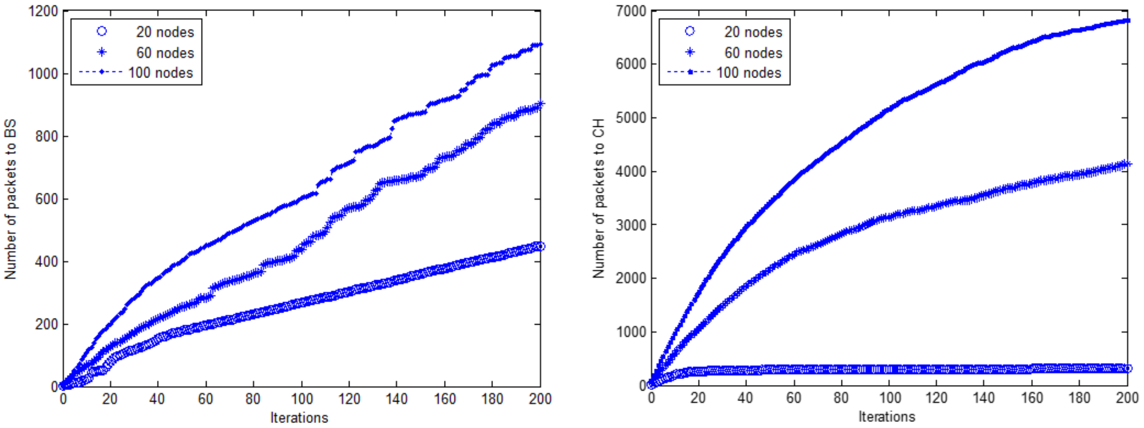

Figure 6. Results from simulations using WSN based on the LEACH algorithm

The results show that when the number of nodes is low, say 20, the number of packets sent to the base station experience a high growth rate as iterations increase. On the other hand, when the number of nodes present is higher, say 60 and 100, the increase in the number of packets to the base station experience a low growth rate which tend to stabilize as iterations increase. The number of packets sent between clusters was simulated as this has an effect on the performance of a WSN. The values plotted in figure 6 shows that when the nodes present in the network is low, say 20 for an area of 800 m X 800 m, the number of packets exchanged between clusters experience high growth levels. According to the values obtained for 200 iterations, the number of packets sent by 20 nodes to the base station reaches 449, for 60 nodes the number of packets sent reaches 902 for 100 nodes the number of packets sent to the base station reaches 1093 for 200 iterations. For 20 nodes the number of packets sent to the cluster head is equal to 315. For 60 nodes the number of packets sent is equal to 4138 and for 100 nodes the number of packets reaches 6835. For 20 nodes the initial energy supplied is equal to 10 J, for 60 nodes is 30 J and for 100 the amount is 50 J. In a seaport scenario, the number of packets sent can be related to data traffic associated to metered readings required in environments such as seaports. The transmission of metered readings take place while running jobs involving the loading and unloading of a vessel where quay cranes, rail mounted gantry cranes, yard hostlers and other vehicles transmit the consumption of power. Furthermore, the number of iterations can be spread for the total duration of the loading/unloading job. The more nodes present in the network the more packets and frequent readings can be sent however this will entail an increase in energy consumption. The adequate management of energy in the network means nodes will have enough energy left to complete the iterations associated to loading/unloading jobs in a seaport. The amount of energy supplied to the network of sensors is still negligible as for 100 nodes the total amount of energy supplied was 50 J which equals 0.0138 watt-hour. Moreover, the energy supplied to the network and the packets transmitted can suit the conditions faced by some energy consumers where energy price updates take place in short periods of time. Finally, for the deployment of WSN in industrial environments, it is important to consider the physical obstructions present in the site.

5. Conclusions and future opportunities

Based on the principles of WSN this paper presents a common network platform for the smart grid and ITS using the low-energy adaptive clustering hierarchy (LEACH) algorithm. The use of WSN offers several advantages such as low network clustering which allows bandwidth reuse, better resource allocation and better energy management/power control. These are important characteristics required to support the operation of the smart grid in locations which are important consumers of electricity like seaports. Given the requirements of a seaport location the results of the simulations for 20, 60 and 100 nodes show that packets can transmit data which can be associated to metered readings taking place while running jobs involving the loading and unloading of vessels. The nodes can be associated to vehicles found in seaports like quay cranes, rail mounted gantry cranes, yard hostlers, straddle carriers and others which need to transmit readings on power consumption. Furthermore, mirroring vehicle movements in a seaport location, WSN nodes can be stationary or moving, they can be aware of their location or not and they can be homogeneous or not. Also low energy supplied and data transmission capabilities make WSN nodes suitable for dealing with environments characterized for the need of continuous energy price updates.

The results of using WSN for a platform to support the smart grid and ITS are relevant as in recent years, seaport terminals have been replacing diesel-powered equipment with the use of electric power. This action, not only motivated by the need to reduce emissions, has opened the door for the adoption of common platforms to provide the functionality required by the smart grid and ITS. For many, the smart grid is about the economic efficiency and sustainability of power systems at a time electric vehicles and plug-in hybrid are growing in use, not to mention that these types of vehicles will be linked to other vehicles and to the roadside infrastructure through seamless communications channels. The scale of potential impact of VANETs/WSNs is substantial as other locations such as airports, urban downtown areas or the highway network may benefit extensively from the existence of a convergence platform capable of serving the needs of the smart grid and ITS.

Given the magnitude of the challenges ahead, future research work on data traffic associated to smart grid operations would give the opportunity to improve the optimization of the energy supply in the smart grid by obtaining secure real-time traffic flow information at the recharging station via VANETs/WSNs. Thus, this would result in an accurate assessment in the smart grid of the actual energy consumption patterns at every single distribution point. Key information to be exchanged using a secure communication model might include meter readings and transactions related to energy storage as well as non-safety messaging linked to

ITS-related commercial service applications supported by VANETs/WSNs and road traffic safety messaging.

The potential deployment of a convergence network platform for the smart grid and ITS has several economic implications to multimodal hubs, hence the need also to investigate the contribution of network structures in terms of economic outcomes, sustainability, resilience and security. Multimodal hubs are characterized for the proximity of transportation infrastructure including seaports, motorway networks, airports, main roads and railways which also themselves represent hubs of economic activity that also affect industrial and residential areas. Further research work needs to investigate the associated economic impact of the requirements of a convergence network platform to support the integration of the smart grid and ITS.

References

[1] ERGEG -European Regulators' Group for Electricity and Gas, 2009. *Position paper on smart grids. An ERGEG public consultation paper.* Ref: E09-EQS-30-04; 10 December.

[2] U.S. Department-Of-Energy. Grid 2030: A National Vision for Electricity's Second 100 Years. Technical Report, Department of Energy, 2003.

[3] European Commission, 2011. European Energy 2020 Strategy. Smart Grids: from innovation to deployment. Accessed: 8/05/2014 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0202:EN:HTML:NOT

[4] Lund H., Andersen A.N. Ostergaard P.A., Vad Mathiesen B. & Connolly D., 2012. From electricity smart grids to smart energy systems – A market operation based approach and understanding. *Energy, 42,* 96-102.

[5] Honarmand M., Zakariazadeh A. & Jadid S., 2014. Optimal scheduling of electric vehicles in an intelligent parking lot considering vehicle-to-grid concept and battery option. *Energy, 65,* 572-579.

[6] Zomer G. & Anten N., 2008. Vision on the crucial role of ITS for efficient and green European Logistics. Proceedings of the 15th World Congress on ITS, November 16-20, New York, New York, USA.

[7] ERTICO, 2014. ITS Europe, http://www.ertico.com Accessed: 8/05/2014

[8] Faezipour M., Norani M., Saeed A. & Addepalli S., 2012. Progress and Challenges in Intelligent Vehicle Area Networks. *Communications of the ACM, 55, 2,* 90-100.

[9] European Commission, 2011. Smart Grids Task Force. Accessed: 8/05/2014. http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/mission_and_workprogramme.pdf

[10] European Commission - Directorate General for Research and Innovation, 2011. Short notes of the informal meeting with Country Representatives to discuss transport in the forthcoming "Common Strategic Framework for Research and Innovation" 14th July 2011. Accessed: 8/05/2014 http://ec.europa.eu/research/horizon2020/pdf/workshops/smart_green_integrated_transport/summary_report_workshop_on_22_june_2011.pdf

[11] NHTSA, 2005. DOT HS 809 859 nhtsa. Vehicle safety communications project task 3 final report. Identify intelligent vehicle safety applications enabled by DSRC, March.

[12] Zhao, X., Kivinen, J., Vainikainen P. & Skog K., 2002. Propagation characteristics for wideband outdoor mobile communications at 5.3 GHz. IEEE Journal on Selected Areas in Communications, *20*, 507–514.

[13] Coronado Mondragon A.E., Coronado Mondragon E.S., Coronado Mondragon E.C. & Mung'au F., 2012. Estimating the performance of intelligent transport systems wireless services for multimodal logistics applications. *Expert Systems with Applications, An International Journal*, *39*, *4*, 3939-3949.

[14] Buratti C., Conti A., Dardari D. & Verdone R., 2009. An Overview on Wireless Sensor Networks Technology and Evolution, *Sensors*, *9*, 6869-6898.

[15] Verdone, R.; Dardari, D.; Mazzini, G. & Conti, A., 2008. Wireless Sensor and Actuator Networks; Elsevier: London, UK.

[16] Verdone, R., 2008. Wireless Sensor Networks. In *Proceedings of the 5th European Conference*, Bologna, Italy, 2008.

[17] Grob, G.R., 2009. Future transportation with smart grids & sustainable energy. 6th International Multi-Conference on Systems, Signals and Devices, 2009. SSD '09. , 1-5. Accessed: 8/05/2014 http://www.iiisci.org/journal/CV$/sci/pdfs/XF463SC.pdf

[18] Alagoz B.B., Kaygusuz A. and Karabiber A., 2012. A user-mode distributed energy management architecture for smart grid applications. *Energy, 44,* 167-177.

[19] Ganesh K.V., 2011. Intelligent sense-making for smart grid stability. IEEE: power and energy society general meeting, 1-3.

[20] Katz M. & Shapiro C., 1994. Systems Competition and Network Effects. *The Journal of Economic Perspectives*, *8,* 93-115.

[21] Hendricks K., Piccione M., & Tan G., 1995. *The Economics of Hubs: The Case of Monopoly,* Review of Economic Studies *62, 1,* 83-99.

[22] Bas E., 2013. The integrated framework for analysis of electricity supply chain using an integrated SWOT-fuzzy TOPSIS methodology combined with AHP: The case of Turkey. *Electrical Power and Energy Systems*, *44*, 897-907.

[23] Musa, A., Gunasekaran, A. & Yusuf, Y., 2014. Supply chain product visibility: Methods, systems and impacts. *Expert Systems with Applications*, *41*, *1*, 76-194.

[24] Rodon, J., Pastor, J.A., Sesé, F. & Christiaanse E. (2008) Unravelling the dynamics of IOIS implementation: an actor-network study of an IOIS in the seaport of Barcelona. *Journal of Information Technology, 23*, 97-108.

[25] Coronado, E. & Cherkaoui S., 2007. Secure service provisioning for vehicular networks. In International workshop for ITS Ubiroads, co-located with IEEE GIIS 2007, July 2–6 Morocco.

[26] Coronado Mondragon A.E., Coronado Mondragon E.S., Coronado Mondragon C.E. and Mung'au F., 2012. Estimating the performance of intelligent transport systems wireless services for multimodal logistics applications. *Expert Systems with Applications, An International Journal*, *39*, *4*, 3939-3949.

[27] Kwon, T & Gerla M. (1999) Clustering with power control. *Proceedings of MILCOM*, 2, November, Atlantic City:NJ.

[28] Heinzelman W., Chandrakasan A. & Balakrishnan H. (2002). An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on Wireless Communications*, *1*, *4*, 660-670.

[29] Alagoz B.B., Kaygusuz A., Akcin M. & Alagoz S. (2013). A closed-loop energy price controlling method for real-time energy balancing in a smart grid energy market, *Energy* 59, 95-104, 2013.