American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Wireless Sensor Networks (WSN): An Overview

Nnaemeka Chiemezie Onuekwusi[a*], Chinedu Reginald Okpara[b]

[a,b]Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Imo State, Nigeria

[a]Email: nnaemekaonuekwusi@futo.edu.ng

[b]Email: chinedu.okpara@futo.edu.ng

Abstract

The plethora of research and development efforts on Wireless Sensor Networks is an indication that the technology has emerged an active research area in recent times. In this paper, a review of this intelligent technology is undertaken. Its working mechanisms, merits, challenges, transmission technologies, simulating tools and applications are considered. The paper concludes with a clear conviction that a sound knowledge of the basics of this technology is a sine qua non to research and development of the technology.

Keywords: Wireless Sensor networks; challenges; transmission technologies; simulators; applications.

1. Introduction

Advances in science and technology have continued to seek and aid man effectively monitors, sense interprets and responds to events in his environment. In recent years, development in Micro Electro-Mechanical Systems Technology (MEMS), wireless communication and digital electronics have created rapid advancements in the invaluable technology of WSNs [1]. It is envisioned that in the near future, WSNs will be ubiquitous and become an integral part of normal live more than the personal computer [2]. WSN can simply be described as a collection of sensor nodes organized into a cooperative and synergistic wireless network [3]. It can be further explained as a network of (possibly low-size and low-complex) devices denoted as nodes that can sense the environment and communicate the information gathered from the monitored field through wireless links, to a sink that can use it locally, or is connected to other networks (e.g., the Internet) through a gateway [4]. The varied application areas and other immense advantages of the WSN have made it the de facto name and standard for sensor networks. WSNs leverage on the wireless networking and communications techniques of ad hoc network for their operations.

---

* Corresponding author

They are however distinguished from the adhoc networks by their energy constraints, environmental interaction, sensing and computation, node battery depletion and its resultant node failure, node mobility, densely populated nodes and possible absence of unique global identification per node [5 – 8].

2. Mechanism of WSN

Sensing, data processing and communication characterise the basic operation of the WSN. Figure 1 shows a basic architecture of a sensor node.

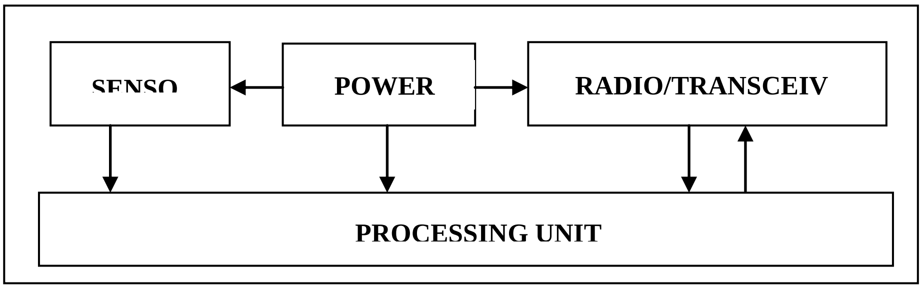

Figure 1: Basic architecture of a sensor node.

The sensor nodes are usually small, lightweight and portable and serve as multiple detection stations for the WSN. They can be stationary or moving, aware of their location or not and can be either homogeneous or heterogeneous. The node basically consists of a processing unit which is usually a microprocessor, sensors, radio transceiver (transmitter and receiver) and power supply [9]. The sensor is a transducer which does the actual sensing of the node. It usually generates electrical signals as a result of the Sensed Phenomenon of Interest (POI). The microprocessor coordinates the different components and activities in the sensor node. It also interprets and processes data of the POI. The microprocessor employs the memory to store the data of the sensed POI and its interpretation. The Communication module often referred to as the transceiver has the function of communicating (transmitting and receiving) signals to and fro the microprocessor and other nodes in a WSN. The Battery is responsible for meeting the power needs of the different functionalities of the sensor node and therefore largely determines the lifetime of a WSN.

3. WSN transmission technologies

The choice of a transmission technology for the wireless communication of WSNs is application specific as a transmission technology suitable for a certain application may be inappropriate for another. The goal in employing any of the technologies is nearly always to optimize the signal-to-noise ratio, subject to specified constraints like power consumption, bandwidth requirements, cost, reliability, equipment and antenna size [10]. Some of the popular transmission technologies employed in WSNs as listed in [11 -12] include: Bluetooth, Zigbee and Wi-Fi.

3.1 Bluetooth

This is a popular wireless transmission technology employed in WSNs and many other wireless communication applications. It is of the IEEE 802.15.1 standard. The popularity of the Bluetooth technology is a function of its merits which include: low power, low cost and robustness. Bluetooth networks can be established quite easily, but they are generally used for point to point communication. Although its data rate of 25Mbps and maximum range of 10-100m are considered moderate, the Bluetooth may however be undesirable for certain WSN setups that require higher data rates and ranges [11].

3.2 Zigbee

The zigbee also referred to as the IEEE 802.15.4 wireless technology is a short range communication technology which offers low complexity, low cost, and low data rates at very low energy levels. Zigbee technology offers the ease to add or remove nodes from the network and is suitable for WSN applications requiring smaller data transfer. Its data rate and range are smaller than that of the Bluetooth and as such may not be suitable for WSN setups that require higher data rates and ranges [10].

3.3 Wi-Fi

Wi-Fi which means Wireless Fidelity represents group of WLAN technologies defined under IEEE 802.11 standard. Wi-Fi technology in WSNs provides for high data rates, bandwidths and longer ranges but however at the expense of high energy depletion. Energy considerations, complexity and higher bandwidth than what is mostly needed for typical sensor applications make the Wi-Fi an unpopular choice for WSNs. It can however be used with some low power WSN transmission technologies with it serving as a gateway transmission technology between the WSN and other networks like the internet [13].

4. Challenges of WSN

The immense prospects of WSN notwithstanding, there exists few challenges militating against their full exploitation. The need to overcome these challenges has elicited a lot of research interest. Popular challenges associated with WSNs include:

4.1 Energy constraint

Research is consistent in identifying energy constraint as the most significant challenge facing WSNs. This is as a function of the fact that all operational activities (Sensing, Processing and Communication) of the sensor node contribute to energy drain and lifetime reduction of WSNs [14]. Of the three operational activities, communication contributes the most significant energy drain as identified in [15 – 17]. This is followed by the sensing operation and then processing. The trend in most research efforts on energy management schemes in WSNs is that they rely on the fact that sensing and processing operations consume significantly less energy compared to communication, and so, concentrate all efforts on communication activity minimization [18 – 19]. However, [20 – 23] in their different studies show that this fact does not hold in a number of practical applications, where the energy consumption of the sensing and processing operations may be comparable to, or even greater than, that of the communication. Incorporating energy awareness into every stage of WSN design and operation, thus empowering the system to make dynamic tradeoffs between energy consumption, system performance, and operational fidelity will be the best approach to maximise energy efficiency and network lifetime [24]. A critical look at the different activities of the sensor node with the view of minimising energy consumption at each operation is therefore a sine qua non to the design and deployment of energy efficient WSNs.

4.2 Communication and routing

As data are being cooperatively transferred within the network and externally, issues about the choice of optimal and efficient communication pathways arise. Many WSNs challenges can summarily be captured under communication and routing. Some of these issues include: communication range, bandwidth, data rate, packet loss rate, network topology and routing protocols. To address challenges related with WSN communication and routing, a lot of routing schemes have been developed [25].

4.3 Security

WSNs are often times deployed in restricted areas and required to communicate discrete information, therefore secure communication becomes a mission critical requirement. WSNs mostly use radio frequency channels which are sometimes susceptible to eavesdropping and malicious attacks. The network is however expected to operate in the presence of such attacks without compromising its operation information communicated [26].

5. Simulators and emulators for WSN

The use of simulation and emulation in the evaluation of different WSN parameters has been necessitated by the cost, time and expertise required to deploy a WSN test bed. These seeming advantages of simulators and emulators over the test bed have still not nullified the use of the test beds as viable analytical setups for WSNs. The available simulators and emulators however show some limitations in meeting up with the diverse characteristics and performance criteria of WSNs. While some may be apt in the evaluation of certain parameters, they may be inadequate for other parameter evaluations. Simulation and emulation tools for WSNs are however constantly on the increase. NS-2, TOSSIM, OMNET ++ are amongst the popular ones.

5.1 NS-2

NS-2 is an acronym for Network Simulator Version Two, a discrete event network simulator built in an object oriented extension of tool command language and C++. It is an open source, general purpose WSN simulator which runs on Linux Operating Systems or on Cygwin, a Unix-like environment and command-line interface running on Windows [27]. The NS-2 as a non-specific WSN simulator can support a considerable range of protocols in all layers. As open source, it saves the cost of simulation, and its online documents allow users modify and improve the codes. The creditable merits of NS-2 notwithstanding, it still has some limitations as identified by [28 – 30] amongst others. NS-2 has no Graphical User Interface (GUI) and as such its users have to directly face text commands of the electronic devices. Users are expected to be familiar with writing scripting language and modelling techniques. They are also expected to understand and write its Tool Command Language. These result in the continuous change of the code base with the attendant effect in result inconsistency and possible high presence of bugs. Also NS-2 fails to consider some unique characteristics of WSN. It is generally unsuitable to simulate problems of WSN bandwidth, power consumption and energy management.

5.2 TOSSIM

This is an open source emulator specifically designed for WSN running on TinyOS, an open source operating system for embedded systems. TOSSIM is built in high-level programming languages, Python and C++ and can run on Linux Operating Systems or on Cygwin on Windows. Studies by [27, 31, 32] show that like the NS-2, TOSSIM as an open source emulator saves cost but unlike the NS-2, it has a GUI. Its GUI (TinyViz) provides the user the convenience to interact with electronic devices because it provides images instead of text commands. It supports simulation of larger networks, evaluates each node under perfect transmission conditions and captures the hidden terminal problems. TOSSIM is however unsuitable for simulating WSN energy management issues. Although the POWERTOSSIM (an improved version of TOSSIM) seeks to address this limitation, yet it failed to address it completely. TOSSIM is rigid as it is specifically designed to simulate behaviours and applications of TinyOS, and unable to simulate the performance metrics of other new protocols.

5.3 OMNeT++

This is a discrete event network simulator built in C++ and can run on Linux Operating System, Unix-like system and Windows. It is an open source, non-specific network simulator, which supports module programming model. It has a good GUI which relatively makes tracing and debugging much easier. It is suitable for the simulation of channel controls in WSNs, but due to lack of sufficient sensing and energy models, it is only suitable to simulate basic energy consumption issues [33]. OMNeT++ has limited number of protocols and its module programming model can introduce compatibility challenges, since individual researching groups developed the models separately. This makes the combination of models difficult and programs may have high probability report bugs [34].

6. Applications

The challenges of WSNs notwithstanding, its applications have continued to undergo rapid advancement in varied areas. WSN can be applied for the monitoring and management of key infrastructure areas like Transportation, Agriculture, Health, Security, Energy, Smart homes, Environmental monitoring and Disaster Management as explained in [35].

6.1 Transportation

WSNs can play vital roles in the increase of transport efficiency. They have the potentials to transform the present transport system to Intelligent Transport System (ITS). WSNs can be applied in the design of intelligent vehicles that have the potentials for obstacle detection, collision avoidance, in-vehicle crash detectors, navigation and route guidance. They can also be employed in traffic signal control, lane management, warning systems, operations and fleet management, freight and asset tracking [36]. The implementation of WSN technology in the transportation infrastructure will also contribute to better tracking of goods and vehicles, save lives, time, money, energy and even the environment [37].

6.2 Agriculture

Agriculture is a major infrastructure for the sustenance and improvement of the economy. Land over-exploitation, one of the major concerns of intensive agriculture, leads to problems such as soil compaction, erosion, salinity and declining water quality [38]. WSN can be used to overcome this concern by adopting them for real-time monitoring of variables such as soil fertility, soil water availability and soil compaction. In livestock, the movement of herds and the health of animals can be controlled and monitored via WSN. WSNs can also be used for precision irrigation, and for systems developed for remotely controlled, automatic irrigation [39].

6.3 Health

Advances in wireless sensor networking have opened up new opportunities in healthcare systems. A variety of equipments used in health care systems have sensors monitoring, evaluating and interpreting patients' medical conditions. In some modern hospitals, sensor networks are employed to monitor patients' physiological data, control drug administration, track and monitor patients and doctors [40]. Pressure sensors monitor a patient's condition by providing accurate and reliable diagnostics in a broad range of conditions. In-homes and nursing-homes, pervasive sensor networks may assist patients and their caregivers by providing continuous medical monitoring, memory enhancement, control of appliances, medical data access, and emergency communication [41].

6.4 Security

In Security and surveillance WSNs can be used for surveillance of boarders and other environments. Different kinds of sensors monitoring temperature, light, acoustics and movement can be used in isolation or together for security of restricted areas or in areas under surveillance. WSNs are becoming an integral part of military command, control, communication and intelligence systems. They can be deployed in a battle field to monitor the presence of forces vehicles, track their movements and enable close surveillance of opposing forces [42]. The use of unmanned vehicles for surveillance of dangerous terrain, search and rescue, bomb disposal and combat in war zones as explored in [43] are amongst laudable use of WSN in the improvement of security.

6.5 Energy

WSN brings to bear its smart infrastructure to improve on the operations of the different components of the grid (Generation, Transmission, Distribution and Consumers). WSNs play a major role in turning traditional grids into smart grids. WSN employs its intelligent communication infrastructure to effectively harness alternative green energy sources, enable possibility to read consumption both locally and remotely, enable secure and adaptable information flow in the electricity grid, assess the health of the grid in real time, predict and anticipate disturbances, and perhaps adapt and respond to ensure that steady power is provided to the consumers [44 - 46].

6.6 Environmental monitoring and disaster management

A Large number of environmental monitoring applications make use of WSNs. Wireless sensor networks facilitate monitoring and controlling of physical environments from remote locations with better accuracy. Temperature, wind (speed and direction), relative humidity, light and barometric pressure are amongst possible environmental parameters and events that can be detected, measured and controlled with WSNs. In disaster management, nodes monitor and sense seismic events and report generated data to base stations [47]. WSNs can be employed to detect and prevent forest fires by the detection of flames, heat and gases. Studies in [48] explain that the WSN can acquire the daily values for temperature and relative humidity in order to determine the likelihood of a fire in the environment under surveillance. Also WSNs can be employed in flood and erosion monitoring and control.

6.7 Industry

There are varieties of applications of WSNs in the industry to monitor operations, ensure safety and in general boost efficiency. In [49] industrial application of sensors networks are categorized the into: i) process control, ii) control of (physical) properties during the production process, and iii) equipment management and control. WSNs deliver real-time data on the production process and are able to detect process variation. They can monitor physical properties such as temperature, pressure, humidity and vibrations as well as monitor health of machines [50]. WSNs summarily ensure fault minimization in the whole of the industrial process.

7. Conclusion

WSNs remain a technology of immense prospects. There is need to overcome its challenges and leverage on its intelligent infrastructure to exploit its capabilities some of which are yet to be envisioned. An understanding of its basics will surely aid in the realization of its current research and development vision of Ubiquitous Sensor Networks (USN) which involves the placement of WSNs anywhere that is useful and economical viable.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci. "Wireless sensor networks: a survey". Computer Networks, Vol 38, pp. 393 – 422, 2002.

[2] M. C. Ndinechi and F. K. Opara. "Design issues and applications of wireless sensor networks", International Journal of Natural and Applied Sciences, Vol. 3, Issue 1, pp 1 - 10, 2007.

[3] J. A. Stankovic, "Wireless sensor networks", June 19, 2006. http://www.cs.virginia.edu/~stankovic/psfiles/wsn.pdf [Accessed: Aug. 7, 2019].

[4] S. La Malfa. "Wireless sensor networks", Jan 2010. http://www.dees.unict.it/users/bando/files/wsn.pdf [Accessed: Aug. 7, 2019].

[5] P. Papageorgiou. “Wireless sensor networks an overview”, 2003, http://www.cs.umd.edu/~pavlos/papers/unpublished/papageorgiou03sensors-talk.pdf [Accessed: Aug. 7, 2019].

[6] H. Karl. “Ad hoc and Sensor Networks”, 2005 http://www.cacs.louisiana.edu/~akk6481/files/courses/wsn/ch1 [Accessed: Aug. 8, 2019].

[7] V. Jindal, A. K. Verma, S. Bawa. “How the two adhoc networks can be different: MANET & WSNs”. International Journal of Computer Science & Technology, Vol. 2, Issue 4, Oct. - Dec. 2011.

[8] P. Garg, K. Saroha, R. Lochab. “Review of wireless sensor networks – architecture and applications”, IJCSMS International Journal of Computer Science & Management Studies, Vol. 11, Issue 01, May 2011.

[9] F. Oldewurtel, P. Mahonen. “Neural wireless sensor networks”, Proceedings in IEEE International Conference on Systems and Networks Communications (ICSNC '06), Tahiti, October 2006.

[10] K. Sohraby, D. Minoli, T. Znati. "Wireless sensor networks: technology, protocols, and applications”, John Wiley and Sons, 2007.

[11] G. Sharma, M. Verma, N. Mishra. “Analysis of transmission technologies in wireless sensor networks”, International Journal of Engineering Research & Technology (IJERT), Vol. 3 Issue 1, January – 2014.

[12] O. Kumari, S. Kumar. “Study of wireless communication technologies: bluetooth, Wi-Fi, cellular and WiMAX”, IJCSC , Vol. 5, Issue 2, pp. 61 – 70, July - Sept 2014.

[13] C. Saad, B. Mostafa, E. Cheikh, H. Abderrahmane. “Comparative performance analysis of wireless communication protocols for intelligent sensors and their applications”. International Journal of Advanced Computer Science and Application, Vol. 5, Issue 4, 2014.

[14] P. Kaur, V. Kumar. “A survey of energy optimization techniques in wireless sensor networks”, International Journal of Advanced Research in Computer and Communication Engineering, Vol. 4, Issue 5, May 2015.

[15] Q. Wang, M. Hempstead and W. Yang, “A realistic power consumption model for wireless sensor network devices”, Division of Engineering and Applied Sciences Harvard University, 2005. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.136.1084&rep=rep1&type=pdf [Accessed: Aug. 3, 2019].

[16] Y. Kubo, K. Yanagihara, M. Nozak. “Electric power conservation technology for wireless sensor networks”, Oki Technical Review Special Edition on the Environment: Aiming for Low Carbon

Society, Vol.76, Issue 214, No.1, April 2009.

[17] J. Saraswat, P. P. Bhattacharya. "Effect of duty cycle on energy consumption in wireless sensor networks", International Journal of Computer Networks & Communications (IJCNC) Vol.5, No.1, January 2013.

[18] G. Anastasi, M. Conti, M. Di Francesco, A. Passarella. "Energy conservation in wireless sensor networks: a survey", Ad Hoc Network., Vol. 2009, Issue 7, pp 537 – 568, 2009.

[19] M. A. Razzaque, C. Bleakley, S. Dobson. "Compression in wireless sensor networks: A survey and comparative evaluation". ACM Trans. Sens. Netw. 2013, 10, 5:1–5:44.

[20] M. A. Razzaque, S. Dobson. "Energy-efficient sensing in wireless sensor networks using compressed sensing". 2014. www.mdpi.com/journal/sensors. [Accessed: Aug. 3, 2019].

[21] M. L. Sichitiu, R. Dutta. "Benefits of multiple battery levels for the lifetime of large wireless sensor networks" In: Boutaba R., Almeroth K., Puigjaner R., Shen S., Black J.P. (eds), Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems. Springer, Berlin, Germany, 2005.

[22] C. Alippi, G. Anastasi, M. Di Francesco, M. Roveri. "Energy management in wireless sensor networks with energy-hungry sensors. IEEE Instrum. Meas. Mag., Vol 12, pp 16 – 23, 2009.

[23] C. Buratti, A. Conti, D. Dardari, R. Verdone. "An overview on wireless sensor networks technology and evolution", August 2009. www.mdpi.com/journal/sensors. [Accessed Aug. 9, 2019]

[24] V. Raghunathan, C. Schurgers, S. Park, M. Srivastava, B. Shaw. "Energy-aware wireless microsensor networks". IEEE Signal Process. May. 2002, 19, 40–50.

[25] N. Shabbir, S. R. Hassan. "Routing protocols for wireless sensor networks (WSNs)". Wireless Sensor Networks - Insights and Innovations, 2017. DOI: 10.5772/intechopen.70208

[26] I. Eisa, H. M. El-Bakry, S. M. Abd Elrazik, I. Q. Hasan, A. Q. Hasan, S. Zaid. "Challenges in Wireless Sensor Networks". International Journal of Advanced Research in Computer Science & Technology. Vol. 4, Issue 4, 2016.

[27] F. Yu, and R. Jain. "A Survey of Wireless Sensor Network Simulation Tools". 2011. http://www.cse.wustl.edu/~jain/cse567-11/ftp/sensor.pdf [Accessed: Sept. 4, 2019].

[28] Y. Xue, H. S. Lee, M. Yang, P. Kumarawadu, H. H. Ghenniwa, W. Shen. "Performance evaluation of NS-2 simulator for wireless sensor networks". Electrical and Computer Engineering Conference, Canada. April 22 – 26 2007, pp. 1372 – 1375, http://gdauto.gdut.edu.cn/lab1/lwfy_files/Performance%20Evaluation%20of%20NS2%20Simulator%2

0for%20Wireless%20Sensor%20Networks.pdf [Accessed: Sept. 4, 2019].

[29] S. Yi, H. Min, Y. Cho, J. Hong. "SensorMaker: a wireless sensor network simulator for scalable and fine-grained instrumentation", Computational Science and its Application-ICCSA, Vol. 5072 pp. 800 - 810,2008. http://www.springerlink.com/content/135t337v633v6240/ [Accessed: Sept. 4, 2019].

[30] C. Stevens, C. Lyons, R. Hendrych, R. S. Carbajo, M. Huggard, C. Mc Goldrick. "Simulating mobility in WSNs: Bridging the gap between NS-2 and TOSSIM 2.x". Proceedings of 13th IEEE/ACM International Symposium on Distributed Simulation and Real Time Applications, Singapore, 2009. http://portal.acm.org/citation.cfm?id=1671365&dl=ACM&coll=DL [Accessed: Sept. 4, 2019].

[31] L. Shu, C. Wu, Y. Zhang, J. Chen, L. Wang, M. Hauswirth. "NetTopo: beyond simulator and visualizer for wireless sensor networks", Future Generation Communication and Networking - FGCN, Vol. 1, pp. 17 - 20, 2008. http://www.cs.virginia.edu/sigbed/archives/2008-10 [Accessed: Sept. 4, 2019].

[32] M. Imran, A. M. Said and H. Hasbullah. "A survey of simulators, emulators and testbeds for wireless sensor networks", Information Technology (ITSim) International Symposium, pp. 897 – 902. Kuala Lumpur, Malaysia. June 2010. http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5561571 [Accessed: Sept. 4, 2019].

[33] G. V. Merrett, N. M. White, N. R. Harris, B. M. Al-Hashimi. "Energy-aware simulation for wireless sensor networks", IEEE Xplore, 2009. http://www.researchgate.net/publication/224565048 [Accessed: Aug, 29, 2019].

[34] E. Egea-Lopez, J. Vales-Alonso, A. S. Martinez-Sala, P. Pavon-Marino and J. Garcia-Haro. "Simulation tools for wireless sensor networks", Proceedings of Summer Simulation Multi-Conference, SPECTS, pp. 2 – 9, 2005. http://ait.upct.es/~eegea/pub/spects05.pdf [Accessed: Aug, 29, 2019].

[35] N. Onuekwusi, I. Achumba, N. Chukwuchekwa, G. Chukwudebe and G. Ononiwu. "Leveraging wireless sensor networks for improved infrastructure management in the energy sector", Proceedings of the Nigerian Society of Engineers Annual National Conference, Akure, Nigeria, November 16 – 20, 2015.

[36] U.S. Department of Transportation. "Intelligent transportation systems applications overview" Research and Innovative Technology Administration, (RITA), 2009. www.itsoverview.its.dot.gov/, [Accessed July 1, 2019].

[37] Intelligent Transportation Systems Society (ITS Canada). "About intelligent transportation systems (ITS)". www.itscanada.ca/english/aboutits.htm, 2009 [Accessed July, 1, 2019].

[38] T. Wark, P. Corke, P. Sikka, L. Klingbeil, Y. Guo, C. Crossman, P. Valencia, D. Swain, G. Hurley. "Transforming agriculture through pervasive wireless networks". Pervasive Computing, pp 50-57, 2007.

[39] R. Evans, J. Bergman. "Relationships between cropping sequences and irrigation frequency under self-propelled irrigation systems in the northern great plains". USDA Annual Report, 2003.

[40] P. Sharma. "Socio-economic implications of wireless sensor networks with special reference to its application in agriculture", IEEE African Journal of Computing & ICT, Vol 6. No. 2, June 2013.

[41] S. Qingshan, L. Ying, D. Gareth, and D. Brown. "Wireless intelligent sensor networks for refrigerated vehicle". In IEEE 6th Symposium on Emerging Technologies Mobile and Wireless Communication, Shanghai, China 2004.

[42] S. Prasanna, S. Rao. "An overview of wireless sensor networks applications and security", International Journal of Soft Computing and Engineering (IJSCE),Vol. 2, Issue-2, May 2012.

[43] D. Okereafor, U. Diala, N. Onuekwusi, L. Uzoechi and G. Chukwudebe. "Improving security and emergency response through the use of unmanned vehicles" paper presented at the IEEE Nigeria Section 2nd International Conference on Emerging & Sustainable Technologies for Power & ICT in a Developing Society (NIGERCON). Owerri, Nigeria, November 14 – 16, 2013.

[44] O. Gulich. "Technological and business challenges of smart grids" M.sc Thesis, Department of Electrical Engineering, Faculty of Technology, Lappeenranta University of Technology, Finland, 2010.

[45] J. Momoh. "Smart grid design for electric power networks". Presented at the International Conference on Power System Operations and Planning (ICPSOP), Abuja, Nigeria, January 2010.

[46] H. Siderius and A. Dijkstra. "Smart metering for households: costs and benefits for the Netherlands". 2006. http://mail.mtprog.com/CD_Layout/Day_2_22.06.06/09001045/ID57_Siderius_final.pdf, [Accessed: July 1, 2019]

[47] G. Werner-Allen, K. Lorincz, M. Welsh, O. Marcillo, J. Johnson, M. Ruiz, J. Lees. "Deploying a wireless sensor network on an active volcano", IEEE Internet Computing, Mar/Apr 2006.

[48] A. Bagula. "Applications of wireless sensor networks" WSN Applications, February 2012

[49] V. Weber. "Smart sensor networks: technologies and applications for green growth", presented at the OECD Conference on ICTs, the Environment and Climate Change, Helsingør, Denmark, May 2009.

[50] R. Verdone, D. Dardari, G. Mazzini, A. Conti. Wireless sensor and actuator networks, Academic Press/Elsevier, London 2008.