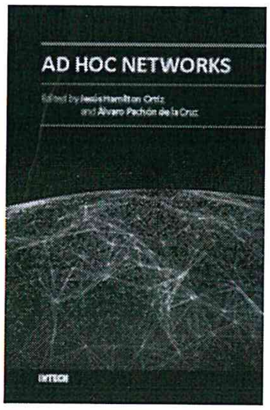

Ad Hoc Networks

Edited by Jesus Hamilton Ortiz and Alvaro Pachon de la Cruz, ISBN 978-953-51-3110-6, Print ISBN 978-953-51-3109-0, 146 pages, Publisher: InTech, Chapters published May 11, 2017 under CC BY 3.0 license

DOI: 10.5772/62746

Edited Volume

OPEN ACCESS

A mobile ad hoc network (MANET) is a collection of two or more wireless devices with the capability to communicate with each other without the aid of any centralized administrator. Ad hoc networks have no fixed routers, these nodes can be connected dynamically in an arbitrary manner. MANETs, due to their operational characteristics, the dynamics of their changes and the precariousness of their resources, offer huge challenges due to the architecture and service nature in the next generation of mobile communications. MANETs play an important role in the future of next-generation networks. This special collection identifies and studies the most important concerns in MANETs, and includes contributions from researchers, academics, etc.

BOOK CONTENTS | BOOK EDITORS | MOST DOWNLOADED CHAPTERS | HOW TO LINK

Chapter 5

MANET Network in Internet of Things System

Rasa Bruzgiene, Lina Narbutaite and
Tomas Adomkus

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/66408

Abstract

In the current world of technology, various physical things can be used for facilitation of a human work. That is why the Internet of Things,an innovative technology and a good solution which allows the connection of the physical things with the digital world through the use of heterogeneous networks and communication technologies, is used. The Internet of Things in smart environments interacts with wireless sensor network (WSN) and mobile ad-hoc network (MANET), making it even more attractive to the users and economically successful. Interaction between wireless sensor and mobile ad-hoc networks with the Internet of Things allows the creation of a new MANET-IoT systems and IT-based networks. Such the system gives the greater mobility for a user and reduces deployment costs of the network. However, at the same time it opens new challenging issues in its networking aspects as well. In this work, the authors propose a routing solution for the Internet of Things system using a combination of MANET protocols and WSN routing principles. The presented results of solution's investigation provide an effective approach to efficient energy consumption in the global MANET-IoT system. And that is a step forward to a reliable provision of services over global Future Internet infrastructure.

Keywords: MANET, IoT, Sensor, energy efficiency, dynamic routing

1. Introduction

The Internet of Things (IoT) is a part of the Future Internet paradigm, which rapidly changes the development of technologies as well as provision of services over different communication networks. The capability of objects (like physical or virtual things) to identify and communicate with each other at any time-evolving communication technologies gives the possibility to provide advanced services over global infrastructure (as Internet) in different areas of everyday life [1]. The interconnection of smart objects and its interoperability with global communications serve as a main idea incorporated in Internet of Things systems. Wireless sensor network (WSN) plays a main role in the IoT system as its components include sensing, acquiring of data, heterogeneous connectivity, data processing, etc. Mobile ad-hoc network (MANET) is a wireless, multi-hop, self-configuring network. Its each node operates as an end system and/or a router for other nodes in the network and is closely related to WSNs. The interaction between MANET and Internet of Things opens new ways for provision of services in smart environments and challenging issues in its networking aspects as well.

One of the important factors in such MANET-IoT systems is the energy balancing over nodes, since the IoT system is based mostly on many different wireless sensors and MANET protocols focus on selecting the shortest and efficient paths for transactions. A proper utilization of sensor's battery power is a significant key in maintaining network connectivity of a multi-hop wireless network. Due to this, many researchers are focusing on designing energy efficient routing protocols that prolong such network lifetime. Wireless network protocols like MANET cannot be used directly due to resource constraints of sensors' nodes, computational speed, human interface with node's devices and density of nodes in network. Therefore, it is a need of composite solution for routing over MANET-IoT networks, which can use efficiently residual energy of nodes and extend the network's lifetime.

In this chapter, the authors propose an algorithm of energy efficient and safe-weighted clustering routing for the mobile IoT system using a combination of MANET and WSN routing principles. Clustering is one method of making routing less complex, and for some sensor networks, more energy efficient. Such combination of MANET and WSN routing principles is able to increase the lifetime of sensors in the overall mobile Internet of Things system. It is important to decide how many cluster heads (CHs) are needed and which of the sensor nodes are going to act as cluster heads. MANET network nodes were chosen as a cluster head and a proactive routing protocol was used in such a way that it is possible to control and update a table of information about the state of the network. Nodes that rapidly lose its energy or that are left with low energy were identified and their workloads were limited for transactions. All investigations for the selection of a routing path over the MANET-IoT system were performed by using the MATLAB simulation platform.

This research work provides important key insights into the combination of MANET and WSN routing principles by increasing the lifetime of sensors in the overall Internet of Things system. The solution of routing optimization with an effective and efficient approach to energy consumption in the global MANET-IoT system is presented as main result of this work, which can help in accessibility and provision of services for a longer period of time over global Future Internet infrastructure.

2. Background

2.1. Mobile ad-hoc network (MANET)

The mobile ad-hoc networks (MANETS) are autonomously self-organized networks without fixed topology. In such a network, each node acts as both router and hosts at the same time.

http://dx.doi.org/10.5772/66408

All network nodes are equivalent to each other and can move out or join in the network freely. The mobile nodes that are in the radio range of each other can directly communicate and transfer the necessary information. All network nodes have a wireless interface to communicate with another node in the range. This kind of network is fully distributed and can work at any place without the help of any fixed infrastructure as access points or base stations. **Figure 1** shows the example of mobile ad-hoc network [2].

It can be assigned two multiple ad-hoc network types: (a) mobile ad-hoc network (MANET) and (b) mobile ad-hoc sensor network. A mobile ad-hoc sensor network has much wider sequences of operational, and at the same time needs a less complex setup procedure compared to typical sensor networks, which communicate directly with the centralized controller [3]. There are six main characteristics of MANETs [2]: distributed operation; multi-hop routing, autonomous terminal, dynamic topology, lightweight terminals, and shared physical medium.

MANET routing protocols can be categorized into three types:

1. Topology-based routing

   The routing types [3] are: (a) proactive routing protocols (routing table-based), (b) reactive routing protocols (demand based) are presented in **Figure 2** and (c) hybrid routing protocols. These protocols are the combination of proactive and reactive routing protocols. One of them is ZRP (zone routing protocol).

2. Location-based routing

   To make routing decision, location-based routing uses the actual position of nodes in any area. Location information can be obtained, for example, using global positioning system (GPS). Location-aided routing (LAR) protocol is an example of location-based routing.

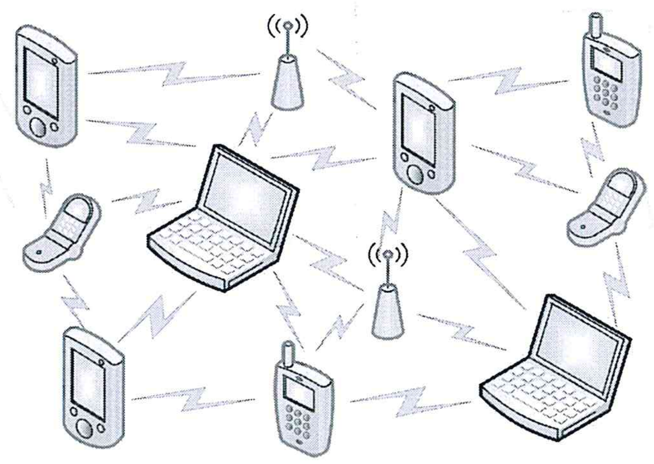

Figure 1. Example of mobile ad-hoc network.

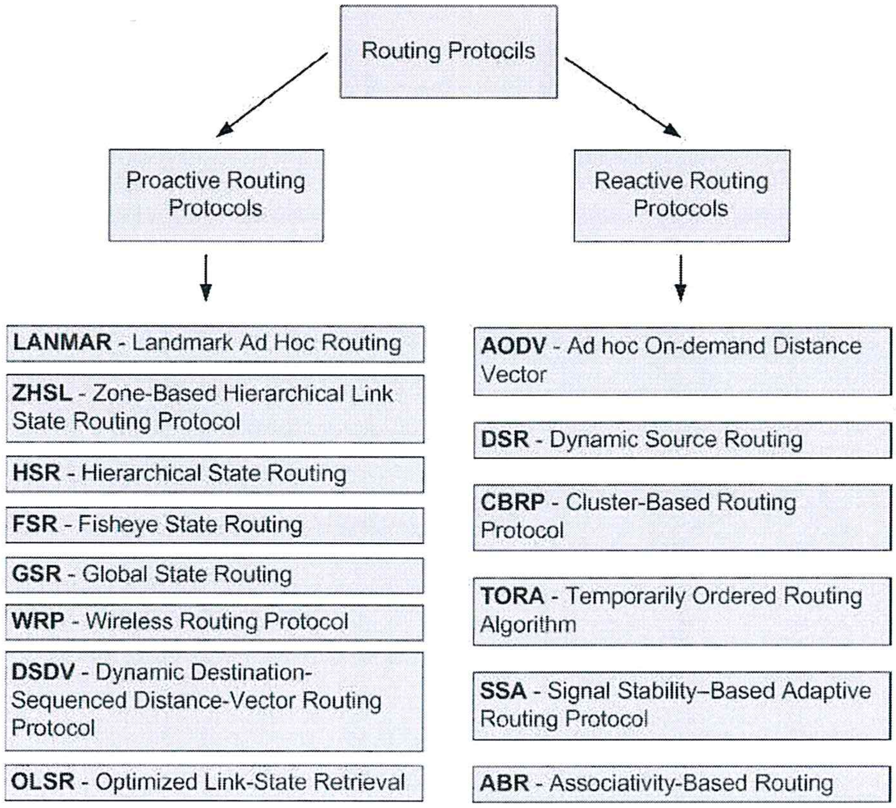

Figure 2. Proactive and reactive routing protocols.

3. Energy awareness-based routing

   Each node in the network supports multiple entries of routing in routing tables. For choosing optimal route in the wireless medium, routing assessing power levels of network nodes is available. In this case, routing table corresponding to the power level of nodes and maintained by transferring hello messages in between nodes at the power level. The number of entries in routing table of nodes is corresponding to the number of nodes reachable by using the power level. Thus, the number of entries in routing tables gives the total number of network nodes [4].

2.2. The characterization of Internet of Things (IoT)

Today a human is surrounded by various things—from the smallest items to the gigantic objects. The need to "recruit" these things was a great reason for the connection of electronics, devices, with digital communications, using the Internet as a main medium for data transmission. The human is just as data traffic end user in such connection, as all communication, management and information exchange are processing among connected things and objects. The capability of real or virtual things and objects to be identifiable, to communicate with anything and to interact with anything lets to build networks of interconnected objects, end users or other entities in the global Internet network. So the term "Internet of Things" mainly

http://dx.doi.org/10.5772/66408

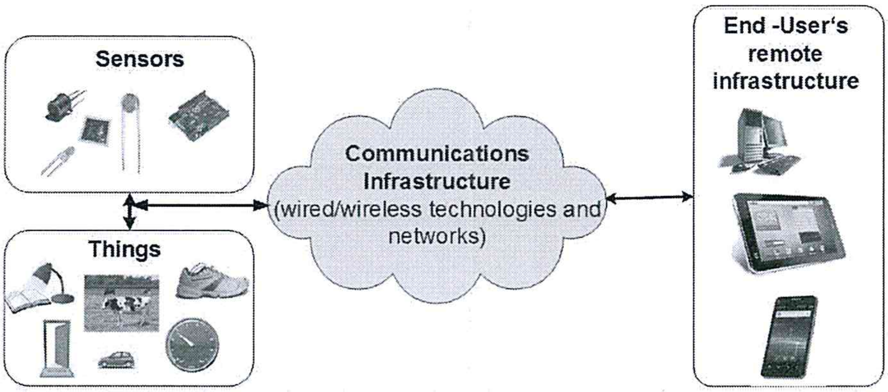

Figure 3. Global structure of Internet of Things system.

means the global infrastructure (**Figure 3**) of interconnected things, devices, or objects, which can communicate, actuate, exchange their information over Internet to the end users using the interaction between communication technologies and networks.

Internet of Things is the part of Future Internet (**Figure 4**) [5]. The concept of Future Internet connects the Internet of Users and Knowledge (IoUK), Internet of Networks (IoN), Internet of Services (IoS) and Internet of Things. IoUK is used for people's social gaming or users monitoring, IoN opens possibilities for unlimited connectivity of networks and IoS is use for provision of web-based services in the global smart industry. Broadly, Internet of Things covers the large potential of computing and communication capabilities into the objects, which can interoperate in global-integrated communication platforms. It serves as a bridge between the real things and digital, information world.

Sensors are the main elements that connect things, their data with remote end users. The sensors collect useful information for the end users data, convert it to digital format and transmit it to the other devices in IoT-based systems with the help of various existing wireless or wired technologies [6]. As sensors are well deployed and it quantity is growing rapidly in the world, it serves as main interface, connecting things, communications and end users. The selection of medium for the data transmission, processing of data routing over different heterogeneous networks are one of the major challenges in the IoT-based systems [7]. Wireless technologies,

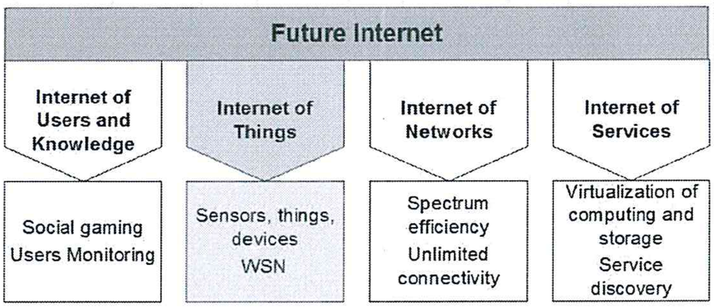

Figure 4. IoT in Future Internet concept.

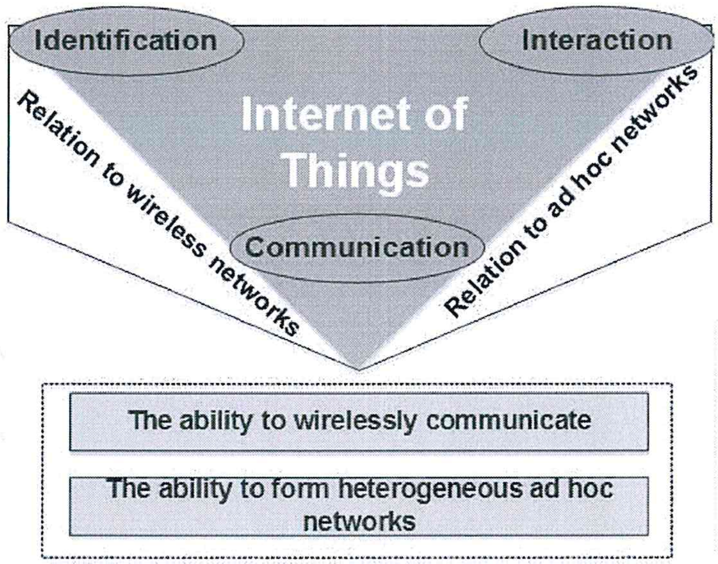

Figure 5. Internet of Things characteristics and it relation with wireless and ad-hoc networks.

ad-hoc wireless networks are the most effective and low-cost way to transmit data in Internet of Things systems. Furthermore, it perfectly solves human's need for the mobility and significantly reduces the cost of installation of such systems, comparing it with the deployment cost of wired technologies.

The main characteristics [8] of Internet of Things and its relation with wireless and ad-hoc networks are presented in **Figure 5**.

The things, which are in the Internet of Things system, are identified and relations among them are specified in the digital domain; it has the ability to communicate to each other using wireless technologies as well to form different ad-hoc wireless networks of interconnected things. Their sensing and actuating capabilities can be used for interaction with the surrounding environment. However, IoT-based system needs to support main factors as heterogeneity of things and devices, efficient energy usage, interoperability and data management as well as security and privacy [8]. The capability of the IoT systems to support these factors ensures IoT application in different areas of smart cities [9]: healthcare, energy, buildings, transport, industry, etc. Moreover, the key technologies for Internet of Things-based systems' application in these areas are wireless sensor networks (WSNs) and MANETs [10, 11].

2.3. Internet of Things interaction with MANET and WSN

Possibilities of wide application of Internet of Things systems in different areas are directly dependent on the opportunities of interoperability between different communication technologies and networks in smart environments. The growth of sensors quantity leads to the increasing need of humans for a remote monitoring of different processes in smart environments. And this is possible by widespread deployment of wireless sensor networks (WSN).

http://dx.doi.org/10.5772/66408

Basically, WSN is a network, which consists of different sensors that are capable autonomously to read information from the object, which is been measured, to handle sensed data, temporarily store it and transfer sensed data to another network node, which is also a sensor. As WSN is a normally centralized network [12], so the data, sensed and transferred from other sensors, are transmitted to the central node, which is usually called the sink. In this manner, the wireless sensors are able to communicate with each other and thus open very wide usability opportunities of wireless sensor networks in IoT systems. Wireless sensor networks mainly are the basic element in the global Internet of Things system, as sensors have the ability to gather information from different things and transmit it over the network. However, the reliability of IoT systems is highly dependent on the power consumption and scalability of WSN [13]. The sensors should transmit measured data so efficiently to the sink, that the energy of their battery would be used at the minimum level. Due to this, the wireless sensor network should be constrained that it can easily accommodate changes in the network. This is related to the lifetime of WSN as well, as low or empty battery leads to the death of sensors. In this way, the routing principles and methods are very important and challenging issue of WSN as data should be transmitted by another sensor, eliminating dead sensor from the routing path. And it should be done with respect to Quality of Service (QoS) over wireless sensor networks [14].

Wireless sensor network in general is similar to a mobile ad-hoc network (MANET), since both are self-organized and multi-hopped networks. However, the topology of MANET is more changeable than WSN. MANET protocols can let it to act as a WSN backbone [15] and access wireless sensor network's nodes as well exchange information with WSN about MANET entry points [10]. Due to the task to use sensors' energy efficiency during the data transmission and to reduce data processing time by selecting proper routing protocols and principles, it is a demand for the convergence of MANET and WSN networks. Also, these two networks can enable more effective and reliable cross-network routing in the Internet of Things context. The intersection of MANET, WSN and Internet of Things the authors called as a MANET-IoT system, which is discussed in detail in Section 3. **Figure 6** presents the main aspects of interaction between Internet of Things, wireless sensor networks and mobile ad-hoc networks.

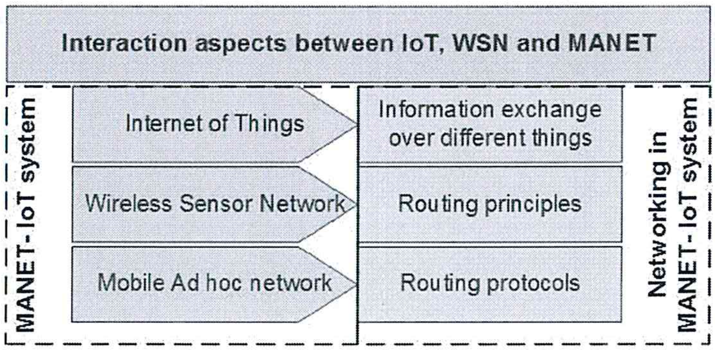

Figure 6. Intersection of IoT, WSN and MANET.

Networking in the MANET-IoT system is based on the routing protocols of MANET, routing principles of wireless sensor network and data sensing from things, handling and processing using Internet of Things. In general, networking of such the system is a very challenging regarding routing aspects. Also, it is related to system mobility and limited resources of all sensors in the network. MANET protocols (most of them) are designed with the focus on QoS [16, 17] and routing in wireless sensor networks is focused on the efficient energy consumption of network nodes [18]. The connection of different things with limited features to the Internet and interaction with different wireless and mobile ad-hoc networks must guarantee connectivity, accessibility and reliability of the MANET-IoT system in smart environments. The solutions for the routing protocols of ad-hoc network modification in order to fulfil the requirements of the Internet of Things were presented by Tian and Hou [19]. Routing principles were changed by integrating IPv6 [20]. However, the interaction of Internet of Things with MANET and WSN requires new, optimized solution for data routing in such the MANET-IoT system. The authors proposed an algorithm for data routing, which is mainly focused on energy efficiency and safe weighted clustering in the MANET-IoT system. The authors' proposed solution is described in Sections 3 and 4.

3. Proposed solution for data routing in the MANET-IoT system

3.1. Mathematical model for calculation of network energy cost function

Sensors establish and maintain routes can proactively or reactively. Proactive protocols periodically monitor peer connectivity to ensure the ready availability of any path among active nodes. Sensors advertise their routing state to the entire network to maintain a common or partially complete topology of the network. Reactive protocols establish paths only upon request. For MANET sensor network in the IoT system information routing we use combination of two routing principles: OLSR (optimized link-state retrieval) and LEACH (low energy adaptive clustering hierarchy).

Clustering network is efficient and scalable way to organize WSN. Clustering is the method by which sensor nodes in a network organize themselves into hierarchical structures. By doing this, sensor nodes can use battery power more efficiently. A cluster head (CH) is responsible for conveying any information gathered by the nodes in its cluster and may aggregate and compress the data before transmitting it to the sink.

LEACH selects cluster head randomly among all nodes completely. Using our propose algorithm of energy efficient and safe-weighted clustering routing for the mobile IoT system, the cluster head is a node that in actual time has more energy than the threshold value.

The sensing range of a sensor is the maximum distance that a sensor can sense. To form clusters, sensor nodes first elect a CH for each cluster. Nodes in the WSN which are not CHs find the closest CH within the range and become cluster members. The nodes in a cluster only communicate with one another and the CH. The number of CH can be different for every network topology. The propose algorithm implementing dynamical CH rotation that allows

http://dx.doi.org/10.5772/66408

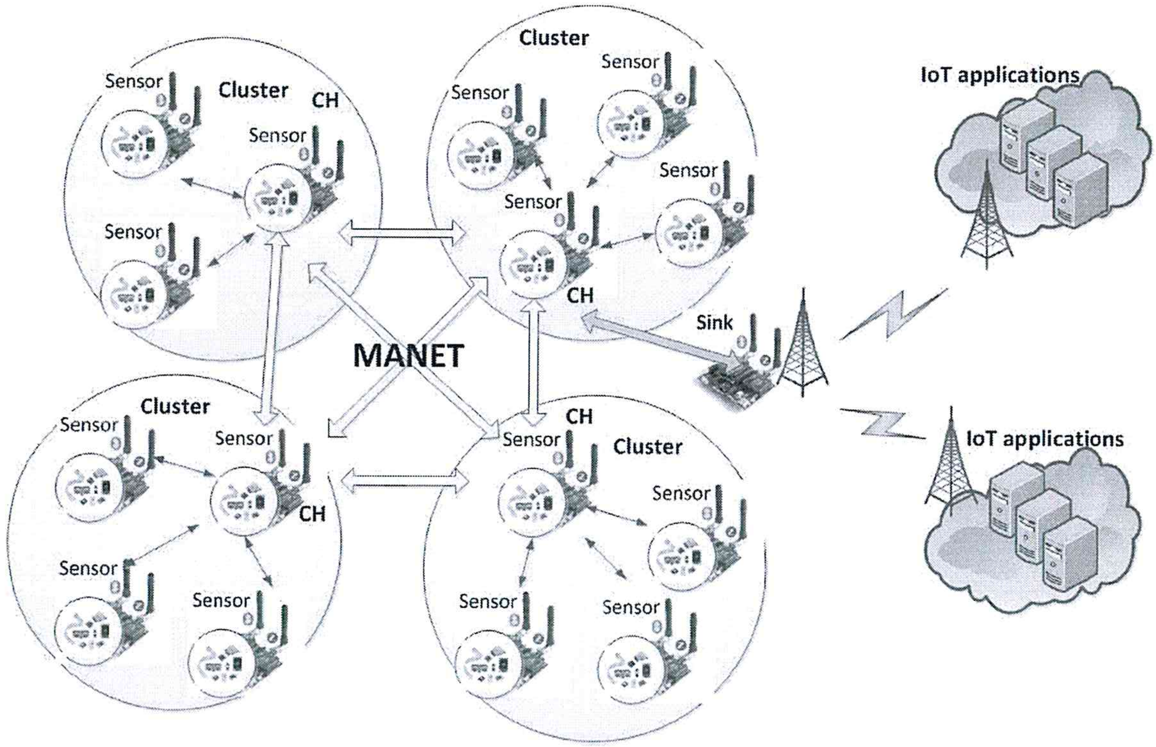

Figure 7. MANET-IoT network with a cluster topology.

us to distribute the workload CH across the mobile MANET-IoT system and extend overall lifetime of our system.

The MANET-IoT network with a cluster topology is shown in **Figure 7**. Sensors are grouped into clusters and individual sensors sense data and transmit to cluster heads (CH). Cluster heads aggregate this data and then forward, depending on the tree structure, to the base station or sink node. We assume that each sensor senses L bits and transmit to CH.

The energy consumed by a sensor node consists of these parts [21]:

- microcontroller processing,
- radio transmission and receiving,
- transient energy,
- sensor sensing,
- sensor logging and actuation.

The sensor energy dissipation for sensing activity and logging is evaluated in references [22, 23]

$$E_s = L * V * I_s * T_s, \quad (1)$$

$$E_{log} = \frac{L * V}{8}(I_r * T_r + I_w * T_w), \quad (2)$$

where L = packet size, V = supply voltage, I_s = current required for sensing, I_r = current required for reading, I_w = current required for writing, T_s = time duration required for sensing, T_r = time duration required for reading, T_w = time duration required for writing.

We assume that energy used by CH is higher than that of a normal sensor node, because of additional data aggregation tasks per cycle from other sensors in parallel. Therefore, use coefficient φ, which indicate how much CH consumes more energy than a regular sensor node and these coefficients are >1. Then we have

$$E_{s(CH)} = \varphi_1 * E_s \quad (3)$$

$$E_{log(CH)} = \varphi_2 * E_{log}. \quad (4)$$

The coefficient φ_1 is related to the number of cluster sensors which sending data to CH at the same time. The coefficient φ_2 is related to scanning the 'b' bit packet of data and loading it into memory.

The communication of neighbouring sensor nodes is enabled by a sensor radio. Radio energy dissipation model is shown in **Figure 8**.

The set of sensor nodes be denoted by $\mathbb{N}$. Each node i is assumed to generate data at a constant rate during its lifetime and the initial energy E_i. According to Ben Alla et al. and Shi et al. [24, 26], the energy consumption for transmitting L bits from node i to j can be determined as follows

$$E_{tx}(ij) = L * E_{elec} + L * E_{amp} * \left(d_{ij}\right)^{\propto} \quad (5)$$

and receive

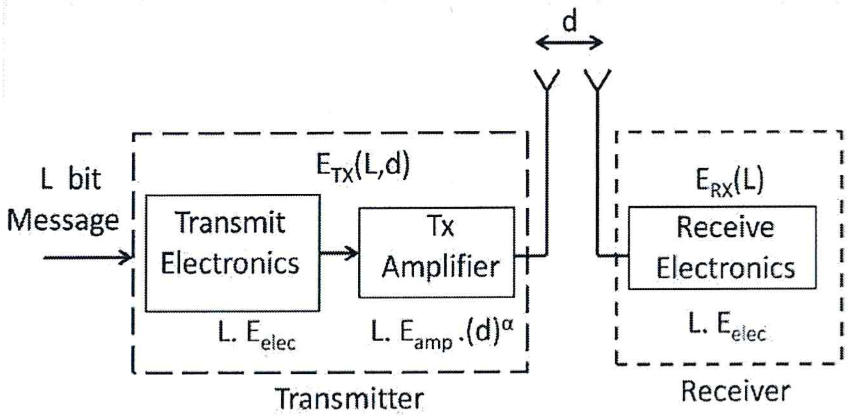

Figure 8. Radio energy dissipation model [24, 25].

http://dx.doi.org/10.5772/66408

similar amount of energy and begins to fall out of the network, all one after the other. When the other two methods fall just in time for most working nodes through which passes the shortest route.

As we can see in **Figure 22** at the end of the network lifetime, there are nodes which energy is not zero and its can still be used in all three cases. It is an indicator of the best network energy resource utilization.

According simulation results, the NP and ER method network resource utilization is very similar. Using the BST routing method we can extend the time up to the first node falling out. This is important for the network when all sensors are the same and send the similar information.

5. Conclusion

In this chapter, we presented the proposed algorithm of energy efficient and safe-weighted clustering routing for the mobile IoT system using a combination of MANET and WSN routing principles. We choose the clustering method, because each sensor nodes in a network organize themselves into hierarchical structures. The simulation result show that if we use combination method for information routing in the wireless sensor network, we increase the lifetime of sensors in overall Internet of Things system. Because we used dynamical cluster head selection, the weighting factors are added for routing from the sensor to the sink. When the network is heterogeneous and mobility, the using routing weight is very important, because sensors have different characteristics, dynamical distance from the sink and CH node and if we want to choose the best route we need to calculate some objectives function. And this function must have possibility to eliminating differences bound parameters. For solving this we used the weight function, and this function will be used for calculations of each sensor node value and then calculation all route cost function.

Acknowledgement

This work was partially supported by the ICT COST Action IC1304—Autonomous Control for a Reliable Internet of Services (ACROSS), November 14, 2013—November 13, 2017, funded by European Union.

Author details

Rasa Bruzgiene*, Lina Narbutaite and Tomas Adomkus

*Address all correspondence to: rasa.bruzgiene@ktu.lt

Faculty of Informatics, Kaunas University of Technology, Kaunas, Lithuania

References

[1] ITU-T/Recommendation Y.2060. Overview of the Internet of Things [Internet]. 2012-06. Available from: http://www.itu.int/itu-t/recommendations/rec.aspx?rec=Y.2060 [Accessed: 2016-06-10]

[2] Aarti, S.S. Tyagi. Study of MANET: Characteristics, Challenges, Application and Security Attacks. International Journal of Advanced Research in Computer Science and Software Engineering. 2013;3(5):252–257.

[3] R. Balakrishna, Z. Hussain. A survey on Manets-Types, Characteristics, Applications and Protocols used. In: R. Balakrishna, L. Naveen, U.G. Nandish, editors. National Conference on Frontiers and Advances in Information Science and Technology FAIST13; 23–24 May, 2013;. Bangalore, India: RRCE; 2013.

[4] P. Nayak., R. Agrawal, S. Verma. Energy Aware Routing Scheme for Mobile Ad Hoc Network Using Variable Range Transmission. International Journal of Ad Hoc, Sensor & Ubiquitous Computing. 2012;3(4):53–63. DOI: 10.5121/ijasuc.2012.3406

[5] S. Agrawal, M. Lal Das. Internet of Things — A Paradigm Shift of Future Internet Applications. In: Nirma University International Conference on Engineering; 8–10 Dec, 2011; Ahmedabad, Gujarat: IEEE; 2011. pp. 1–7. DOI: 10.1109/NUiConE.2011.6153246

[6] O. Vermesan, P. Friess, editors. Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems. 1st ed. Aalborg, Denmark: River Publishers; 2013. 364 p.

[7] P. Suresh., J. Vijay Daniel, V. Parthasarathy, R.H. Aswathy. A State of the Art Review on the Internet of Things (IoT) History, Technology and Fields of Deployment. In: International Conference on Science Engineering and Management Research (ICSEMR); 27–29 Nov, 2014; Chennai. IEEE; 2014. pp. 1–8. DOI: 10.1109/ICSEMR.2014.7043637

[8] D. Miorandi, S. Sicari, F. De Pellegrini, I. Chlamtac. Internet of Things: Vision, Applications and Research Challenges. Ad Hoc Networks. 2012;**10**(7):1497–1516. DOI: 10.1016/j.adhoc.2012.02.016

[9] J. Gubbia, R. Buyyab, S. Marusica, M. Palaniswamia. Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions. Future Generation Computer Systems. 2013;**29**(7):1645–1660. DOI: 10.1016/j.future.2013.01.010

[10] P. Bellavista, G. Cardone, A. Corradi, L. Foschini. Convergence of MANET and WSN in IoT Urban Scenarios. IEEE Sensors Journal. 2013;**13**(10):3558-3567. DOI: 10.1109/JSEN.2013.2272099

[11] Gregory S. Yovanof., George N. Hazapis. An Architectural Framework and Enabling Wireless Technologies for Digital Cities & Intelligent Urban Environments. Wireless Personal Communications. 2009;**49**(3):445–463. DOI: 10.1007/s11277-009-9693-4

[12] N. Bessis, F. Xhafa, D. Varvarigou, R. Hill, M. Li, editors. Internet of Things and Inter-cooperative Computational Technologies for Collective Intelligence. 1st ed. Berlin: Springer-Verlag; 2013. 476 p. DOI: 10.1007/978-3-642-34952-2

[13] M. Potnuru, P. Ganti/University of Illinois Urbana-Champaign. Wireless Sensor Networks: Issues, Challenges and Survey of Solutions [Internet]. 2016. Available from: https://www.academia.edu/890321/Wireless_Sensor_Networks_Issues_Challenges_and_Survey_of_Solutions [Accessed: 02-06-2016]

[14] B. Bhuyan, H. Kumar Deva Sarma, N. Sarma, A. Kar, R. Mall. Quality of Service (QoS) Provisions in Wireless Sensor Networks and Related Challenges. Wireless Sensor Network. 2010;**2**:861–868. DOI: 10.4236/wsn.2010.211104

[15] M. Rath, U.P. Rout. Analysis and Study of Security Aspect and Application Related Issues at the junction of MANET and IoT. International Journal of Research in Engineering and Technology. 2015;**4**(13):426–430.

[16] A. Boukerche, B. Turgut, N. Aydin, M.Z. Ahmad, L. Bölöni, D. Turgut. Routing Protocols in Ad Hoc Networks: A Survey. Computer Networks. 2011;**55**(13):3032–3080. DOI: 10.1016/j.comnet.2011.05.010

[17] L. Hanzo, R. Tafazolli. A Survey of QoS Routing Solutions for Mobile Ad hoc Networks. IEEE Communications Surveys & Tutorials. 2007;**9**(2):50–70. DOI: 10.1109/COMST.2007.382407

[18] K. Akkaya, M. Younis. A Survey on Routing Protocols for Wireless Sensor Networks. Ad Hoc Networks. 2005;**3**(3):325–346. DOI: 10.1016/j.adhoc.2003.09.010

[19] Y. Tian, R. Hou. An Improved AOMDV Routing Protocol for Internet of Things. In: International Conference on Computational Intelligence and Software Engineering (CiSE); 10–12 Dec. 2010; Wuhan. IEEE; 2010. pp. 1–4. DOI: 10.1109/CISE.2010.5676940

[20] T. Tsvetkov. RPL: IPv6 Routing Protocol for Low Power and Lossy Networks. In: Network Architectures and Services; July 2011. pp. 59–66. DOI: 10.2313/NET-2011-07-1_09

[21] X. Wang, editor. Mobile Ad-Hoc Networks: Protocol Design. InTech. Rijeka, Croatia. 2011; 666 p.

[22] R. Tandon. Determination of Optimal Number of Clusters in Wireless Sensor Networks. International Journal of Computer Networks & Communications (IJCNC). 2012;**4**:235–249. DOI: 10.5121/ijcnc.2012.4415

[23] M.A. Matin, editor. Wireless Sensor Networks – Technology and Applications. InTech. Rijeka, Croatia. 2012; 386 p. DOI: doi.org/10.5772/1100

[24] S. Ben Alla, A. Ezzati, A. Mohsen. Hierarchical Adaptive Balanced Routing Protocol for Energy Efficiency in Heterogeneous Wireless Sensor Networks. In: Energy Efficiency – The Innovative Ways for Smart Energy, the Future Towards Modern Utilities. InTech; Rijeka, Croatia. pp. 313–336. DOI: doi.org/10.5772/47789

[25] S. Hussain, A.W. Matin. Energy Efficient Hierarchical Cluster-Based Routing for Wireless Sensor Networks [thesis]. Jodrey School of Computer Science Acadia University Wolfville, Nova Scotia, Canada; 2005; 33 p.

[26] J. Shi, A. Calveras, Y. Cheng, K. Liu. A Novel Power Efficient Location-Based Cooperative Routing with Transmission Power-Upper-Limit for Wireless Sensor Networks. Sensors. 2013;**13**:6448–6476. DOI: 10.3390/s130506448

[27] I. Butun, I-H. Ra, R. Sankar. An Intrusion Detection System Based on Multi-Level Clustering for Hierarchical Wireless Sensor Networks. Sensors. 2015;**15**:28960–28978. DOI: 10.3390/s151128960

[28] P.K. Panda. Study of Energy and Trust Aware Cluster Head Selection for Real Time Wireless Sensor Network [thesis]. Jadavpur University, KolkataWest Bengal, India; 2013. 71 p.

[29] M. Ali Shah, G. Abbas, A.B. Dogar, Z. Halim. Scaling Hierarchical Clustering and Energy Aware Routing for Sensor Networks. Complex Adapt System Model. Berlin: Springer Berlin Heidelberg; 2015. 23 p. DOI: 10.1186/s40294-015-0011-6

[30] M.A. Razzaque, S. Dobson. Energy-Efficient Sensing in Wireless Sensor Networks Using Compressed Sensing. Sensors. 2014;**14**:2822–2859. DOI: 10.3390/s140202822

[31] T-J. Chan, C.-M. Chen, Y-F. Huang, J-Y. Lin, T-R. Chen. Optimal Cluster Number Selection in Ad-hoc Wireless Sensor Networks. WSEAS transactions on Communications. 2008;7(8):837–846.