ENHANCING ENERGY EFFICIENCY IN IOT

Majed Mohaia Alhaisoni
Department of Computer Science, University of Ha'il, Ha'il, Saudi Arabia
E-mail address: m.alhaisoni@uoh.edu.sa

ABSTRACT: *Ubiquitous systems have recently attracted considerable attention in the context of wireless sensors and the Internet of Things (IoT). IoT has moved rapidly from its infancy to be the next common technology for smart communications. However, this type of communication relies heavily on sensors spread at the edge of the network. Yet, each sensor plays a vital role in transmitting and receiving data across networks, which makes it crucial to address efficient spectrum and energy utilization, to avoid that sensors deplete each other. This paper looks at the issue of energy consumption, network centrality and how the network efficiency can be enhanced over the network in case of the high-density type of network. Henceforth, network science has been combined with networking, to pursue network efficiency through the smart use of centrality metrics. Our results show how centrality and efficiency are closely related, leading to a significant improvement in incommunicability and network efficiency, at a manageable computational overhead.*

Keywords: Internet of Things (IoT), Network Centrality, Efficiency, Energy

INTRODUCTION

The Internet of Things (IoT) has exposed a new trend in computing and networking. Every object and sensor around us will be part of the network, for computing, storing and sending data. RFIDs combined with IoT will be leading this revolution, which is bound to generate big data. However, this big data has to be stored, accessed, and streamed in a very efficient way and timely. Examples of IoT systems include smart homes, smart industry, smart cities, to mention but a few. In the case of smart homes, all devices and objects at home would be interconnecting with each other to perform specific actions and timely [1].

Technology trends nowadays are going very fast, so various devices are tapped with different actuators, sensors, and built-in devices. This gives a chance for these devices to communicate with each other by sending and receiving information. Thus, such behavior will not only ease communication but also will enhance people's daily life through intelligent automation processes. However, such communication between devices and objects are often carried out in an ad hoc manner and wirelessly [2].

Referring to Gartner (2015) and HP (2016), growth is expected to be very significant, in terms of the number of devices and applications, for both users and businesses [3]. Reports have indicated that the number of connected devices will reach up to 25 billion by 2020 [4, 5]. However, a recent report released by "Help Net Security" [6] has shown that by 2021, the number of IoT devices is expected to increase by 140% to 50 billion.

IoT sensors are usually spread over the network, in order to collect data, store and forward to the correspondence node directly or through other sensors in the network. This requires sensors to be sustainable in terms of energy and efficiency. Subsequently, this will result in staying prolonged in the network and avoid any sort of sensor depletion due to traffic overload [7].

However, although IoT is creating new ways of communication and management of things to be monitored automatically, it is very important to raise some related issues IoT is facing in such type of paradigm. These include energy efficiency, power consumption, network centrality, and efficiency. As for any type of IoT, such as sensors are storing, sending, receiving, and acting in case of changes and updates. The sensor actually needs to share their resources to be capable to carry out such a contribution in the network.

This paper addresses the issue of maintaining network sensors (nodes) to be fully distributed over the network and avoid any overload at any of these nodes. It is very common that some nodes on the network tend to act and share their resources more heavily than others, which incurs diminution to these nodes and early loss of connectivity. In turn, this results in breaking the network and losing data connectivity.

To address these issues, this paper introduces a new approach to enhancing energy efficiency in IoT, by combining network science and computer networking together. Our results show how centrality and efficiency are closely related, leading to a significant improvement in incommunicability and network efficiency, at a manageable computational overhead.

1. RELATED WORK

Recently, research trends have given more consideration to IoT due to the impact it is having on smart applications. Thus, different researchers and groups have looked at this new technology from various angles. Hence, the detection of unanticipated sensor data, which results either from the sensor system or the environment under scrutiny has been studied by [8]. On the other hand, managing and monitoring the links and connections in low-wireless communications was looked at by [9]. This issue has been examined by monitoring the services provided at the edge, then a rescheduling action was done at well-defined links that were affected by the low power situation. Another study that has considered the centrality metric is in [10] where the centrality metrics were studied and computed in a very dynamic, decentralized environment. On the other hand, decentralized systems were also examined in [11], where useful information was collected in an uncontrolled environment, which would help in managing dynamic, complex IoT.

Another approach to improve the connectivity in IoT sensors is machine learning (ML). This helps in deducting the human intervention and makes the system self-adapt, based upon collected information from the targeted nodes. Applications of ML have been presented in [12]. This was highlighted in various issues, such as coverage problems, power energy issues, and faulty node problems.

In addition to the abovementioned techniques, one of the ways considered to improve the life span of IoT is by reducing power consumption in sensors networks. However, this approach is also considering for achieving an acceptable QoS, to enhance IoT networks. This method has been proposed and introduced in [13], where ML is utilized to monitor the network by located agents gathering information across the nodes. Moreover, a heuristic algorithm is developed to maintain the minimum possible consumed energy by nodes with an acceptable QoS of transmission.

Furthermore, scheduling and efficiency in surveillance are considered by [14] where a method was proposed to enhance the overall performance in surveillance. In this method, different factors were taken into consideration to balance the distribution across the network and in a very dynamic environment. Additionally, the node position was also measured for each case. Mainly those nodes make a decision, based on their importance within the cluster. In return, this has clearly enhanced energy efficiency and node reliability in wireless sensors.

Other critical issues in IoT are coverage problems and power efficiency. These have been carefully looked at by [15] where nodes are either supposed to keep the data or forward it to the appropriate receiver. In this approach, several techniques for maintaining power with consideration of QoS parameters are also examined and verified. Likewise, the lifetime of IoT is gaining more attention due to the dynamicity of networks as well as other factors such as lack of resources, power consumption, and scalability. This is defined as the amount of time that the network can stay alive owing to the nature of sensors, which are very small devices sensing and acting at the same time. One of the studies that recently has looked at this issue is [16] where a heuristic was developed. The algorithm in this study was mainly working and defining the location of the sink, which in return has shown a clear enhancement in network life span.

Moreover, nodes mobility in wireless sensors is another problem that is surveyed by many studies recently, which affects sink positioning and directions. This behavior not only leads to power consumption and energy deduction of nodes but also has a significant influence on the network stability, due to regular updates between nodes. A new algorithm has been proposed in [17], which uses a multi-ring shaped structure to publicize the sink positions frequently. As a consequence, low power intake is accomplished inclusively. Additionally, In [18] energy consumption has been looked at WSN clustering scenario, where nodes at the cluster are managed and led by one of them as a base station. This 'head' node is mainly in charge of transferring, receiving, and forwarding information in the WSN. In this method, nodes are circulated periodically to save power and at the same time balancing the load which in return enhanced the computational efficiency in the cluster, as well as the whole WSN. Nodes budget can be degraded in those nodes being close to the sink since they contribute heavily by sending and receiving greater volumes of data. Thus, this would dramatically harm the power and capability of these nodes, which then impact badly on network stability. Hence, this issue was considered by authors in [19]. Thereafter, an algorithm was proposed to randomly select nodes virtually which shall keep up to date information on the sinks. It was justified on their results that power efficiency and delay were reduced up to an optimum value.

Another dominant problem in WSN is the life span of sensors, which is also covered by [20]. In this study, the data rate transfer is adjusted between senders and receivers after defining the sink properly. Their study has proven and guaranteed longer stay for the nodes which in return prolongs the lifetime. Another approach that was considered to improve the power efficiency is monitoring and dipping the listening time of nodes. This method was proposed by [21], whereby results have shown a reduction on the average time of connection time across the WSN.

Furthermore, a recent study [22] has proposed a method that combined a clustering strategy with the sensing scheme. In this study, the size of the cluster, as well as the dissemination of nodes with the cluster with the head node, is considered. However, to avoid energy depletion which results from a rotation between nodes, a backup node was selected to act in case of cluster-head failure. Their results have shown drastic improvements against existing algorithms in terms of energy and the life span of WSNs.

On the other hand, game theory was introduced in [23] for reducing the energy efficiency of WSNs by presenting a non-cooperative game model in order to reduce the energy consumption, mainly at the cluster heads. Furthermore, a self-organization technique has been proposed in [24] in material tracking, where IoT devices are changing locations frequently, hence, defining the locations of IoT equipped with battery-powered IoT in order to enhance the overall energy efficiency. One more study that has looked at enhancing energy efficiency in WSNs is [25], where path selection is considered by proposing a meta-heuristic based on the dolphin echolocation algorithm (DEA) in order to optimize the route selection in IoT.

In contrast to the above-mentioned related works, this paper examines energy efficiency issues in IoT, where sensors are communicating with each other in a high-density network. Therefore, a new technique based on network science is employed to enhance energy efficiency. This combination of two different domains (networking and network science) has contributed to enhancing the overall energy distribution of nodes and the network life span.

2. PROPOSED METHOD

In contrast to the literature review that was mentioned in Section 2, this paper proposes an algorithm that considers introducing a network science method to enhance energy efficiency in wireless sensor networks. Therefore, various metrics have been incorporated into this new approach from different fields as follow:

A. Network centrality

Network centrality is the main function that gives an insight into the complexity of any type of network. Hence, it has been introduced in the proposed algorithm as of gauging the centrality metric [26]. It reflects as one of the main references to measure the efficiency of any type of a dense network. Moreover, it captures the level of interconnection between entities, nodes, persons, and so on. In IoT, this plays a vital role where nodes are spread all over. Therefore, it is critical to measure the degree of communication between these nodes and pinpoint carefully the best value of centrality in the network.

B. Communicability

Another factor considered in the proposed algorithm is known as the communicability [27]. This refers to measuring the interconnectivity between nodes all over the network topology. In return, after evaluating the communicability values for all nodes, an additional step is taken by the algorithm, to rank the nodes in the network-based upon the communicability, from top to low values.

C. Pruning

A new element introduced in our algorithm is "pruning". This mechanism acts on re-distributing the links among nodes according to the output of the above (A&B). Basically, in some network scenarios, it can be found that some nodes are overwhelmed by the number of outgoing connections whereas other nodes are almost at the level of depletion cause of having no activity in the network and not contributing the overall distribution. Hence, the main target of this technique is to balance the number of connections among the nodes, taking into consideration that each node has at least one connection in the network and staying alive across the network life span.

However, pruning should never isolate the main metric, which is network centrality. Therefore, a trade-off between pruning and network centrality is considered carefully throughout the whole implementation of the algorithm. On the other hand, our algorithm keeps checking the quality of service metrics including packet loss and end-to-end delay, to assure that QoS (quality of service) and QoE (quality of experience) are meeting the minimum acceptable threshold, according to [28]. Next, the experimental section in this paper will give more precise implementation details of this algorithm.

3. EVALUATION METHOD

In order to evaluate the proposed algorithm, the prototype has been implemented in Python [29]. It has shown the high capability of mimicking an IoT scenario. Not only that but also Python is a high-level language with the support of many built-in libraries. However, in order to assure that the experiment is meeting the requirements, all scenarios are fully randomized over various network sizes. Furthermore, the Erdős–Rényi model [30] was used to generate the graphs. Hence, the topology has been generated with full distribution in terms of node values, including the leaf nodes and children. Thereafter at the startup phase, the algorithm checks the interconnectivity between nodes to make sure that the total generated number of nodes is up and fully interconnected.

Subsequently, senders and receivers are elected randomly and start the process of transmission. Therefore, at the initial phase of the algorithm, nodes start the communication with each other by exchanging data and signaling. Successively, the algorithm starts running and managing the network to create a self-adapting scenario over the network. Consequently, in order to collect the default values of all the nodes and weights on the network, communicability [31] is measured to give in return the budget of the overall network as well as for every single node. Hence, interconnectivity among the nodes is shown by looking carefully into the numbers achieved by the first calculation.

On the other hand, after achieving the overall values of all nodes across the network, nodes conditions are recorded which shows those nodes that are overwhelmed by having a lot of outgoing connections. Thereafter, a step further is taken by the algorithm to rank the node's top-down values per the communicability formula presented in [31]. Subsequently, the efficiency gained [i] is then calculated to check the network efficiency. The algorithm then defines those nodes with a high number of links and outgoing connections values, then pruning is exercised at a percentage level. This action allows those nodes with high communicability to enhance their situation, so by pruning links from nodes with low communicability values to those nodes achieving high communicability values.

This action takes place iteratively, up to the point where communicability is no longer changing significantly. With each pruning action, gained efficiency is calculated, to check whether or not the network efficiency is improving. However, for more validations, the algorithm has been examined over a range of number nodes.

4. RESULTS AND DISCUSSION

This section gives more insights into the output of the simulation of the proposed algorithm. Therefore, in order to gauge the performance properly, two scenarios have been introduced. The first scenario represents the proposed algorithm (referred to as "with pruning"); whereas the second scenario was introduced to mimic a randomized scenario without any kind of self-adaptation of the WSN (referred to as "without pruning"). Moreover, various metrics have been introduced to depict the robustness of algorithms such as communicability, gained efficiency, computational time, and a number of iterations. These metrics are defined as follow:

- **Communicability**: This metric gives a clear understanding of the load distribution over the WSN in terms of power and energy. The lower the values achieved in incommunicability, the better the load distribution is realized over the network.
- **Gained Efficiency**: this metric is to show network efficiency and how the nodes are contributing to the overall network. It is interlinked with the overall communicability each time. In the proposed algorithm, gained efficiency (GE) is defined as follows:

GE = (Δ/max values) * 100

Where Δ is (MAX - the overall communicability value). The Max value, in this case, is 1 (depending on the metrics scale).

- **Computational time:** This metric is very valuable in measuring the robustness of the proposed algorithm against the randomized approach. Thus, as the network size goes up, this has a drastic impact on the performance of showing complicated scenarios. Dealing with a large-scale network size has a significant impact on the performance of executing very complicated scenarios.
- **Number of Iterations:** This metric is introduced to gauge the number of iterations. Since the proposed algorithm is based upon execution of pruning to pursue the optimum value. Furthermore, this metric is vital in showing if the algorithm is capable to deal with any kind of network size. Not only that but also it will give a more precise measurement if the examined scenario is able to achieve the best results over various sizes of the WSN.

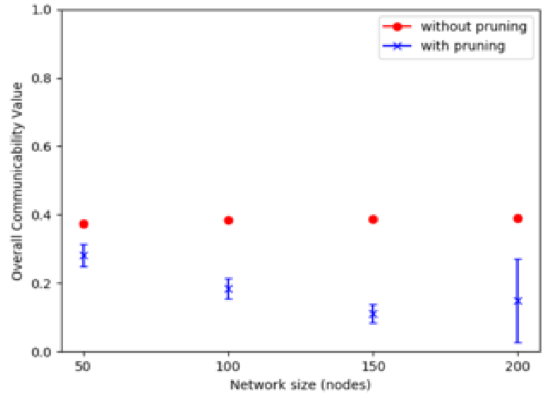

Figure 1 Overall Communicability

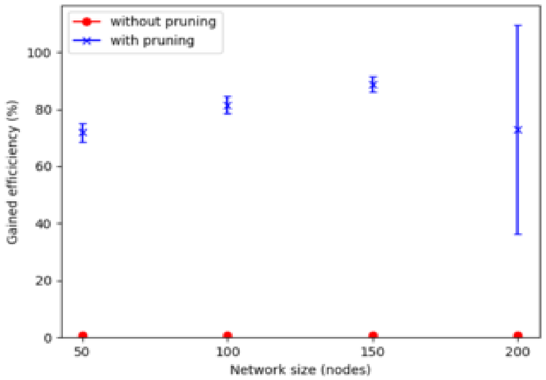

Figure 2 Gained Efficiency

Figure 1 shows the two scenarios (with pruning which represents the proposed algorithm) and the other scenario which shows the opposite behavior of the proposed algorithm where the network is randomly distributed and managed. Figure 1 gives an insight that in case of a pruning scenario, the communicability is showing a steady decrease across network sizes.

This assures that the energy is well distributed among nodes in case of various types of adapted topologies. Moreover, it is well justified that the contribution of the proposed algorithm is clearly shown, which means that reducing the number of links that overwhelm the IoT nodes is an effective method towards enhancing the interconnectivity across the network.

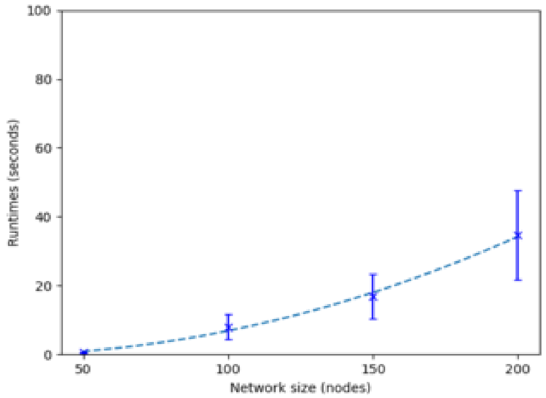

Figure 3 Computational Time

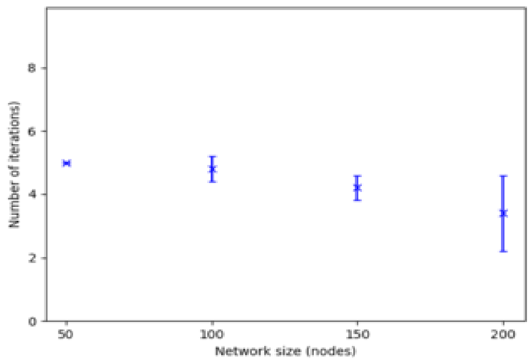

Figure 4 Number of Iterations

On the other hand, looking closely to the randomized scenario (labeled as without pruning), it is clear that no change on the level of energy distribution across the the network has taken place at all levels. This gives an indication that WSNs can be affected heavily when the energy and power are not well distributed over the network topology. Moreover, it is evident that some nodes are always acting and taking the load out of the rest of the network nodes which by the end after their life span, which leads to depletion. However, for the purpose of results validation, the average and standard deviation of many runs were conducted for both scenarios across various network sizes.

Figure 2 depicts the gained efficiency which identifies the network efficiency against the communicability over the network. Hence, looking carefully at the proposed algorithm as defined "with pruning", it is clear that the gained efficiency is increasing smoothly, whereas communicability, as shown in figure 1, is going against the gained efficiency. This gives an indication of the validity of the achieved results. Not only that, but also to gauge the robustness of the proposed algorithm “with pruning”, simulations have been carried out over various network sizes (50, 100, 150, 200). On the other hand, looking at the other scenario in which the network is managed randomly without any kind of intervention labeled as “without pruning”, the gained efficiency is almost not changing. This is due to the fact that communicability values are always static and not distributing the load among nodes across the network. Therefore, the ill effect of such behaviour shall lead to cause overload on the nodes which would consequently affect the node's energy and power. Finally, as a note of the show results in Figures 1 and 2, when the network size is enlarged into 200 nodes, the trend is a little different than what is expected, due to the simulation results.

Figure 3 gives another angle of the proposed scenario "with pruning" against the randomized scenario "without pruning" in terms of computational time. This factor is essential to judge the behaviour of the two scenarios from the point of view of the time needed for execution of the complicated scenarios and algorithm over a various large scale of the network. Thus, figure 3 shows that the execution time is explicitly polynomial against the network size. Hence, this metric is insightful to show how the capability of the algorithm on dealing with complex networks and connections.

Finally, since the core process of the proposed scenario "with pruning" depends heavily on the execution of pruning among the nodes across the network, it was essential to measure the number of iterations to achieve the best results. Therefore, figure 4 shows the required number of iterations versus various scales of the network size. It is clear that the number of iterations is decreasing against the network size, which shows that the algorithm is performing in a very efficient way and will not be affected by the volume of network size.

5. CONCLUSION

Energy efficiency in IoT plays a major role in the sustainability of networks. Hence, distributing the load among the nodes is essential. Thus, this paper has introduced a model to enhance network efficiency. A new technique based upon pruning has been developed in order to distribute the load over the network. However, for more validation and demonstration, the proposed scenario was also run against the default scenario to show the valuable improvement of the proposed algorithm. Results have shown the drastic performance improvement of the proposed algorithm (labeled: “with pruning”) on enhancing the network efficiency and communicability values over various network sizes.

Prospect work is driven to explore more algorithms to improve the scalability of the IoT paradigm. Furthermore, more complex types of networks may be explored to assess the impact on communications among the nodes. This results in high traffic load as well as signaling overhead.

REFERENCES

[1] V. K. Tiwari, “Available Online at www.ijarcs.info Study of Internet of Things (IoT): A Vision , Architectural Elements , and Future Directions,” vol. 7, no. 7, pp. 65–84, 2016.

[2] N. Shahid and S. Aneja, “Internet of Things: Vision, application areas and research challenges,” *Proc. Int. Conf. IoT Soc. Mobile, Anal. Cloud, I-SMAC 2017*, vol. 10, no. 7, pp. 583–587, 2017.

[3] Rob van der Meulen, “Gartner Says 6.4 Billion Connected ‘Things’ Will Be in Use in 2016, Up 30 Percent From 2015,” *Gartner webpage*, 2015. [Online]. Available: http://www.gartner.com/newsroom/id/3165317. [Accessed: 10-Jan-2019].

[4] I. Lee and K. Lee, “The Internet of Things (IoT): Applications, investments, and challenges for enterprises,” *Bus. Horiz.*, vol. 58, no. 4, pp. 431–440, 2015.

[5] “94fd01b2bbdedaafbc8dfeffadf2fb1d60071602 @ www.analyticsvidhya.com,” 2016. [Online]. Available: https://www.analyticsvidhya.com/blog/2016/08/10-youtube-videos-explaining-the-real-world-applications-of-internet-of-things-iot/. [Accessed: 21-Oct-2019].

[6] Helpnet, “helpnetsecurity,” *Helpnetsecurity*, 2018. [Online]. Available: https://www.helpnetsecurity.com/2018/06/14/iot-connections-2022/. [Accessed: 26-Feb-2019].

[7] A. Bashir and A. H. Mir, “Internet of things security issues, threats, attacks and counter measures,” *Int. J. Comput. Digit. Syst.*, vol. 7, no. 2, pp. 111–120, 2018.

[8] F. Cauteruccio *et al.*, “Short-long term anomaly detection in wireless sensor networks based on machine learning and multi-parameterized edit distance,” *Inf. Fusion*, vol. 52, no. June 2018, pp. 13–30, 2019.

[9] T. van der Lee, A. Liotta, and G. Exarchakos, “Interference graphs to monitor and control schedules in low-power WPAN,” *Futur. Gener. Comput. Syst.*, vol. 93, pp. 111–120, 2019.

[10] X. Jin and Y. K. Kwok, “Network aware peer-to-peer media streaming: Capacity or proximity?,” *Comput. Networks*, vol. 69, pp. 1–18, 2014.

[11] H. H. Bosman, G. Iacca, A. Tejada, H. J. Wörtche, and A. Liotta, “Spatial anomaly detection in sensor networks using neighborhood information,” *Inf. Fusion*, vol. 33, pp. 41–56, 2017.

[12] D. Praveen Kumar, T. Amgoth, and C. S. R. Annavarapu, “Machine learning algorithms for wireless sensor networks: A survey,” *Inf. Fusion*, vol. 49, no. April 2018, pp. 1–25, 2019.

[13] M. Chincoli and A. Liotta, “Self-learning power control in wireless sensor networks,” *Sensors (Switzerland)*, vol. 18, no. 2, pp. 1–29, 2018.

[14] K. Xiao, R. Wang, H. Deng, L. Zhang, and C. Yang, “Energy-aware scheduling for information fusion in wireless sensor network surveillance,” *Inf. Fusion*, vol. 48, no. August 2018, pp. 95–106, 2019.

[15] A. Boukerche and P. Sun, “Connectivity and coverage based protocols for wireless sensor networks,” *Ad Hoc Networks*, vol. 80, pp. 54–69, 2018.

[16] B. Kabakulak, “Sensor and Sink Placement, Scheduling and Routing Algorithms for Connected Coverage of Wireless Sensor Networks,” *Ad Hoc Networks*, vol. 86, pp. 1–30, 2018.

[17] R. Yarinezhad, “Reducing delay and prolonging the lifetime of wireless sensor network using efficient routing protocol based on mobile sink and virtual infrastructure,” *Ad Hoc Networks*, vol. 84, pp. 42–55, 2019.

[18] N. Gharaei, K. Abu Bakar, S. Z. M. Hashim, and A. H. Pourasl, “Inter- and intra-cluster movement of mobile sink algorithms for cluster-based networks to enhance the network lifetime,” Ad Hoc Networks, vol. 85, pp. 60–70, 2019.

[19] R. Yarinezhad and A. Sarabi, “Reducing delay and energy consumption in wireless sensor networks by making virtual grid infrastructure and using mobile sink,” *AEU - Int. J. Electron. Commun.*, vol. 84, no. April 2017, pp. 144–152, 2018.

[20] I. Papadimitriou and L. Georgiadis, “Energy-aware Routing to Maximize Lifetime in Wireless Sensor Networks with Mobile Sink,” vol. 2, no. 2, pp. 141–151, 2006.

[21] N. Zaman, L. T. Jung, and M. M. Yasin, “Enhancing Energy Efficiency of Wireless Sensor Network through the Design of Energy Efficient Routing Protocol,” vol. 2016, 2016.

[22] Q. Wang, D. Lin, P. Yang, and Z. Zhang, “An Energy-Efficient Compressive Sensing-Based Clustering Routing Protocol for WSNs,” *IEEE Sens. J.*, vol. 19, no. 10, pp. 3950–3960, 2019.

[23] D. Lin and Q. Wang, “An Energy-Efficient Clustering Algorithm Combined Game Theory and Dual-Cluster-Head Mechanism for WSNs,” *IEEE Access*, vol. 7, pp. 49894–49905, 2019.

[24] G. Škulj, A. Sluga, D. Bračun, P. Butala, and R. Vrabič, “Energy efficient communication based on self-organisation of IoT devices for material flow tracking,” *CIRP Ann.*, vol. 68, no. 1, pp. 495–498, 2019.

[25] M. Masood, M. M. Fouad, S. Seyedzadeh, and I. Glesk, “Energy Efficient Software Defined Networking Algorithm for Wireless Sensor Networks,” *Transp. Res. Procedia*, vol. 40, pp. 1481–1488, 2019.

[26] S. Wang, Y. Du, and Y. Deng, “A new measure of identifying influential nodes: Efficiency centrality,” *Commun. Nonlinear Sci. Numer. Simul.*, vol. 47, pp. 151–163, 2017.

[27] E. Estrada, “The communicability distance in graphs,” *Linear Algebra Appl.*, vol. 436, no. 11, pp. 4317–4328, 2012.

[28] F. Agboma, M. Smy, and A. Liotta, “QoE analysis of a peer-to-peer television system,” *MCCSIS’08 - IADIS Multi Conf. Comput. Sci. Inf. Syst. Proc. Wirel. Appl. Comput. 2008 Telecommun. Networks Syst. 2008*, pp. 114–119, 2008.

[29] “Python.” [Online]. Available: https://www.python.org/.

[30] “Erdos Renyi models.pdf.” [Online]. Available: https://en.wikipedia.org/wiki/Erdős–Rényi_model.

[31] “Communicability.” [Online]. Available: https://networkx.github.io/documentation/networkx-1.10/reference/algorithms.centrality.html.

i