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Algorithms and methods for energy harvesting in wireless networks: A review

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The element of energy harvesting in the wireless network is popular nowadays due to its effectiveness in terms of performance. The effectiveness can be seen in the way it can prolong the battery life as well as increase the performance of the network. In order to have a better understanding of how energy harvesting happens in a wireless network, this paper will present different algorithms and methods used for energy harvesting on the wireless network. The algorithms such as EHWA, SSPCA, NEEC, ANCAEE, QL-SEP and PSO are discussed and reviewed. The methods discussed and reviewed in this paper are spectrum and energy-harvesting technique, Fair Packet Ratio Distributed Computation Method, Power Feedback Control MPPT, TEH technique and Electric Field Energy Harvesting technique. The review on energy harvesting will also include simulation approaches, methods and the result of the different energy harvesting simulations. By conducting this paper review, it will help researchers to see the energy harvesting in different aspects of algorithms and methods.

1. Introduction

Nowadays, the element of a wireless network is implemented in various fields such as vehicular, communication and agriculture because of the benefits of the wireless element in the communication. The reason for the deployment of the wireless network in different areas is because users want to have unlimited communication either between nodes or between the sources and destination. However, it has constraints due to the limitation of energy usage to ensure that the nodes involved in the data transmission have prolonged life and do not cause any negative effect on the network (Anwar and Mui, 2007). It is well-known that the mechanism of wireless communication consumes more energy than computation and sensing. The main sources of energy wastage in a sensor network include overhearing, idle listening, control packet overhead and retransmissions (Kosunalp, 2016). In wireless networks, energy consumption is becoming one of the key issues. This is due to the growing demand in wireless applications that in turn leads to a shortage in energy supply, and the need for environmental protection (Zhao et al., 2015).

To overcome energy usage limitation problems in the wireless network, various algorithms and protocols had been used to ensure that the energy is distributed fairly among the nodes or between the source and destination. Algorithm of Hybrid Energy-Efficient Distributed Clustering (HEED) (Younis and Fahmy, 2004) and routing algorithm of Energy Harvesting Genetic-Based Unequal Clustering-Optimal Adaptive Performance Routing Algorithm (EHGUC-OAPR) (Wu and Liu, 2013) are proposed to overcome the energy usage in a wireless network. Protocols of Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2000) and Hybrid Unequal Clustering with Layering Protocol (HUCL) (Malathi et al., 2005) are proposed, as routing protocol of Adaptive Energy Harvesting Aware Clustering Routing Protocol (AEHAC) (Kausar et al., 2014) is also proposed to overcome energy usage in a wireless network. The similarities between the algorithms and protocols are that they both focus on energy harvesting for the wireless network.

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The definition of energy harvesting in wireless networks (Vilardebo and Gündüz, 2014) is to reduce frequent battery replacements for exponentially increasing the number of connected devices, to limit the growing carbon footprint of the wireless industry, and also to obliterate. Besides that, energy harvesting is also known by other terms such as power harvesting, energy scavenging, and free energy (energy derived from renewable energy) (Little et al., 1998). The energy can also be harvested from ambient sources such as mechanical energy, radiant energy, thermal energy and fluid flow (Panatik et al., 2016). By considering the energy harvesting in the network, it can help the network to have better performance in terms of energy-saving and data transmissions, such as data packet loss, average delay, average throughput and others. Thus, by deploying the energy harvesting method in the wireless network, it can save more energy and have better performance.

This paper describes energy harvesting in a wireless network as a variety of algorithms and methods are analyzed. This paper is organized as follows: algorithms for energy harvesting in the wireless network will be described in Section 2, methods for energy harvesting in the wireless network will be described in Section 3. Finally, the conclusions are set out in Section 4.

2. The algorithms used for energy harvesting in WSN

2.1. Novel energy efficient clustering (NEEC)

Bozorgi et al. (2017) focused on hybrid methodology involving static and dynamic clustering operation. It uses a distributed-centralized approach and multi-hop routing for energy harvesting in Energy Harvesting Wireless Sensor Network (EH-WSN). The usage of the EH-WSN is different compared to the typical WSN due to the features in the routing protocol. By considering the hybrid methodology, the selection of the cluster head (CH) is based on the energy level and the amount of energy harvesting for each node's requirements is to be selected as CH.

Bozorgi et al. (2017) introduced new algorithm harvesting, which is Novel Energy Efficient Clustering (NEEC). This algorithm is used to perform in a distributed and centralized manner and hybridization of static and dynamic clustering. The operation of the proposed algorithm is as follows:

1. Base station (BS) centralized the handling phase
2. 2 phases distributed which is setup phase and data transmission phase

Fig. 1 shows operations that occur in NEEC. In the energy harvesting nodes, it classifies 2 thresholds which are low and high thresholds. If the node is below the low threshold, the nodes will be blocked and the data transmission cannot be done as the nodes will not participate in the data transmission. However, if the node is above the high threshold level, the nodes will participate in the network and the data transmission will happen involving the nodes and no node is blocked. As shown in Fig. 1, the operation is split into 3 phases which are handling phase involving information collection, layer construction, and radius calculation and location degree determination. Meanwhile, in the setup phase, it involves delay calculation, CH selection, cluster formation and route construction. In the data transmission phase, it contains the sub-phase which is inter-cluster transmission and intra-cluster transmission.

The operation in NEEC results in sending more packets and better performance. Furthermore, it also increases the number of available nodes, avoidance of data transmission for the long distance and better throughput and minimum lost packets.

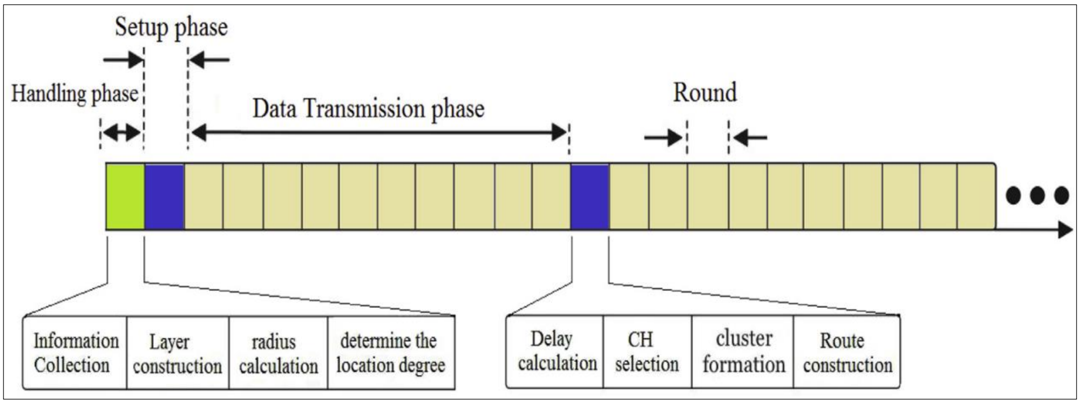


Fig. 1: NEEC operation (Bozorgi et al., 2017)

2.2. A new clustering algorithm for energy efficiency (ANCAEE)

Abidoye et al. (2011) discussed on how to consume less energy during data transmission based on cluster formation and the election of cluster heads method in ANCAEE. A cluster head (CH) is a group leader in each cluster that collects sensed data from member nodes, aggregates, and transmits the aggregated data to the next CH or to the base station (Yang and Zhang, 2009; Wei et al., 2008). The ANCAEE partitioned the sensor field into different clusters and elects a node as the cluster head for each cluster. Each node within the cluster sends its data to the cluster head with single hop transmission and cluster heads receive, aggregate the data and transmit to the base station via multi-hops transmission.

Fig. 2 shows cluster formation and cluster head selection after randomly distributed sensor nodes are created using MATLAB. In order to see the effectiveness of the ANCAEE algorithm, a comparison between ANCAEE, LEACH and TL-LEACH is done using MATLAB with 100 randomly distributed sensor nodes.

Based on Fig. 3, the result of ANCAEE is outstanding compared to LEACH and TL-LEACH. It was observed that the first node dies in LEACH and TL-LEACH after about 135 and 148 rounds respectively, while in ANCAEE, the first node dies after about 185 rounds. Furthermore, the last dies in LEACH after about 640 rounds and 710 rounds in TL-LEACH, while the last node dies after 800 rounds in ANCAEE.

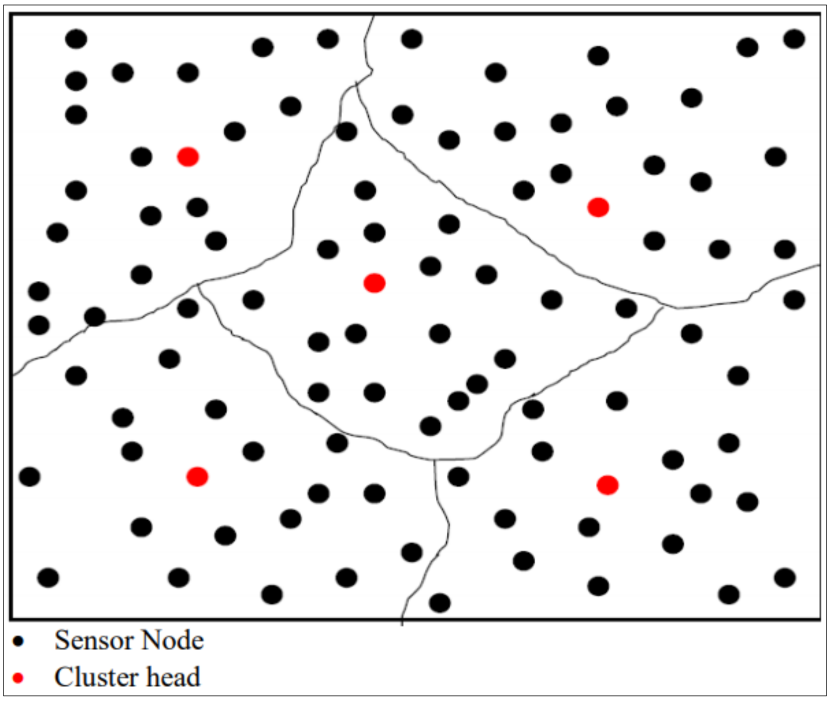


Fig. 2: Cluster formation and cluster head selection (Abidoye et al., 2011)

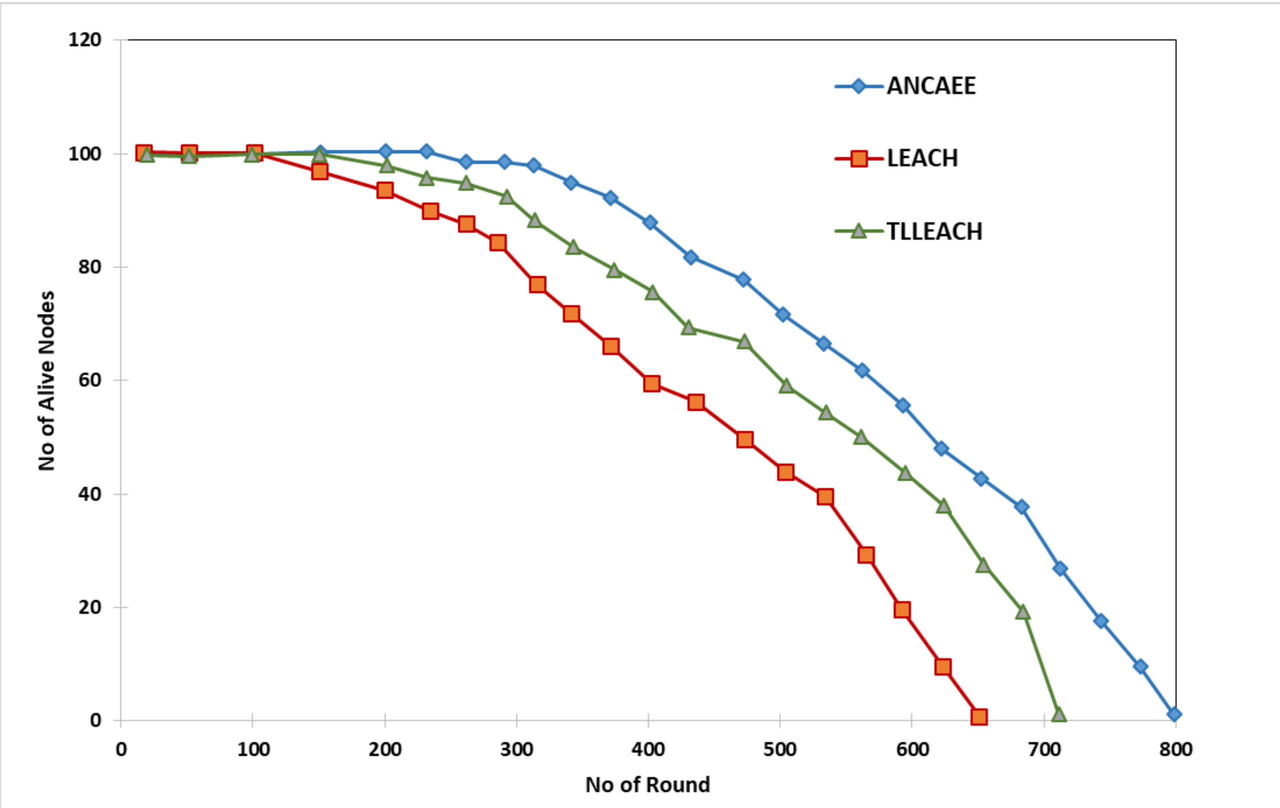


Fig. 3: Comparison result between ANCAEE, LEACH and TL-LEACH (Abidoye et al., 2011)

These simulation results show that ANCAEE algorithm extends battery lifetime, thus prolongs sensor network utilization.

2.3. Solar energy-prediction with Q-learning (QL-SEP)

Kosunalp (2016) proposed a solar energy-prediction algorithm with Q-learning called QL-SEP. The majority of the proposed prediction algorithms have attempted to predict solar energy because of its advantages over other forms of environmental energy (Bergonzini et al., 2009). QL-SEP algorithm used to rely on the assumption that solar energy exhibits a cycle as a periodic energy source in which time domain is split into equal-length slots that are repeated daily. This is because by splitting the time into an equal slot, prediction for the next slot can be done based on the previous slot and the results will be more accurate. Besides, QL-SEP takes advantage of exponentially-weighted moving average (EWMA) properties, in that, a feature acquiring the status of current solar condition employed as the EMWA is a very efficient way to observe the long-term conditions.

In addition, the QL-SEP updates the equation in EMWA by adding the parameter of the daily ratio (DR). DR is considered as the average energy of decrease or increase from previous slot allocation. The increase or decrease of harvested energy from the previous slot will determine the value of DR. Each slot in QL-SEP maintains a level of prediction accuracy which represents a reliability of prediction in the slot. Thus, it will lead to combining increase or decrease ratios and reliability of prediction in order to significantly endow the predictions with high reliability. In order to give greater importance to the closing time slots, the most recent slots would carry the most recent information and it is weighted by the increasing index.

Moreover, the element of reliability (R) in QL-SEP has a significant effect on the algorithm as it represents goodness level of prediction and should be explicitly explored in order to identify the best choice. Furthermore, QL-SEP employs a Q-learning approach in which each slot is initiated with a Q-value independently to denote the reliability level of this slot.

To see the effectiveness of QL-SEP, simulation is conducted in the algorithm by setting the total number of time slots in a day as 24. This is used to show a whole day was represented by 24 time slots, and each of them corresponded to a one-hour duration. A number of the previous slots up to current slots and learning rate in Q-Learning acts as parameters and used for the prediction algorithm. The evaluation of QL-SEP is done by comparing other prediction algorithms such as ASEA, EMWA and Pro-Energy. Based on the results obtained, it shows that QL-SEP has better performance in terms of prediction error ratios for months. This is because QL-SEP is able to adapt to temporal change quickly and it checks the status of the most recent slots. As a result, QL-SEP turned out to be the best scheme in all aspects as shown in Table 1.

Table 1: Prediction error ratios for months, α D 0.7 (Kosunalp, 2016)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EWMA	0.61	0.57	0.44	0.7	0.42	0.13	0.18	0.19	0.27	0.4	0.4	0.52
ASEA	0.42	0.46	0.4	0.42	0.45	0.16	0.2	0.21	0.3	0.38	0.42	0.46
Pro-Energy	0.79	0.72	0.7	0.62	0.5	0.4	0.35	0.35	0.47	0.61	0.65	0.73
QL-SEP	0.35	0.36	0.32	0.3	0.35	0.15	0.14	0.14	0.22	0.27	0.3	0.36

2.4. Power splitting optimization (PSO) algorithm

Zhao et al. (2015) discussed on wireless energy harvesting in interference alignments networks. Recently, interference alignment (IA) has emerged as a promising solution to the interference management in wireless networks, thanks to its ability to approach the sum capacity of the interference channel (Zhao et al., 2015; Cadambe and Jafar, 2008; Jafar, 2011; Rasan and Al-Nafiey, 2019; Zhao et al., 2013; Chen and Yuen, 2014). The usage of energy harvesting in wireless networking is beneficial to the network because the nodes in the network will try to preserve energy or to harvest energy in order to have low energy consumption. Zhao et al. (2015) analyzed the implementation of the power splitting optimization (PSO) algorithm and power allocation in wireless to see the effectiveness of the algorithm in terms of harvesting energy. In order to see the optimization of information transmission (IT) and wireless energy harvesting (WEH) in the interference alignment (IA), PSO will perform operations and see the effectiveness of the algorithm.

The function of PSO is to equip power splitter on each node to induce received power from antennas to ID or EH terminals according to requirements of the system. Besides, PSO will optimize IT and WEH performance to ensure IT and WEH performed at each receiver simultaneously according to the specific requirements of the system. This leads the PSO algorithm to be more flexible to use and can satisfy the needs of all users in the IA networks. Parameters measured in PSO are weight for specific requirements of the needed rate and energy of the user. An example of PSO in the network is when weight for specific requirements of the needed rate and energy of the user becomes larger, it means that the IT requirements of the user are relatively high or battery power is sufficient and vice versa.

Implementation of power allocation in PSO is for better performance of IT and WEH in IA networks. The function of power allocation is when ID terminals are active at all receivers and the optimization problem becomes a conventional power allocation problem in the IA networks; it can be solved by the famous "water-filling" power allocation strategy. Therefore, PSO with power allocation will satisfy the specific requirements of all IA users through power splitting to perform WEH and IT at each receiver simultaneously.

As a result, the increase of the sum of rate in the network and the decrease of the sum harvested power happen whenever weights for the specific requirements of the needed rate become larger in the PSO algorithm. In addition, the power-rate performance of the PSO algorithm is better compared to the PRRS and RRS algorithm. Fig. 4 shows the result of a comparison between PSO, PRRS and RRS. The significance of power allocation in PSO is when it results in the improvement of the PSO algorithm itself. Thus, the deployment of power allocation in the PSO algorithm is very important to help improve the PSO algorithm performance.

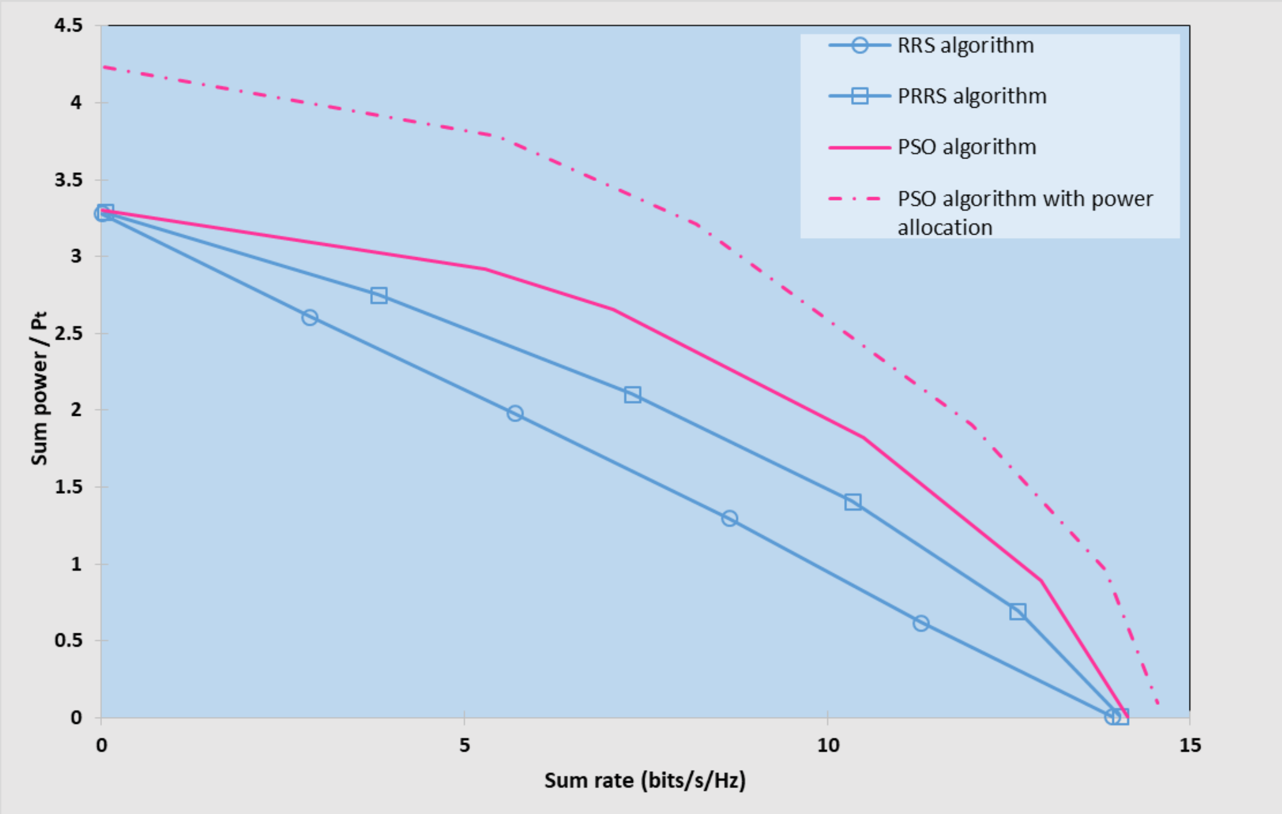


Fig. 4: Power-rate tradeoffs of the PSO algorithms with and without power allocation, and the PRRS and RRS algorithms, for WEH in the five-user IA network (Zhao et al., 2015)

2.5. Sleep-wake scheduling and power control algorithm (SSPCA)

Du et al. (2017) focused on minimizing the distortion in EH-WSN by implementing and optimizing sleep-wake scheduling and transmitting power or implementing sleep-wake scheduling and power control algorithm (SSPCA). In order to minimize distortion, formulation on the Mean Square Error (MSE) (Argyriou and Alay, 2016) is done and then converted into tractable convex one. Then, using developed SSPCA, it will minimize distortion in the EH-WSN.

Du et al. (2017) wanted to see how effective the SSPCA in the sensor nodes (SN) is for EH-WSN. Firstly, the MSE minimization problem is formulated with prior knowledge of channel power gain and harvested energy of each SN and then it will be transformed into a convex optimization framework. The method involved in the SSPCA is the exploitation of the Lagrangian duality approach and the computational complexity of SSCPA which consists of an inner loop and outer loop.

Implementing SSPCA to minimize distortion in the sensor node will result in improvement in the average MSE. This leads to the increment of storage efficiency and higher storage efficiency, thus enabling larger parts of harvested energy to be stored in a battery for future use. Fig. 5 illustrates the results of the average MSE performance of schemes with HUS and traditional HSU modes versus ηB. Besides that, higher circuit power leads available energy to transmit SN's measurement increase and also increase of MSE in the network. Fig. 6 shows the results of the average MSE performance of both the SSPCA and the random SN selection algorithm with respect to PC_i. Moreover, the implementation of SSPCA results significantly in need of considering the charging inefficiency of an actual battery. The results of SSPCA implementation is measured based on network topology comprising eight SNs and a fusion center (FC).

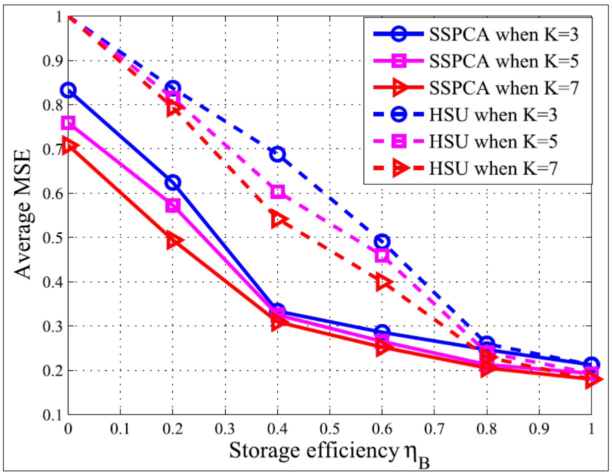


Fig. 5: Comparison result between SSPCA and HSU (Du et al., 2017)

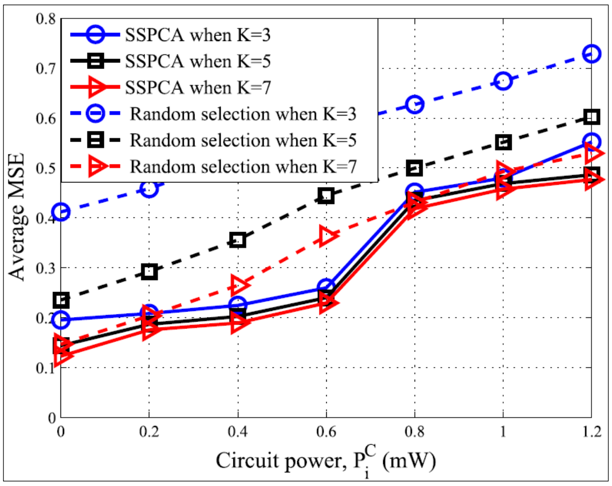


Fig. 6: Comparison result between SSPCA and random selection (Du et al., 2017)

2.6. Energy-harvesting wastage-aware (EHWA) routing algorithm

Martinez et al. (2014) proposed a scheme of route selection based on two metrics which is energy consumption due to the transmission of packets and energy harvest wastage due to overcharge. The route selection scheme considers network energy wastage due to the overcharge of finite-capacity batteries and it is done by minimizing transmission, and the energy wastage due to battery overcharge. The main objective of this scheme is to maximize the total remaining network energy and aim to manage the energy using harvesting routing.

Besides, the proposed energy harvesting wastage-aware (EHWA) routing algorithm aims to select a route that has a maximum total resultant network energy. Then, the effectiveness of EHWA with the route selection scheme is evaluated based on topology and traffic, shadowing, prediction error and evaluation section. EHWA focuses more on Dynamic Source Routing (DSR) or on-demand routing because it has better energy saving as compared to others as it will only create a path for data transmission when required or requested by sources.

For DSR, if Route Request (RREQ) cost fields are implemented, it will result in larger RREQ header overhead meanwhile, if RREQ forwarding is deployed in DSR, it leads to alternate routes with potentially lower costs being ignored. In order to have better performance in DSR, the usage of RREQ timer is beneficial because it is a timer with duration and it is started at a destination when a new RREQ is received. In route expiration implementation of DSR, new route discovery is initiated if the source requires a route to destination but the cached route had expired. In order to see the effectiveness of EHWA in DSR, routing simulation is done using network simulator 2 (NS2).

Simulation results are based on the topology and traffic, shadowing, prediction error and evaluation section. For the topology and traffic section, EHWA shows the usage of energy wastage in different areas. It is shown that the portion of energy being wasted elsewhere in the network provides an additional incentive to avoid low-energy nodes and gives the opportunity to recharge for low-energy nodes. In addition, EHWA also shows average residual battery levels which maximize total residual network energy. Moreover, EHWA also shows maximum improvement for high harvest rate at noon with the number of nodes of 25. It indicates that EHWA can be deployed in a large network. Fig. 7 shows the simulation results obtained in the topology and traffic sections. Comparison between Energy harvesting aware (EHA) (Nguyen et al., 2017; Gong et al., 2014) and EHWA is done to see the effectiveness of EHWA.

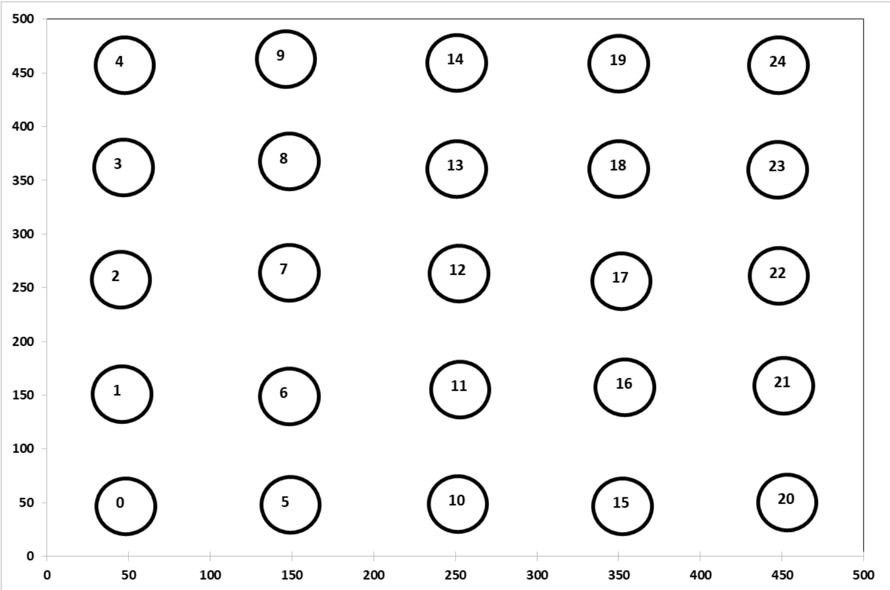
Furthermore, in the shadowing section, it shows that EHWA will choose a route that includes *v*0 instead of *v*6 since energy would otherwise be wasted in *v*0 which provides an additional incentive to avoid *v*6. Meanwhile, in the evaluation section, EHWA will alternate routes with the same length as the shortest path used in 99.9% of cases shows how effective EHWA is in the wireless network. Thus, more harvest energy will be utilized and a much larger total residual energy in the network will remain. Therefore, it indicates that EHWA could be applicable to other sources that cannot be accurately modeled and large improvements on the minimum and standard deviation of battery levels compared to non-wastage aware case.

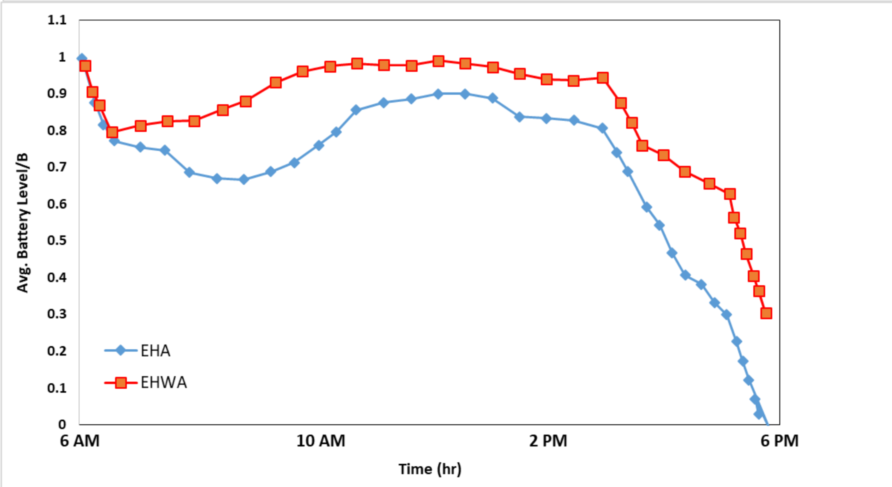
3. Methods used for energy harvesting in WSN

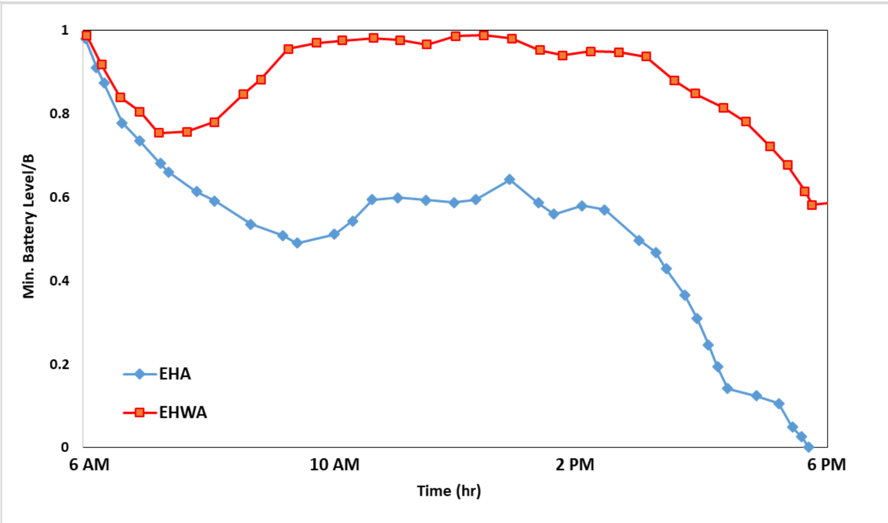
3.1. Fair packet ratio distributed computation method

Aoudia et al. (2017) focused on packet distribution between the nodes involved in the network as fairness between the nodes of a packet will lead to energy harvesting or energy saving and better performance can be obtained. The designation of a distributed algorithm to set packet generation nodes (PGRs) of sensor nodes forming a multi-hop EH-WSN is the main reason for the experiment to be done. By having the distributed algorithm for the nodes, it can help more in energy saving and will lead to better network communication.

The solution approach involved is a distributed algorithm for computation of fair packet rates and fast alternating direction methods of multipliers. The methods involved in the solution approach is how the distribution of PGRs, parameters of energy cost for nodes, and energy cost of relying on alternating direction method of multipliers (ADMM) are used. The results obtained from the algorithm are that higher PGR is obtained by the nodes if it harvests more energy and the decrease of the overhead of energy managers (EM) also reduces the average number of iterations required. Fig. 8 and Fig. 9 show the result obtained.







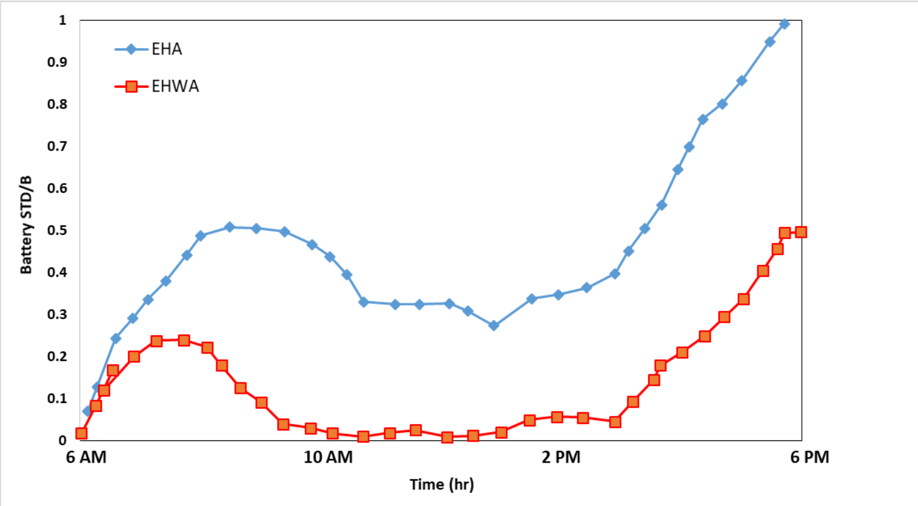


Fig. 7: Comparison results obtained between EHA and EHWA (Martinez et al., 2014)

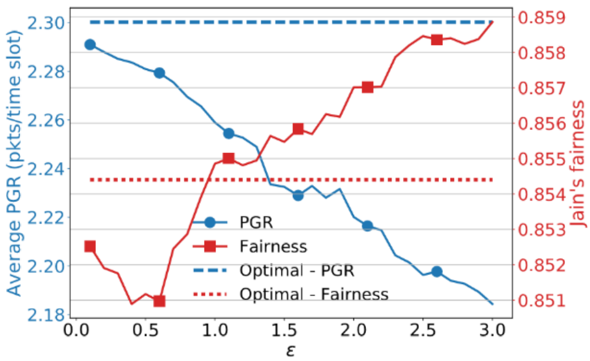


Fig. 8: Average PGR and fairness (Aoudia et al., 2017)

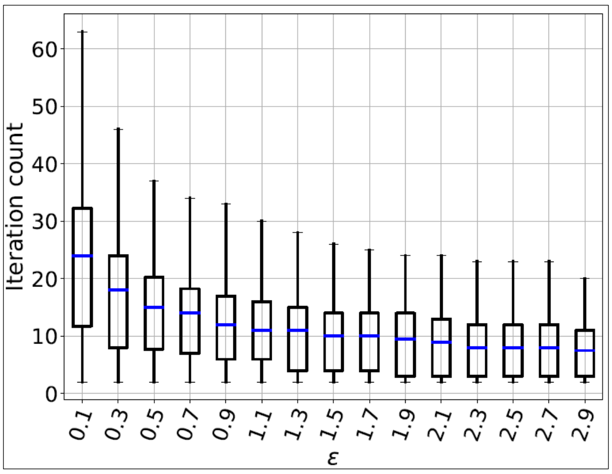


Fig. 9: Iteration count (Aoudia et al., 2017)

3.2. Spectrum and energy harvesting technique

Ansari and Han (2016) introduced the FreeNet system. FreeNet stands for Free Network which deploys spectrum and energy harvesting in the network to have better performance. The spectrum technique consists of 3 major functions which are spectrum sensing (Yucek and Arslan, 2009), spectrum management and spectrum sharing (Akyildiz et al., 2008). The implementation of spectrum and energy harvesting techniques is used to alleviate the spectrum and energy constraints by sensing and harvesting the spare spectrum for data communications and utilizing renewable energy as power supplies. By deploying spectrum and energy harvesting techniques, it increases the spectrum and energy efficiency in wireless networks and enhances network availability. Besides, FreeNet liberates wireless networks from spectrum constraint, in which wireless nodes sense and utilize available spectrum for data communications. Thus, FreeNet will enhance spectrum agility and energy efficiency in the network, improving network ubiquity and by easily incorporating new technologies as long as rules on sensing and utilizing the spectrum are followed.

FreeNet is deployed in three major purposes which are alleviating network congestion in urban areas, provisioning broadband services in rural areas and enhancing emergency communications capability in unexpected critical situations (Ansari et al., 2008) caused by natural disasters such as hurricane or earthquake. For the first major purpose, FreeNet dynamically exploits an under-utilized spectrum to enhance the spectrum efficiency of wireless networks. Meanwhile, in the second major purpose, FreeNet is used to deploy multiple infrastructure-based energy harvesting BSs which is to provide broadband services in remote rural areas. For the third major purposes, it is used to provide users with basic communication connectivity, extending the lifetime and coverage area of an access network.

The method involved in FreeNet is an infrastructure of the network which consists of both infrastructures based wireless access networks and mesh-based wireless access networks. For infrastructure-based access networks, Base Stations with higher renewable energy may adopt advanced transmission techniques and aggregate more bandwidth to serve more traffic demands. Meanwhile, for mesh-based wireless access networks, routing strategies are optimized to maximize the utilization of available spectrum and renewable energy while reducing grid power consumption.

Usage of user plane protocol in FreeNet causes minimal packet delay and packet loss between two networks, thus enabling packet routing via heterogeneous networking. In addition, it leads to minimum overhead in FreeNet due to the communication protocol suite which consists of a control plane, energy plane and user plane. In the power plane protocol deployed in FreeNet, it shared renewable energy information among wireless access points as well as control renewable energy sharing and distribution among wireless access points to enhance the utilization of renewable energy. Thus, deployment of the FreeNet for energy harvesting in wireless networking leads to a more positive effect than a negative effect. Therefore, it is significant to have an energy harvesting element in wireless networking for better performance in the network as well as nodes. Fig. 10 shows the FreeNet concept.

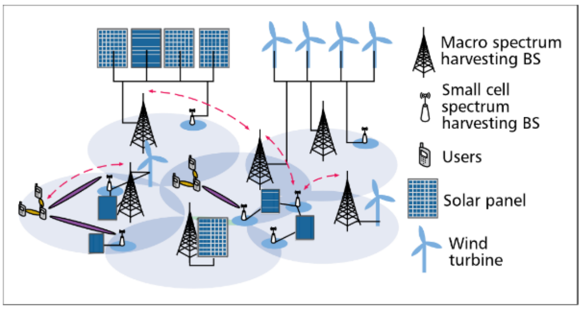


Fig. 10: FreeNet: spectrum and energy harvesting wireless network (Ansari and Han, 2016)

3.3. Power feedback control MPPT

Deorankar and Markande (2014) proposed the power feedback control maximum power control tracker (MPPT) technique in harvesting energy for a solar panel. This technique is used when the LDR sensor for energy harvesting on the solar panel is off and the power feedback control MPPT takes over the process of energy harvesting. The maximum power point tracking (MPPT) modifies the electrical operating point of a solar energy system to ensure it generates the maximum amount of power. Therefore, it involves finding the maximum power generated on the solar panel by finding the maximum voltage or current of the solar panel. Besides, MPPT improves the electrical efficiency of a solar energy system, thus reducing the number of solar panels or arrays required to generate the desired output. In order to see the effectiveness of the proposed technique, the experiment is conducted.

Fig. 11 shows the experiment set up to test the technique and to obtain the result using the solar panel and microcontroller. One of the types of equipment involved is a microcontroller which is used to switch the LDR technique to power feedback control MPPT technique. The other equipment is ultra-capacitor which is used to store the harvested energy on the solar panel. The ultra-capacitor is used because of the ability to store the maximum amount of energy with minimum leakage current which is more efficient. But the back power is also provided in case of any power failure.

Fig. 11: Experiment set up (Deorankar and Markande, 2014)

Based on Fig. 12, it can be seen that in the bottom graph, the power feedback control MPPT techniques find the maximum point of maximum power generated at a certain level, meanwhile, without the technique of the power feedback control MPPT, the searching of the maximum power generated is continuous and it will lead to increased usage of battery to power up the system. Thus, using the power feedback control MPPT will save energy and prolong the battery life and more energy can be harvested using low battery usage.

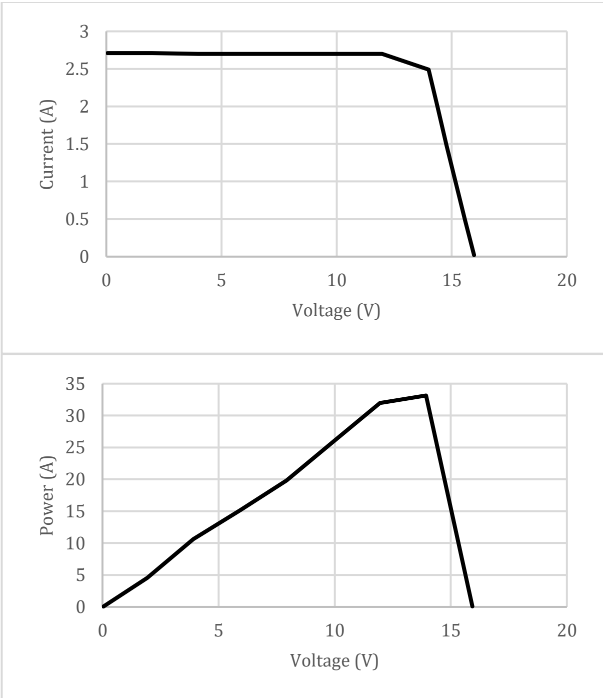


Fig. 12: PV-output power with and without MPPT (Deorankar and Markande, 2014)

3.4. Thermal energy harvesting (TEH) technique

Hoang et al. (2009) proposed the thermal energy harvesting technique to harvest energy for the wireless area body network (WBAN). This technique is used to support a selective gateway method where this selective gateway method uses the concept of residual energy in each of the nodes present in the topology of the network. Among ambient energy, thermal energy is one of the potential energy sources 7 in which a thermoelectric generator (TEG) is used to extract energy from human warmth.

According to Stark (2006), the warmness of a human body (and also an animal body) can be used as a steady energy source for powering the sensor node in WBAN. For the thermal energy harvesting technique, once the input thermal energy is known, the equivalent electrical circuit of the thermal energy harvesting (TEH) structure with the thermoelectric generator (TEG) can be used.

Fig. 13 shows the thermal equivalent circuit representation of a TEG in contact with the human skin. In order to harvest energy using TEG in TEH, the components used in TEG are aluminum and Teflon.

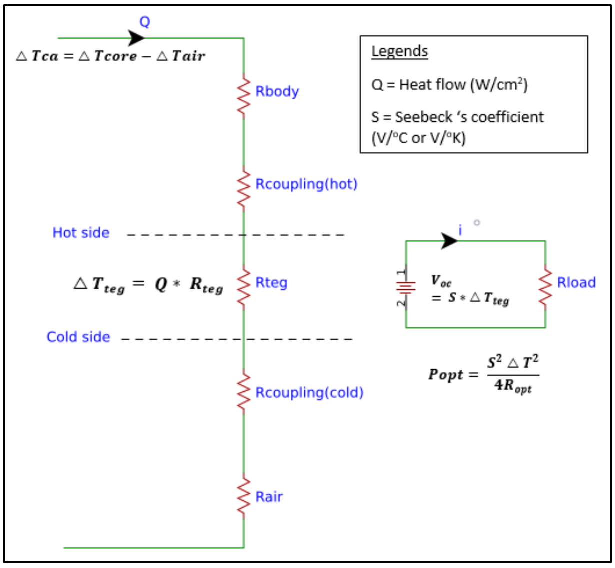


Fig. 13: Thermal analysis of the thermoelectric generator (TEG) (Hoang et al., 2009)

Fig. 14 shows the prototype of TEG in TEH. The Teflon is sandwiched between the cold plate and hot plate aluminum to effectively reduce the convection and radiation of heat from the hot plate and the cold plate, preventing it from warming up which is highly undesirable as it reduces the thermal gradient between the plates thus affecting the heat flow and power output.

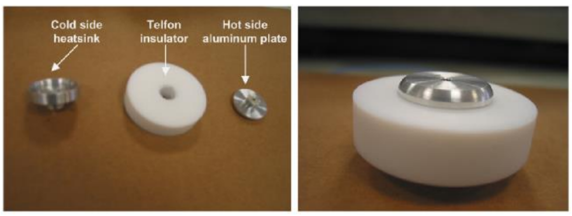


Fig. 14: Prototype of the thermoelectric generator (TEG) (Hoang et al., 2009)

To see the effectiveness of TEH for WBAN, Fig. 15 illustrates the results obtained from the experiments conducted.

Fig. 15 shows the power generated by the TEG for various loading conditions. Different thermal gradients applied across the thermal energy harvester between 3 degrees to 15 degrees, results in maximum electrical power generated ranging from 40 µW to 520 µW respectively at the same load resistance of 16KΩ. It can be seen that the higher the thermal energy harvester applied, the higher the maximum electrical power generated and it is sufficient to power up the WBAN implemented inside or outside the human body. Therefore, this TEH technique can help the selective gateway method to prolong the life of nodes involved and also the battery of the WBAN.

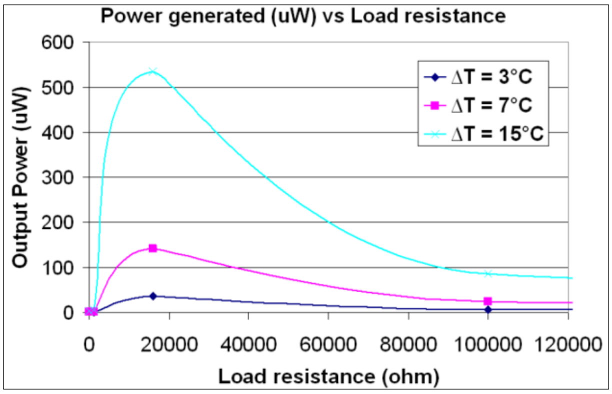


Fig. 15: Power generated by the thermoelectric generator for various loading conditions (Hoang et al., 2009)

3.5. Electric field energy harvesting technique

This electric field energy harvesting technique is proposed by Chang et al. (2012) to solve the problem of current flow through the power line in order to harvest energy using magnetic field around power lines. This harvesting technique used the commercial insulated 220 V power line to harvest electric field energy. This technique is called an electric field energy harvesting due to energy harvested from the stray electric field of the current carrying (voltage applied) conductor. Chang et al. (2012) used to wrap the aluminum foil cylindrically around an insulated AC power line to harvest the electric field energy without removing the insulating sheet. Then, the harvested energy experiments to power up the low-power wireless sensor nodes. Fig. 16 shows the experiment set up to harvest electric field energy.

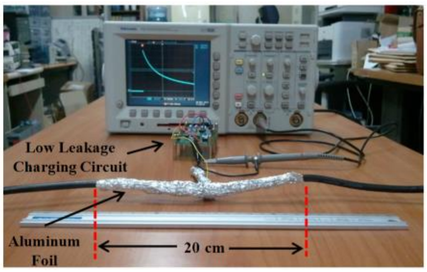


Fig. 16: Experimental setup for stray electric field energy harvesting (Chang et al., 2012)

Based on Fig. 16, the aluminum foil is wrapped along 20 cm around the insulated 220 V power line in a cylinder shape. The inner conducting wire and the foil will generate stray capacitance. Fig. 17 shows the result of electric field energy harvesting in the experiment.

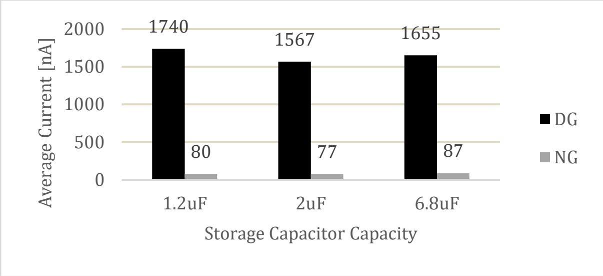


Fig. 17: Average current with respect to storage capacitor capacitance (Chang et al., 2012)

Fig. 17 shows the result of the experiment. The results involve the average current and storage capacitor. About 1600 nA of current flows into the storage capacitor regardless of storage capacitor capacitance, when the power line and the harvesting circuit are directly grounded together (DG) during energy harvest. Meanwhile, about 70~80 nA of current flows when the harvesting circuit is not grounded (No Ground, NG).

Based on Fig. 18, it is found that about 2 mJ of energy is collected in 35 seconds. The results imply that temperature measurement, A/D conversion, digital signal processing, and RF data transmission can be performed every 35 seconds, using the energy collected by wrapping 60 cm aluminum foil wrapping around the AC power line without peeling off the insulating sheath.

Thus, it shows that energy can be harvested using a very simple energy harvesting circuit from the power line and metallic foil wrapped around the power line (without peeling off the insulating sheath). Besides, it is experimentally confirmed that RF data transmission every 35 seconds is possible when 60 cm-long aluminum foil is wrapped around a 220 V insulated power line. Therefore, this technique is suitable for low cost installation and low power wireless sensor nodes.

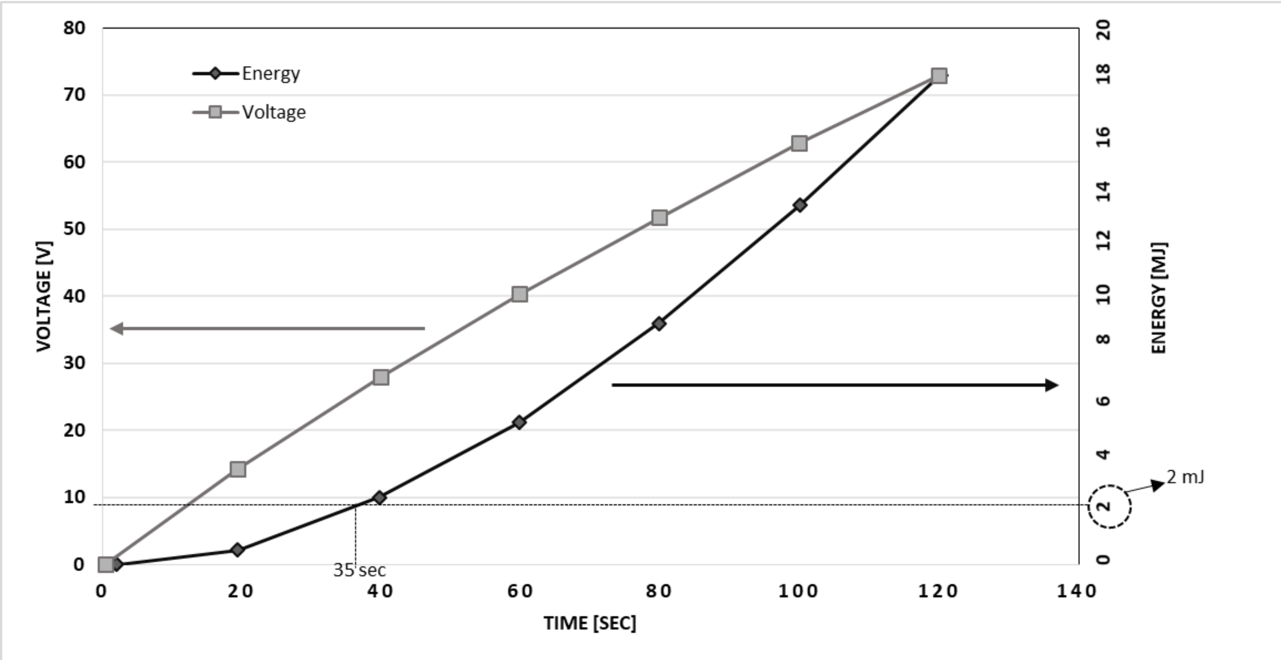


Fig. 18: Voltage and energy charged in the storage capacitor over time for energy harvesting wireless sensor node result (Chang et al., 2012)

4. Discussion and conclusion

Table 2 shows the algorithms in terms of approaches and results reviewed in this paper. Meanwhile, Table 3 shows the methods in terms of approaches and results. These tables can be used for better understanding, for the researchers or readers.

Based on algorithms and methods review done, it can be seen that each of the algorithms and methods have different functions and purposes, but only one goal which is to save energy and prolong the battery life in a wireless sensor network. Besides, the benefit of them also can help in better data transmission and better performance such as using the SSPCA. Based on the comparison result obtained, the reduction of 30% average MSE performance was gained when SSPCA (K=7) compared to HSU (K=7). Meanwhile, using the ANCAEE algorithm can prolong the lifetimes of the nodes in the network and better performance is obtained as the first node dies after 500 rounds and the last node dies after 800 rounds. It shows how better the ANCAEE algorithm works as compared to LEACH and TLLEACH. For methods in energy harvesting of wireless networks, the technique of electric field energy harvesting and thermal energy harvesting is seen to be beneficial as compared to others. In thermal energy harvesting, usage of energy harvesting in the WBAN is effective. The TEG used can harvest energy based on the thermal difference for WBAN either in or outside the human body. This gives an advantage because it shows that the human body can also produce energy in certain terms. Meanwhile, for electric field energy, it can power up the low power wireless sensor nodes with a small amount of energy produced and low cost installation is needed to set up the project or experiment.

Table 2: Algorithms in terms of approaches and results

Algorithms	Approaches	Results
Novel Energy Efficient Clustering (NEEC)	Hybridization of static and dynamic operation usage Distributed-centralized approach and multi hop routing	More packet can be sent Increased number of available nodes Avoidance of data transmission for long distance Minimum packet lost Better throughput
A Novel Clustering Algorithms for Energy Efficiency in WSN (ANCAEE)	Cluster Head (CH) selection Single hop data transmission to CH for each node Multi hop data transmission from CH to Base Station	Extends battery life time Prolong sensor network utilization Saves more energy Increase the life period for first mode and last nodes
QL-SEP	Daily Ratio (DR) parameter is added to EHWA equation Each slot is initiated with a Q-value Time domain is split into equal length slots	Better performance in terms of prediction errors Ability to adapt to temporal changes quickly
Power Splitting Optimization (PSO) algorithm	Implementation of power allocation in PSO “Water-filling” power allocation strategy	Increased sum of rate in the network Decrease the sum harvested power happen
Sleep-Wake Power Control Algorithm (SSPCA)	Exploitation of the Lagrangian duality approach Computational complexity of SSPCA (inner loop and outer loop)	Increment of storage efficiency Increase of MSE in the network Increased the SN’s measurement transmission
Energy-Harvesting Wastage Aware (EHWA) Routing Algorithm	Scheme of route selection On-demand routing or Dynamic Source Routing	Additional incentive to avoid low energy nodes Maximizing total residual network energy More harvest energy will be utilized Larger total residual energy in network remains

Table 3: Methods in terms of approaches and results

Methods	Approaches	Results
Fair Packet Ration Distributed Computation Method	Distribution of PGRs Parameters of energy cost for nodes Energy cost of relying ADMM	Decrease of energy management (EM) overhead Reduces average number of iterations Harvests more energy
Spectrum and Energy Harvesting Technique	Sensing and harvesting spare spectrum for data transmission Utilizing renewable energy Infrastructure based wireless access networks Mesh-based wireless access networks	Increased spectrum and energy efficiency in wireless networks Enhanced network availability
Power Feedback Control MPPT	Find the maximum voltage or current of the solar panel	Saves energy Prolongs the battery life More energy can be harvested with low battery usage
Thermal Energy Harvsting (TEH) technique	Concept of residual energy in each of the nodes Thermo-electric generator (TEG) usage	Higher maximum electrical power generated Prolongs the life of nodes involved Prolongs the life battery of WBAN
Electric Field Energy Harvesting Technique	Wrapped AC power line Energy harvested from the stray electric field of the current carrying (voltage applied) conductor	Fast data transmission, such as RF data, temperature measurement, A/D conversion and digital data processing

By reviewing the algorithms and methods used to harvest energy in the wireless network, it can give a better understanding to the researchers and they can compare algorithms and methods and select the most suitable one for their project. Therefore, we can say that based on the different algorithms and methods, energy harvesting in the wireless network is beneficial and effective according to various implementations. Thus, this review is beneficial for the researchers to study on the variation of algorithms and methods that existed for energy harvesting in the wireless network.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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