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E^2BNAR: Energy Efficient Backup Node Assisted Routing for Wireless Sensor Networks

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Abstract: In Wireless Sensor Networks (WSNs), each sensor node can only use so much power before recharging. If energy is depleted too quickly, nodes will fail one by one, bringing down the network as a whole. To this end, a design is needed to reduce the burden on the sensor nodes' power supplies while extending the network's useful life. This paper proposes a new approach, called Energy Efficient Backup Node Assisted Routing, to accomplish this (E2BNAR). Each primary node in the network has a group of backup nodes to ensure the network continues functioning. Assuming that the sensor nodes are capable of energy harvesting, E2BNAR finds the best backup node by analyzing the statistical relationship between energy harvesting and consumption rates. Periodically, residual energy is used to analyze the current energy consumption rate. When evaluating performance, several different indicators are taken into account. These include the Packet Delivery Ratio, Throughput, Average Energy Consumption, and Number of Awakened Sensor Nodes. Through analysis and experimentation in several settings, the proposed method's efficacy has been established.

Keywords: Energy Harvesting, Backup Nodes, Harvesting Rate, Depletion Rate, Activation Energy, Awaken Sensor Number.

I. INTRODUCTION

For the past three decades, with advancements in the communication technology, there is a huge demand for sensing devices for different applications in different domains. In the networking field, WSNs have obtained a great significance in the research due to its potential applicability in several applications like environmental sensing and monitoring [1], surveillance [2], machine and structural health monitoring [3], precision agriculture [4], object tracking and monitoring, monitoring of natural and man-made crises like earthquakes, disasters, acoustic data gathering and health care etc.., [5, 6]. The main working theme of WSNs is to maintain connectivity between sensor nodes (SNs) through wireless links to achieve ubiquitous communication. A typical WSN is established by a number of SNs which are capable of three activities namely, Sensing, Processing and Transmitting data to other SNs or to sink node through wireless links. The SNs are smaller in size and thus they have limited resource availability. In maximum number of applications, once the network is deployed for some purpose, the replacement of nodes is a tough task because, their deployment may be done in such kind of areas where the power supply is a tedious task, for example deserts, hilly and terrain areas. In addition to the issues related to power supply of SNs, they also have inadequate storage and computational abilities which are generally considered during the research in WSNs.

The major challenge in WSNs is the limited battery-oriented power supply [7, 8] which shows a significant influence on the network lifetime and restricts the nodes to offer various types of services for a longer time period. In WSNs, the SN consumes energy for data transmission, computations, processing and sensing. Among these four tasks, sensing needs more energy consumption. Hence it is required to optimize data transmission at sensor nodes such that the limited resource can be utilized more efficiently. To do this, routing protocols are developed by numerical studies [10]. A substantial extent of research work has been carried and tried to lessen the energy consumption during the process of data communication between SNs [9]. However, there exists a research gap over the limitations of energy and its proper utilization in WSNs. Additionally due to the environment and structure of network architecture, working atmosphere and application domain, the SNs are probable to be constrained to function with small range communication, low packet delivery ratio, significant delay from SNs to base station and frequent path losses. These issues lessen the reliability of communication accomplished by SNs.

Even though there are so many energy efficient mechanisms derived in the past, the battery would ultimately drain out and the network may die [11]. To solve this problem, a new direction of research has been emerged where the sensor nodes have small renewable energy harvesters. Compared to the traditional energy preservation mechanisms, these methods show a superior performance in the improvisation of network lifetime [12]. In this research paradigm, the power supply of sensor node is substituted with renewable counterpart that prolongs its lifetime to some degree [13]. However, the death of network is not preventable, as the energy harvesting module moves into harvesting mode after dozing off. Moreover, the depletion rate is more than the harvesting rate because the energy consumption is more due to the execution of multiple tasks [14]. An optimal solution for this problem is the provision of alternative backup nodes for the nodes dozing off. This could avoid the network demise and hence the network would be sustainable.

With this inspiration, we propose a new routing mechanism called as Energy Efficient Backup Node Assisted Routing (E^2BNAR) that ensures minimum set of backup nodes for every SN in WSNs. This method avoids the network demise by providing alternative nodes for every SN in the WSN. Whenever a source node finds that the current supporting node tends to move into harvesting mode, it searches for alternative nodes. For alternative node selection, the source node considers two parameters; they are energy harvesting rate and energy depletion rate and establish a statistical relation between them. Based on the relation among the available alternative nodes, one node is finalized which has smaller depletion rate.

The residual paper is structured as; the particulars of literature survey explored in 2nd section, the full-fledged particulars of proposed Energy Efficient Backup Node Assisted Routing are illustrated in 3rd section, section 4 illustrates the complete particulars of experimental analysis and the concluding remarks are provided in the last section.

II. LITERATURE SURVEY

In the design of any routing protocol for WSNs, the sensor node's energy is the prime aspect which needs to be considered. The sensor nodes with low energy have impact on the routing decisions and cause a serious deprivation in the network performance. For the energy aware routing mechanism, the minimum hop count scheme [15] is not suitable as they might result in the exhaustion of node's energy in the shortest path (SP) at larger rate than other SNs in the network. Rong Cui et al. [16] considered four parameters during the selection of routes. They are Bit Error Rate (BER), Energy Wasting, Quality of Transmission and Energy Consumption. A vibrant design is employed to determine a SP after the division of entire WSN into several layers. Hence the conventional routing protocols are modified and energy aware parameters are included. For instance, Jacobson et al. [17] proposed Distributed Energy-Harvesting Aware Routing Algorithm (DEHAR) to determine an optimal route between source and destination nodes. DEHAR proposed a new metrics called as energy distance which is the combined form of hop count and energy consumed in the path.

Some approaches considered residual energy and some more methods considered energy consumption prediction model during the shortest path selection in WSNs. By the invention of energy harvesting sensors, a paradigm shift has been occurred from energy aware routing approaches to energy harvesting aware routing approaches as they focus on achieving quality at the availability of an ambient energy [18]. In this section, we discuss different routing methods which considered the energy harvesting rate over the routing cost. Kollias and Nikolaidis [19] implemented an offline routing protocol that constructs routing tables with the help of harvesting rates of solar energy and the earlier established paths. This approach is fairly simple and the main advantage is less energy wastage. For the sources with periodical energy harvesting nature, this kind of methods is much beneficial. Yifeng Cao et al. [20] designed a new routing protocol called as Energy Harvesting Routing (EHR) which considers energy harvesting as the major factor to enhance the energy efficiency. Each sensor node maintains two tables (self-table and neighbor table) and consists of three attributes such as Energy harvesting Rate, Energy consumed per data packet transmission and residual energy. In this method, every node maintains dynamic energy information of its neighbors and chooses an optimal next hop. However, the major drawback of these methods is that if a SN dies the probability of node recovery in a table based routing protocol is very less. Hence, the online mode routing protocols are one of the best option which enhances the routing performance in WSNs.

The online based routing protocols are also called as dynamic routing protocols because they can adjust the network settings dynamically according to the current status of sensor nodes. Generally they measure route cost during the selection of route between source and sink nodes. Towards the routing selection in energy harvested WSNs, the route cost generally use the parameters related to energy harvesting. Gong et al. [21] proposed a new routing protocol by modifying the most popular Ad hoc On-Demand Distance Vector (AODV). The modification is done at the hop count field by replacing it with the energy count such that it can find a route which has least cost of energy and it is assessed based on the SNs energy harvesting capability. Pais et al. [22] considered three attributes to model the route cost. They are source node's harvested energy, source node's residual energy and hop count between source and destination. However, the above mentioned three parameters are effective only when the routing is done from source node, i.e., Dynamic Source Routing (DSR). The lack of information about intermediate nodes characteristics results in network failures. This method is further enhanced by Cheng et al. [23] by considering the statuses of future path hops along with the information related to next hop.

S. Peng and C.P. Low [24] designed an Energy Neural Routing (ENR) protocol created on direct diffusion. Each node in ENR has a choice to admit or reject the requests regarding the packet relaying based on its status of energy harvesting and helps in the fair distribution of network traffic load to obtain Energy Neutral Operation (ENO). Bai et al. [25] proposed a Smart Energy Harvesting Routing (SEHR) that formulated the route cost function as a function of three attributes such as expected energy harvesting rate, node's energy and the type of data which was sent in earlier transmission. SEHR chooses the routes based on three main strategies such as stability, mobility and the power estimation of SN in real time. The Power Estimation attribute is measured with the help of energy drain rate and energy harvesting rate. Finally SEHR utilizes the data types and allocates priority for routes and selects only the route with high priority. However, these approaches didn't consider the wastage of harvested energy. Wastage in the harvested energy was considered in the Energy Harvesting Wastage Aware (EHWA) approach proposed by Martinez et al. [26]. It chooses the best route based on the evaluation of route cost linked with node's level of battery which gives the information about resultant energy. Among the available routes, the route with maximum resultant energy is chosen for data transmission. Further, the authors [27] extended their work by optimizing the entire network energy through the joint optimization multiple routing requests. The extended model is focused on the maximization of minimum residual energy (max-min) through Linear Programming (LP) model. For the maximization of remaining energy, the approach chose the shortest path while for maximization of minimum residual energy, longer paths are chosen that avoids low energy nodes. T. D. Nguyen et al. [28] proposed Energy Harvesting Aware Routing Algorithm (EHARA) which aimed at the improvisation of network lifetime. EHARA introduced a new parameter called as Energy back-off and combined several energy harvesting methods to improve the Quality under different traffic and different conditions of energy obtainability.

Topology control is one more strategy that manages the energy consumption of the WSN by a proper adaption of number of neighbors and transmission power of SNs. Tan et al. [29] modeled the SN behavior as an ordinal potential game where the Nash Equilibrium will be present. In the game theory, the harvesting capability and energy status of SNs is considered. Accordingly this method provided coordination between the SNs with low and high harvesting capabilities to maintain the network connectivity along with topology optimization. Yoon et al. [30] adopted a hierarchical topology control mechanism where the SNs are organized in different layers depending on the availability of their remaining energies. Since the SNs that lay nearer to the base station need more energy to procure data from multiple SNs, the load is shifted to the nodes with higher residual energies. X. Wang, V. S. Rao, R. V. Prasad, and I. Niemegeers [31] proposed a localized topology controlling method that chooses the neighbor nodes based on remaining energy levels and distance. This approach demonstrated the process as Bernoulli random process to deliberate the energy harvesting characteristics of SNs. Hieu et al. [32] proposed a Stability-Aware Geographic Routing in Energy-Harvesting Wireless Sensor Networks (SAGREH) that selects the routes based on the quality of link of neighbor nodes, solar harvested energy, remaining energy and the information about SNs location. The link quality is assessed with the help of Packet Reception Rate (PRR) which is defined as the ratio of total receiver count within a particular distance from transmitter to the average receiver count within the same distance.

Clustering is one more strategy in which the network lifetime can be improved by the optimization of energy consumption at node level. The Low Energy Adaptive Clustering Hierarchy (LEACH) [33] is one of the most popular clustering protocols that works based on the random rotation of Cluster Head. LEACH aims at the balancing of energy consumption between sensor nodes. However, the researchers in [34] found that the Clustering Hierarchy (CH) selection in LEACH doesn't consider the energy status of nodes. Upon getting the CH, a node with low energy dies immediately and makes network disconnected. Kumar et al. [35] proposed an Energy Efficient Heterogeneous Clustering (EEHC) in which the CH selection is done based on the residual energy of nodes. This approach combined the concept of EEHC with data aggregation to achieve a better QoS in WSN. In addition to effective clustering, this approach also regulates a route of data transmission that consists of multi-hop SNs those are available and also have larger remaining energy. A. Hosen and G. Cho [36] proposed an Energy Centric Cluster based Routing (ECCR) which assigns a unique rank to every node. The node rank helps in the selection of CH which is formulated based on the SN's remaining energy and distance from members. Initially the SN with higher rank is chosen as CH and in the next rounds, the previous CH stakes the information about rank.

Recently, the clustering is applied for WSN with energy harvesting capabilities to further improve the network lifetime. Peng et al. [37] proposed an Energy Neutral

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Clustering (ENC) for WSNs in which the SNs are able to harvest their own energy. ENC adopted a new concept in which the CHs can share load if the size of data is larger. Multiple CHs can reduce the frequency of cluster reformation such that the control overhead is reduced. This approach applied a convex optimization method for the determination of optimal number of clusters. Han et al. [38] proposed a clustered routing approach called as Clustering Hierarchy Solar Energy Supply (CHSES) in which the sensor nodes are assumed to have solar energy supply. This approach considers two kinds of nodes in network; they are the nodes with energy harvesting capability and the nodes with non-energy harvesting capability. During the selection of CH, two thresholds are involved for two kinds of nodes. For first kind of nodes, the threshold is influenced by self-recharge state and residual energy of nodes while the second threshold is influenced by only residual energy. The nodes having maximum remaining energy and maximum harvesting rate have more chance to get selected as CH. Yu Han et al. [39] suggested a Clustering Protocol for Energy Harvesting (CPEH) for WSNs that considered the diversity of energy harvesting capability between sensors during the formation of cluster. CPEH considers several parameters like remote degree of nodes, local density and local energy state and used fuzzy logic to perform CH selection and the allocation of cluster size. Moreover, they also applied Ant Colony Optimization (ACO) to find a highly effective inter cluster routing between CHs and base station.

Even though several methods are developed earlier for the improvisation of network lifetime in WSN by adopting energy harvesting capabilities to sensor nodes, no method is concentrated on the provision of alternative nodes at the time of harvesting mode. Even though every sensor node is able to harvest energy, the network demise is not avoidable when the multi-hop node is moved into harvesting mode. At that phase, every sensor nodes needs alternative nodes which can take the responsibility of departed nodes. Moreover, almost all the methods focused on the residual energy and harvested energies but no method has provided a relationship between depletion rate and harvesting rate. With the provision of this relation, the sender node will get more clarity about the existence of currently supporting node, i.e., how much time the node can support for data forwarding. Hence in our method, we modeled a statistical relationship between energy depletion and harvesting rates and selects an optimal node that have less depletion rate such that it can support for longer time.

III. PROPOSED MECHANISM

3.1 Overview

A new routing strategy that optimizes the network lifetime in WSNs is proposed. The proposed strategy mainly aims at the provision of alternative nodes at every instant such that the data transmission between SNs and base station won't get interrupted. For this purpose, the sensor nodes are modelled with energy harvesting capabilities and also provided with full freedom in the selection of next hop nodes. The next hop node selection is completely based on the two rates; they are Energy Harvesting Rate (EHR) and Energy Depletion Rate (EDR). Once the data transmission is started between source node and base station through the established path, the multi-hop nodes present on the path may get depleted as the time progresses. At this situation, nodes cannot support for further data transmission. Hence they move into harvesting mode and gains adequate energy to become active again. In such conditions, the source needs an alternative node so that it can forward the data to base station through it. However, there exists so many alternative nodes and only one node is required. Towards this selection, our method provides a statistical relation between the harvesting and depletion rates and based on the available information, one node is finally selected as an alternative node. In this section, network model and energy consumption model id discussed and finally energy harvesting model followed by node selection is proposed. Figure.1 demonstrates the functional block diagram of proposed method.

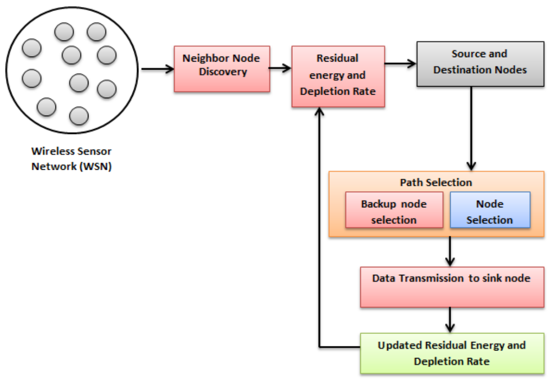

Figure.1 Functional Schematic of Proposed Method

3.2. Network Model

Here, the WSN is considered as a random network which consists of different SNs and one base station or sink node and the deployment of SNs is totally random in nature. The communication range of SNs is noted as *r*, while the communication range of base station is noted as *R*. Further the *R* is supposed to be much larger than the *r* (R>>r). Here, the SNs are anticipated to have the capability of energy harvesting. At the time of data forwarding, if any SN is found to have lower residual energy, then that SN dozes off (turns off all jobs like sensing, transmitting, receiving etc.) and moves into harvesting mode. The SN will get activated only after harvesting sufficient energy and it is named as activation energy. Further, the process of energy harvesting is said to be a stochastic process where the harvesting rate of SNs is totally dependent on various factors like environmental conditions, harvesting circuitry, location of sensor nodes etc. Hence it is considered as Spatio-temporal process where the spatial process is linked with the spatial locations and temporal process involves different time like day time and night time. Furthermore, it is assumed that the Energy Harvesting Rate (EHR) is always slower than the Energy Depletion Rate (EDR).

In the initial phase, for a randomly deployed network, the neighbor node discovery is accomplished. Under this phase, every sensor nodes tries to find the set of neighbor nodes which are within the *r*. For this purpose, the distance is measured from each node to every node. Here the Euclidean distance is considered as the distance between two sensor nodes. Consider two sensor nodes n_i and n_j, the distance $\left(d\left(n_i,n_j\right)\right)$ between them is calculated as,

$$d\left(n_i,n_j\right)=\sqrt{\left(x_i-x_j\right)^2+\left(y_i-y_j\right)^2} \quad (1)$$

Where (x_i,y_i) is the location of SN, n_i and $\left(x_j,y_j\right)$ is the location of SN, n_j. After the distance computation, it is compared with the communication range of node and if the distance is observed as less than *r*, then those two nodes are said to be neighbor nodes otherwise they are considered as non-neighbor nodes.

$$n_j=\begin{cases} neighbor,\ if d\left(n_i,n_j\right)\leq r \\ Non-neighbor,\ otherwise \end{cases} \quad (2)$$

Now, every node is having a set of neighbor nodes and if any node wants to transmit the data to sink node, it starts route discovery followed by data transmission over the discovered path. Once the path is discovered, the source node starts data transmission and keeps on tracking the resources of multi-hop nodes such that it can take immediate decision based on the current statuses.

3.3. Energy Consumption Model

In WSNs, the SNs have limited energy and there are fewer chances for energy replenishment. Hence the energy preservation is more important which has a direct link with network lifetime. During the networking process, if any node is moved out of communication due to its energy depletion, then the entire network may get useless or fragile. Hence there is a need to keep on tracking the energy of multi-hop nodes that are participating in the data forwarding process. Hence this work considers the energy consumption as main reference parameter for node selection. SNs require more energy when operating in relay mode to receive packets from sender nodes and forward them to either the next hop nodes or the base station. While exploring their environment, SNs may consume more energy than usual. This is because SNs must exert a substantial amount of effort to broadcast route request packets to the most remote parts of the communication network. After establishing a connection with the base station, multi-hop nodes will aid the source node in transmitting data to the destination node. Common multi-hop nodes quickly deplete the network's resources. The source node must continually monitor the energy levels of the multi-hop nodes. The source node's power is essential for transmission. There are four distinct configurations for sensor nodes in a network. They are responsible for signal processing, transmission, and reception. The third mode, which involves the transmission and reception of data, is the most energy-intensive of the three. This technique disregards the energy expended during the first two modes. Only the transmission and reception power are considered. Transmission requires significantly more energy than reception. According to these studies, the total amount of energy a node consumes at time t is equal to the amount of energy it expends when receiving and transmitting data. The remaining energy of a node is determined by measuring the rate at which its energy is being depleted, followed by the total amount of energy it has consumed. Based on the obtained depletion rate, the node's forwarding capacity is measured. Consider $T_E(t)$ is the transmitting energy, $R_E(t)$ is the receiving energy at particular time instant t_c, the Overall Energy $(O_E(t))$ is computed as

$$O_E(t_c)=T_E(t_c)+R_E(t_c) \quad (3)$$

The mathematical expression for Transmitting and receiving energies are expressed as

$$T_E(t_c)=E_e\times k+E_a\times k\times d^2 \quad (4)$$

And

$$R_E(t_c)=E_e\times k \quad (5)$$

Where E_e stands for the unit energy, E_a stands for the unit amplification energy, k stands for the number of bits, and d stands for the distance between the nodes that are transmitting and receiving information. In terms of the total energy, denoted by $O_E(t)$, the amount of energy that is still present at the node is measured as

$$Re_E(t_c)=Re_E\left(t_p\right)-O_E(t_c) \quad (6)$$

Where $Re_E(t_c)$ is the residual energy of a SN at current instant t_c, $Re_E\left(t_p\right)$ is the residual energy of a SN at previous instant t_p. Depending on the present residual energy

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$Re_E(t_c)$ and initial energy, the Energy Depletion Rate (R_d) is computed as

$$R_d = \frac{(Re_E(t_p) - Re_E(t_c))}{(t_c - t_p)} \quad (7)$$

According to the above expression, the depletion rate is simply measured as a slope between two points if we draw the residual energy plot with respect to time. As the time progresses, the energy of nodes decrease hence the plot follows decreasing characteristics with increasing time characteristics. In Eq.(7), the numerator gives the difference of residual energies and the denominator gives the difference between time instances. The simple plot for residual energy versus time period is shown in the Figure.2. According to this figure, the depletion rate is nothing but slope calculation, as the numerator gives the difference between residual energies and denominator gives the difference between time instances. Based on the obtained values at every current instance, the node's existence can be estimated, i.e., the node can exist until the delivery of current set of packets or not. If the current Depletion rate is more than the previous value of depletion rate, then that node is not considered for data forwarding because it is assumed to be working as a relay for more source nodes. For a particular node, if the number of nodes seeking the help is more, then the depletion rate is high and the node's energy gets depleted quickly.

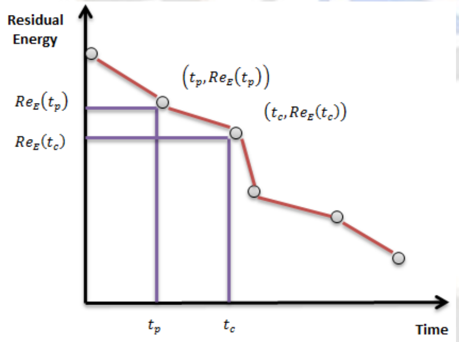

Figure.2 Residual energy at different time instances

3.4 Energy Harvesting Model

In general, for a network area with larger size, most of the SNs do not exist within the communication range of base station. Thus, it is not possible to transmit the sensed data directly to the base station and seeks the help of other sensor nodes. Thus, the major responsibility of a SN in WSN is not only sensing the environment but also relaying, means helping other SNs to forward their data to base station. Because of the execution of these multiple tasks, the SNs are awake for almost all time and this consequence to quick energy depletion. At this instant, the provision of an additional backup energy source is required but it is a tough issue and involves huge hardware cost. The best solution for this problem is providing the energy harvesting capabilities for SNs. If a SN is able to generate the energy itself from natural resources, then it has so many advantages like longer network lifetime, larger data processing support etc.

In this work, we presumed that the sensor nodes can harvest the energy from sunlight and utilizes it for the communication process. This work proposes a new mechanism for the selection of multi-hop nodes based on their harvesting capacity. For any node on the established path, if the source node finds that its depletion rate is high and residual energy is below threshold, then it starts to find the alternative node. At this phase, the source node considers the harvesting and depletion rates. Here the harvesting rate is well-defined as the time incurred for a SN to procure sufficient amount of energy such that it is in active condition. On the other hand, the depletion rate is well-defined as the time taken by a SN to deplete its energy below the threshold limit. For a multi-hop node, the major reason of energy depletion is data receiving and transmitting. Compared to the EDR of source node, the multi-hop nodes EDR is larger because the source node has only one job, i.e., transmitting but the multi-hop nodes executes two jobs such as receiving and transmitting.

In this work, to model the energy harvesting capabilities of SNs, we consider the features of energy harvesting of SNs where they will get active only after harvesting adequate amount of energy. After harvesting sufficient energy, the SN becomes active and allows communication through it. As time progresses the energy will get depleted and again the node will go into harvesting mode. Hence we derived a statistical relation between harvesting rate and depletion rate in our model. Let R_d is energy depletion rate and R_h is energy harvesting rate, an intermediate (multi-hop) node may present in three possible modes, they are

$$I_n = \begin{cases} R_d = R_h, & Neutral \\ R_d < R_h, & Preservation \\ R_d > R_h, & Depletion \end{cases} \quad (8)$$

Where I_n is the intermediate node.

Let $Re_E(t_c)$ be the residual energy of particular node at current time instant t_c, if it is less than the energy threshold (generally considered as 20% of initial energy), then it turns off it's transceiver and moves into harvesting mode. Due to the off condition of transceiver, it can't allow any kind of communication through it. Due to this reason, the source node is not able to forward data to it and results in the network getting disconnected, means the nodes those were taking help of corresponding intermediate node becomes fragile. Hence there is a necessity to keep backup nodes to execute the tasks of departed node. However the main

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challenge is to identify the alternative nodes which have efficient harvesting capabilities. One best solution is to select the backup nodes that are located nearer to the location of departed node. This solution is arrived based on the assumption that the nodes located very close have similar harvesting rates. However, this is not a feasible solution because there is no accurate prediction about the location and its harvesting rates. Moreover, the selection of backup nodes nearer to departed node may also come up with several problems including shades, barriers, location damages and physical destruction etc. Along with these effects, the inaccurate estimation about the availability of energy may cause a severe damage to the network lifetime, due to an uneven relationship between depletion rate and harvesting rate.

In the energy harvesting process, the natural resources like vibration, heat, sun and wind are generally used for harvesting, but they are totally unreliable and uncontrollable. Thus, the energy harvesting process is demonstrated as a Spatio-temporal process in which the spatial model signifies the location of nodes while the temporal model signifies different time instances. The process of energy harvesting is treated as periodic process because the maximum possible energy is harvested at day time while in the night time there is only limited energy harvesting possibility. All these constraints make the selection of multi-hop nodes highly unstable. Hence, in this work, we proposed a new concept of backup nodes selection which is totally independent of the constraints related to energy harvesting and the future availability of energy. In this work, we develop an efficient backup node selection mechanism through which every source node will get a 'z' number of backup intermediate nodes in its neighborhood. For the selection of backup nodes, we derived statistical relationship between energy depletion and harvesting rates. Further, the first condition which needs to satisfy is that the EHR must be less than the EDR. Initially the harvesting rate is measured as the quantity of energy harvested per second and the time required to get sufficient activation energy is calculated as

$$t_h = \frac{A_E}{R_h^p}, p \in P \qquad (9)$$

Next, the time of depletion is calculated with the help of residual energy and depletion rate, as

$$t_d = \frac{R_E^q}{R_d^q}, q \in Q \qquad (10)$$

Based on the obtained values in Eq.(4) and Eq.(5), the energy constraint is modeled as

$$t_h \leq \frac{1}{Q}\sum_{q \in \boldsymbol{Q}} t_d^q \qquad (11)$$

Where R_h^p and R_h^q is the energy harvesting rates of a Departed node $p \in P$ and backup intermediate node $q \in Q$ respectively. Next, R_d^p and R_d^q are the energy depletion rates of a departed node $p \in P$ and backup intermediate node $q \in Q$ respectively. Next, R_E^q is called as the residual energy of the backup intermediate node, $q \in Q$. The constriction in Eq.(11) is, it explores that the time elapsed to fetch activation energy by the departed SN to get active must be less than the average energy depletion time of all the available intermediate nodes of a particular source node. That is, the departed node $p \in P$ should harvest as minimum as E amount of energy (activation energy) by the time the backup nodes $q \in Q$ deplete their residual energies. This condition is checked at source node such that first it will get confirmation about the present node whether it is able to forward or not. After satisfying the condition, only one backup node is selected for data forwarding which has less depletion rate. The selection of final forwarding node is done as

$$I_q = \arg\min_q\left(t_d^q\right), \forall\ q \in Q \qquad (12)$$

Where I_q signifies the ID of backup node that has less depletion rate among the all available backup nodes of the corresponding source node.

IV. EXPERIMENTAL ANALYSIS

In the following paragraphs, we will discuss how the simulation works. First, we will discuss the simulation setup, and the specially-made network environment used to test the proposed procedure. The next step is to look at and talk about the simulation results. Several ways to measure efficiency were used in this study. Then, we compare the results to show that the approach is promising.

4.1 Simulation Setup

The default configuration for the simulation has N SNs dispersed randomly over a 1000-square-meter area. The simulation is set up to reproduce the unpredictable behavior of SNs accurately. That means the SNs will be in different positions in each simulation, making for a diverse group of neighbors. Once the SNs have been dispersed, individual nodes can use the channels at their disposal to discover and acquire knowledge about their immediate neighbors. Once the probe is complete, the initiating node will broadcast a "route request" packet into the network. Once the best path to the destination node has been determined by analyzing the collected route responses, data transmission along that path can begin. After the data has been successfully transferred from the origin to the destination, various performance metrics are used to assess the process's success. Many simulations need to be run while simultaneously changing network parameters, like the number of nodes and the rate at which data is transferred, to determine whether or

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not the recently developed mechanism is effective. Between 30 and 50 nodes can be supported, and data transfer rates of 200 to 1000 bytes per second are doable. Even though the number of nodes in the network may change as the exercise progresses, the packet size will remain constant at 500 bytes. Therefore, when the data rate is not constant, neither is the packet rate. The data rate can be adjusted while the total number of nodes in the network stays the same. Table 1 provides a comprehensive breakdown of the simulation setting.

Table.1 Experimental Setup for simulation

Network parameter	Value
Node Count	30-60
Network area	1000*1000 m^2
Transmission Range	15% of network area
Node's deployment	Random
Size of each packet	500 byte
Initial energy of SN	1 joule
Maximum Sensor Energy Capacity	2 Joule
Base station location	Randomly Changed for every simulation
Size of Control packet	25 byte
E_e	50 nJ/bit
E_a	0.0013 pJ/bit
Harvesting rates	25 μW-250μW
Activation Energy	0.5 J
Data rate	200 – 1000 bytes/sec

4.2 Results

In the "Results" section, the efficacy of the proposed method is assessed via four performance metrics. These metrics include average energy consumption (AEC) in millijoules (mj), packet delivery ratio (PDR), average awake sensor number (ASN), and throughput (in kilobytes per second [kbps]). These figures represent the mean of the distribution; the mean was arrived at by averaging the results of 25 individual tests. It is compared to several other methods, including the recently proposed EEBNAR method and LEACH [33], and CPEH [39]. Changes are made to the data rate and the total number of nodes to make a fair comparison. Throughput, the average number of awake sensors, energy consumption, and packet delivery rate are just some of the performance metrics we track in our first case study comparing different data rates. The number of packets sent per second can range from 20 to 100. The metrics related to a change in the total number of packets transmitted between nodes must be investigated whenever this number fluctuates.Next, in the second case, the number of node deployed in the network are varied and the total number of awaken sensor nodes are measured. At this phase, the data rate is kept constant, i.e., 60 packets/sec.

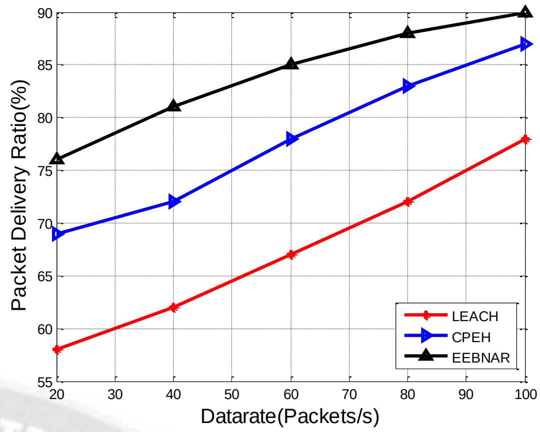

Figure.3 packet Delivery ration at different data rates

With an increase in the data rate the nodes capability gets increased thereby they can forward the data to their next hop node efficiently. As the data packets received at destination node increases, the packet delivery ratio increases. For the available data at source node, if it was forwarded in a small size (lower data rates), then the packet loss at each node increases because the nodes may or may not exist until the complete transmission of entire data. In such conditions the packet loss increases and packet delivery rate decreases. From Figure.3, we can see that the PDR at lower data rates is less while it is more at larger data rates. Moreover, we can also see that the PDR of EEBNAR is higher compared to LEACH and CPEH. The main problem of these two methods is that they didn't consider the energy harvesting capabilities. Hence, the multi-hop nodes obtained at first interaction won't exist until the completion of entire data transmission. Due to the consideration of energy harvesting capabilities, our method tries to keep the network active thereby the entire data gets delivered at sink node and results in larger PDRs.

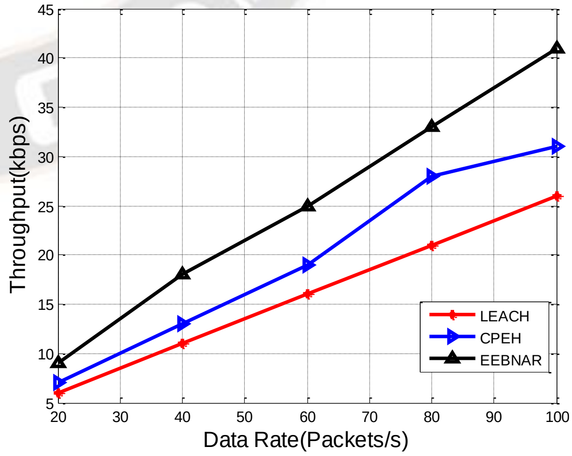

Figure.4 Throughput (kbps) at different data rates

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In WSNs, Throughput is directly related to data delivered at sink node and inversely linked with time taken for that delivery. As the total numbers of packets delivered at sink node increases, the throughput also increases, but it decreases with an increase in time taken for delivery. For a constant time period, for lower data rates, the throughput is less because the sender node sends data in smaller sizes. In contrary, the throughput is observed as high for larger data rates because the huge amount of data will get forwarded within the given time period. Thus the throughput increases with an increase in the data rate, as shown in Figure.4. Moreover, the throughput of EEBNAR is high compared to LEACH and CPEH because the proposed approach is employed to choose the intermediate nodes with larger residual energy characteristics. The earlier LEACH and CPEH employed clustering in which the CHs are only responsible for data communication. Since only CH can forward that, first of all it needs to acquire data from cluster member nodes which consumed more time and results in fewer throughputs. Moreover, LEACH won't consider energy status of CH when altering them.

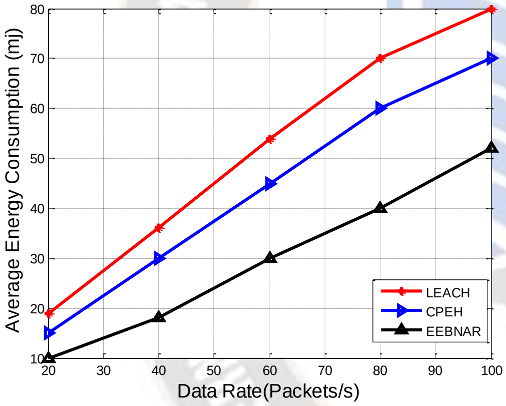

Figure.5 Average Energy Consumption at different data rates

The increase in Data rate increases the total number of bits that are to be forwarded in data at a time. As the number of bits to be forwarded increases, the node has to use more energy to forward them. Hence the Average Energy Consumption shown in Figure.5 followed an increasing order with data rate. In the earlier LEACH and CPEH, the energy consumption is high because the data forwarding responsibility is assigned for CHs but not for Cluster nodes. In such conditions, the CH consumes more energy because it has to forward the data for multiple cluster nodes. For such type of CHs, there is a need of additional power supply otherwise they will die quickly. Due to this, the packet retransmission increases which also increases the energy consumption. To solve this problem, our method introduced the concept of back up nodes provision with energy harvesting capabilities. So, the burden of larger sized data forwarding is equally distributed in all nodes such that no node will die quickly. Hence the average energy consumption of proposed EEBNAR is less compared to the earlier methods.

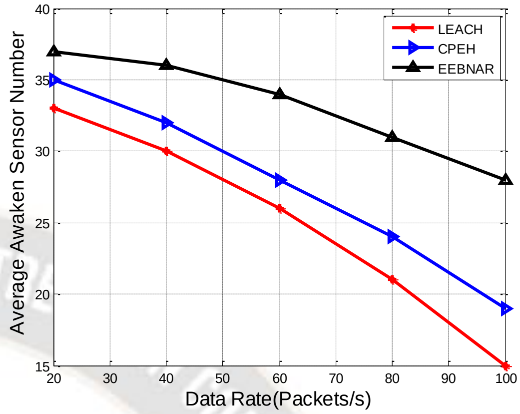

Figure.6 Average Awaken Sensor Number at different data rates

As the energy depletion rate increase, the sensor nodes will die quickly and results in less awaken sensor nodes. The rise in energy consumption is directly proportional to data rate, as more data transmission needs more energy. So, from Figure.6, we can see that the total number of awaken sensor nodes are high at lower data rates and are low at higher data rates. Since we applied energy harvesting concept, most of the nodes in the network are in awaken state. For example, consider above figure, the number of awaken senor nodes through EEBNAR at data rate of 60 packets/sec are approximately 34 while the average awaken number of sensor nodes through LEACH and CPEH are 26 and 28 respectively. In this simulation, we simulated the network only with 40 nodes. Among the 40 nodes, the proposed method keep 34 nodes awaken even at larger data rate (60 packets/sec). Due to the non-consideration of backup nodes concept in LEACH and CPEH, they are observed to have less number of awaken sensor nodes.

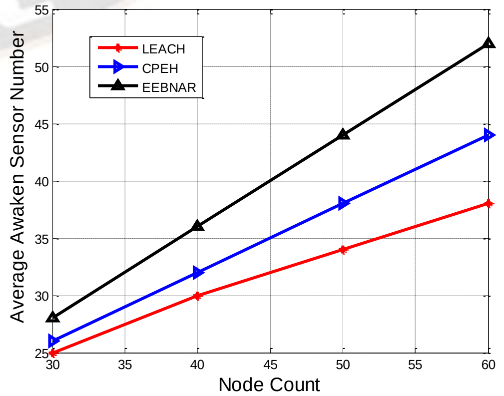

Figure.7 Average Awaken Sensor Number at different node count

Figure.7 shows the average awaken sensor nodes for varying node count. As the number of nodes deployed in network increases, the probability of awakens number also increases because every design methodology tries to keep maximum number of node to be awaken. However, the awaken time is directly linked with energy consumption, as the residual energy goes decreasing, the probability of node to die increases. This probability can be reduced by providing the node an external power supply. However, it is not possible because their deployment is generally done in uneven areas where power provision is not possible. In the E^2BNAR, the SNs are assumed to gain the energy through harvesting process thereby they are almost awaken for more time. For the deployed count, the proposed method tried to keep approximately 85% of nodes awaken in all instances, as shown in Figure.7. However, the LEACH and CPEH ensured less count of awaken nodes because the methods did not provide energy harvesting capability or back up node provision strategy, thus most of the nodes will die through those methods.

V. CONCLUSION

In WSNs, network lifetime improvisation is the prime aspect which needs to be considered because the long lasting network can improve the QoS. With this objective, we have proposed a new method called as Energy Efficient Backup node assisted Routing which ensures at least one backup node for every SN in the WSN. For this purpose, the EEBNAR applied an energy harvesting rate and energy depletion rate aware routing. EEBNAR selects the multi-hop nodes based on a statistical relationship between EHR and EDR. For a currently supporting node, if it is found that its energy is below the energy threshold, then it halts entire communication and switches into the harvesting mode. At that instant, the EEBNAR finds an optimal backup node and makes the network alive and helps in the improvisation of QoS. Simulation experiments reveals the effectiveness of proposed approach through packet delivery ratio, energy consumption and number of awaken nodes.

Declaration of Originality

We declare that this research is entirely our own work and no portion of the research has been submitted in any form in support of an application for another Publication. Information obtained from external sources has been duly acknowledged and referenced. We hereby declare that the work being presented in this research entitled "E2BNAR: ENERGY EFFICIENT BACKUP NODE ASSISTED ROUTING FOR WIRELESS SENSOR NETWORKS"; is an authentic record of our own work carried out during the period 2017-22.

We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

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