A Duty-Cycle based Cooperative Clustering Protocol for Energy Harvesting WSN

Prof. Dr. A. Lenin Fred,
Professor,
Computer Science and Engineering,
Mar Ephraem College of
Engineering and Technology,
Marthandam, India

Mrs. J. Janila,
Assistant Professor,
Computer Science and Engineering,
Mar Ephraem College of
Engineering and Technology,
Marthandam, India

Mrs. L. T. Herlin,
Assistant Professor,
Computer Science and Engineering,
Mar Ephraem College of
Engineering and Technology,
Marthandam, India

Mrs. Austy B Evangeline
Assistant Professor,
Computer Science and Engineering,
Mar Ephraem College of
Engineering and Technology,
Marthandam, India

Mrs. Lincy C T
Assistant Professor,
Computer Science and Engineering,
Mar Ephraem College of
Engineering and Technology,
Marthandam, India

Mr. Arun Kumar,
UG Scholar,
Computer Science and Engineering,
Mar Ephraem College of
Engineering and Technology,
Marthandam, India

Abstract*— Wireless sensor network (WSN) offers a wide range of applications in areas such as traffic monitoring, medical care, inhospitable terrain, robotic exploration, and agriculture surveillance. The battery life of the sensor nodes deployed and energy efficient routing are the major areas that to be considered or improving the overall performance of the wireless sensor network. To address this issues researcher has proposed low energy adaptive clustering hierarchy(LEACH) approach. But the cluster head chosen by the LEACH approach is not that efficient. To overcome the problem, a cooperative clustering protocol based on the low energy adaptive clustering hierarchy(LEACH) approach to enhance the longevity of energy harvesting based wireless sensor networks(EH-WSN) is proposed. In the proposed protocol, to ensure that any energy consumption associated with the role of the cluster head(CH) is shared between the nodes, the CH role is alternated between the nodes using duty cycling as a function of their individual energy harvesting capability. Furthermore, to maintain an energy neutral operation when not acting as a CH, the nodes packets. To optimize the relaying performance, a novel cross layer cooperative TDMA scheme is also presented. The optimal number of clusters in an EH-WSN are analyzed in terms of energy consumption, latency and bandwidth utilization. Simulations, performed using MATLAB, demonstrate tangible performance enhancements in adopting the proposed protocol over benchmark schemes in terms of throughput and lifetime, particularly under highly constrained energy conditions.

Keywords—Clustering, LEACH protocol, duty cycle, energy harvesting

I. INTRODUCTION

Wireless sensor network (WSN) offers a wide range of applications in areas such as traffic monitoring, medical care, inhospitable terrain, robotic exploration, and agriculture surveillance. The advent of efficient wireless communications and advancement in electronics has enabled the development of low-power, low-cost, and multifunctional wireless sensor nodes that are characterized by miniaturization and integration[1].

In WSNs, thousands of physically embedded sensor nodes are distributed in possibly harsh terrain and in most applications, it is impossible to replenish energy via replacing batteries. In order to cooperatively monitor physical or environmental conditions, the main task of sensor nodes is to collect and transmit data. Sensory data comes from multiple sensors in distributed locations in the area where the sensor nodes are deployed. Wireless sensor networks perform the function of sensing and processing the sensed data depending on the requirement of the network. The occurrence of an event may cause sensor to register the data or sensing may be done periodically depending on the application to which they are used. It is well known that transmitting data consumes much more energy than collecting data.

The lifetime of a sensor node is limited by the life of the battery contained in the nodes. Because of the wireless nature of nodes, the applications demand long life for sensor nodes. This requires energy of the sensor nodes to be used very efficiently. Many applications demand minimum delay in data transmission, good throughput, and longer network lifetime.

In wireless sensor networks, the sensor nodes are battery powered and are considered intelligent with acquisitional, processing, storage, and communication capacities. However, these resources are generally very limited, especially in terms of storage and energy, and the sensor nodes activities are sometimes not negligible in energy consumption. One of the most used techniques to save power is to activate only necessary nodes and to put other nodes to sleep.

Therefore, extending the network lifetime is a major objective in WSN protocols. Many energy conservation techniques including multi-hop, cooperative transmission and duty-cycling were proposed in the literature. Specifically, multi-hop and data aggregation[8], implemented through clustering, can provide energy savings at the network layer, whereas a periodic wake-up and sleep strategy at the MAC layer can extend the network lifetime for a certain QoS requirement. Cooperative transmission at the physical layer utilizes the energy wasted in broadcast transmission by creating multiple independent paths between a source and a destination node to improve the channel capacity. Despite the improvements offered by these schemes, nodes eventually die after their energies have been exhausted. Recently, it was shown that WSN with energy harvesting (EH) capabilities, whereby nodes can harvest energy from the environment, such as solar and wind power, can sustain a perpetual lifetime. Due to the random nature of such energy sources, current protocols designed for battery powered networks must be adapted to EH scenarios. In response, EH clustering protocols were proposed that extend the LEACH protocol, in which cluster heads (CH) aggregate and then forward data packets of their cluster members to the sink node. Unlike LEACH, which evenly distributes the CH role among the nodes, the aforementioned schemes elect CHs based on their residual energies and forecasted harvesting rates. For instance, , a CH decision threshold termed the energy potential (EP) function is computed for each node in terms of its energy harvesting rate and current available energy as well as the potential functions of neighboring nodes. The optimal percentage of CHs is incorporated into a new CH threshold function that gets updated by the sink throughout the operation of the protocol. Specifically, a search algorithm is used by the sink to compare the current round's average throughput against that in the last round then a regulation factor is updated accordingly. The above solutions do not guarantee a perpetual operation and require the exchange of information among nodes, which creates additional overheads. The protocol in proposes cluster head groups (CHG), in which nodes take turns in becoming the CH to minimize the overheads of the CH selection process. Analyzed an optimal multi-hop clustering architecture to achieve a perpetual operation in EH-WSNs. Particularly, energy neutrality constraints were defined and used to obtain the minimum network data transmission cycle using convex optimization. Lastly, an EH aware routing protocol based on the gradient model is proposed for WSNs. Also, a CH selection scheme based on the residual energy of nodes and their relative positions is suggested. Then, a packet forwarding mechanism is presented, that balances the energy consumption among the EH nodes.

II. RELATED WORKS

Owing to the limited resources of the sensor nodes, designing energy-efficient routing mechanism to prolong the overall network lifetime becomes one of the most important technologies in wireless sensor networks (WSNs). As an active branch of routing technology, cluster-based routing protocols have proven to be effective in network topology management, energy minimization, data aggregation and so on. In this paper, we present a survey of state-of-the-art routing techniques in WSNs. We first outline the clustering architecture in WSNs, and classify the proposed approaches based on their objectives and design principles. Furthermore, we highlight the challenges in clustering WSNs, including rotating the role of cluster heads, optimization of cluster size and communication mode, followed by a comprehensive survey of routing techniques. Finally, the paper concludes with possible future research areas. LEACH[8] is one of the first energy-efficient clustering approach proposed for WSNs, and its thoughts of clustering run through most of the subsequent clustering algorithms, such as HEED ,TEEN . LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. It assumes that sensor nodes communicate with each by single-hop. Its operation is divided into rounds and each round is composed of two phases, In the setup phase, the clusters are organized and CHs are selected. Initially a node decides to be a CH with a probability and broadcasts its decision. Each non-CH node choose the proper cluster to join according to the signal strength from the CHs. Once the clusters are formed, the CH node create TDMA schedule and assigns each node a timeslot when it can transmit. In the steady state phase, the sensor nodes can begin sensing and transmitting data to the CHs. The CH node, after receiving all the data, aggregates it before sending it to the BS. After a certain time, which is determined a priori, the network goes back into the setup phase again and enters another round of selecting new CHs. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters. Recent developments in wireless communications have enabled the development of low-cost, low-power WSNs with wide applicability. Minimizing energy consumption and hence prolonging the network lifetime are key requirements in the design of optimum sensor networking protocols and algorithms. Node clustering is a useful energy-efficient approach to reduce the communication overhead and exploit data aggregation in sensor networks. We classified the different clustering approaches according to the clustering criteria, and further highlighted some of the basic challenges that have hindered the use of clustering in current applications, such as how to select the CHs, how to compute the optimal cluster size, and how to select the proper communication mode between sensor nodes and CHs. Although the performance of the presented protocols is promising in terms of energy efficiency, further research is needed to address issues such as the consideration of node mobility. Most current protocols assume that the sensor nodes and BS are stationary. However, there might be situations such as battle environments where the BS and possibly the sensors need to be mobile. In such cases, frequent update of the position of the command node and sensor nodes and propagation of that information through the network may excessively drain the energy of nodes. New routing algorithms are needed in order to handle the overhead of mobility and topology changes in such an energy-constrained environment . Another interesting issue for routing protocols is the integration of WSNs with wired networks[14]. More specifically, most of the applications in environmental monitoring require the data, gathered from the sensor nodes, to be transmitted to a server, so that further analysis can be done. On the other hand, the requests from the user's side should be made to the BS through Internet. Since the energy-efficiency routing[2],[6],[7],[9],[10],[11],[12],[13] requirements of each environment are quite different, further research is needed to face this kind of situations.

III. ECO-LEACH PROTOCOL

Clustering, duty cycling and cooperative transmission are combined into a novel cross-layer design for EH-WSNs. The new protocol named Energy-Harvesting and Cooperative LEACH (ECO-LEACH), modifies the LEACH technique by replacing its probabilistic CH selection process with a duty cycle based one to efficiently regulate the frequency at which a node undertakes the CH role. Besides the inherent duty cycling used by the TDMA scheduler in LEACH, another duty cycle is adopted here, by which the cluster members can skip certain allocated timeslots to maintain an ENO state. Moreover, each node follows another duty cycle to select the TDMA frames in which it is available to act as a relay. To complete the protocol, a novel cooperative TDMA scheme is proposed whereby a time-slot is split into two sub-slots. All potential relays listen to the active node's transmission in the first sub-slot then the best relay transmits the received packet to the destination in the second sub-slot. The selection of the above duty cycles accounts for the node's energy harvesting rate, packet arrival rate and the optimal percentage of CHs in the network. Hence, a rigorous analysis of the optimal CH percentage (OCHP) is given, which unlike in the case of LEACH, may not necessarily minimize the network energy consumption. Instead, the optimal percentage is the one that minimizes the latency while simultaneously achieves the ENO state and bandwidth requirements. Simulations of the proposed protocol, assuming a solar energy source with random shadows, were performed using MATLAB simulators. The results obtained show significant improvements in throughput, latency and network lifetime compared with the conventional LEACH as well as a generic energy-aware LEACH protocol. Remarkably, these gains can be realized for both EH and battery powered networks. The contributions of this work can be listed as follows:

- Formulated the optimal CH percentage problem for EH clustering based networks that guarantees ENO, while satisfying the bandwidth and latency requirements. The problem is then solved using an iterative method for which complexity is bounded by the number of nodes in the network.
- Proposed a distributed CH selection scheme, using the OCHP, based on duty cycling that adapts to the energy harvesting rates. This deterministic CH selection in ECO-LEACH is compatible with rapidly changing energy sources such that the required CH percentage can be maintained over a few number of rounds. In contrast, LEACH requires a number of rounds equal to the number of nodes before the required CH percentage is maintained. Another feature of the proposed CH selection is the absence of harvesting rate information exchanged between the nodes as in. Instead, only the average nodes' harvesting rates are required. Moreover, the proposed protocol is applicable in non-homogeneous networks, in which nodes have different capabilities and QoS requirements.
- Proposed a data transmission duty cycle to ensure ENO when the OCHP problem has no feasible solution.
- Proposed a novel TDMA-based cooperative mechanism based on sub-slots along with a relaying duty cycle design that utilizes the energy unconsumed in data transmission. The sub-slot based relaying scheme has a lower latency compared to, as the relayed transmission starts immediately after the direct one. In summary, the proposed protocol first determines the OCHP (assuming nodes transmit in every allocated timeslot) since it is the most energy consuming role. If no feasible solution is found the data transmission phase of LEACH is regulated through duty cycling to maintain the ENO constraint. Any remaining energy is then invested in cooperative relaying by following another ENO duty cycle.

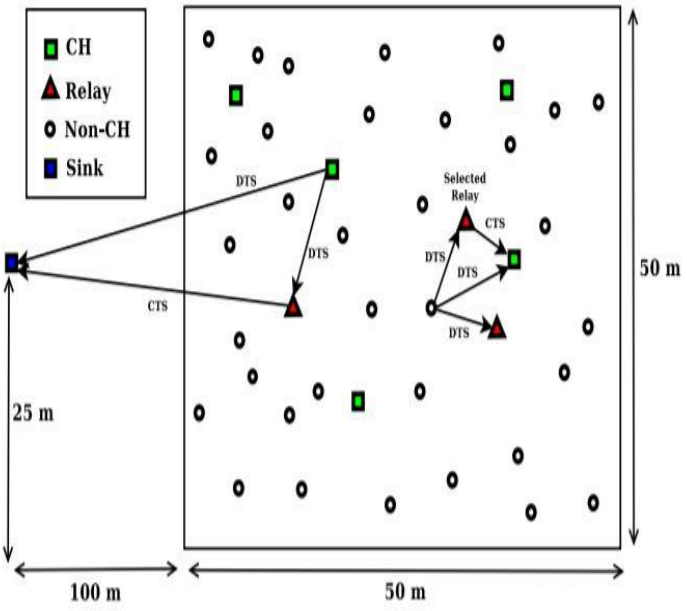

Fig. 3.1 Network Model

A. SYSTEM MODEL

Clustering protocol that incorporates duty cycling and cooperative transmission for energy harvesting WSNs. CH selection based on determination of CH duty cycle. A periodic wake-up/sleep strategy is implemented in TDMA, as nodes sleep in non-allocated timeslots. The node may relay packets of other cluster members to the CH during their allocated time-slots. The members to the CH relay the aggregated packet of the CH to the sink

B. THE ECO-LEACH PROTOCOL

The operation of LEACH, described, consists of multiple rounds. Each round begins with a short setup phase followed by a long data transmission phase. During the setup phase of a round t, each node declares itself as a CH with a probability that maintains the CH percentage at π after $1/\pi$ rounds have passed. Once a node becomes a CH, it will never become a CH again until all other nodes have taken their turns. CHs then invite non-CH nodes to join their clusters by broadcasting invitation beacons. A non-CH (NCH) node joins a cluster based on the RSSI of the received beacon and selects it transmit power P CH tx such that the received power at the CH is just above the sensitivity of the receiver. Upon receiving join requests, a CH creates then broadcasts a TDMA schedule to its cluster members. The data transmission phase (steady state) of a round consists of multiple TDMA frames. In each time slot of a TDMA frame, a single node (active node) sends its data packet to the CH at a time, while other nodes switch to sleep mode. In the last timeslot of a frame, the CH aggregates then transmits the received packets to the sink node at power P sink tx . This process repeats until the round is over. To eliminate possible collisions between clusters, each cluster randomly selects a unique channel (frequency/code) from a pool of available channel resources. Despite the performance gains over direct transmission, the uniform distribution of CHs does not consider the residual energy of each node. Hence, nodes that become CHs first will deplete their energies soon reducing network connectivity that in turn causes higher transmit power by the remaining nodes ultimately reducing the network lifetime.

The proposed ECO-LEACH protocol extends LEACH by replacing its CH selection process while introducing duty cycling and cooperative transmission. Each of these features is separately discussed as follows

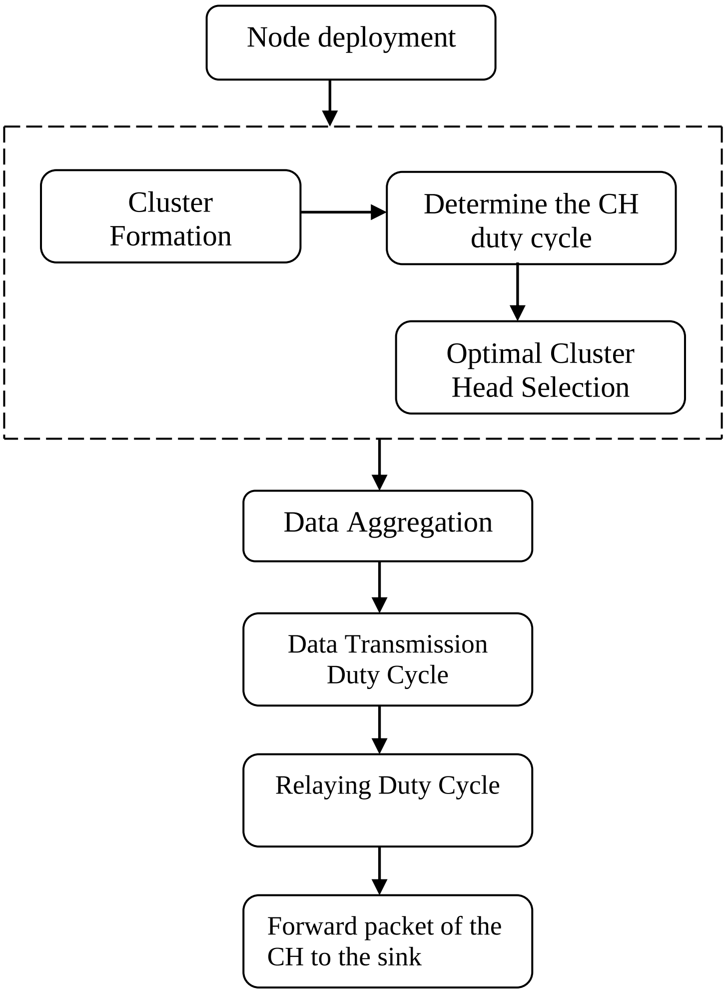

Fig. 3.2. System Architecture

C. COOPERATIVE TRANSMISSION PROTOCOL

In the proposed cooperative scheme, a time-slot of duration Ts is evenly split into a direct transmission sub-slot (DTS) followed by a cooperative transmission sub-slot (CTS). During a DTS, the active node transmits its data packet to the CH and cooperating nodes. The CH responds with an acknowledgement (ACK) beacon if the packet was successfully received. Otherwise, a non − acknowledgement beacon (NACK) is sent. The reception of a NACK at potential relay nodes initiates a contention process, whereby a relay node replies with a relay advertisement beacon (RAB) after a delay inversely proportional to the RSSI of the received NACK. All potential relays that receive the RAB beacon, while waiting to send their RAB beacons, will back off and remain silent in the CTS sub-slot. Because some relays may be hidden from others, a relay acknowledgement beacon (RACK) is broadcasted by the destination upon receiving the first RAB so that relays will only transmit upon receiving a RACK destined to themselves. The selected relay then transmits the relayed packet in the CTS sub-slot of the current time-slot. In case an ACK beacon is transmitted by the destination in the DTS, all potential relays will sleep during the CTS sub-slot. To fully utilize the allocated time-slot, the active node may transmit another data packet in the CTS as the second packet is likely to be successful without cooperation due to the correlated channels of consecutive sub-slots Clearly, the above scheme implements a decode-and-forward incremental relaying protocol with the opportunistic single relay selection . It is noteworthy to mention that different cooperative schemes such as space time block code (STBC) can be implemented without affecting the above strategy. However, stringent time synchronization among relays is necessary, which is generally complex to implement.

D. CLUSTER HEAD DUTY CYCLE DESIGN

Unlike the random CH selection in LEACH, in this work, a node follows a CH duty cycle (DCH) that determines how often it will become a CH in a given time horizon Lhor defined as the number of rounds over which the average harvested energy can be predicted. For instance, if DCH = 3 the node becomes a CH only once every 3 rounds in Lhor . The CH duty cycle is calculated at the beginning of each Lhor rounds as shown in (1) at the top of the next page. In this function, Tr = LrTs is the round duration, Lr is the number of timeslots in a single round and αCH ∈ (0, 1] is the proportion of the harvested energy allocated to the CH role. Also, Er CH is the average energy consumed by a CH node in a single round. When the allocated CH energy per round is greater than Er CH, DCH takes its minimum value of 1.

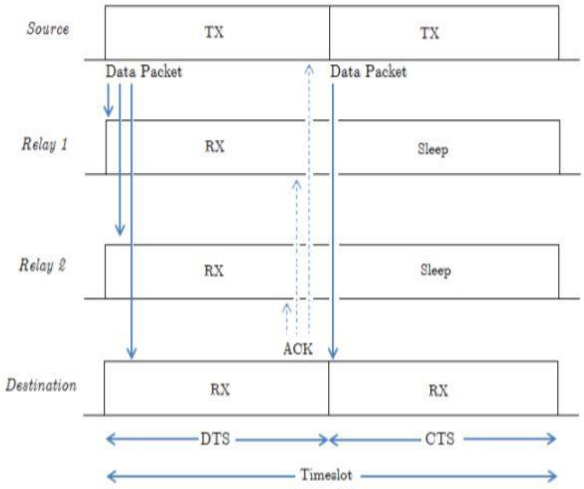

Fig. 3.3. Cooperative TDMA Scheme - Case 1

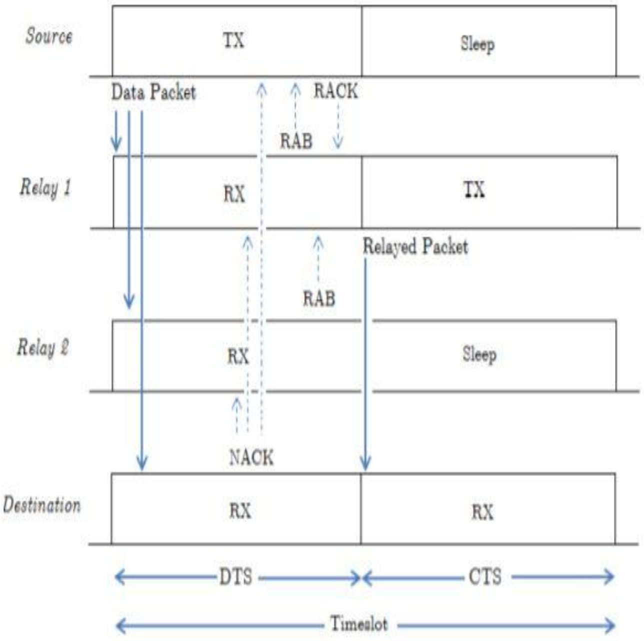

Fig. 3.4. Cooperative TDMA Scheme - Case 2

Otherwise, DCH will be the ratio of the required energy to the allocated energy rounded to the next integer value. At the start of each round, the node determines if its duty round has come using a CH-DC counter that counts up to DCH and then resets to 1. To maintain the targeted percentage of CHs, each node starts its CH-DC counter with a random integer value between 1 and DCH such that 1 indicates the duty round. If a node enters the duty round with no sufficient energy, the duty round is temporarily shifted to the next round and so on. Therefore, a node's likelihood to become a CH in a given round is the inverse of its DCH. Hence, to maintain the targeted percentage of CHs π = k/N , where k denotes the number of CHs, the factor αCH, given in (3) below, is used to limit the CH-DCs of nodes when their mean harvesting rate η¯ is too high causing them to afford to turn into CHs more often than required.

$$D_{CH} = \begin{cases} ceil\left(\frac{E^r_{CH} L_{hor}}{\bar{\eta}_z T_r L_{hor} \alpha_{CH}}\right) & \frac{E^r_{CH} L_{hor}}{\bar{\eta}_z T_r L_{hor} \alpha_{CH}} \geq 1 \\ 1 & \frac{E^r_{CH} L_{hor}}{\bar{\eta}_z T_r L_{hor} \alpha_{CH}} < 1 \end{cases}$$

$$E^r_{net}(k) = k(E^r_{CH}(k) + E^r_{NCH}(k)) = \frac{L_r}{N}\left(k^2 P^{sink}_{tx} T_s + (kN - k^2)(P_{rx} T_s + E_{agg}) + (N-k) T_s \frac{M^2}{2\pi}\right) \quad (1)$$

$$\alpha_{CH} = \left[\frac{E^r_{CH}\pi}{\bar{\eta} T_r}\right]_0^1 . \quad (2)$$

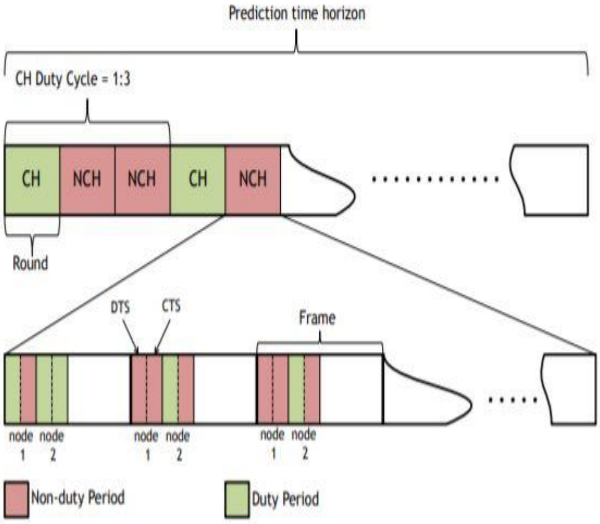

Fig. 3.5 Duty Cycle Structure

E. OPTIMAL CLUSTER HEAD PERCENTAGE

The number of cluster heads has different effects on the network throughput, latency, bandwidth utilization and lifetime. First, the throughput and latency affect the number of cluster heads as follows. Given the packet arrival rate ρ (packets/second) and the maximum latency tolerated by the application layer Δmax (seconds), the maximum possible frame duration would be T max f = min(1 ρ , Δmax) leading to a minimum number of k min = ceil(NTs/T max f) CHs. On the other hand, the number of available orthogonal channels defines the maximum number of clusters, k max, above which collisions will occur. Thus, the optimal number of CHs, k opt , lies in the interval [k min,k max] and maintains an average network energy consumption Er net(k opt) below the total energy harvested by all nodes in the network Er har during a single round. To find Er net(k), we first calculate the average energy spent by a CH during a given round as a function of k as:

$$E^r_{CH}(k) = N_f(E^{sink}_{tx} + (L_c - 1)E_{rx} + E_{agg}) + E_{setup}, \quad (3)$$

where Lc = N k is the average cluster size, Nf = Lr k N is the average number of TDMA frames in a given round, whereas Eagg and Esetup are the energies consumed in data aggregation and cluster setup respectively. Similarly, the energy needed by all NCH nodes per round in terms of k becomes

$$E^r_{NCH}(k) = N_f(L_c - 1)T_s\bar{P}^{CH}_{tx}, \tag{4}$$

where the term P¯CH tx = M2 2πk approximates the average squared distance (path loss) to the CH assuming uniformly distributed nodes. Also, it is assumed that each NCH utilizes all its allocated data transmission slots. Thus, the network energy consumption is given in (2) shown at the top of the page. With more clusters (smaller average cluster size) the node-tonode distance is reduced causing less energy spent by the NCH nodes in conveying their data packets to their CHs. However, data aggregation is reduced and more energy consuming CHs are introduced. Therefore, the OCHP is unique to the network topology and parameters, which can be formulated as:

$$k^{opt} = \max k$$

$$\text{s.t.}$$

$$E^r_{net}(k) \leq E^r_{har} = L_r T_s \sum_{z=1}^{N} \eta_z$$

$$k \leq k^{max}, k \geq k^{min}$$

$$k \in \{1, \ldots, N\} \tag{5}$$

The optimization problem above gives the highest k (maximum spectral efficiency) that maintains the ENO (constraint) for any value of k in the range defined by constraints. Unlike the OCHP analysis, the proposed optimal solution may not necessarily minimize the network energy consumption, as some values of k 6= k opt may result in a lower energy consumption. However, these values may degrade the system performance, since by having more clusters than orthogonal channels, backoffs induced by CSMA at the MAC layer may result in longer delays and more collisions. Conversely, choosing a value of k below k min leads to more dropped packets due to buffer overflow and timeouts. The solution to the non-linear integer programming problem formulated above can be centrally obtained by evaluating Er net(k) starting from k max until a value that satisfies the constraint is found. Thus, the solution has a linear complexity in the number of nodes. However, a feasible solution may not exist if Er net(k) > Er har ∀k ∈ {k min, kmin+ 1, . . . , kmax − 1, kmax}, in which case reducing the data transmission duty cycle is necessary as will be discussed next. Due to the absence of a central station in many WSN scenarios, the OCHP can be obtained in a distributed fashion, where each node independently determines k opt assuming the knowledge of the network parameters and the mean average energy harvesting η¯ instead of PN z=1 ηz in (7). Each node then substitutes k opt/N to find its CH-DC. Henceforth, the OCHP will refer to the distributed OCHP. As the harvesting rate changes with time, the OCHP is dynamically updated at the beginning of each Lhor period as will be demonstrated in Section V.

F. DATA TRANSMISSION DUTY CYCLE DESIGN

A periodic wake-up/sleep strategy is inherently implemented in TDMA, as nodes sleep in non-allocated timeslots. In LEACH, this will cause each cluster member to undergo an average duty cycle of 1:Lc. However, if the predicted harvested energy is still insufficient to maintain an ENO, the duty cycle should be further reduced by skipping the allocated slot in certain TDMA frames. In addition, the duty cycle should also adapt to the packet arrival rate ρ since switching to transmit mode with no data packet to send results in an unnecessary energy waste. Hence, a data transmission duty cycle DDT , based on the harvesting power and the packet arrival rate, is proposed that defines the number of TDMA frames to skip after each data transmission. For example, node 1 utilizes its allocated slot only once every 3 TDMA frames, hence its DDT is 3, whereas node 2 with DDT = 1 uses its timeslot in every frame. A node z computes its DDT at the beginning of every round by first finding the expected remaining harvested energy per NCH round given as:

$$E^{rem}_{NCH} = (\bar{\eta}_z T_s L_r L_{hor} - E^r_{CH}(L_{hor} - L_{NCH}))/L_{NCH} \tag{6}$$

where LNCH = Lhor – Lhor/DCH is the number of NCH rounds in Lhor. The node then computes a duty cycle with respect to the harvesting rate and another for the data arrival rate as:

$$D^{ene}_{DT} = \begin{cases} ceil(\frac{E^{CH}_{tx} N_f}{E^{rem}_{NCH}}) & 1 \leq (\frac{E^{CH}_{tx} N_f}{E^{rem}_{NCH}}) \leq N_f \\ 1 & (\frac{E^{CH}_{tx} N_f}{E^{rem}_{NCH}}) < 1 \end{cases},$$

$$D^{data}_{DT} = \begin{cases} floor(\frac{N_f}{\rho T_r}) & 1 \leq (\frac{N_f}{\rho T_r}) \leq N_f \\ 1 & (\frac{N_f}{\rho T_r}) < 1 \end{cases}, \tag{7}$$

where ECH tx = P CH tx Ts is the energy consumed in transmitting a packet to the CH. Hence, DDT is found as:

$$D_{DT} = \begin{cases} 0 & \max(D^{ene}_{DT}, D^{data}_{DT}) > N_f \\ \max(D^{ene}_{DT}, D^{data}_{DT}) & 1 \leq \max(D^{ene}_{DT}, D^{data}_{DT}) \leq N_f \end{cases} \tag{8}$$

Similar to the CH-DC design, when the average energy available in an NCH round is greater than that consumed when the node transmits in every frame in the round and that the number of generated packets is greater than Nf , then DDT is set to 1. Conversely, if the energy available for data transmission is less than that needed for a single data. transmission or the number of generated packets is less than 1, the node will not join any CH and will remain silent in the whole round, that is, DDT = 0. For any intermediate values, the node will be active once every DDT frames. Again, a DC counter is employed to keep track of the duty cycle as in CH-DC.

G.RELAYING DUTY CYCLE DESIGN

For the energy available for data transmission is less than that needed for a single data transmission or the number of generated packets is less than 1, the node will not join any CH and will remain silent in the whole round, that is, DDT = 0. For any intermediate values, the node will be active once every DDT frames. Again, a DC counter is employed to keep track of the duty cycle as in CH-DC. In certain TDMA frames, a node may act as a potential relay according to the cooperative strategy explained in Section IV-A. Particularly, the node may relay packets of other cluster members to the CH during their allocated time-slots at power P CH tx and may also relay the aggregated packet of the CH to the sink at power P sink tx . Hence, we define the relaying duty cycle DRL as the number of frames in which the node becomes a potential relay only once. Node 1 never acts as a relay and hence its relaying DC is zero, whereas the DRL of node 2 is 3. The relaying duty cycle is computed at the beginning of each round, after calculating DDT, by first finding the remaining energy from Erem NCH, after subtracting the energy reserved for data transmission, as:

$$E^{rem}_{NCH-R} = E^{rem}_{NCH} - \frac{N_f}{D_{DT}} E^{CH}_{tx} \qquad (9)$$

Thus, the relay transmission duty cycle can be given as:

$$D_{RT} = \begin{cases} 0 & \frac{E^{f}_{RL} N_f}{E^{rem}_{NCH-R}} > N_f \\ ceil\left(\frac{E^{f}_{RL} N_f}{E^{rem}_{NCH-R}}\right) & 1 \leq \frac{E^{f}_{RL} N_f}{E^{rem}_{NCH-R}} \leq N_f \\ 1 & \frac{E^{f}_{RL} N_f}{E^{rem}_{NCH-R}} < 1 \end{cases} \qquad (10)$$

where E f RL = Prx(Lc−1) Ts 2 +P CH tx (Lc−2) Ts 2 +P Sink tx Ts 2 is the energy needed by a node to act as a relay during a single frame. Similar to the above DCs, a relaying DC counter is employed.

IV. RESULT AND DISCUSSION

A. RESULTS

Network Model

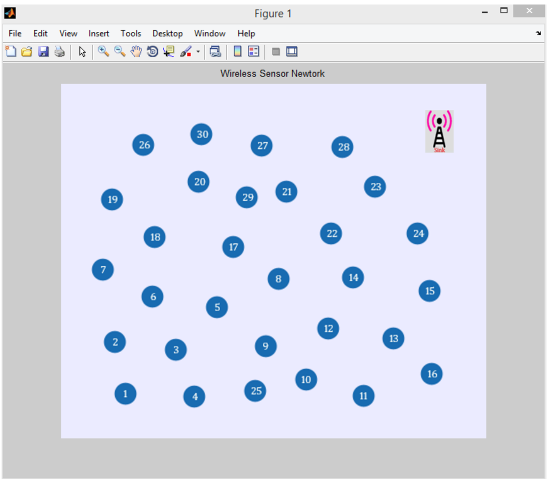

Fig:4.1 Network model

Packet Generation

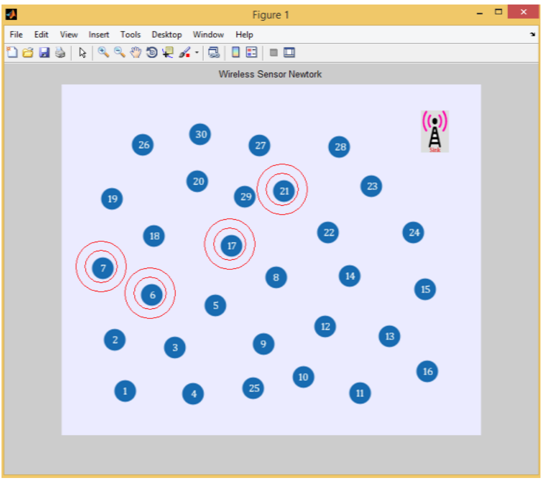

Fig:4.2 Sensing of nodes

Each sensor nodes are sensed and the packet present In the sensor is analysed and the data are interpreted during the Matlab runtime.

Cluster Head Selection

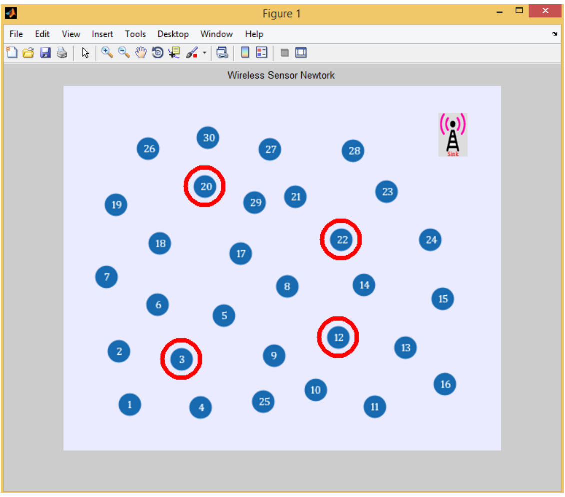

Fig:4.3 Cluster Head Selection

Optimal cluster head is chosen by the optimal cluster percentage method in order to improve the network life time the chosen CH are seen in the above diagram.

Cluster Group Formation

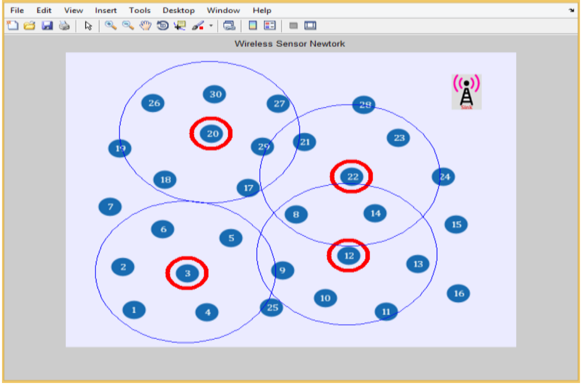

Fig:4.4 Cluster Formation

Based on the cluster head a cluster group formation takes place and after the formation of the cluster group the data will be started to transmitted and the data will be aggregated by the CH.

Periodic wake-up/sleep strategy

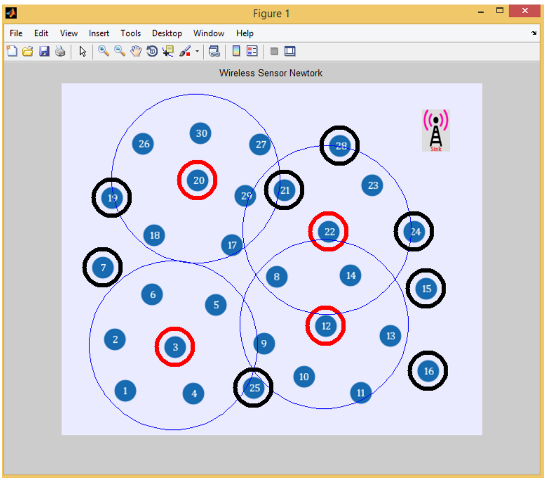

Fig: 4.5 Sleep Nodes

Sleep strategy is used to enhance the longitivity of the sensor network and the lifetime of the network to solve this deal we are using the sleep wake up strategy.

Co-operative Transmission

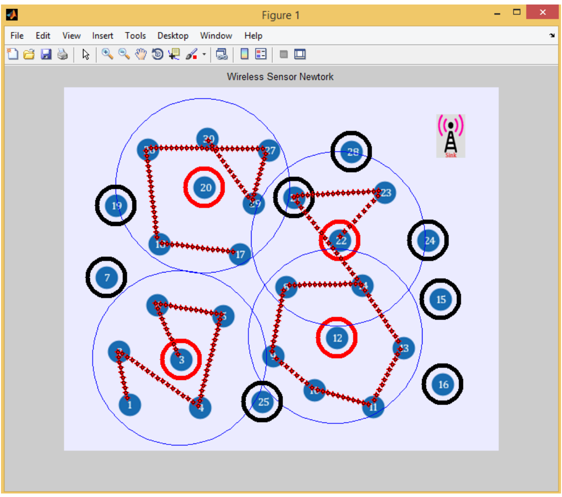

Fig: 4.6 Transmission of Data packets

Active node transmits its data packet to the CH. Here the transmission of the data takes place and the aggregation of the data is done by combining all the data of each node by another and finally the aggregated data of all nodes reach the CH. The CH perform the final aggregation of data and inreturn sends a acknowledgement beacon.

CH responds with an ACK beacon

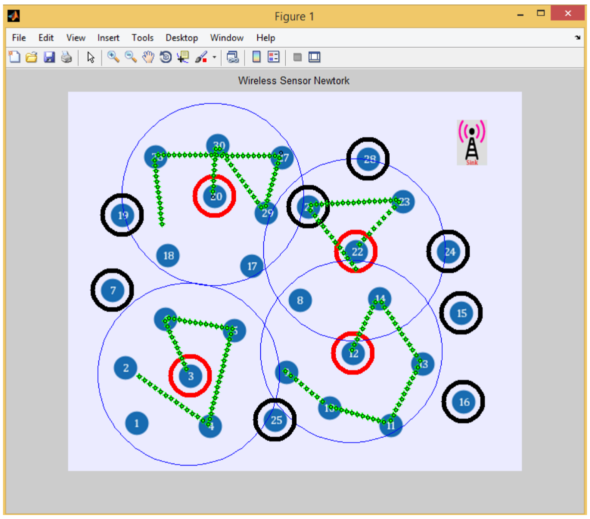

Fig: 4.7 CH sends Ack Beacon

All nodes receive a acknowledgement beacon from the CH. This will clearly show that the data is received from each node and that it is processed by the CH.

CH Member relay the aggregated packet of the CH to the sink

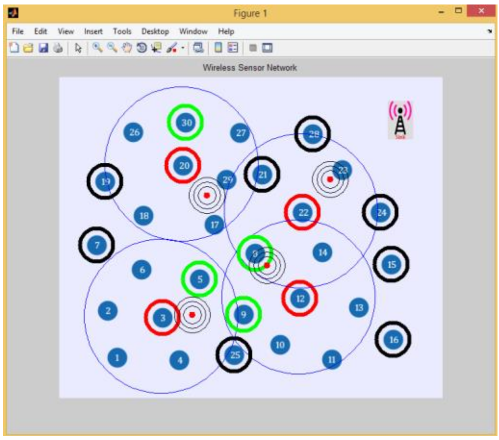

Fig: 4.8 sending packets to BS

The data transmission take place by the help of the relay node. The CH send the nodes to the relay nodes and they will transmit the data to the base station.

B. DISCUSSION

The proposed protocol was simulated using MATLABR2013A. The default log-normal shadowing radio model was used with a path loss exponent of 2.0. In addition, the temporal channel model, based on real channel measurements, was adopted to demonstrate the spatial diversity gains of cooperative transmission.

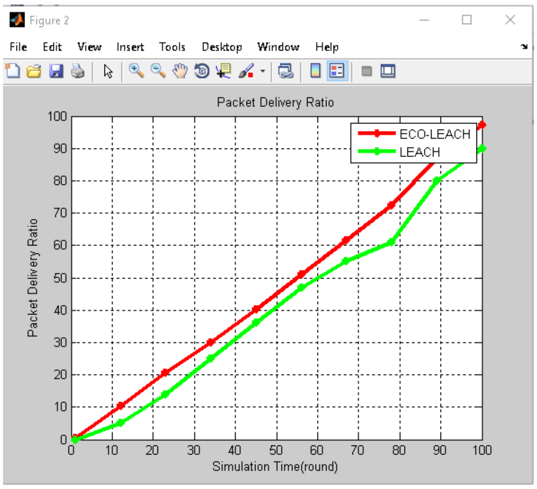

Fig: 4.9 packet Delivery Ratio

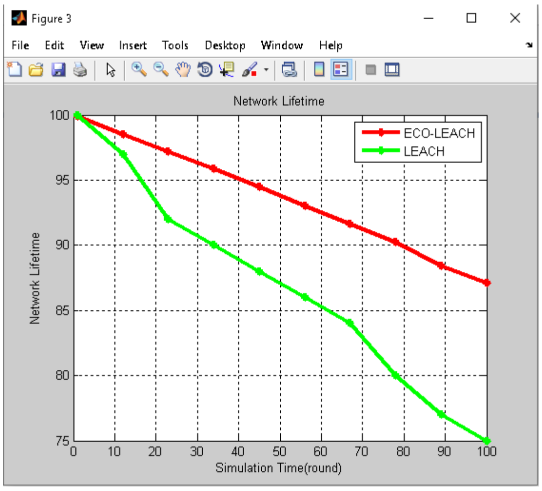

Fig: 4.10 Network Lifetime

IV. CONCLUSION

A clustering protocol that incorporates duty cycling and cooperative transmission is proposed for energy harvesting WSNs. The duty cycle for the CH assignment that guarantees a targeted CH percentage was derived and its optimal value was investigated. An efficient DC that ensures a perpetual network operation was developed. Besides, a cross-layer cooperative transmission strategy was designed to enable nodes to relay undelivered packets from cluster members to CHs and also. From CHs to the sink node. The results obtained using event driven simulations have demonstrated an enhanced network performance in terms of throughput and lifetime with respect to the conventional LEACH as well as a generic energy-aware LEACH in EH and conventional battery powered WSNs.

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