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Energy Harvesting Multi-Relay Multi-Hop Models For Sustainable Wireless Sensor Network

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Abstract: The load inequality of sensor node is a relentless issue for Wireless Sensor Networks (WSNs). In this paper, we firstly propose a Multi-hop Multi-relay Network Model (MMNM) with Relaying Head (RH) to balance the load among sensor nodes. The evolution of recent energy harvesting delivers us the Energy accumulation Wireless Sensor Networks (EH-WSNs). Due to the indeterminacy of energy that can be harvested in ambient environment, study on energy management mechanism to achieve energy neutral is significant. We proposed a novel Sensor Nodes Pair (SNP) policy separate all the sensor nodes into two groups GSN and GSN'. With the function rotation of GSN and GSN', we achieve continuous data transmission avoiding time delay. Also a Historical Harvested Energy Assigning Mechanism (H-HEAM) is proposed to ensure the energy neutral constrains and perpetual network operation. Extensive simulation results verify that our MMNM and H-HEAM are indeed able to improve the network overall performance on throughput, energy utilization efficiency and time delay.

***Keywords**:* -Energy Neutral, Energy Mechanism Management, Wireless Sensor Networks (WSNs), Energy Harvesting.

I. INTRODUCTION

Wireless sensor networks (WSNs) facilitate reliable monitoring of diverse intelligence and control applications.WSN s consisted of huge numbers of low-power and cheap sensor nodes have been widely used in many areas such as environment surveillance, medical and target tracking, health services, military area and numerous information gathering applications. Sensor nodes of conventional WSNs are usually equipped with battery possessing finite energy source. Once the energy of battery is exhausted, the whole network would stop functioning and the data transmission would be interrupted and it is inconvenient to replace or recharge the battery. Thus the battery life is an intensely vital factor that restricts the lifetime and performance of network. Since the nodes are usually equipped with batteries having restricted power supply, one of the primary restraining factors of WSN is the network lifetime.

In order to conquer this issue, multi-relay hop communication is an energy efficient strategy used in WSNs. The information arrives at the sink node/Base Station (BS) via multiple hops, using sensor nodes as relays. Routing heavy data traffic through nearby nodes of sink arises energy holes, so a portion of the sensing area will remain undetected. Removing energy holes enhances the network lifetime, so increasing the lifetime of networks is one of the most critical challenges in designing a WSN. Nowadays energy harvesting and Wireless Energy Transfer (WET) are considered as potential solution to increase the lifetime of WSNs. In energy harvesting, nodes harvest energy from unpredictable ambient conditions and the harvested energy rate is very small in the case of sensor nodes in shadow areas. Energy sources are intentionally deployed in surroundings of WSNs in wireless energy transfer and it is the most suitable choice for a WSN for enhancing the lifetime of nodes.

With the emergence of Energy Harvesting Wireless Sensor Networks (EHWSN) network lifetime and the possibility of perpetuity is receiving renewed attention. In EHWSNs primary source of energy is either the tiny battery or harvested energy from renewable energy sources (e.g. solar, wind, vibration, etc). EHWSN uses energy harvesting wireless sensor nodes to sense data and transfer it through the network to the destination or sink. For maximam of the EHWSN applications, the sink or the base station is out of the transmission range of EH-sensor sink. Therefore, the sensed data is transferred using different types of relay methods. However, to burden the tiny EH-sensor nodes with additional transmission responsibilities from other nodes is unrealistic. Therefore a strategy to avoid energy holes in multi-hop WSN using dedicated energy transmitters for wireless energy transfer is proposed in this paper.

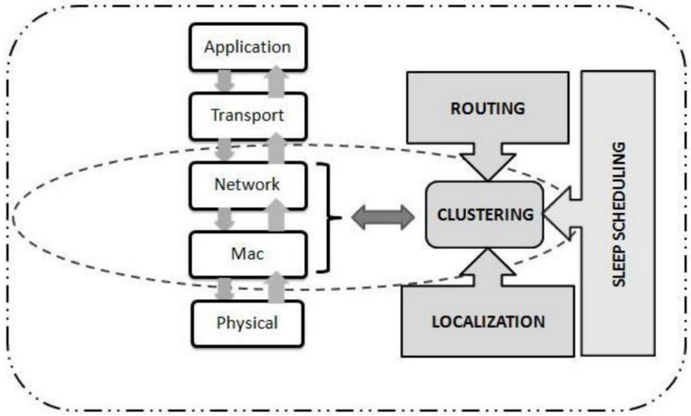

Figure 1: Sleep scheduling approach in cross-layer protocol

The main contributions of our proposed methods are

- Multi-hop Multi-relay Network Model (MMNM) and a Relaying Head (RH) selection policy to balance the data transmission are load of EH-WSNs.
- We propose a novel Sensor Nodes Pair (SNP), dividing all the sensor nodes into two groups, GSN and GSN'. Each group can achieve the acquired network performance independently.
- We adopt GSN and GSN' function rotation mechanism achieving the continuous data collection and transmission avoiding the time delay caused by DC.
- We propose a Historical Harvested Energy Assigning Mechanism (H-HEAM) to ensure the energy neutral constrains and perpetual network operation.

The rest of the proposed paper is referred as follows: - A review of existing works is done in Section II. Section III includes the network model and proposed energy harvesting technique. Simulation results and performance analysis is done in Section IV.. Section III includes the network model and proposed energy harvesting technique. Simulation results and performance analysis is done in Section IV.

II. LITERATURE REVIEW

Energy harvesting is one of the enormous disputes faced by WSNs. As the data traffic in multi-hop transformation to the BS via relays follows a many-to-one pattern, the probability of forming energy holes around the sink is very high. No more information can be transferred to the sink after the composition of energy holes in multihop communication [1]. Consequently, a appreciable values of energy is emaciated in the form of leftover energy of sensor sinks and the network lifetime ends too early. For example to highlight the importance of this problem, in [2] it is shown that up to 90 percent of the energy of the network is left unused when the network lifetime is over, if the sinks are evenly assigned in the network.

Currently various existing studies have been experimented on energy management mechanisms to provide both Energy Neutral Operation (ENO) and optimal network performances.The drawback of RF energy harvesting based on ambient energy is that, we cannot always guarantee the availability of ambient energy sources and they may be uncontrollable. External energy sources are purposely expanded in environment to increase the lifetime of WSNs in WET [3].WET provides reliable, predictable energy harvesting, offers high efficiency, immunity to neighbouring environment, and no requirement of LOS, so WET is the appropriate preferred for a rechargeable WSNs to enlarge the networks lifetime [4]. Energy analysis and models of wireless energy transfer by 3D and 2D placement of different RF energy transmitter is given in [5]. An ILP model namely MAPIT, which reduces the placement of RF- depended chargers in the WSNs by inflate the number of nodes receiving power from a landmark is presented in [6]. The methods for combination of multiple energy transmitters and frequency assignment for each group to transfer RF energy simultaneously are proposed in [7]. This work is further extended in [8], to study the impact of energy transmitters and chosen frequencies on the charging time of sensors.

Awake-sleeping mechanism is an effective method of energy management mechanism to achieve ENO [9]. Zhang et al. in [10] present an Opportunistic Duty Cycling (ODC) arrangement represents of both natural energy utilization stochastic accuracy and parameters value of data's (Vod). In their scheme, the Duty Cycle (DC) can be adjusted according to historical information to achieve network ENO. Knasal et al. proposed a oscillate DC adaption mechanism to peak values of the energy utilization efficiency based on the prediction of the amount of energy that can be harvested form encompassing habitat in the future [11]. Pent et al. proposed an energy neutral management policy ensuring the optimal throughput and use Shannon's channel capacity function to guarantee the data queue length stability in [12]. Furthermore, they proposed an increased determination for free energy Budget Assigning Principles (BAPs) energy management mechanism in [13] to guarantee network ENO with maximum harvested energy utilization efficiency, taking battery inefficacy into consideration to adaptively adjust DC. However, all the aforementioned works on energy management mechanisms have one familiar problem that the time delay of network operation and data transmission is inevitable, which is caused by continuous awake-sleeping actions especially when there is a low DC. And for energy mechanisms management depands on the prognosis energy that can be harvested in the future, the prediction error is inevitable no matter how accurate the prediction algorithm.

III. PROPOSED SYSTEM

1. ***Network Model***

This section describes our presented system network model MMNM for EH-WSNs. in Figure 3, represents monitoring area as a rectangle, and the sensor sinks are redistribute randomly. The Base Station (BS) deceit on one postern of the monitoring area. All the sensor sinks are separated into several equal size clusters and the assembled information is transmitted to BS among clusters through multi-hop method.

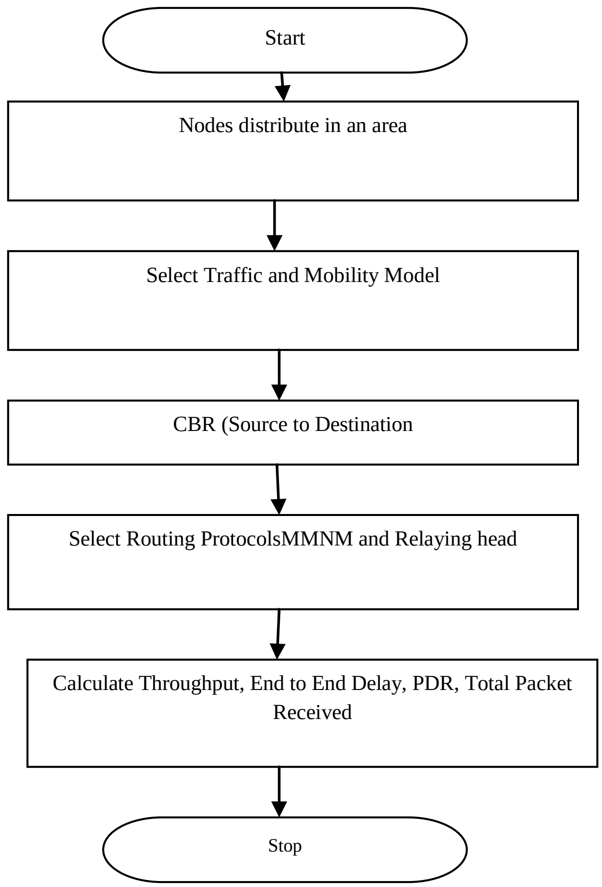

Figure 2: Proposed System Flowchart For WSN

The communication ability of all the sensor nodes is always limited. Thus once numerous sensor nodes are deployed into the large-scale target field, they must organize into ad hoc network and several clusters. In our network model, the formation of clusters is conducted by the BS through broadcasting information of cluster units according to target area. Once one sensor receives the clustering message from BS, it becomes a member of the cluster that it lives in. Once the n×m cluster matrix units establish where n and m represent the rows and columns respectively, they keep position invariance as long as the monitoring field stays unchanged. So cluster unit at row n and column m can be donated by n m U n×m. After the formation of clusters, the monitoring area is divided into several clusters.

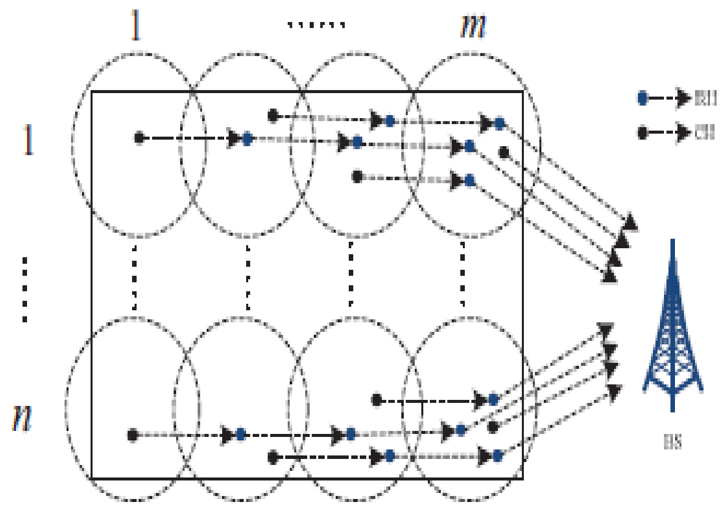

Figure 3: Multi-relay Multi-hop Network Model of EH-WSNs

2. RELAYING HEAD

a) Number of Relaying Head

In our network model, the formation of cluster is antecedent the other cluster functions. Three functions are assigned in the cluster, Cluster Head (CH), Cluster Member (CM) and Relaying Head (RH). Cluster farthest sway form the BS is composed of one CH and numerous CMs. But apart from the farthest cluster, the other clusters have also one CH but several Relaying Head (RH) and numerous CMs. And we have equation (1) as follows:

$N\frac{mxn}{RH}=m-1$ ------1

Where N represents the number of RH in cluster unit U m×n and m represents the column of n m U m×n .

We propose the RH in order to equalize the load among the sensor sinks. The CH has to transmit both the data gathered by its CMs and the data received from other CH in neighboring cluster if there is only one CH. In our case, once one sensor node is elected as the RH, the RH just performs transmission of the data received from the CH in its superior cluster and not to gather information data from the monitoring area any more. The RH nearest to the BS sends the data to the BS.

We have to state that the number of sensor nodes in each cluster is even according to the broadcast message of BS. Once the cluster matrix units are established, two SNs having minimum distance with each other combine to be the SNP. The SNP has equal status but they cannot work at the same time. All sensor nodes marked with SN combine into one group (GSN) to perform data collection and transmission, and the others turn to be the other group (GSN'). Each group in any cluster has the ability to monitor the target area that the cluster covers.

b) Selection Mechanism of Relaying Head

We confirm that the communication radius of all the sensor nodes is equal to the radius of cluster of cluster matrix units, and it is illustrate by R_c. When one node i in U_{nxm} is selected as the CH, its RH, jmust be selected in $U_{nx(m+1)}$ according to the distance $d_{i\text{-}j}$ between node i and node j . The node j in $U_{nx(m+1)}$ satisfies the equation (2) as follows will be selected as the RH.

$di-j=min\{\ di-j-Rc, j=1,2,3,\dots,q\}$ ------ 2

Where q represents the number of sensor nodes in U $nx(m+1)$. Note that the node selected as RH obeys the policy of CH selection in LEACH [19]. Once one node is selected as the RH in one round, it will not be CH or RH again unless all the other sensor nodes have been CH or RH. In this case, we ensure that each sensor node is equivalent to be RH or CH for one time during one round cycle. Equation (2) weakens the imbalance of data transmission load between CH and RH.

c) Sensor Nodes Pair

In this paper, we also propose the Sensor Node Pair (SNP) shown in Figure 4 as follows.

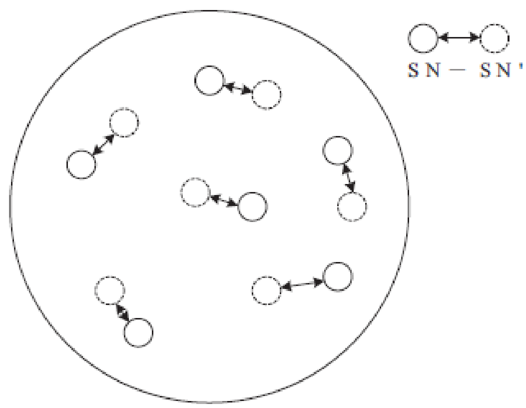

Figure 4: Sensor Nodes Pair

3. Historical Harvested Energy Assigning Mechanism

Energy Assigning and Energy Neutral Constrains For many energy management mechanisms of EH-WSNs, adjusting the DC adaptively due to the energy harvested in settled period leads to severe time delay of system performance.

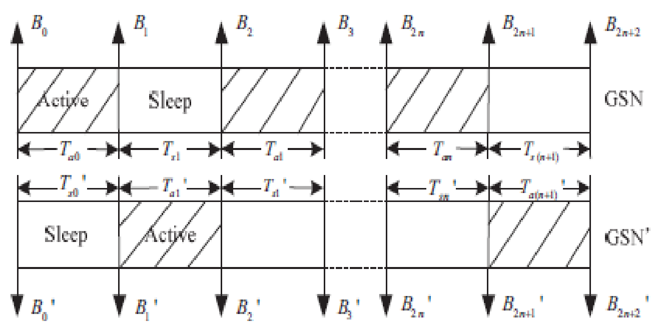

Figure 5: GSN and GSN' functioning rotation

Considering this condition, we adopt that the GSN and GSN' take turns to function to avoid time delay. As described in Figure 5 When GSN is active, the GSN' is in sleep state. Otherwise, the GSN' wakes up to be in active state.

4. Battery Energy Levels

We define several battery energy levels and give our rechargeable battery energy level segmentations model shown figure 6. Battery initial energy level $B_0$is set high enough for the function of nodes in initial active duration T_{a0}.$B_n$represents the up-and-down battery energy level that is caused by the network operation. Battery full energy level B_{full}represents the physical capacity of the rechargeable battery equipped on sensor node. Note that we assume that the capacity of the battery is large enough to contain the energy harvested in ambient environment so that the condition that energy overflows is avoided.

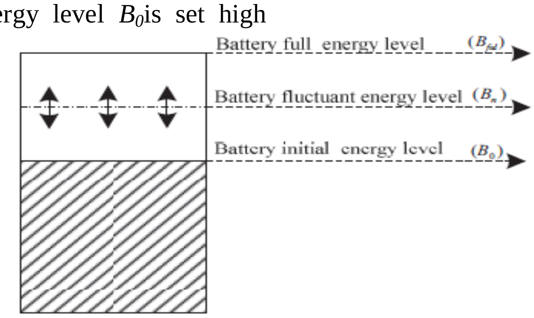

Figure 6: Battery energy level segmentations

Hence we can calculate the energy consumed in stipulated past duration time through measuring the battery energy level at the end point of any time period. Then GSN and GSN' take turns to function according to the setting active state time $T_{an}$and $T_{an'}$. In this way, the whole network achieves perpetual operation. The performance of our network model and H-

HEAM will be verified by extensive simulations in next section.

IV. RESULT AND DISCUSSION

In this section, extensive experiments are carried out to verify the performance of H-HEAM and MMNM proposed by us through network simulator 2 tool simulation platforms.Before conducting the simulations, the initial parameters must be set ahead. The battery initial energy level $B_0$is set as 2000J . The active power P_c of sensor node and initial active state $T_{a0}$of are set as 16mW and 5h respectively, $T_{an}{-}_{\min}$ is set as 1h . The sensor node density ρ is one node per 100m2 and the communication radius of sensor node is set as 10m. The energy harvesting power is randomly set during different time periods. Afterwards, we conduct the simulation experiments and the specific results are described as follows.

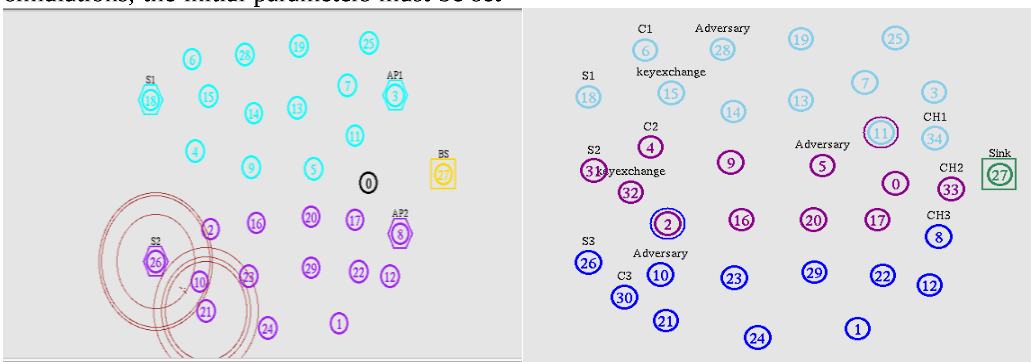

Figure 7: An efficient and secure data communication model

The comparison of battery energy level between our proposed energy policy H-HEAM and P-FREE is given in Figure 5 as the network operates. From this figure, the fluctuation of battery energy level in GSN over the level $B_0 - P_C T_{a0}$and that in GSN' over the level 0 B in our H-HEAM is obviously smaller than that in the P-FREE. And our battery energy level is nearly always above the initial level at which battery starts being charged. figure 7 explain data separation. The reason is that H-HEAN utilizes the accurate historical harvested energy, and no extra battery energy is assigned for network operation. Thus the battery energy level will not drop to the energy threshold $B_0 - P_C T_{a0}$and B_0level for GSN and GSN' respectively unless the harvested energy is not enough to meet the minimum active state duration anmin $T_{an\text{-}min}$. However, for P-FREE, when the harvested energy in last time slots has large deviation with energy harvested in next time slot, especially when the former is much more larger that the later, extra energy in battery will be consumed which leads to that the battery energy level declines under the energy threshold B_0level. Hence our H-HEAM has stronger stability on adapting to the variation of ambient environment. Note that the line of GSN' rises up to a very high level at the beginning of network operation, this is because that nodes in GSN' are in sleep state and harvest energy from ambient till the state turns to be active.

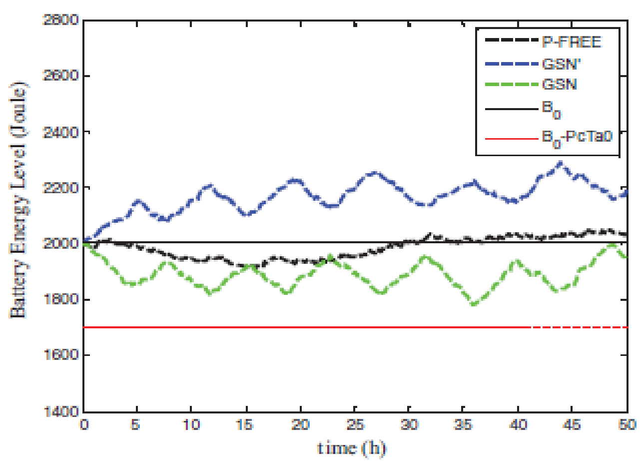

Figure 8: the comparison of battery energy level between H-HEAM and P-FREE

For MENC model, the average energy consumption increases along with the increase of the counts of cluster units. The reason is that in our network model, the RH takes an import role to balance the energy load of sensor nodes, which avoids

CH in cluster close to BS undertaking overmuch mission of data transmission. We ensure that each node transmits equal amount of data in each round cycle with the function of RHs. However in other routing protocols, such as MENC, when a node is selected as the CH, it consumes much more energy because of transmitting the extra data received from other CHs, which as a result causes the load imbalance.

V. CONCLUSION

In this paper, taking load imbalance of sensor node, time delay of data transmission and energy neutral operation of network into consideration for EH-WSNs, we propose a novel Multi-hop Multi-relay Network Model (MMNM) and a novel Sensor Nodes Pair (SNP). The MMNM policy based on Relaying Head (RH) balances the data transmission load of EH-WSNs. All the sensor sinks in monitoring area are splited into two groups, GSN and GSN'. With the function rotation of GSN and GSN', the time delay of network performance is avoided. We proposed a Historical Harvested Energy Mechanism (H-HEAM) to assign the energy harvested in historical duration of last active and sleep state to be utilized in current active state for sensor nodes. Under our energy assigning mechanism, GSN and GSN' can achieve the acquired network performance independently. Through extensive simulation results, we verify the MMNM and SNP have outstanding efficacy to balance the sensor load and avoid the time delay of network performance. Our H-HEAM have better efficacy on energy neutral constrains.

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