# Enhanced SWEET Protocol for Energy Efficient Wireless Sensor Networks

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***Abstract*—SWEET routing protocol is one of the many pro- tocols developed for cluster formation and routing in wireless sensor networks. The SWEET protocol is a decentralized clus- tering protocol, it uses timers and interim updated cluster head estimation probability. This paper focus on the details of the initialization waiting time, sleeping mode and base station in order to increase the life cycle of the network. The initial waiting time's resizing procedure is carried by a weighting factor which is computed from the delay slot time and delay frame time. Other improvements are the introduction of sleeping mode energy saving technique. The last contribution is through the enabled base station's ability to become a cluster head. A simulation based performance evaluation of our proposed EN-SWEET protocol shows superiority in energy efficiency.**

***Index Terms*—Wireless sensor networks, cluster, cluster head, energy efficiency, microsensor (MIS), nodes**

## I. INTRODUCTION

Wireless sensor networks (WSN) have recently received a tremendous interest from researches due to their extraordinary sensing capability. A WSN is used to continuously monitor a phenomenon through data extraction, processing and transmission of the collected data to the central base station. Moreover, WSN have a wide range of applications, such as military surveillance, machine failure diagnosis, chemical/biological detection and many more, in both civil and military domain. WSN is a group of microsensors (MIS) interconnected through a wireless medium. Furthermore, all sensors operate independently and yet in cohesion, constituting a network through a way of self-organization. MIS's are characterized by their low transmit power, small-size and inexpensiveness. However, energy management remains a major topic in most research related to WSN design because MIS nodes are battery powered and battery resuscitation is often not practical [1], [2].

Clustering protocols have been proposed as a mechanism to alleviate energy constraint in WSN networks. In clustered WSN, the network forms a group / cluster of MIS with similar characteristics. One special MIS within the cluster operates as gateway or cluster-head (CLH) while the other remaining MIS's are described as member microsensors (MMIS). The CLH is responsible for the aggregation of the data collected by MMIS and for transmitting the sensed data to the data centre or base station. On the other hand, the communication in clustered WSN is either multi-hop or single-hop and it is either configured in a homogeneous or heterogeneous manner.

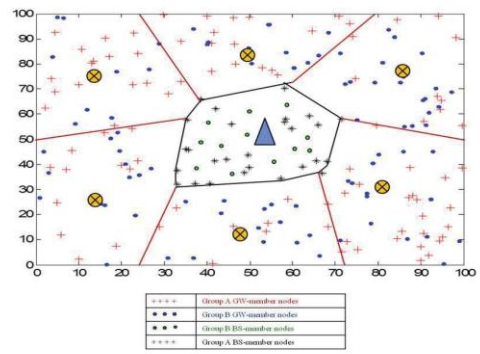


Fig. 1: Spatial location of CLH nodes, MMIS, base station associated MIS and the dividing of the MIS by the EN-SWEET protocol

In homogeneous configuration the network's MIS's have the same battery characteristics and computing complexity, while heterogeneous networks are characterized by few special MIS with advanced computing or/and battery superiority. Each cluster is independent yet works collaboratively, while the number of MIS nodes in a cluster either varies or remain fixed [3], [4], [5].

Varying the number of MIS nodes ensures that energy consumption is minimized through decreased services. In [6], LEACH is presented as a standard energy efficient routing and cluster forming protocol with balanced energy dissipation. LEACH is a homogeneous protocol which operates by electing MIS node for CLH role in a stochastic and periodic manner. However, divergence of the number of cluster and the unbalanced distribution of CLH limits the effectiveness of this protocol [7]. Many other protocols have been proposed, where most of them are an improvement to the LEACH protocol (W-LACH, EL-LEACH, I-LEACH and e.t.c) [8], [9],
[10]. In [11], a WBCHN protocol is suggested, it adopts a heterogeneous configuration by giving energy privileges to a limited number of nodes as potential CLH for the entire lifetime of the network. However, fixing the CLH node disable CLH rotation; which results to an increase in the distance between nodes, resulting to communication breakdown. In another study [12], a protocol called SWEET is suggested. SWEET protocol uses an energy distribution mechanism, such that each node becomes a CLH using a timer and recurring

updated probability over slotted time interval. However, this protocol's initial waiting period is not proportional to the surplus energy in the nodes, which increases the probability for a node with less surplus energy to become a CLH. The focus of this study is to further enhance the energy efficiency of the SWEET protocol, the resulting protocol is called enhanced SWEET protocol (EN-SWEET). Our proposed protocol adopts three approaches. Firstly, it is proportionally resizing of the initial waiting time through a weighting factor derived from both delay slot time and delay frame time. Secondly, the protocol allows the system to identify member of the base-station based cluster and thirdly, divide the entire MIS nodes into two groups which works in both even and odd round frame time through synchronization of the timeline of the two groups as shown in Fig. 1.

The rest of the paper is organized as follows. Section II presents the background work for this study. The proposed EN-SWEET protocol is presented in Section III. Performance evaluation (simulation) is presented in Section IV and section V is the summary of the paper and finally conclusions are drawn from section VI.

## II. BACKGROUND

### A. SWEET Protocol

SWEET protocol as mentioned above, selects a CLH by using timer and reoccurring probability update over a slotted time intervals. The MIS node with high surplus energy has a low waiting time, which enables it to advertise its CLH position earlier. The initial probability is initialized by each MIS through its distributed mean network surplus energy. SWEET protocol always locates its CLH in the centre of its MMISs with respect to the radius of the cluster. The advantage about this protocol is that it ensures that the distance between the CLH is limited, this imply that interference is mitigated.

### B. Disadvantage of SWEET Protocol

In SWEET Protocol, during initialization the waiting time computed is not proportional and fair with respect to the surplus energy. Moreover, sleeping mode of the nodes is not considered, while BS station based energy efficient approach is not mentioned. While SWEET protocol is an improved version of the LEACH, yet it can still be enhanced for a long life cycle.

## III. PROPOSED PROTOCOL

### A. Network Model

In this work, we consider a single-hop communication sys- tem for simplicity of the investigation. The network is designed to have $N$ static number of MIS uniformly distributed in area $A$. The rest of the network model is taken from the SWEET, in terms of both energy model and network layout. A CLH once elected, it sends an advertisement message called *ADV CLH* to all nodes in its vicinity, which then enforce the other nodes to give up their pursuit for becoming CLH. Each MIS is equipped with a transceiver which operates in a half-duplex mode. Moreover, the nodes have power control with a capability to adjust their transmit power to alter its coverage distance.

All MIS are powered by a battery with an initial energy of $e_0^i$, its surplus energy is computed at time $t$ and is given by $e^i(t)$. The node is alive until the surplus energy is zero (exhausted). On the other hand, note that for this study we adopt different initial energies, which is contrary to most studies. We consider the surplus energy $e^i(t)$ as a random variable $c;^i$. The network surplus energy (NSE) is given by $c;$ it is the sum of all the surplus energies from all the MIS in the network. If the network has $N$ nodes, the NSE is given by

$$c; = \sum_{i=1}^{N} c;^i . \quad (1)$$

The proof for this network surplus energy is provided in [13]. The following is the probability distribution of node $n_i$'s neighbourhood average surplus energy (NASE) which is expressed as follows $ð_i = \sum_{i=j}^{N-1} c;_j^i/\hat{N}$. Since it is shown in [13] that it follows a Gaussian distribution, it then estimate the mean $\hat{\mu}_ð$ and the variance $\hat{\sigma}^2_ð$ of its NASE by using the residual energies. The final probability density function ($pdf$) is given by the following

$$pdf = \frac{1}{\sqrt{2\pi\hat{\sigma}_{ð_i}}} \exp\left(-\frac{(ð_i - \hat{\mu}_{ð_i})^2}{\hat{\sigma}^2_{ð_i}}\right) . \quad (2)$$

The proof of this derivation is extensively conducted in [13], hence it is ignored in this work.

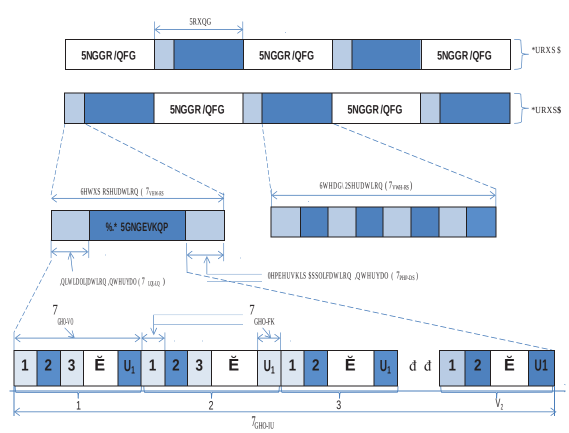

Fig. 2: Timeline of EN-SWEET clustering protocol

### B. Initial Waiting Time

Our protocol suggested in this work is divided into two operations, the setup operation and the steady operation. In the setup operation the network forms cluster and selects CLHs while in steady operation the sensed data is transmitted to the data centre. This is clearly depicted in Fig. 2; our protocol operates in rounds, which are divided into two operations, the setup operation and steady operation. The setup operation is responsible for initialization, CLH selection and cluster formation through member association. The latter which refers to cluster formation and CLH selection, have not been changed and have been extensively discussed in other studies [12], [13]. We only focus on the initialization procedure since it also has a significant contribution to the effectiveness of the protocol. The rounds last for $T_{rou}$ seconds, while the setup operation last for $T_{set-op}$ and the steady operation last for $T_{ste-op}$. This can be summarized as $T_{rou} = T_{set-op} + T_{ste-op}$. At the starting point of every round, node $n_i$ launches a timer to start the initial waiting time $T^i_{IW}$ operation which last for $T_{del-fr}$. In this study we always resize $T^i_{IW}$ by multiplying with a weight $\psi$. The resulting $T^i_{IW}$ is called weighted initial weighting time $T_{WIW}$, which is given by

$$T^i_{WIW} = \psi T_{IW}, \quad (3)$$

where

$$\psi = T_{del-slo}/T_{del-fr}. \quad (4)$$

As observed in Fig. 3, the weight force all the initial waiting time to be inside one $T_{del-sl}$ in a proportional manner, since all the initial waiting time are weighted.

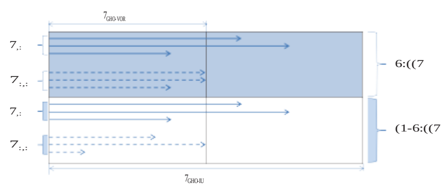

Fig. 3. Resizing the initial waiting time both in EN-SWEET and SWEET

Thereafter, node $n_i$ listens for advertising message from the neighboring node while try to select itself as a CLH.

### C. Sleep Mode

Another contribution for this study is to introduce a sleeping mode procedure on the SWEET algorithm. This is achieved by dividing the nodes into two groups, one group's sleeps while the other MIS are monitoring and extracting data from its environment. This requires that the number of nodes be doubled if the same accuracy level is required. Otherwise this approach deteriorates the system throughput while it doubles the life time of the network. This approach requires an advanced synchronization technique and this is possible as it is already a hot topic in sensor networks [14]. This sleeping mode is shown in Fig. 3 where two groups with contrary active rounds are shown. The resulting energy cost are shown below and are derived from [15], the energy cost for CLH is given by

$$e_{CLH} = \frac{l}{2}(e_{ec} + e_{ttr} d^4_{toBS}), \quad (5)$$

where $e_{ec}$ denotes the energy dissipated as a results of electric circuitry, $e_{ttr}$ represents two-ray transmit power or energy and energy dissipated, $d_{toBS}$ is the distance to the central base station and lastly $l$ denotes the length of the packet. On the other hand, the energy cost for member nodes is given by

$$e_{CLH} = \frac{l}{2}(e_{ec} + e_{apb} d^4_{toCLH}) \quad (6)$$

### D. Base station based cluster

The proposed protocol adopts a single-hop for computa- tional simplicity. The nodes within a specified distance are disabled to participate in the MIS based CLH, rather treat the base station as the CLH. This approach significantly mitigates the high power transmission involved with being a CLH and initialization procedures. All MIS nodes in the network wait for the pilot signal from the base station, thereafter, MIS estimates the distance from the base station. If the distance is less than $d_{max}$ ($d_max$: maximum threshold distance for base station cluster), the node ignore all the advertisement from all the broadcasting CLH. This implies that the base station should be always placed at the centre of the area being evaluated or monitored. The following section presents the performance of this few enhancement techniques introduced in this study.

## IV. SIMULATION

To evaluate the performance of EN-SWEET protocol, we implemented the simulation using the model mentioned in Fig. 1, where nodes are randomly distributed in a $100^2$ x $100^2$ area. One base station is located in the centre of the area. The number of MIS nodes depends on the simulation in consideration; this includes the initial surplus energies. The packet size used in the simulation is equal to that in SWEET protocol. The energy cost for transmitting a bit to the receiver is given by $e_t = e_{ec} + e_{apb}d^{\tau}$. Where $e_{ec}$ represents the energy dissipated in an electric circuitry and $e_{apb}$ represents the energy dissipated in the amplifier per bit. On the other hand $d$ denotes the distance between two communicating nodes and $\tau$ denotes the path loss exponent. Message for membership application is 25 bytes and packet to upload data is 500 bytes. Also Energy consumption for data aggregation by the CLH is 5 nJpb and receiver sensitivity is -2 dBm. The remaining parameters are summarized in Table I.

TABLE I
SIMULATION PARAMETERS

| Parameter | Description/Assumption |
|---|---|
| Area A | $10^4 m^2$ |
| Free space transmit power $e_{tfs}$ | 10 pJbpm$^2$ |
| Two-ray transmit power $e_{ttr}$ | 0.0013pJpm$^4$ |
| Electric circuitry transmit power $e_{ec}$ | 50nJpb |
| Signal Transmit delay $T_{delay}$ | 50 $\mu$s |
| Initialization period $T_{inp}$ | 3 s |
| member application period $T_{map}$ | 1 s |
| Steady phase perion $T_{spp}$ | 15 s |
| CLH notification message *ADV_ CLH* | 25 bytes |

Fig. 4-Fig.6 simulation assume the following: 200 MIS nodes are considered with an initial energy of 2 J, where the cluster distance is varied from 15 to 40 m. Fig.4 shows the results for number rounds before the first node dies in the system. We make the following observation; EN-SWEET is inferior than LEACH but superior than SWEET protocol.

LEACH's superiority maybe a results of its CLH assignment which is fair over rounds relatively. Fig. 5 to Fig 6. shows similar results in that the EN-SWEET performs better than

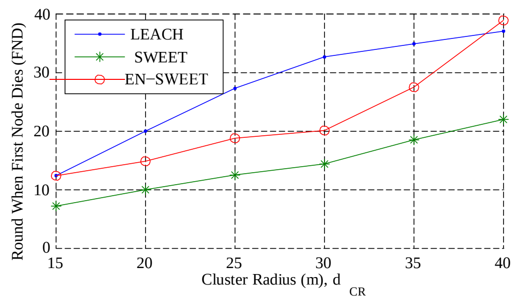


Fig. 4. Number of rounds before first node dies vs the radius size

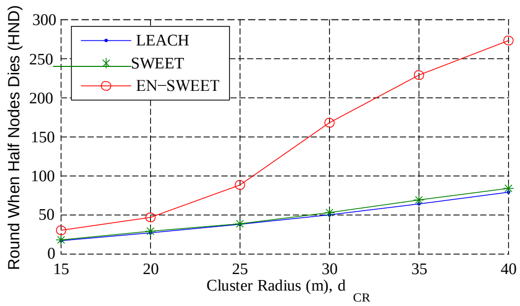


Fig. 5: Number of rounds before 50% of the nodes in the network dies vs the radius size

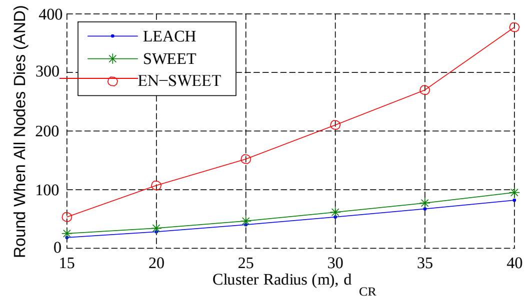


Fig. 6. Number of rounds before all nodes in the network dies vs the radius size

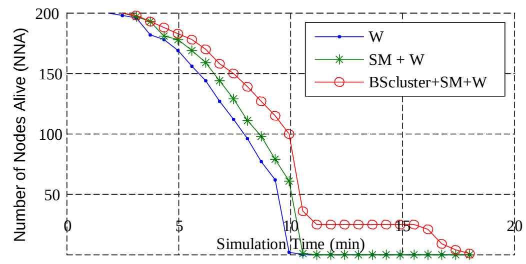


Fig. 7: Life cycle of the network with respect to difference enhancements

both LEACH and SWEET. This is explained by the fair initial waiting time resizing which is relative to the surplus energy, so as the saved energy through MIS associated with base station and the contribution by the reduction of the load to about 50 % for the entire lifetime of the node. In Fig. 7, we show the improvements brought by the protocol as a results of all the three changes made from the SWEET. It can be noted that they all supplement each other, the more one enhancement technique is introduced, the life cycle increases.

## V. SUMMARY

An energy efficient wireless sensor network can be achieved with Enhanced-SWEET algorithm when the initial weighting time of the nodes is resized, the sleeping mode is applied and by taking the base station node into consideration.

Resizing the initial weighting time gives more clusters, according to literature, when there many clusters in the network, the more energy is saved. Clusters are equivalent to the number of gateways in the network. Allowing other nodes to sleep in the network increase the lifetime of the network and base station aware nodes saves a lot of energy.

## VI. CONCLUSIONS

In this paper, we first studied the SWEET protocol and its features for wireless sensor networks. The numerical results demonstrate that the proposed EN-SWEET can lead to tremen- dous energy efficiency gain compared to SWEET and LEACH protocol. EN-SWEET shows to be useful in improving the life cycle of wireless sensor network, while data capacity might be deteriorated by the sleeping mode technique.

## REFERENCES

[1] A.A. Ahmed, S. Hongchi, S. Yi , “A survey on network protocols for wireless sensor networks,” IEEE ITRE I, pp.301-305, Aug. 2003.
[2] M.A.M. Vieira, C.N. Coelho, Jr D.C. da Silva, J.M. da Mata, “Survey on wireless sensor network devices,” IEEE ETFA , pp.537-544, Sept. 2003
[3] V. Mhatre, Rosenberg, C., ”Homogeneous vs heterogeneous clustered sensor networks: a comparative study,” IEEE International Conference on Communications, pp.3646-3651 Jun. 2004
[4] A. Bari, R. Chaturvedi, A. aekel, S. Bandyopadhyay, “Energy Aware Distributed Clustering in Two-Tiered Sensor Networks,” ICCCN pp.1,8, 3-6 Aug. 2009
[5] N. Vlajic and D. Xia, Wireless Sensor Networks: To Cluster or Not to Cluster? WoWMoM, Jun. 2006.

[6] W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, “An application-specific protocol architecture for wireless microsensor networks,” IEEE transaction on Wireless Communications, pp.660-670, Oct. 2002.
[7] H. Gou; Y. Yoo, “An Energy Balancing LEACH Algorithm for Wireless Sensor Networks,” IEE ITNG, pp.822-827, Apr. 2010.
[8] S.H. Gajjar, K.S. Dasgupta, S.N. Pradhan, K.M. Vala, “Lifetime improvement of LEACH protocol for Wireless Sensor Network,” ENUiCONE, pp.1-6, Dec. 2012.
[9] T. Quynh, K. Phung, H. Quoc, ”Improvement of energy consumption and load balance for LEACH in Wireless Sensors Networks,” IIEEE CTC, pp.583-588, Oct. 2012.
[10] H.M. Abdulsalam, L.K. Kamel, “W-LEACH: Weighted Low Energy Adaptive Clustering Hierarchy Aggregation Algorithm for Data Streams in Wireless Sensor Networks,” IEEE ICDMW, pp.1-8, Dec. 2010.
[11] T. Ravi; D. Biswanath, N. Sukumar, ”Weight based clustering in wireless sensor networks,” IEEE NCC, pp.1-5, Feb. 2013.
[12] S. Fang, S.M. Berber, A.K. Swain, ‘”An Overhead Free Clustering Algorithm for Wireless Sensor Networks,” IEEE GLOBECOM, pp.1144-1148, Nov. 2007.
[13] S. Fang, S.M. Berber, A.K. Swain, “Energy distribution-aware clustering algorithm for dense wireless sensor networks,” International Journal of Communication System, pp. 1223-1251, Feb. 2010
[14] J. Arias, E. Santos, I. Marin, J. Jimenez, Lazaro, A. Zuloaga, “Node Synchronization in Wireless Sensor Networks,” ICWMC, pp.50-50, Jul. 2006.