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Hierarchical Energy Efficient MAC protocol for Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) are known to be a highly resource constrained class of network where energy consumption is of prime concern. The characteristics of WSN are different from the conventional networks. These unique characteristics are often taken into account for addressing the issues and challenges related to network coverage, node distribution, node administration, network deployment, energy efficiency/consumption, and so forth. MAC layer is liable for establishing an efficient and reliable communication link between WSN nodes. This paper proposes a hierarchical MAC protocol with cross-layer optimization for energy-efficient WSNs. The main goal of the proposed protocol is to combine the strengths of LEACH and CSMA based MAC protocol while balancing their weaknesses. This protocol makes use of CSMA data transmission with neighbor acknowledgement (N-Ack) that enables it to take appropriate decisions to improve throughput and reduction in energy consumption. Results show that proposed algorithm delivers high throughput, less energy consumption and higher network lifetime in critical environments.

Keywords: DRESEP, LEACH, MAC, WSN, Network lifetime, Residual energy

INTRODUCTION

An infrastructure required for various industrial and governmental organizations to observe events occurring in a physical world is provided by sensor network. Wireless sensor networks (WSNs) consists of unattended multifunctioning sensors that are typically deployed in large quantities and in a high density manner with limited energy resource [1]. These sensing nodes are linked by wireless medium using radio, infrared, or optical frequency band. These networks have various applications like flood and fire detection in remote areas, traffic surveillance, air traffic control, and so forth. Sensors jointly gather ambient condition information such as temperature, pressure, and humidity from their surrounding environment and forward it towards static data sink. In many scenarios, as nodes are deployed in remote and dangerous area, replacement of their batteries becomes impossible. So they must work without replacing their batteries for many years [2]. Thus power management has become one of the fundamental issues of WSNs. Using a multi-hop communication, it allows the measured data to be forwarded over a long distance to the main location which is known as a sink. WSNs have been used for environment monitoring, healthcare, structure health monitoring, military, and many other applications. These sensor nodes rely on the use of small and limited energy batteries to supply electrical energy to these devices. Batteries need to be replaced or recharged regularly whenever it is depleted. This regular maintenance could easily become the greatest cost of installing a WSN for many applications [2].

Replacing or recharging batteries is not preferred or unfeasible because of the rising cost of regular maintenance when sensors are deployed over a wide region. In addition, sometimes the nodes may be not reachable, that is, when they are embedded in building materials or deployed in a hostile region for some military applications. During the past decade, the researchers proposed many solutions to prolong the lifetime of network. One of these techniques uses duty cycling strategy where the different units of the nodes are switched off or entered low-power (sleep) mode when they are inactive [3, 4]. Another approach is to design energy-aware medium access control protocols (MACs) and routing protocols [5]. Data aggregation also reduces the number of transmitted packets by removing packets that carry redundant data for the same region [6, 7]. Despite the fact that previous solutions reduce energy depletion to extend network lifetime or enhance the time period between battery replacements, it does not resolve the problem completely.

To reduce the energy consumption in WSN requires optimization across all layers. In the overall energy efficiency of communication protocol, MAC layer plays one of the most crucial role. Since sensors have limited resources, it is urgent to introduce the energy-saving techniques to enhance the network lifetime. To pursue the effective routing protocols, Recently many researchers have done lots of studies and got the result that a scheme with clustering is promising to improve scalability and network lifetime. LEACH protocol is an efficient clustering method to handle scalability problem and energy consumption challenge in WSNs.

The characteristics of routing protocols are strongly related to the activity of the transceiver and MAC protocol design. Therefore, an efficient MAC protocol is necessary for minimizing the energy consumption cost of WSN. Keeping these requirements in mind, the aim of our work is twofold. First to create a modified MAC protocol in WSN which could overcome the disadvantages of existing protocols in relation to energy efficiency, reliability and high throughput. Secondly, to apply this modified MAC protocol to the network layer routing protocol to achieve higher energy efficiency.

This paper describes the result of our work and is divided into six sections. The second section provides related work on common MAC and routing protocols and their characteristics. The third and fourth sections describe the modified MAC protocol and proposed routing protocol respectively. The fifth section shows the simulation scenario and the results. The sixth section concludes the paper.

RELATED WORK

There are different types of MAC protocols that are categorized as CSMA with collision avoidance (CSMA/CA) and TDMA protocols [8-10]. CSMA/CA protocols are based on CSMA in which each node listens before it transmits and if nobody transmits, the node will try to send a packet. The term multiple access means that multiple sensor nodes can access the channel at the same time, and a concurrent transmission causes a collision which has to be resolved by a technique such as Binary Exponential Backoff (BEB). In contrast to collision-based protocols, TDMA protocols are known as deterministic protocols. These protocols use a schedule plan which associates a time slot for each sensor node and enable avoiding collisions and reducing effects of overhearing and idle listening problem [8, 11]. The following discussion describes some common MAC protocols used in WSN. A common trend to diminish the power depletion is to let the nodes sleep as soon as possible. This avoids idle listening as soon as possible but causes synchronization overhead.

IEEE 802.11 is a CSMA/CA-based MAC protocol that implements control packets to avoid a collision as soon as possible. The Power Save Mode (PSM) reduces idle listening by periodically entering into the sleep state. Unfortunately, PSM is not suitable for multi-hop networks and is therefore not useful in WSNs [8].

Sensor-MAC (S-MAC) is another CSMA/CA-based protocol in WSN [11]. It is a modification of the IEEE 802.11 protocol [8] which overcomes the disadvantages of IEEE 802.11. The listening session enables sensor nodes to communicate with others to exchange some control packets. During the sleep session, the nodes turn off their radios to save energy [8]. In the listening session, during synchronization, a node broadcasts its schedule to all its neighbours [12]. Using synchronization (SYNC) packet, every node now has the schedule of its neighbor and can arrange a data transfer, and this enables the usage of this protocol in a multi-hop network [1]. It is required that every node maintains its scheduling table after a certain number of scheduled synchronizations. Therefore, every node should listen for a full period to find the neighbours that have different time schedules, causes packet overhead and is the disadvantage of this protocol [13].

The main operational sustainability concern in WSN is its energy resource constraint. A great number of energy-efficient routing protocols have been suggested for WSNs based on the network organization and the routing protocol operations. Most of research work in cluster-based routing has extensively focused on lifetime, stability, energy efficiency and scalability. Numerous energy-efficient clustering algorithms have been proposed in this aspect for a wide range of applications.

Heinzelman et al. presented a low energy efficient adaptive clustering hierarchy (LEACH) algorithm in which sensors arrange themselves into clusters for data aggregation [14]. In this protocol, data aggregation is performed periodically by cluster-heads (CHs) to reduce the redundancy in information to be communicated to BS. In setup phase, CHs are elected using two parameters: CH selection probability and number of times a particular node has been appointed as CH. To make a decision, a random number (between 0 and 1) is chosen by the node. To become a CH, the number picked by node should be less than threshold value $T(n)$ given by:

$$T(n)_{LEACH} = \begin{cases} \frac{p}{1-p(r \bmod \frac{1}{p})} & if\ n \in G \\ 0 & otherwise \end{cases} \qquad (1)$$

where r is the current round, p is CH selection probability, G is set of nodes which have not been CHs in last $\frac{1}{p}$ rounds.

The elected CHs send an advertisement message to all non CH nodes. On the basis of received signal strength, non-CH node decides to which cluster it wants to join. After cluster joining, the CH performs the function of TDMA scheduling in which particular time slot is being provided to each node. The nodes carry out transmission in their allotted time slots only. During steady state phase, the data transmission takes place between non CHs to CH, and then data is transmitted finally to BS [14].

Many LEACH-type schemes are applied in homogeneous WSNs. In homogenous sensor networks, sensor nodes cannot adapt well to the presence of heterogeneity when the network is in operation. The nodes which consume more energy will die first, and as a result the LEACH-type protocols turn out to be unstable. On the whole, there are lots of specific WSN applications that could highly benefit from being equipped with a percentage of the nodes which have more initial energy, these nodes make sure that there is more stable or dependable feedback from the network. And, in some cases, the stable period is a very important concern.

Manjeshwar et al. presented a reactive clustering algorithm named threshold energy- efficient sensor network (TEEN). It senses the medium continuously and transfers the data less frequently [15]. In TEEN, the network consists of homogeneous nodes and is divided into two level CHs. First level and second level CHs are distinguished in such a way that the CHs far from BS are termed as first level CHs and the closer ones are called second level CHs. It is efficient for the time-critical data sensing applications. In this, CHs send their members the values of hard and soft threshold [15]. Once hard threshold value is achieved, nodes forward the data to CH. The successive data is conveyed only when the environment changes by at least soft threshold value. TEEN can never transfer data to BS if the threshold values are not achieved.

To get better performance, stable election protocol (SEP) [16] is proposed to maintain the hierarchical routing in WSNs where two types of nodes have their own election probability. SEP extended (SEP-E) considers three level of heterogeneity. Three tier node hierarchy considers three types of nodes. Threshold-sensitive SEP (TSEP) is a reactive protocol with three-tier node classification [17]. In TSEP, similar to TEEN, the data transmission depends upon threshold parameters. TSEP increases the stability, network lifespan and network throughput as compared with LEACH, TEEN and SEP. In [18], Kumar et al. presented a clustering protocol named EEHC in the heterogeneous model. The network is divided into three categories in terms of initial energy of nodes. EEHC is based on SEP, and the three types of nodes in EEHC have their own election probability to be CHs within a fixed time to keep stable. Energy efficient and scalable sensor network can be achieved through clustering and multi-hop transmission. It has attracted much attention of the researchers. In [19], Kumar et al. improved EEHC further and proposed a multi-hop clustering protocol called MCR. In MCR, the multi-hop path is built to reduce the energy consumption.

Mittal et al. proposed a clustering algorithm using dual-hop communication between CH and BS, suitable for event driven applications called DRESEP [20]. Mittal et al. also proposed SEECP protocol that yields higher network stability but at the cost of overall network lifetime [21]. Mittal et al. designed threshold-sensitive energy-efficient clustering protocol (TECP) with the consideration of meta-heuristic optimization algorithms like differential evolution [22], harmony search algorithm [23], and spider monkey algorithm [24] for CH selection. The stability aware model of TECP is developed to extend the stability period of the network.

Sharma et al. proposed ANN based framework for energy efficient and optimal cost path routing in multi-hop WSNs [25]. The integrated link cost measure is the function of three parameter such as throughput, residual energy and delay.

CSMA/N-ACK PROTOCOL DESIGN

The different types of MAC protocols are proposed for WSN, but none of them was accepted as standard. The choices of the appropriate MAC protocol depend on the application, and this is one reason why there is no specific one standardized MAC protocol for WSN. The standardization at other lower layers such as physical layer and sensor hardware is another reason why none of these protocols is standardized.

The proposed CSMA/N-Ack MAC protocol in this research uses an improved variant of CSMA. It uses weak signal detection to divide collisions from weak signals and take appropriate decisions to reduce energy consumption. Apart from the TDMA based protocols which try to avoid collisions, the majority uses CSMA as a base to handle collisions. The collision detection in wired Ethernet is archived by participants who transmit a packet and continue listening for incoming signal (collisions) and in the case of a collision, these participants emit jamming signals which notify all other participants that a collision is detected. The receiver which is close to a transmitter is not able to receive another concurrent transmission and detect collision [26] like in wired scenario.

Some attempts use the second antenna to detect and abort collisions during the transmission immediately [27]. But the major problem is still the cost for the second antenna. The most WSN applications are still using only one antenna and a simple transceiver for communication to save costs in the design and the implementation phase. The CSMA/CA should be a solution to this problem because the receiver will send an Ack to confirm that the data packet has arrived successfully. If a collision occurs, the transmitter which waits for an Ack will identify the occurrence of a collision after a timeout. However, there are several other reasons why a data transmission is not confirmed by an Ack reply [26].

Figure 1 shows that node A forwards a packet to node B, but this node does not reply to node A by an Ack.

However, wireless signal transmissions are influenced by multiple external factors such as reflection and absorption. These effects can influence the data as well as the possible Ack response. Following CSMA/CA protocol, this case is a collision, and the back off transmission algorithm will retransmit the packet at a randomly chosen time. This brings an additional delay which affects the throughput, and the nodes are confronted with longer idle listening periods which cause higher energy consumption.

If node A could recognize the reason for packet loss, it could take appropriate strategy to handle in this situation. As shown in Figure 2, node A was not receiving any Ack from node B. However, node C receives the data successfully and knows it was addressed to its neighbour B. As node B never replied with Ack, node C assumes that the data packet was forwarded to B without any collisions between A and B. The problems why node B was not able to reply with an Ack are as follows:

i. Node B is off or in sleep mode.

ii. The data packet from A to B has a weak signal.

iii. The Ack reply from B to A has a weak signal.

iv. Another node which is not visible for A and C was causing a collision with the original data or Ack packet.

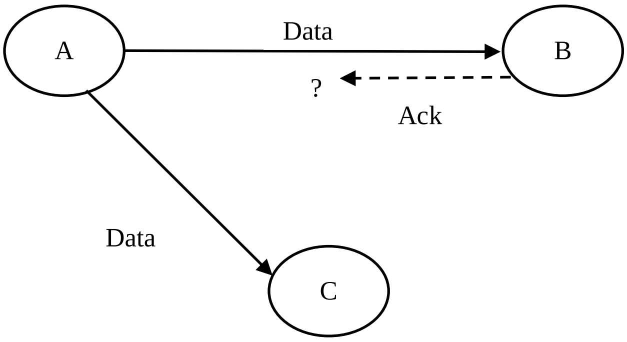


Figure 1: Data transmission with no Ack reply.

The last case is only visible to node B and is not a collision between these three nodes. As node C knows that there is no collision between node A and B, it assumes that there could only be a weak signal and sends a neighbour-Ack (N-Ack) packet after a timeout to node A. After receiving N-Ack packet, node A recognizes that C is not the destination node and it assumes this packet has not arrived properly at node B. Using the back-off algorithm in this scenario would increase the time and energy consumption by idle listening. Instead of this, node A should retransmit the data packet immediately.

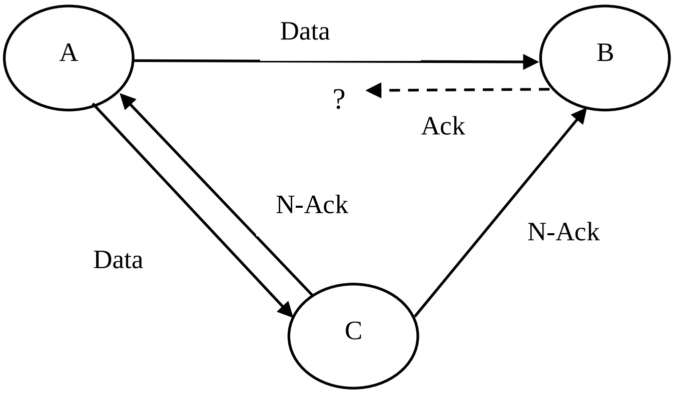


Figure 2: Data transmission with N-Ack reply

Figure 3 shows the timely behaviour of the protocol idea. If node A sends a packet, it defines an Ack timeout and within that it expects an Ack from node B. In this case, due to the weak signal, node B will be unable to respond with an Ack. After the Ack timeout, node C sends a neighbour-Ack (N-Ack) to show that it does not receive an Ack at all which offers node A to retransmit the packet immediately.

The Short Inter-frame Space (SIFS) is a short time-span between data and Ack packet. It ensures the sender (node A) has enough time to switch from transmitting to receiving mode and to receive the Ack reply. Initially, this new protocol idea decreases the throughput slightly in an ideal environment with no packet loss. Figure 4 compares both protocols, the original CSMA (a) and CSMA/N-Ack (b) which have the same Ack timeout. However, the new protocol waits additionally for N-Ack which decreases the protocol throughput slightly.

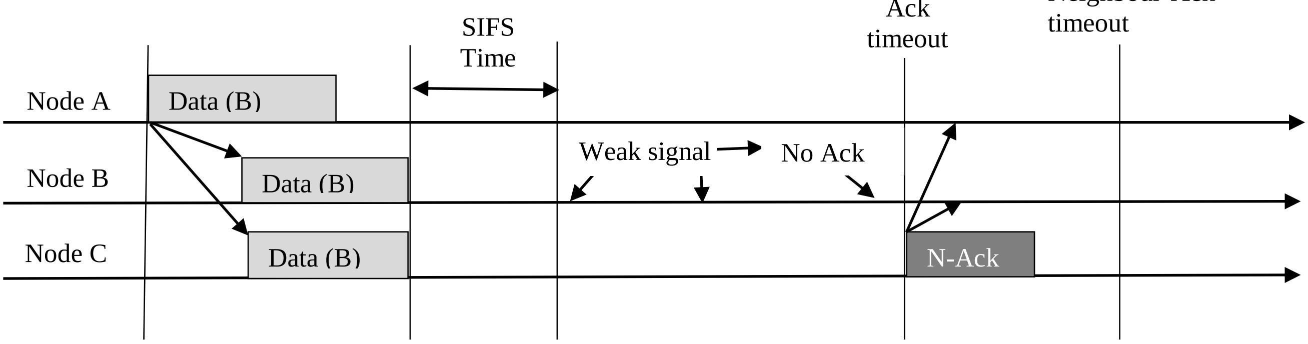
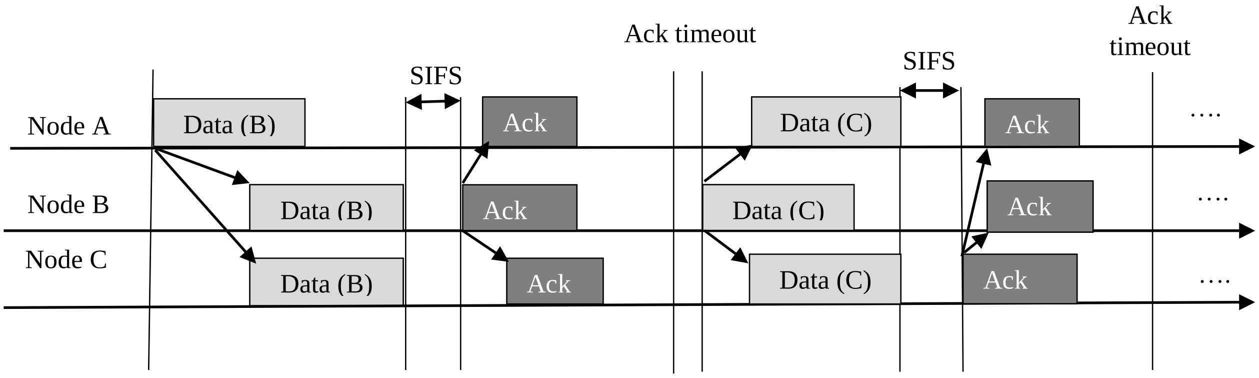
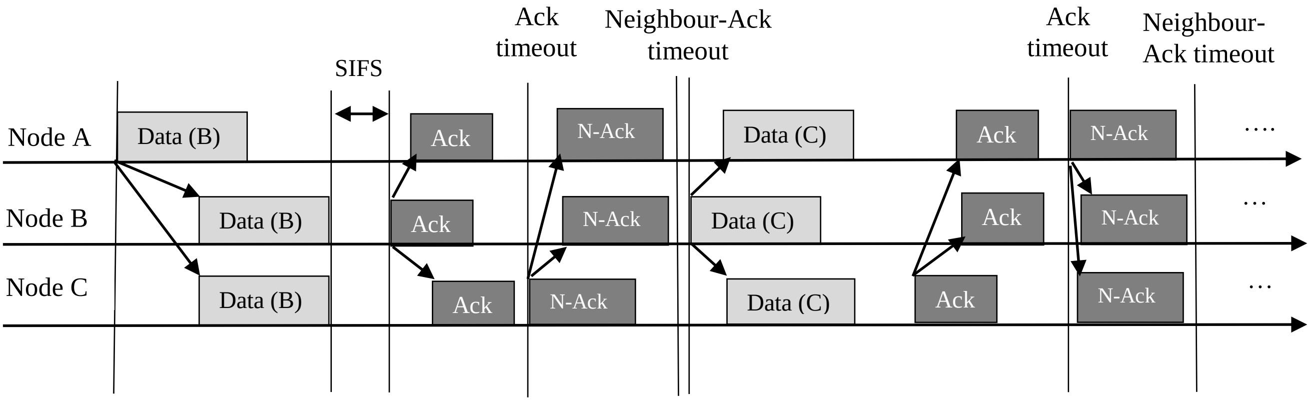


Figure 3: CSMA/N-Ack behaviour under weak signal conditions.



(a)



(b)

Figure 4: Throughput comparison between (a) CSMA and (b) CSMA/N-Ack

The new idea results in a small mean back off time and a high throughput. If the wireless channel causes packet loss due to weak signal, N-Ack provides support by keeping the back off time reduced. This enables transmitting more packets in a short period and therefore increases the throughput. In case of a collision, a back off relay transmission algorithm will be triggered to increase the retransmission time and in the case of a weak signal, N-Ack will be received and the packet directly retransmitted.

PROPOSED CSMA/N-ACK BASED ROUTING PROTOCOL

Recently, many routing solutions have been developed to enhance the performance of the network. They can be categorize into flat protocols and cluster-based protocols. In flat protocols, all sensor nodes play same role and functionality. Flat network structure provides an acceptable overhead so that infrastructure among nodes can be maintained. In flat based routing every node performs sensing and sending operation. Therefore, all the data collected from nodes can be duplicated or remain same. For example, flooding and gossiping. In clustering, sensor nodes are properly arranged and categorized into different clusters and a CH is chosen from each cluster. CH node has higher energy as compared to other nodes. Member nodes forward data to CHs which further process the data and direct it to BS. For example, LEACH [14].

As we all know that LEACH is proposed based on the homogeneous WSNs, while in the practical applications, heterogeneity of nodes cannot be avoided. Proposing the protocol which is suitable for HWSNs is needed. In this work, a LEACH-based clustering protocol is proposed in heterogeneous environment using CSMA/N-Ack algorithm.

The proposed cluster-based routing protocol named hierarchical energy efficient MAC (HEEMAC) protocol mainly focus on three aspects: (1) electing the cluster head by the energy prediction scheme; (2) reduces some of the sources of energy wastage by using CSMA/N-Ack algorithm; (3) saving energy consumption by threshold-decision based intra-cluster transmission, and multi-hop transmission between cluster head and sink.

HEEMAC, an adaptive reactive clustering algorithm, is a self-organizing two-level hierarchy that uses three kinds of nodes:

advanced, intermediate and normal nodes in heterogeneous WSN (HWSN). Heterogeneous protocol improves the stability period of the clustering algorithm using heterogeneity parameters, namely the fraction of advanced (m) and intermediate nodes (m_0) having additional energy factor between advanced-normal nodes (α) and intermediate-normal nodes (β) respectively. Assume E_0 is defined as initial energy of the normal node; therefore, initial energy of intermediate and advanced node should be $E_0(1+\beta)$ and $E_0(1+\alpha)$, respectively.

As described above, the total energy of the whole HWSN setting can be

$$E_{Total} = n(1-m-m_0)E_0 + nmE_0(1+\alpha) + nm_0E_0(1+\beta) = nE_0(1+m\alpha+m_0\beta) \tag{2}$$

As we can see from E_{Total}, the total initial energy is increased $1+m\alpha+m_0\beta$ times compared with the homogeneous network. To make sure that the election of CHs of the network is stable, which means making these three kinds of nodes elect CHs separately, the new optimal epoch is defined as $\frac{1}{p_{opt}}(1+m\alpha+m_0\beta)$.

Then, the weighted probabilities of three kinds of nodes to become CHs are as follows:

$$p_{nrm} = \frac{p_{opt}}{(1+m\alpha+m_0\beta)} \tag{3}$$

$$p_{int} = \frac{p_{opt}}{(1+m\alpha+m_0\beta)}(1+\beta) \tag{4}$$

$$p_{adv} = \frac{p_{opt}}{(1+m\alpha+m_0\beta)}(1+\alpha) \tag{5}$$

In HEEMAC, the threshold function $T(n)$ of the node is used based on CH selection probability, remaining energy, and distance of a node to BS [20]. Threshold function for homogeneous network is, therefore, given by:

$$T(n) = \begin{cases} \frac{p_{opt}}{1-p_{opt}\left(r \bmod \frac{1}{p_{opt}}\right)} \frac{D_{avg}}{D_{sink}} \left[\frac{E_{current}}{E_{max}} + \left(r_s div \frac{1}{p_{opt}}\right)\left(1-\frac{E_{current}}{E_{max}}\right)\right] & if\ n \in G \\ 0 & otherwise \end{cases} \tag{6}$$

where p_{opt} is CH nomination probability, $E_{current}$ and E_{max} (or E_0) is the is the current and initial energy of the node respectively, r_s is range of consecutive rounds during which a node has not been CH, D_{avg} is average distance of all alive nodes from BS, and D_{sink} is distance from node i to BS as follows:

$$D_{sink} = D_{iBS} = \sqrt{(X_i - X_{BS})^2 + (Y_i - Y_{BS})^2} \tag{7}$$

Using the above formulas (3-7), the threshold value to elect the CHs for normal intermediate and advanced nodes (for heterogeneous network), respectively are:

$$T(n_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-p_{nrm}(r \bmod \frac{1}{p_{nrm}})} \frac{D_{avg}}{D_{sink}} [\frac{E_{current}}{E_{max}} + (r_s div \frac{1}{p_{nrm}})(1-\frac{E_{current}}{E_{max}})] & if\ n_{nrm} \in G' \\ 0 & otherwise \end{cases} \tag{8}$$

$$T(n_{int}) = \begin{cases} \frac{p_{int}}{1-p_{int}(r \bmod \frac{1}{p_{int}})} \frac{D_{avg}}{D_{sink}} [\frac{E_{current}}{E_{max}} + (r_s div \frac{1}{p_{int}})(1-\frac{E_{current}}{E_{max}})] & if\ n_{int} \in G'' \\ 0 & otherwise \end{cases} \tag{9}$$

$$T(n_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{adv}(r \bmod \frac{1}{p_{adv}})} \frac{D_{avg}}{D_{sink}} [\frac{E_{current}}{E_{max}} + (r_s div \frac{1}{p_{adv}})(1-\frac{E_{current}}{E_{max}})] & if\ n_{adv} \in G''' \\ 0 & otherwise \end{cases} \tag{10}$$

where G', G'' and G''' is set of nodes that have not been elected as CHs in last $\frac{1}{p_{nrm}}$, $\frac{1}{p_{int}}$ and $\frac{1}{p_{adv}}$ rounds respectively.

Operation of HEEMAC Protocol

The operation of HEEMAC is studied in terms of rounds. As shown in Figure 5, the proposed framework initiates with set-up phase followed by steady state phase. In HEEMAC, the set-up phase is divided into the following main phases:

CH Election: Each node initially decides whether to become a CH or not for the present round based on CH selection probability. The judgment is made by node n by selecting a random number between 0 and 1. If this number is less than $T(n)$ using equations (8-10), sensor node nominates itself to be CH for present round.

Cluster Formation: The nominated CHs announce their status to the network using advertisement message that contains its ID. Each sensor responds the join request to their respective CH using CSMA N-Ack protocol discussed above.

TDMA Schedule Design: Each CH builds a TDMA plan for its members to permit their communication. It specifies time slots during which cluster members need to be in active state only when they are certified to send their information.

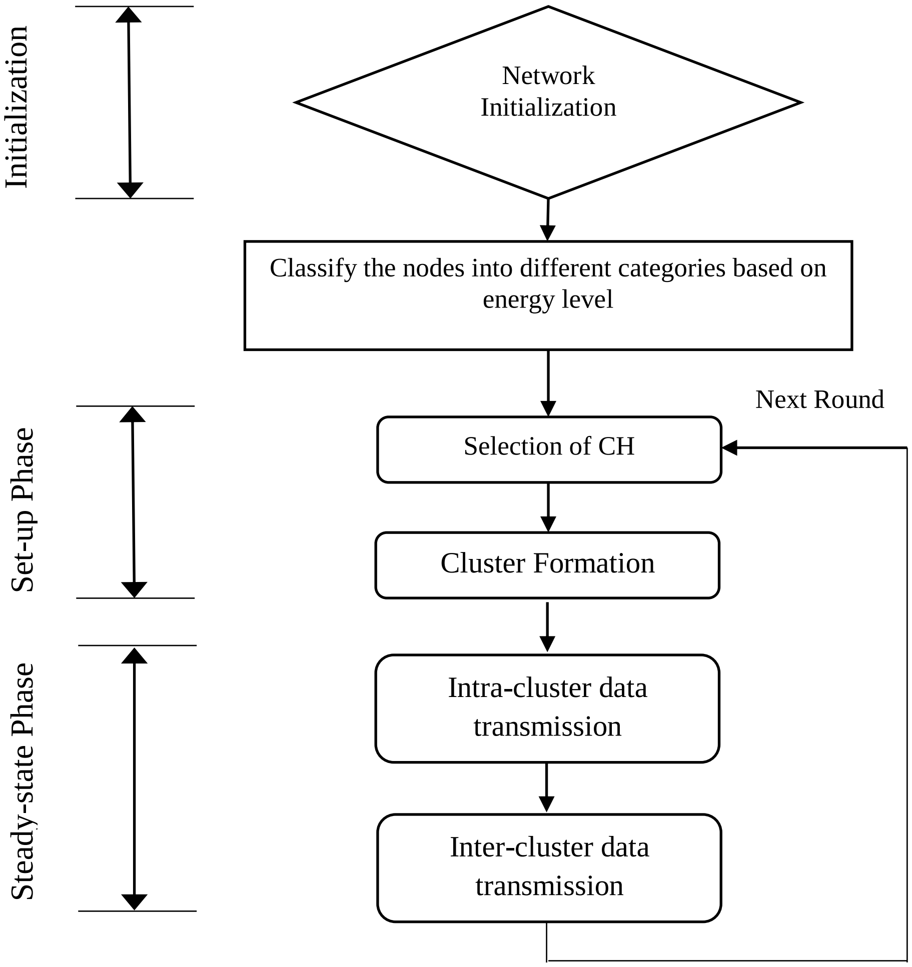


Figure 5: Network operation of HEEMAC protocol.

In intra-cluster data transmission phase, the protocol uses a reactive strategy for communication from CMs to respective CH. Once nodes join CH, it senses the environment continuously. Each non-CH node switch ON their radio and transmit their sensed information to their respective head once the event is activated (i.e. current sensed value surpasses hard threshold value H(T)). When H(T) value is attained, the subsequent transmission is realistic if variation in sensed value surpasses the soft threshold value S(T) [15]. The nodes transmit their sensed information to the CH as per their assigned TDMA schedule of transmission. This enables nodes to keep their radio off until its transmission time occurs. The sleep periods save node energy.

HEEMAC protocol uses both single-hop and multi-hop transmission in the network. CMs communicate directly with the CH, and CH communicates with the sink through multi-hop communication by choosing the proper CH nearest to the sink as the next hop.

Since the clustering operation in HEEMAC is dynamic, the dead of CH in present round will not cause the sensors of the corresponding cluster become disconnected from BS as they may become members to another cluster in the next round.

SIMULATION RESULTS

The performance of proposed algorithm is evaluated by carrying out extensive simulations. All simulations were carried out using MATLAB R2015a. The performance of HEEMAC is compared with several state-of-the-art energy efficient cluster-based protocols including LEACH, TEEN and DRESEP. Simulation results are produced by deploying 100 nodes randomly within a 100m $*$ 100m area. In homogeneous setup, the network consists of 100 nodes having initial energy E_0, in which the deployment area is 100m × 100m and BS is located at (50, 50). For heterogeneous setup, intermediate and advanced nodes are set to 20% and 10% of the total nodes and have initial energy 2 times and 3 times greater than normal nodes (having initial energy E_0)

respectively. The parameters setting for proposed protocol is given in Table 1.

Table 1: Simulation parameters used for HEEMAC.

Parameter	**Value**
Number of nodes	100
Network size	$100m \times 100m$
Location of BS	(50, 50)
Initial energy, E_0	$1\ J$
Radio electronics energy, $E_{Tx} = E_{Rx}$	$50\ nJ/bit$
Energy for data-aggregation, E_{DA}	$5\ nJ/bit$
Radio amplifier energy, ε_{friss_amp}	$100\ pJ/bit/m^2$
Radio amplifier energy, $\varepsilon_{two\_ray\_amp}$	$0.0013\ pJ/bit/m^4$
Temperature range on the field	0°F – 200°F
Hard threshold	50°F
Soft threshold	2°F

The simulation results reveal that in HEEMAC, total energy consumption during cluster formation, CH selection, and transmission has been reduced. To analyze the network lifespan against each method, various simulations were run for initial energy of 1 J for 100 nodes and packet size of 4000 bits. In Figure 5, it is clear that HEEMAC surpasses the competitive algorithms in terms of energy efficiency and prolong lifetime. This increases the number of rounds and maximizes network lifetime. In addition, HEEMAC uses CSMA/N-Ack protocol instead of CSMA protocol for intra-cluster communication that helps in reduced collisions from weak signals and hence reduces the energy consumption. Also, HEEMAC is threshold-sensitive protocol in which data transmission is feasible only when certain conditions are satisfied. Hence, energy consumption is less and network lifetime is enhanced.

Table 2 shows the round history of dead nodes and average network lifetime in terms of number of rounds it takes until first node dies (FND), half of nodes die (HND) and last node dies (LND) for homogeneous setup.

Figure 6 shows total energy consumed against the number of rounds. The results show that energy consumed by HEEMAC is less than others with increase in number of rounds. In comparison with LEACH, TEEN and DRESEP, the proposed protocol maximizes the lifetime approximately by 175.14%, 25.12% and 10.52% respectively.

Table 2: Round history of dead nodes for simulated protocols.

%dead Nodes	**LEACH**	**TEEN**	**DRESEP**	**HEEMAC**
1 (FND)	1805.2	3518.3	4101.6	4901.8
10	2022.8	4048.3	4504.2	5265.8
20	2069.3	4228.9	4769.9	5492.3
30	2141	4379.2	4881.4	5575.7
40	2169.4	4460.7	4983.5	5687.9
50 (HND)	2215.2	4569.6	5126.7	5777.4
60	2280.1	4731.5	5294.2	5982.5
70	2346.3	4820.1	5395.4	6129
80	2394.8	4972.3	5621.1	6304.4
90	2485.6	5154.7	5770.7	6666.6
100 (LND)	2763.5	5388.2	6402.2	7109.2

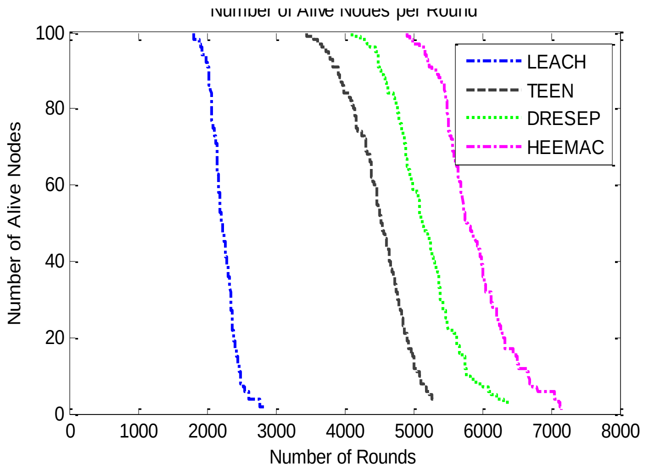


Figure 5: Network lifetime comparison for LEACH, TEEN, DRESEP and HEEMAC

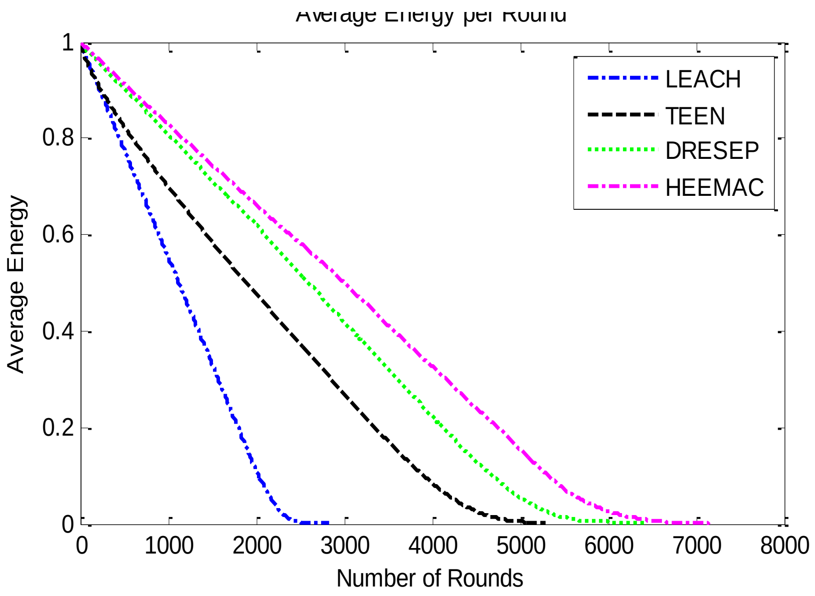


Figure 6: Average energy per round for simulated protocols for homogeneous set-up.

HEEMAC protocol using CSMA/N-Ack is designed to detect weak signals and to increase the throughput. The statistics of total number of data packets received at BS for homogeneous setup before FND, HND and LND is given in Table 3. The number of data packets received at BS for HEEMAC is higher in comparison to TEEN and DRESEP as it makes use of CSMA/N-Ack MAC protocol for intra-cluster communication between CH and its members that increases the throughput significantly. The performance of HEEMAC, TEEN and DRESEP lags behind LEACH, this is expected as these protocols only transmit time-critical data while sensing the environment continuously.

Table 3: Total number of data packets received at BS for homogeneous setup.

Protocol	FND	HND	LND
LEACH	66,545.7	78,217.3	84,356.2
TEEN	42, 321.2	48,548.8	52, 782.4
DRESEP	44,386.5	51,752.7	56,383.8
HEEMAC	47,952.7	53,596.7	57,893.4

The behaviour of proposed protocols for heterogeneous setup is shown in Figures 7 and 8, and the statistics are given in Tables 4 and 5.

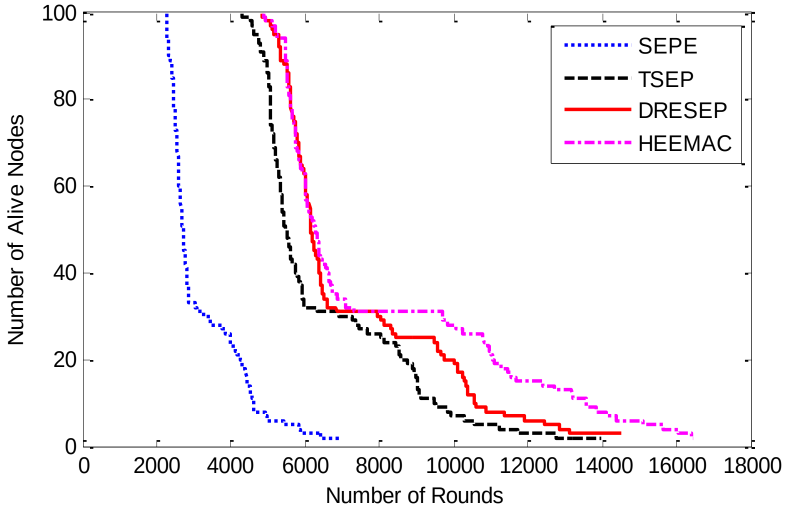


Figure 7: Lifetime comparison of simulated protocols for heterogeneous set-up.

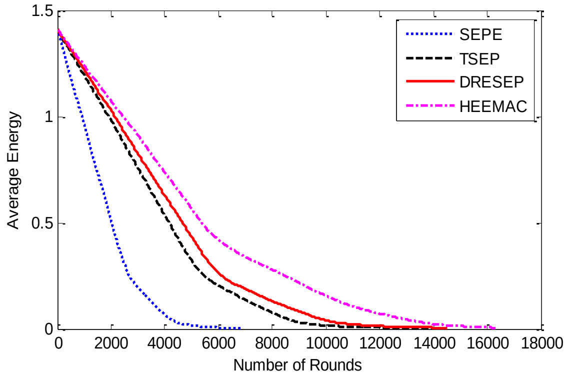


Figure 8: Average energy per round for simulated protocols for heterogeneous set-up.

HEEMAC takes additional time in comparison to LEACH, SEP-E, TEEN and TSEP protocols to run each round. The average time needed for LEACH, SEP-E, TEEN and TSEP is 0.129s, 0.141s, 0.1446s and 0.149s respectively in comparison to the time needed for HEEMAC is 0.161s. The proposed protocol take additional time to run in each round due to the fact that HEEMAC handles more computational cost for making the threshold-decision and to handle multi-hop communication at each round. In addition, CSMA/N-Ack needs a little more time in HEEMAC protocol because it waits for an additional neighbour-Ack. However, the time for calculation does not make substantial impact on network as compare to efficiency achieved.

Table 4: Round history of dead nodes for heterogeneous

%dead Nodes	SEP-E	TSEP	DRESEP	HEEMAC
1 (FND)	2269.5	4249.9	4846.6	4901.7
10	2309.4	4844.2	5331.7	5474.8
20	2452.5	5050.5	5597.1	5583
30	2552.6	5152.7	5789.5	5746.4
40	2607.8	5312.8	5995.4	6004.1
50 (HND)	2701.3	5455.3	6140.1	6258.2
60	2790.5	5724.4	6376	6591.6
70	3251.9	6876.8	7920.6	9679.4
80	4272.1	8569.6	9759.3	11041.3
90	4605.5	9438.2	10568.9	13574.8
100 (LND)	5872.8	13962.1	14528	16384.4

Table 5: Total number of data packets received at BS for heterogeneous setup.

Protocol	FND	HND	LND
SEP-E	72, 285.9	86, 542.4	1,58,741.3
TSEP	49,528.7	57,485.4	93,425.8
DRESEP	51,892.7	59,845.3	96,284.3
HEEMAC	52,106.4	61,852.3	97,576.7

CONCLUSION AND FUTURE WORK

The aim of this work is to create a CSMA/N-Ack based routing protocol in WSN which will overcome the disadvantages of existing routing protocols are based on the CSMA. CSMA/ N-Ack MAC protocol is a contention-based protocol which allows more throughput. In this paper, HEEMAC protocol based on CSMA/ N-Ack MAC is proposed that is well suited for time critical applications. The redundancy in the data transmission can be controlled by adjusting the threshold parameters to achieve higher network lifetime. In addition, it minimizes the energy usage and improves network lifetime by applying multi-hop transmission to BS from distant CHs. The proposed method is better than other competitive algorithms in terms of network lifetime, and total energy consumption. HEEMAC takes a bit more time to run in each round than other protocols but the time for calculation does not make substantial impact on network as compare to efficiency achieved.

By integrating the results, it is evident that a protocol that is heterogeneity-aware (i.e. with energy-diversity of nodes) proves to be more energy efficient in terms of the overall network lifetime compared with a protocol using single-node energy setting (i.e. homogeneous) in a hierarchically clustered WSN. For energy heterogeneity among nodes, one can extend and improve the management of energy resources for the proposed protocols to cope with more than three-tier node setting. For example, one can investigate the applicability of the proposed protocols with a multi-tier SNs setting, where there are more than three levels of energy setting.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: a survey,” Computer Networks, vol. 38, no. 4, pp. 393–422, 2002.

[2] I. Stojmenovi´c, Ed., *Handbook of Sensor Networks: Algorithms and Architectures*, John Wiley & Sons, 2005.

[3] J. Polastre, J. Hill, and D. Culler, “Versatile low power media access for wireless sensor networks,” in *Proceedings of the 2nd International Conference on*

Embedded Networked Sensor Systems, pp. 95–107, ACM, Baltimore, Md, USA, 2004.

[4] W. Ye, J. Heidemann, and D. Estrin, "An energy-efficient MAC protocol for wireless sensor networks," in *Proceedings of the 21st Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '02)*, vol. 3, pp. 1567–1576, Piscataway, NJ, USA, June 2002.

[5] S. K. Singh, M. P. Singh, and D. K. Singh, "Routing protocols in wireless sensor networks—a survey," *International Journal of Computer Science & Engineering Survey*, vol. 1, no. 2, pp. 63–83, 2010.

[6] Y. Chen, J. Shu, S. Zhang, L. Liu, and L. Sun, "Data fusion in wireless sensor networks," in *Proceedings of the International Symposium on Electronic Commerce and Security (ISECS '09)*, vol. 2, pp. 504–509, May 2009.

[7] K. Ramanan and E. Baburaj, "Data gathering algorithms for wireless sensor networks: a survey", *International Journal of Ad Hoc, Sensor & Ubiquitous Computing*, vol. 1, no. 4, pp. 102–114, 2010.

[8] R. Yadav, S. Varma, andN.Malaviya, "A survey of MAC protocols for wireless sensor networks," *UbiCC Journal*, vol. 4, no. 3, pp. 827–833, 2009.

[9] V. Cionca, T. Newe, and V. Dˇadˆarlat, "TDMA protocol requirements for wireless sensor networks," in *2nd International Conference on Sensor Technologies and Applications, SENSORCOMM 2008*, pp. 30–35, fra, August 2008.

[10] R. Sharma, B. S. Sohi, "A Compartitve Study on MAC Protocols for Wireless Sensor Networks on Energy Reduction", *International Journal of Computer Science and Information Security, Vol 15, No 11, pp. 35-40, Nov.*2017.

[11] T. Bernard and H. Fouchal, "A low energy consumption MAC protocol for WSN," in *Proceedings of the IEEE International Conference on Communications (ICC'12)*, pp. 533–537, Ottawa, Canada, June 2012.

[12] W. Ye, J. Heidemann, and D. Estrin, "An energy-efficient MAC protocol for wireless sensor networks," in *Proceedings of the 21st Annual Joint Conference of the IEEE Computer and Communications Societies*, vol. 3, pp. 1567–1576, IEEE, 2002.

[13] H. Feng, L. Ma, and S. Leng, "A low overhead wireless sensor networks MAC protocol," in *Proceedings of the 2nd International Conference on Computer Engineering and Technology (ICCET'10)*, pp. V4-128–V4-131, Shandong, China, 2010.

[14] W. R. Heinzelman, A. Chandrakasan, and H. Balakrish-Nan, "Energy-efficient communication protocol for wireless microsensor networks," in Proceedings of the IEEE 33rd Annual Hawaii International Conference on System Sciences (HICSS '00), vol. 2, p. 10, January 2000.

[15] A. Manjeshwar, D. Agrawal, "TEEN: A routing protocol for enhanced efficiency in wireless sensor networks", in *15th International Parallel and Distributed Processing Symposium (IPDPS'01) Workshops*, USA, California, 2001, pp. 2009-2015.

[16] G. Smaragdakis, I. Matta, A. Bestavros, "SEP: A stable election protocol for clustered heterogeneous wireless sensor networks", in *International Workshop on SANPA*, 2004.

[17] A. Kashaf, N. Javaid, Z. A. Khan, I. A. Khan, "TSEP: Threshold-sensitive stable election protocol for WSNs", in *10th international conference on frontiers of information technology (FIT),* 2012, 164 (168), pp. 17–19

[18] D. Kumar, T. C. Aseri, R. B. Patel, "EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks", *Computer Communications*, vol. *32*, pp. 662–667, 2009.

[19] D. Kumar, T. C. Aseri, R. B. Patel, "Multi-hop communication routing (MCR) protocol for heterogeneous wireless sensor networks". *Journal of Information Technology, Communications and Convergence*, vol. 1, no. 2, pp. 130–145, 2011.

[20] N. Mittal, U. Singh, "Distance-based Residual Energy Efficient Stable Election Protocol for WSNs", *Arabian Journal of Science and Engineering (AJSE), Springer,* vol. 40, Issue 6, pp 1637-1646, June 2015.

[21] N. Mittal, U. Singh, B. S. Sohi, "A Stable Energy Efficient Clustering Protocol for Wireless Sensor Networks", *Wireless Networks (WINE), Springer,* pp 1-13, March 2016. DOI: 10.1007/s11276-016-1255-6.

[22] N. Mittal, U. Singh, B. S. Sohi, "A Novel Energy Efficient Stable Clustering Approach for Wireless Sensor Networks", *Wireless Personal Communications,* Springer, pp 1-25, Jan., 2017.

[23] N. Mittal, U. Singh, B. S. Sohi, "Harmony Search Algorithm Based Threshold-sensitive Energy-efficient Clustering Protocols For WSNs", *Ad Hoc & Sensor Wireless Networks,* pp 1-26, *September 2016.*

[24] N. Mittal, U. Singh, B. S. Sohi, "A Boolean Spider Monkey Optimization Based Energy Efficient Clustering Approach For WSNs", *Wireless Networks,* Springer, pp 1-17, Jan., 2017.

[25] R. Sharma, B.S. Sohi, Amar Singh, Shakti Kumar "ANN Based Framework for Energy Efficient Routing in Multi-Hop WSN's," *International Journal of Advanced*

Research in Computer Science, Vol.8, No.5, May-June 2017

[26] S. Rayanchu, A. Mishra, D. Agrawal, S. Saha, and S. Banerjee, “Diagnosing wireless packet losses in 802.11: separating collision from weak signal,” in *Proceedings of the 27th IEEE Communications Society Conference on Computer Communications (INFOCOM ’08)*, pp. 1409–1417, IEEE, Phoenix, Ariz, USA, April 2008.

[27] D. Hamdan, O.E. Aktouf, I. Parissis, A. Hijazi, M. Sarkis, and B. E. Hassan, “SMART service for fault diagnosis in wireless sensor networks,” in *Proceedings of the 6th International Conference on Next Generation Mobile Applications, Services, and Technologies (NGMAST ’12)*, pp. 211–216, Paris, France, September 2012.