$(ACH)^2$: Routing Scheme to Maximize Lifetime and Throughput of Wireless Sensor Networks

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***Abstract*— Regarding energy efficiency in wireless sensor networks (WSNs), routing protocols are engaged in a playful manner suggesting a consciousness of high value. In this paper, we present away cluster heads (CHs) with adaptive clustering habit ($(ACH)^2$) scheme for WSNs. Our proposed scheme increases the stability period, network lifetime, and throughput of the WSN. The beauty of our proposed scheme is its away CHs formation, and free association mechanisms. The $(ACH)^2$ controls the CHs' election and selection in such a way that uniform load on CHs is ensured. On the other hand, free association mechanism removes back transmissions. Thus, the scheme operations minimize the over all energy consumption of the network. In subject to throughput maximization, a linear programming-based mathematical formulation is carried out in which the induced subproblem of bandwidth allocation is solved by mixed-bias resource allocation scheme. We implement $(ACH)^2$ scheme, by varying node density and initial energy of nodes in homogeneous, heterogeneous, reactive, and proactive simulation environments. Results justify its applicability.**

***Index Terms*— Wireless sensor networks, clustered routing, energy efficiency, received signal strength, throughput maximization, linear programming, resource allocation.**

I. Introduction

LARGE number of wireless sensors (nodes) together with Base Station (BS) form a unionized structure called WSN. The sensing circuitry of node measures certain parameters of the surrounding environment, and transforms them into electrical signals. These signals are then processed to extract the information of interest actually occurring in nodes' vicinity. Such information is generally sent, directly or indirectly, to an end station via radio waves [1]. WSNs may consist of different types of nodes such as infrared, acoustic, seismic, visual, radar, thermal and many others; which extends their application range. Some applications of WSNs are as follows [2].

- **Military applications:** These include: monitoring friendly forces, battle field surveillance, nuclear attacks, battle damage assessment, etc.
- **Environmental applications:** Such as forest fire detection, bio complexity mapping, flood detection, and many more.
- **Health applications:** Like tele-monitoring of human physiological data, patient monitoring, doctor tracking, drug administration in hospitals, etc.
- **Home applications:** For example home appliance automation, smart environment formation, and so on.
- **Commercial applications:** Such to liking of car theft detection, interactive museums, and inventory control, etc.

Energy efficiency is the future trend in information and communication technology [3]. Since data transmission from source to destination is the main task in WSNs, the method adopted to forward these data turns out to be of extreme significance [4]. Due to intrinsic limited battery capacity of nodes, routing in WSNs becomes more challenging as compared to wireless ad hoc networks [5]. Keeping the fact in mind that nodes' density is high in these networks, the need of routing protocols with the capability to transfer data along lengthy routes is becoming much more demanding. Irrespective of the network size, and all the way through the network operation, some of the engaged nodes may not work properly due to their energy depletion. However, this issue should not have an effect upon the ongoing network operation. Moreover, as nodes have limited battery power, memory capacity, processing capability and available bandwidth, routing in terms of efficient resource utilization needs to be performed [6].

In direct transmission, each node communicates with BS on individual basis i.e., directly. Thus, distant nodes die at a faster rate as compared to nearer ones. In hop-by-hop transmission, each node communicates with its nearest neighbour node which in turn transmits to its neighbour, the process continues till data reaches BS. As a result, nearer nodes consume more energy and die at a faster rate as compared to distant ones [7]. Regarding energy efficiency in the field of WSNs, current research body is much more attracted towards clustering based routing protocols in which the nodes are organized into clusters [8]. Each node is responsible to communicate

Manuscript received March 3, 2014; revised May 12, 2014; accepted May 25, 2014. Date of publication June 4, 2014; date of current version August 29, 2014. The associate editor coordinating the review of this paper and approving it for publication was Dr. M. R Yuce.

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Digital Object Identifier 10.1109/JSEN.2014.2328613

with its respective CH and CHs are responsible to convey the gathered information to BS. Thus, saving energy because global communication is reduced due to local compression. Unbalanced energy consumption among the nodes causes network partition and node failures, where, transmission from some nodes to the BS becomes blocked. Therefore, construction of a stable backbone is one of the challenges in sensor network applications.

The proposed routing scheme aims to maximize the lifetime, and throughput of the network. After nodes' deployment, information sharing among the nodes and BS is carried out with the help of HELLO messages broadcast mechanism. BS first elects the candidate set for the selection of CHs and then finalizes this set by removing the candidates remained with less than average residual energy of individual nodes' in the network. The central control, calculates optimal number of CHs from the available resources in the network, and compares it with the finalized candidate set. If these elected CHs are found to be more than the optimal value, then, the extra candidates are unmarked by selecting away CHs based on received signal strengths. The away CHs mechanism results in clusters of almost similar size and optimum in number. In this way the unbalanced load problem of CHs is solved. Furthermore, with balanced cluster size, the contending nodes for channel access are minimized in number. Thereby leading to relatively less number of packets being dropped. Moreover, the $(ACH)^2$ associates nodes with CHs in an adaptive free manner such that back transmissions are removed and the over all length of the path traversed by locally gathered data is reduced. As the association mechanism of $(ACH)^2$ minimize the overall communication distance, so energy consumption is reduced which means increased network lifetime. Here it is worthy to note that this research work is extended form of the work in [9].

Rest of the paper is organized as: in section II related work is provided, section III deals with motivation, section IV contains brief description of the proposed $(ACH)^2$, section V aims for throughput maximization with the help of linear programming based mathematical modeling and bandwidth allocation via mixed-bias resource allocation scheme, section VI takes the discussions of simulation results into consideration, section VII ends the research work with conclusion and future work, and finally references are given at the end.

II. Related Work

Based on energy, WSNs are of two types: homogeneous and heterogeneous. In homogeneous networks, all the nodes are initially supplied with same energy levels, whereas, different energy levels are assigned to nodes in the case of heterogeneous networks. On the other hand, with reference to their operational mode, these networks are categorized into proactive and reactive. Nodes in a proactive network transmit periodically. Whereas, reactive networks respond immediately, whenever, parameters of interest undergo a change. The general idea of clusters organization in WSNs has been studied in many published research works [10] and [11]. However, due to space limitation, only some of these works are described here.

LEACH [12] is one of the very first clustering based hierarchical protocol for homogenous WSNs. The main content of cognition is to reduce global communication by the formation of local clusters of the nodes based on minimum distance or received signal strength. In each cluster, CHs, responsible for data aggregation and fusion, are selected according to the criteria set by LEACH. As transmissions to BS are only done by CHs, we can say that they are localized and energy efficiency is enhanced. CHs in LEACH are randomly rotated over time to balance the energy consumption of nodes. A given node i generates a random number, and compares it with a threshold value; $Th(i)$, given in [12] as:

$$Th(i) = \begin{cases} \frac{p}{1-p(mod(r,\frac{1}{p}))} & \text{if } i \in G \\ 0 & \text{Otherwise} \end{cases} \tag{1}$$

where, p is the probability of CHs which is defined initially, G is the set of nodes which are eligible for the selection of CHs, and $mod(r, \frac{1}{p}))$ returns the modulus after division of r by $\frac{1}{p}$. When the value of threshold is greater than the random number, node is selected as CH. In eqn. 1, r represents the round in progress. Optimal number of CHs is suggested to be 10% of the total nodes in the network. However, the randomly selected CHs are not optimum in number, and the resulting clusters are of different sizes. These drawbacks lead to unbalanced energy consumption, which leads to decreased network lifetime.

The goal of proposed TEEN [13], is to design a routing layer protocol with the capability to react immediately after the detection of change in the sensed attribute of interest. The CHs selection and nodes' association techniques of TEEN are similar to those of LEACH. Where, each node generates a random number and compares it with a threshold value. If the generated random number is less than the threshold value, and the node has not been CH for the last $\frac{1}{p}$ rounds. The node broadcast a message, telling every other node that it has been selected as CH. TEEN differs from LEACH in the steady state phase. In the case of LEACH, there is no check on the transmission of data. However, in TEEN, when a node has data to send, there are checks of hard and soft thresholds. Nodes first time transmit, when the sensed value reaches its hard threshold. Next time transmissions occur, only when, the sensed value is greater than hard threshold and the current value of the sensed attribute differs from soft threshold by an amount greater than or equal to the soft threshold. However, in addition to the drawbacks of LEACH this protocol has decreased network throughput.

Before SEP [14], clustered routing protocols assumed that all the nodes are equipped with same initial energy. In order to take full advantage of nodes' heterogeneity, SEP defines two energy levels. Based on these energy levels, nodes are categorized into two types i.e., normal and advanced. Nodes having α times more energy in comparison to normal ones are called advanced nodes. Thus, the advanced nodes are more preferred for the selection of CHs due to their assigned probability weights. The probability of normal nodes p_n differs from advanced nodes p_a as follows,

$$p_n = \frac{p_{opt}}{1+\alpha.m} \tag{2}$$

$$p_a = \frac{p_{opt}(1+\alpha)}{1+\alpha.m} \tag{3}$$

where, m is the fraction of advanced nodes. From eqn. 2 and 3, it is clear that advanced nodes are more probable for the selection of CHs as compared to normal ones. Rest of the protocol's operation is similar to that of LEACH. However, the nodes always send the sensed data to the CH(s) even if these lie at comparatively shorter distance from the BS. Thus, extra energy is consumed which causes shrinkage in the network lifetime.

Li Qing *et al.* in [15] propose DEEC routing protocol for heterogeneous WSNs. In this protocol, nodes are equipped with different energy levels as the network operation starts. The CHs selection is based on the ratio of the residual energy of a node to average energy of the network. The nodes with higher residual energy have more chances to be CHs for a particular round. This makes the energy distribution even among the nodes. DEEC prolongs stability period as nodes with more residual energy become CHs frequently. The CH formation in DEEC is similar as in LEACH, however, the probability for nodes to become CHs is different i.e., rotating probability given by,

$$p(i) = \frac{p_{opt}N(1+\alpha)E_i(r)}{(N+\sum_{i=1}^{i_{imax}} a_i)\overline{E}(r)} \tag{4}$$

where p_{opt} is the desired probability of CHs, N is the total number of nodes, $E_i(r)$ is residual energy of a node, and $\overline{E}(r)$ is network's average energy. However, the clusters formed due to random selection of CHs are of different sizes. Thus, leading to quick energy depletion of the CHs belonging to the cluster with dense concentration of nodes as compared to that of the sparse ones.

Authors in [16] propose a routing protocol, in which hexagonal sectoring method is introduced for nodes' deployment. This sectoring method guarantees uniform load on CHs throughout the network field. The beauty of this method is the way in which nodes associate with CHs. Nodes of any sector can associate with any of the CHs (irrespective of its sector), based on minimum distance. While taking remaining energy and node's degree into account, weight equation is used for the selection of CHs.

$$W_i = \frac{D_i}{D_{avg}}.\frac{E_i}{E_{avg}} \tag{5}$$

where, W_i is the weight of a node, D_i as its degree, and E_i represents its energy. Moreover, D_{avg} and E_{avg} shows average degree and average energy of the nodes. However, the sectors are of fixed sizes which lack adaptivity.

In [17], authors propose a Link aware Clustering Mechanism (LCM) for WSNs. The goal of LCM is to establish a reliable path with balanced load. In order to do so, the CHs are selected on the bases of node status and link condition. Where, link condition refers to quality and node status to residual energy. This mechanism determines a clustering metric called predicted transmission count. Thus, the CHs selection depends on priority, and candidates with highest priority are selected as CHs. The deficiencies of LCM include; unbalanced cluster size and non optimum number of CHs.

Conventional routing protocols focus on finding the shortest path, however, authors in [18] are concerned with efficient routing in a duty-cycled network. They divide the network field into a number of overlapping clusters, such that, sleep scheduling of a node causes a network topology change. Moreover, the CHs are selected on the basis of energy availability. However, the selected CHs are more in number as compared to the optimum value.

III. Motivation

Regarding energy efficiency, many network layer protocols have been proposed [12]–[15]. However, these protocols are not as energy efficient as needed. Firstly, these protocols randomly select the CHs. So the selection criterion of these protocols can be improved in many ways. The randomly selected CHs are not optimum in number. The clusters thus formed exhibit variation in size i.e., the CHs of large sized clusters consume more energy as compared to that of the CHs of small sized clusters which leads to unbalanced energy consumption. Secondly, each member node, which belongs to a specific cluster, sends data to the CH even if its distance from BS is less than that from the CH. In doing so, surplus energy is consumed due to which the network lifetime steps down. Thirdly, the association mechanism of these protocols increases the overall communication distance. In order to overcome the aforementioned deficiencies, new routing protocol(s) needs to be proposed.

IV. The $(ACH)^2$

Efficient energy utilization, sometimes called energy efficiency, is to deliver equal or greater level of services with less energy supply. In WSNs, energy efficiency is in direct relation with the lifetime of the nodes.

Network model: We consider a WSN in which nodes gather the information of interest from the environment, and send these data to the selected CHs which in turn forward the locally gathered and compressed data to BS. So, in a WSN nodes are of three types: Non-CH nodes (nodes), CH nodes (CHs) and BS. In WSN model, the positions of nodes and CHs are random, whereas that of BS is predetermined based on application. We suppose BS at the centre of the network field.

Let N be the set of nodes and C be the set of CHs, where, $N = \{i|i \in N \wedge 1 \leq i \leq i_{max}\}$, and $C = \{c|c \in C \wedge 1 \leq c \leq c_{max}\}$. Each node can establish a link within its communication range R_{com}. This discussion leads us to the following connectivity parameter.

$$U_{(x,y)} = \begin{cases} 1 & \text{if } x \text{ establishes a link with } y \\ 0 & \text{Otherwise} \end{cases}$$

if $x = i$ then (1) $y = j \;\; \forall j \in N$ and $j \neq i$ or (2) $y = c$ or (3) $y = BS$, and if $x = c$ then $y = BS$. It is important to note that any of the above links depend upon the received signal strength or distance. The degree of closeness is directly

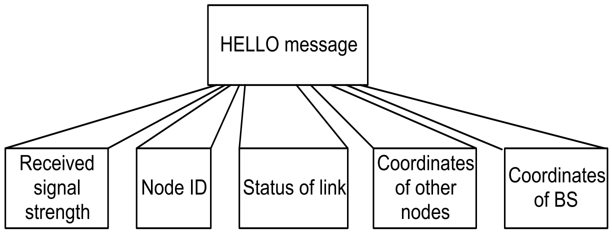


Fig. 1. HELLO message format.

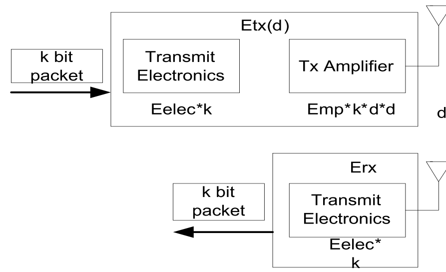


Fig. 2. Radio Model.

related with the strength of received signal which is in turn related with the quality of link.

We divide the scheme operation into rounds. Each round is further divided into five phases; (1) network configuration, (2) random election for the selection of CHs, (3) natural selection of CHs, (4) free association, and (5) data scheduling and transmission. While keeping in mind that the second and third phase provide solution to the unbalanced load problem as well as the throughput maximization problem, and the fourth phase account for overall energy consumption minimization, details about each phase are discussed in the following subsections.

A. Network Configuration

Due to the fact that newly deployed nodes are in the state of missing reliable infrastructure for communication, information sharing becomes indispensable for WSNs. Initialization phase begins at the start of each round, and with the basic aim to up grade all the network configurations. Once the nodes in a WSN have information about their relative coordinates, received signal strengths, and area IDs, the chances of organizing successful communications increase. We use a HELLO message exchange mechanism (shown in fig. 1) to inform each node with the received signal strengths, node IDs, status of links, and the coordinates of all other nodes along with BS in the network.

B. Random Election for the Selection of CHs

Once nodes are deployed in the network field, these locally coordinate for cluster setup and operation. The decision to elect itself or not for the selection of CHs, rests with each node. The node generates a random number $rand$ and compares it with the threshold value Th. There are two possible cases,

Case1 ($rnd > Th$)**:** Node can not be elected for the selection of CHs, and is marked as type 'N' i.e., normal node.

Case2 ($rnd \leq Th$)**:** If the node has not been CH for the last $\frac{1}{p}$ rounds, then it belongs the candidate set for the selection of CHs, and is marked as type '$\bar{C}$' i.e., elected CH. Where, p is the probability of a node to become CH.

Furthermore, BS calculates average residual energy of the network and compares the residual energy of the elected CHs with it. Elected CHs are eliminated from the candidate set for the selection of CHs, if their energy is smaller than the average residual energy of individual nodes' in the network. On the other hand, elected CHs are not eliminated from the candidate set for the selection of CHs, if converse is found to be true.

The $(ACH)^2$ considers the calculation of nodes' average residual energy at the start of each round. As the rounds proceed, the nodes consume energy and their average residual value decreases. This means that during each round, the remaining energy of some nodes is greater than the average residual energy of individual nodes' whereas for others it is less than or equal to average residual value of energy. Therefore, the possibility that all the candidate nodes are remained with less than the average residual value of energy is negligible. If we do not neglect then these nodes send data to the nearest in-range node (alive) or BS. The $(ACH)^2$ implements the later approach.

C. Natural Selection of CHs

After the random election for the selection of CHs, new needs in terms of optimal number of CHs selection arise. In order to fulfil these needs, use or disuse of certain techniques takes place which results in uniform load on CHs. Natural selection refers to the selection of optimal number of CHs, as a function of spatial density, and after the uniform distribution of nodes over the network field. The term, "*optimal number of CHs selection*", is emphasized by the fact that the total energy consumption is minimum, and energy consumption per round is well distributed over all the nodes in the network field.

To find the actual value of the so-called optimal number of CHs, We use similar radio model as used in LEACH, TEEN, SEP and DEEC, i.e., first order radio model. Fig. 2 shows pictorial representation of the first order radio model, which illustrates the expense of energy used by transmitting b bit packet over a distance d to achieve an acceptable signal to noise ratio.

$$E_{Tx}(b,d) = \begin{cases} b.E_{elec} + b.\epsilon_{fs}.d^2 & \text{if } d < d_o \\ b.E_{elec} + b.\epsilon_{mp}.d^4 & \text{if } d \geq d_o \end{cases} \quad (6)$$

Where E_{elec} in eqn. 6 is the energy expense per bit of the transmitter or receiver circuitry. ϵ_{fs} and ϵ_{mp} are the amplifier types, d is the distance between transmitter and receiver, and d_0 is the reference distance ($d_o = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$). Receiving b bit message, the radio expends:

$$E_{rx} = b.E_{elec}$$

Let N number of nodes are distributed randomly in the network field with a centrally positioned BS. The most distant node from BS is at a distance $d \leq d_o$, such that the energy consumed by a CH per round is given by:

$$E_{CH} = b.E_{elec}(\frac{N}{k} - 1) + b.E_{da}\frac{N}{k} + b.\epsilon_{fs}d^2_{toBS} \qquad (7)$$

in eqn. 7, k is the number of clusters, E_{da} is the energy consumed by CH in data aggregation and d_{toBS} is the distance between BS and CH. To transmit b bit data to CH, the normal node consumes E_{norm} given by,

$$E_{norm} = b.E_{elec} + b.\epsilon_{fs}.d^2_{toCH} \qquad (8)$$

Where d_{toCH} represent the distance between a normal node and its CH. As per our assumption the nodes are uniformly distributed, thus according to [19], it can be shown that:

$$E(d^2_{toCH}) = \int\int (x^2 + y^2) l(x, y)\, dxdy = \frac{M^2}{2\pi k} \qquad (9)$$

in eqn. 9, $l(x, y)$ shows the nodes distribution. Energy consumption of the whole cluster is as follows,

$$E_{cluster} = E_{CH} + (\frac{N}{k} - 1)E_{norm} \qquad (10)$$

The total amount of energy consumed by the network is,

$$E_T = b.(2NE_{elec} + NE_{da} + \epsilon_{fs}(k.d^2_{toBS} + N\frac{M^2}{2\pi k})) \qquad (11)$$

Optimal number of CHs k_{opt} is found by differentiating E_T with respect to k and equating to zero,

$$k_{opt} = \sqrt{\frac{NM}{2\pi d_{toBS}}} = \sqrt{\frac{2N}{2\pi 0.765}} \qquad (12)$$

It is now easy to determine the optimal probability of a node to become CH p_{opt}, that is given as:

$$p_{opt} = \frac{k_{opt}}{N} \qquad (13)$$

Soon after the election for the selection of CHs, such that the set of candidate nodes is finalized. The number of nodes that belongs to $\bar{C}$ i.e., $n_{\bar{C}}$, is compared with k_{opt}. Three possible cases are handled as,

- **if** $(n_{\bar{C}} < k_{opt})$**:** Next election for the selection of CHs is carried out.
- **if** $(n_{\bar{C}} > k_{opt})$**:** CHs are minimized in number.
- **if** $(n_{\bar{C}} = k_{opt})$**:** Scheme operation is carried to the next phase.

Whether it is next election or next phase, the scheme operation is already described enough to understand the concept, however, the CHs minimization technique is worthy to discuss in detail. The elected CHs send a confirmation message to one another using CSMA-MAC protocol. The CH which receives a strong response from its adjacent CH will be marked as a normal node. For simplicity in our simulations, we replace received signal strength by distance. We assume the CH will be made unmark and will become a normal node if its distance from the nearest CH is less than $10m$. The whole scenario is figured in fig. 3 and fig. 4, where, the elected CHs having a distance less than $10m$ between them are shown by "overlapping dashed circles" around them (refer fig. 3). After the

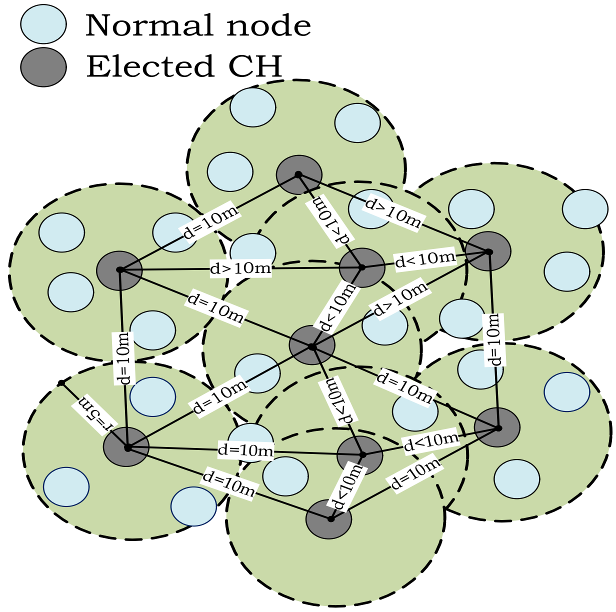


Fig. 3. Elected CHs' network.

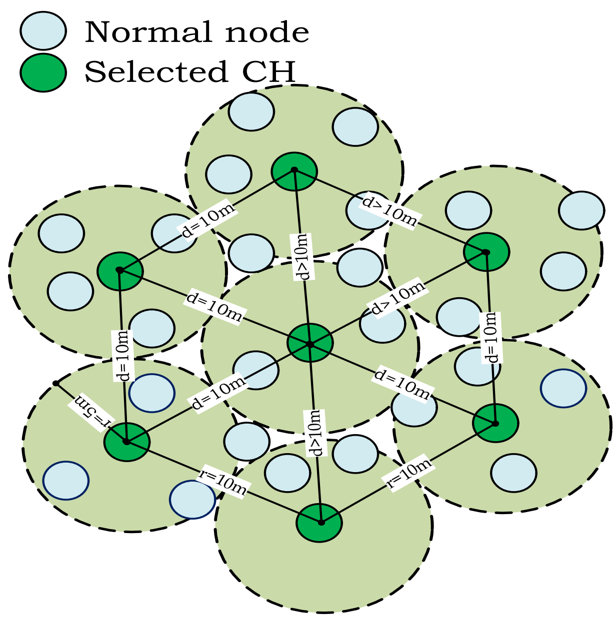


Fig. 4. Selected CHs' network.

confirmation of elected CHs, nodes receive an association message from them and respond according to the strength of the received signal. The clusters are thus formed and the CHs are well distributed in the network. This makes clusters even in terms of number of nodes in each cluster. In this way the dissipated energy of CHs in each round is comparably equal. Furthermore, due to balanced clusters the contending nodes for channel access are now properly adjusted such that the chances of collision between packets are minimized which leads to increased number of successfully received packets at the BS. The distant CHs' network is shown in fig. 4.

The parameter $10\,m$ is actually due the following reasons. (i) For 100 nodes, $k_{opt} = 6.4$ (as per Eqn. 13). (ii) From extensive simulation results as well as literature review, we conclude that better results are obtained when the selected CHs are about 10% of the total nodes. So, $d_{factor} = \lceil K_{opt} \rceil + S$ Where S is a scaling factor (here $S = 3$).

D. Free Association

Soon after the selection of optimal number of CHs, data reporting procedure of type N nodes needs to be addressed. The selected CHs broadcast their IDs, signal strengths, relative positions and status of links to normal nodes. Type N nodes record the updated information along with the information received during the network configuration, and based on this recorded information these decide the data reporting procedures which are discussed in detail as follows.

In conventional routing protocols, when a node receives broadcast messages from the selected CHs, it compares their received signal strengths and associates with the strongest among them. Such type of localization helps to reduce the volume of inter-node communication, however, the major points of concern are as follows.

- Size of the clusters is non uniform resulting in non uniform load on CHs.
- When a node associates with a CH located backwards relative to its direction of propagation towards BS, *back transmissions* occur. These transmissions increase the overall length of the path traversed by locally gathered data.
- Individual nodes are abandoned to communicate with BS on their own, even if they exist at a shorter distance from BS as compared to any one of the CHs.

In order to solve the afore mentioned problems, we propose an association mechanism in which each node has global knowledge about the WSN. On individual basis, nodes compare the received signal strengths from CHs and BS. If they receive strong response from BS as compared to CHs, then decision is taken against association i.e., the locally gathered data is transmitted directly to BS. On the other hand, if a given node receives a strong response from any of the CHs as compared to BS, then in the best interest of the node in terms of energy efficiency, decision is taken in the favour of association. One might think, how and in favour of whom, the decision of association is taken?

To answer the question in queue, let us consider a specific case shown in fig. 5. Node n finds its distance d_{n_BS} from BS, and calculates mid point M from it. At this mid point, node n compares the relative signal strengths received from both the CHs i.e., CH1 and CH2. As at point M the received signal strength from CH2 is higher than that of CH1. Therefore, node n sends association confirmation message to CH2. Here, it is worthy to note that, even when node n is located at a shorter distance from CH1 (d_{n_CH1}) as compared to that of CH2 (d_{n_CH2}), still it associates with CH2. The reason is straight forward i.e., in doing so *back transmissions* are removed. To prove that this association is in the best interest of the node in terms of efficient energy utilization, consider the following mathematical approach.

Assumptions:
d_{CH2_BS}: Distance between CH2 and BS.
d_{M_CH2}: Distance between M and CH2.

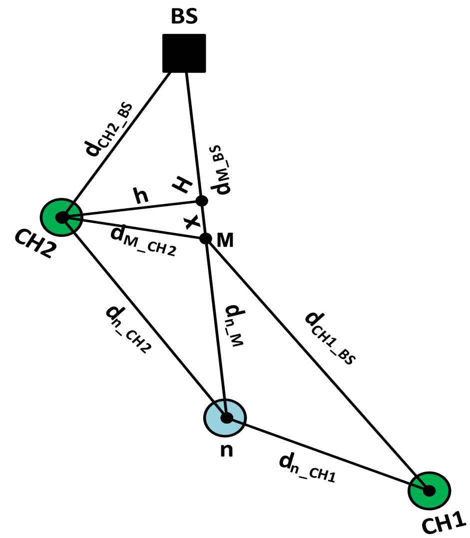


Fig. 5. Association of a node with CH.

H: Perpendicular drawn from CH2 on the line joining M and BS.
h: Distance between CH2 and H.

By using the famous pythagorean theorem,

$$(d_{CH2\_BS})^2 = h^2 + (\frac{d_{n\_BS}}{2} - x)^2 \tag{14}$$

$$(d_{n\_CH2})^2 = h^2 + (\frac{d_{n\_BS}}{2} + x)^2 \tag{15}$$

where, $d_{n\_BS} = d_{n\_M} + d_{M\_BS}$. Adding the above two equations, we get

$$(d_{CH2\_BS})^2 + (d_{n\_CH2})^2 = 2h^2 + \frac{(d_{n\_BS})^2}{2} + 2x^2 \tag{16}$$

After substituting $x^2 = (d_{M\_CH2})^2 - h^2$ in eqn. 16, we can write

$$(d_{CH2\_BS})^2 + (d_{n\_CH2})^2 = 2h^2 + \frac{(d_{n\_BS})^2}{2} + 2(d_{M\_CH2})^2 - 2h^2 \tag{17}$$

$$(d_{CH2\_BS})^2 + (d_{n\_CH2})^2 = \frac{(d_{n\_BS})^2}{2} + 2(d_{M\_CH2})^2 \tag{18}$$

From eqn. 18, we can see that when the value of d_{n_BS} is fixed, $(d_{CH2\_BS})^2 + (d_{n\_CH2})^2$ is only related to d_{M_CH2}. Here, our objective is to minimize the L.H.S of eqn. 18 i.e., Min $((d_{CH2\_BS})^2 + (d_{n\_CH2})^2)$ which is equivalent to Min (d_{M_CH2}). As a result, if a node chooses its CH closest to the midpoint of this node and the BS, the squared distance of their communication is smallest. Which means that energy consumption of the nodes in minimized, thus leading to increased network lifetime.

E. Data Scheduling and Transmission

Whether it is CHs selection or association of nodes, when all the pre-requisites regarding the cluster setup are performed, the CHs receive messages from nodes intended to associate with them. Similarly, BS receives messages from CHs and nodes intended to communicate directly with it. These message receptions are followed by data scheduling, where the CHs assign Time Division Multiple Access (TDMA) schedules to their respective cluster members, and the BS then creates TDMA schedules to individual nodes and CHs, telling them when to transmit. Data transmissions, with the assumption that nodes and CHs always have data to send, begin soon after the fixed assignment of TDMA based schedules. These transmissions minimize the energy consumption due to the CHs selection and nodes association mechanisms. The radio of each node is turned off until the nodes' allocated TDMA based schedules, thus the energy consumption is further minimized. The receiver of CH is kept on to receive all the gathered information. The CH, after receiving locally gathered data, perform signal processing functions to compress these data into a single composite signal. These high energy composite signals are then sent to the BS. When all these data transmissions end, then next round begins with the network configuration deciding the next CHs or non-CHs based on the scheme operation. Flow chart of the proposed scheme is shown in fig. 6.

V. Throughput Maximization

To achieve the best possible outcome, *linear programming* is one of the widely used mathematical techniques. This extensive approach begins with problem formulation i.e., *objective function* which is followed by *linear constraints*. This section deals with the proposition of linear programming based model which aims to maximize the throughput.

During the operation of $(ACH)^2$, BS directly receives packets from the selected CHs as well as some of the non-CH nodes. Whereas, rest of the nodes send packets to their selected CHs. We define throughput as the number of successfully received packets at BS, where, the aggregated data of a given cluster is forwarded to BS as a single composite packet and the sensed data of a node directly transmitted to BS is also assumed to be one packet. Based on these assumptions, we develop objective function as follows.

$$Max \sum_{r=1}^{r_{max}} Np(r) \quad \forall \ r \in R \tag{19}$$

where,

$$Np(r) = \sum_{np=1}^{np_{max}} \ell.np \quad \forall \ np \in Np \tag{20}$$

and,

$$\ell = \begin{cases} 1 & \text{if CH\textbackslash node communicates with BS} \\ 0 & \text{if node communicates with CH} \end{cases} \tag{21}$$

such that;

$$C_1 : E_i \leq E_0 \quad \forall \ \ i \in N \tag{19-a}$$

$$C_2 : p_{link} \geq p_{good} \quad \forall \ \ i \in N \tag{19-b}$$

$$C_3 : E_i \geq E_i^{min} \quad \forall \ \ i \in N \tag{19-c}$$

$$C_4 : f_{ij} \leq f_{ij}^{max} \quad \forall \ \ i, j \in N \tag{19-d}$$

$$C_5 : Max \sum_{c=1}^{c_{max}} B_c \quad \forall \ \ c \in C \tag{19-e}$$

$$C_6 : Min \sum_{\overline{c}=1}^{\overline{c}_{max}} B_{\overline{c}} \quad \forall \ \ \overline{c} \in \overline{C} \tag{19-f}$$

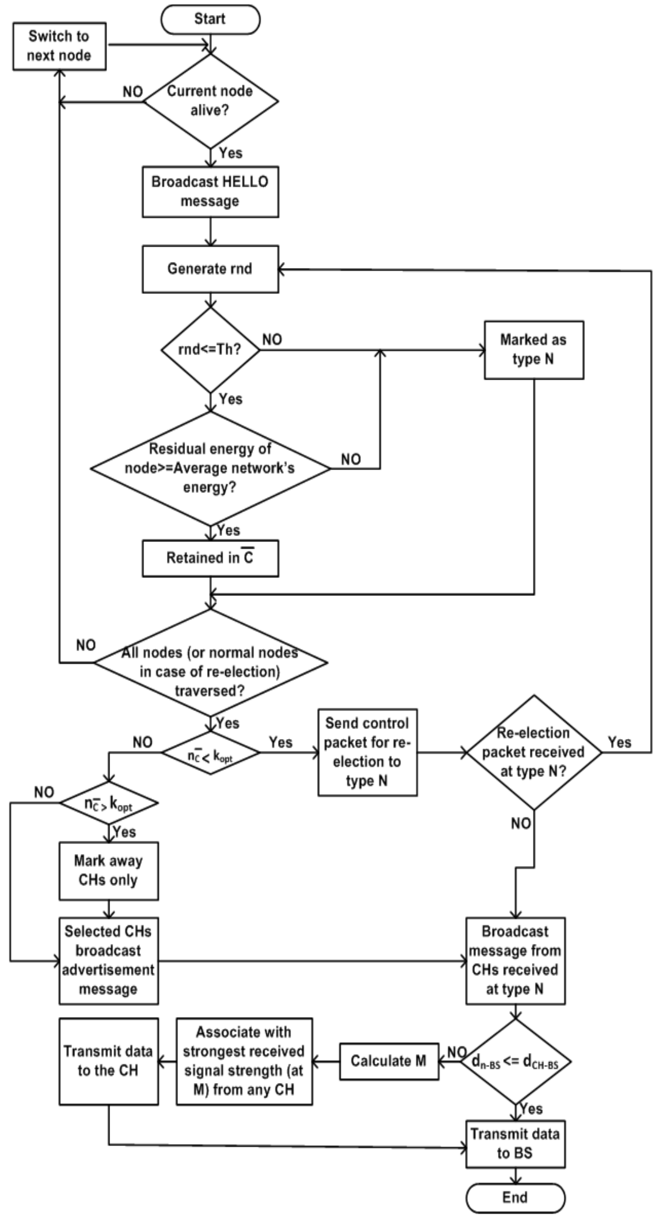


Fig. 6. The $(ACH)^2$: flow chart.

Our main objective in eqn. 19 is to maximize the number of successfully received packets Np at the BS for the current round r such that summation over r results in an increased throughput throughout the network lifetime. Where, eqn. 20 and eqn. 21 provide the explanation about the type of packets accounting to throughput. In eqn. 20, counter for the number of packets np is incremented, if and only if, the link flag ℓ (from eqn. 21) is high. Eqn. 19-a deals with energy constraint; each node i that belongs to the set of nodes N is supplied with an energy source E_i provided the upper bound E_0. This means that nodes are equipped with limited energy supply. From this perspective, throughput can be maximized by increasing the network lifetime which is in turn achieved by efficient utilization of the energy resources. The $(ACH)^2$ provides solution to this problem by exploiting the routing layer. Constraint in eqn. 19-b suggests that it is necessary for a given link, with probability p_{link} indicating its current status, to have at least the minimum required probability for successful packet delivery i.e., p_{good}. If this condition is not fulfilled, then the packet drop chances would increase. Constraint in eqn. 19-c indicates that before packet transmission it is necessary to check the energy of a node whether it is above the minimum required level E_i^{min} or not. An adaptive power management scheme would greatly enhance the system's performance in terms of throughput maximization. Eqn. 19-d illustrates the flow constraint through the physical link; flow f from i to j exceeding the upper bound f_{ij}^{min} causes packet(s) loss. In subject to the induced sub problems in eqn. 19-e and eqn. 19-f: high data rate CHs are needed as compared to the non-CH nodes because CHs forward the locally gathered data towards BS. This means that high bandwidth must be allocated to the CHs using a strongly biased policy, whereas, rest of the bandwidth must be allocated to nodes with a fairer policy. Therefore, for C_5 and C_6, we use *Mixed-bias* [20], [21] resource allocation scheme as follows.

Suppose, the total available bandwidth is B Hz, such that,

$$B = B_C + B_{\overline{C}} \quad \forall \quad C, \overline{C} \in N \tag{22}$$

where B_C is the allocated bandwidth to the set of CHs C and $B_{\overline{C}}$ is the allocated bandwidth to the set of non-CH nodes $\overline{C}$. Let, B_i is allocated to a node (CH or non-CH) via *Round Robin* resource allocation scheme. Then, the biased allocation to the CH is,

$$B_c = B_i \times Z^a \tag{23}$$

where $a = [0, 0.1, 0.2, 0.3, 0.4, 0.5]$. Mixed biasing is provided in relation to the cluster size Z indicating the number of nodes in a given cluster. If k clusters are formed during the current round, then, the bandwidth allocated to all the CHs is,

$$B_C = B_c \times k \tag{24}$$

Now, the allocated bandwidth for all the non-CH nodes is calculated as,

$$B_{\overline{C}} = B - B_C \tag{25}$$

such that, the share of each non-CH node is,

$$B_{\overline{c}} = \frac{B_{\overline{C}}}{N-k} \tag{26}$$

where $\overline{c}$ represent a non-CH node belonging to the set $\overline{C}$.

Here, it is worthy to note that this allocation scheme provides biasing levels according to the need of individual nodes which provides positive results in response to objective function in eqn. 19.

Graphical analysis: Consider a scenario where $B = 1367.6KHz \ to \ 2MHz$, $N = 100$, $k = 10$, and $Z = 10$. From the values of B and N the calculated value of B_i is $20KHz$, and by using eqn. 23; $B_c = 20KHz$ for $a = 0$ and $B_c = 63.24KHz$ for $a = 0.5$. Now, eqns. 22, 24 and 25 could be represented (with units in KHz) as,

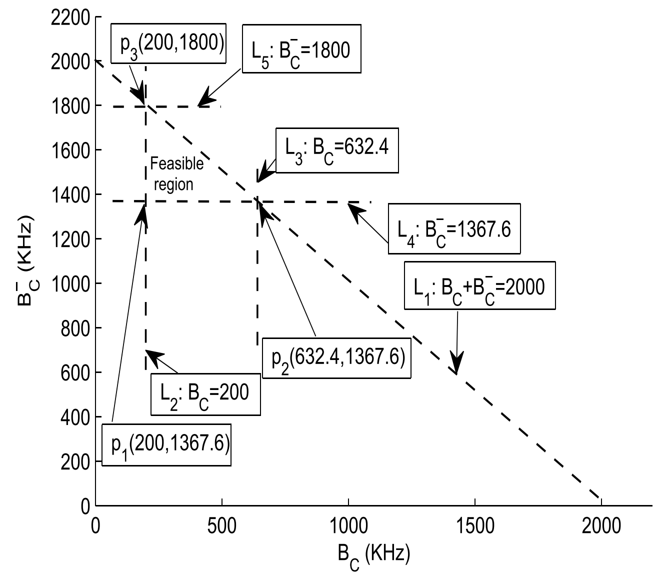


Fig. 7. Bandwidth allocation: feasible region.

TABLE I
RADIO PARAMETERS

Operation	Energy dissipated
Transmitter / Receiver Electronics	50nJ/bit
Data aggregation	50nJ/bit/signal
Transmit amplifier (if d to $BS \leq d_0$)	10pJ/bit/m^2
Transmit amplifier (if d to $BS > d_0$)	0.0013pJ/bit/m^4
Data rate	250 kbps

$$1567.6 \leq B_C + B_{\overline{C}} \leq 2000 \tag{27}$$

$$200 \leq B_C \leq 632.4 \tag{28}$$

$$1367.6 \leq B_{\overline{C}} \leq 1800 \tag{29}$$

In subject to the bounds provided by eqns. 27, 28 and 29; fig. 7 shows the intersection of lines L_1, L_2, L_3, L_4, and L_5 resulting in a bounded region which represents the set of all feasible solutions. This bounded region is known as feasible region. Each point in this region yields a valid solution. Now testing each vertex of the depicted region in fig. 7 as:
at $p_1 : (200, 1367.6) = 200 + 1367.6 = 1567.6KHz$,
at $p_2 : (632.4, 1367.6) = 632.4 + 1367.6 = 2MHz$, and
at $p_3 : (200, 1800) = 200 + 1800 = 2MHz$.
Therefore, it is proved that all the feasible solutions are valid. So, bandwidth between CHs and non CHs could be allocated at any point lying within the premises of the illustrated region.

VI. RESULTS AND DISCUSSIONS

Our goal in conducting simulations is to evaluate the performance of our proposed scheme by comparing it with four popular routing protocols: LEACH, TEEN, SEP and DEEC. Tests are performed using static nodes and plane coordinates, and the effects of channel interference on the propagation of radio waves are ignored. 100 nodes are randomly deployed in

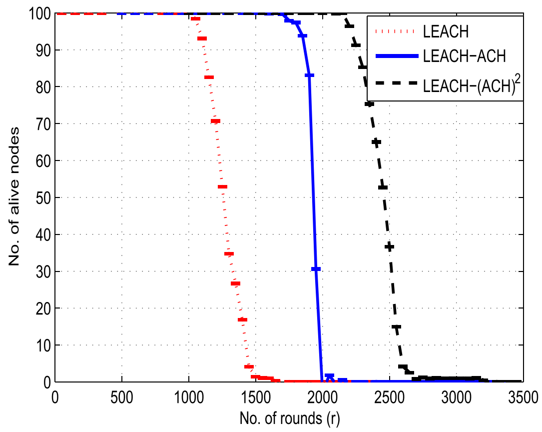


Fig. 8. Rate of alive nodes.

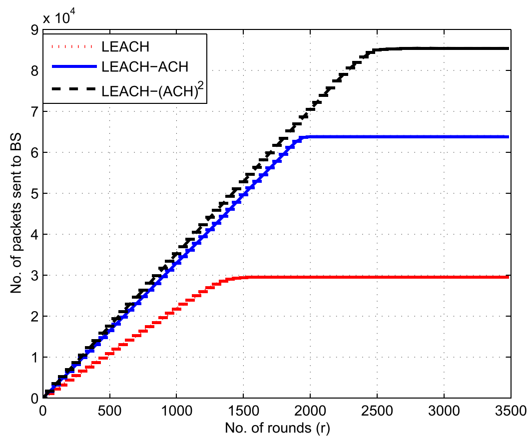


Fig. 9. Transmitter side.

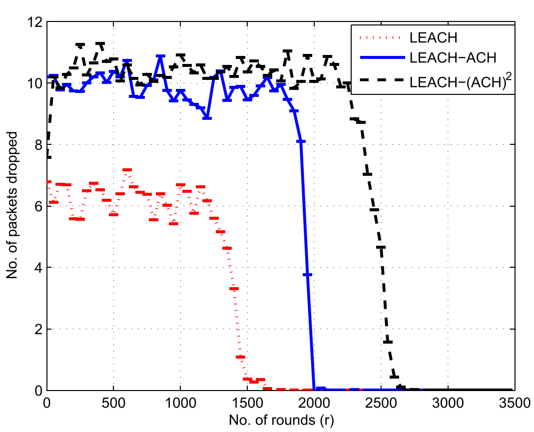


Fig. 10. Packets dropped.

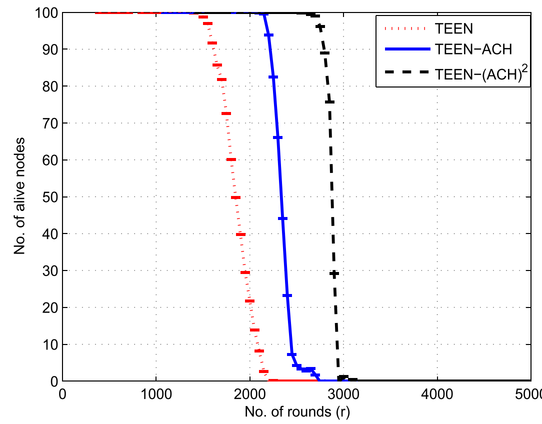


Fig. 11. Rate of alive nodes.

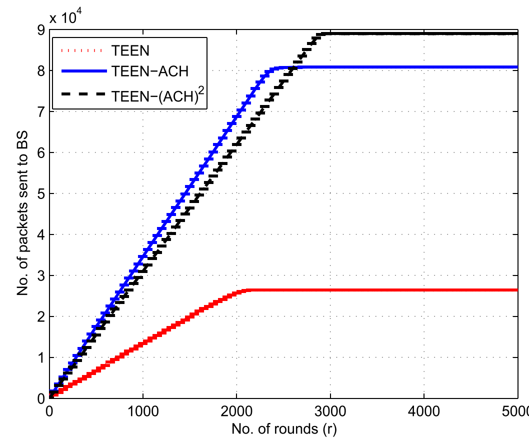


Fig. 12. Transmitter side.

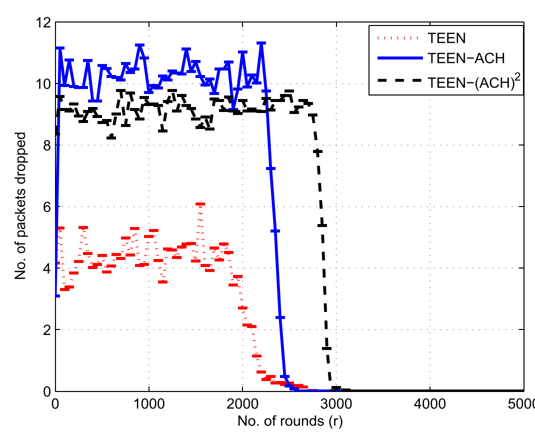


Fig. 13. Packets dropped.

the network field of $100m \times 100m$. As nodes are equipped with limited energy source, when they use up their initial energy during the course of simulation, they cease to transmit or receive data. For these simulations, energy is consumed whenever a node receives or transmits or aggregates data. Average results with 90% confidence interval shown in this section are obtained after running the simulation 5 times. Moreover, the parameters of first order radio model used in our simulation are shown in Table I.

When data packets travel from source to destination across a wireless channel, some of them fail to reach destination point. In technical language it is referred as packet drops or dropped packets. To compensate for packet drops, we use *Random Uniformed Model* [22] with the assumption that packet drop is related to the status of that link through which it is propagating. If a given link is in bad status, packet is dropped, otherwise it is successfully received. For simulation

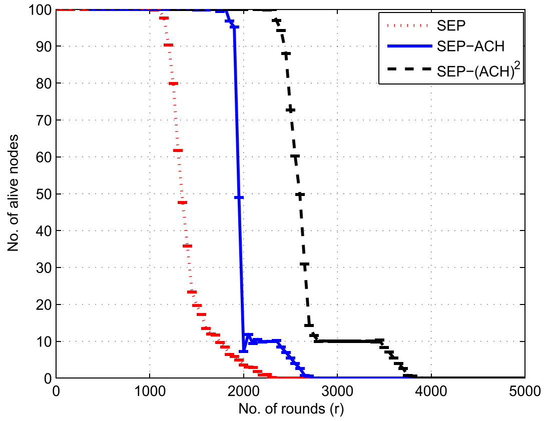


Fig. 14. Rate of alive nodes.

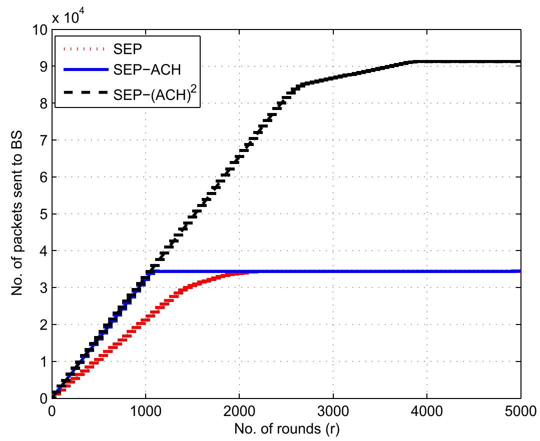


Fig. 15. Transmitter side.

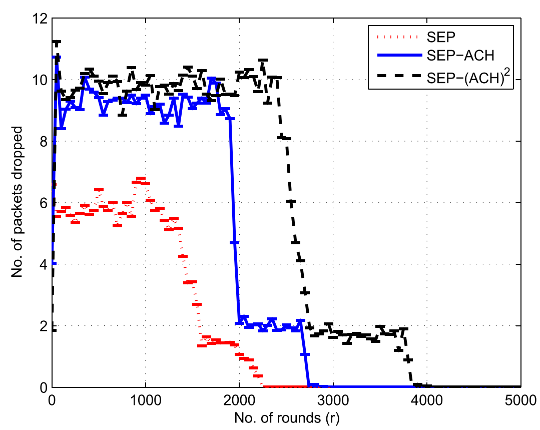


Fig. 16. Packets dropped.

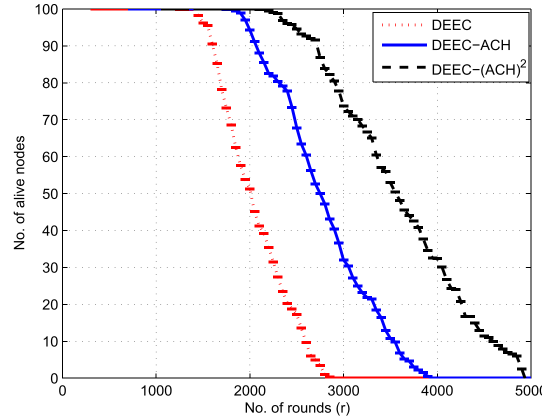


Fig. 17. Rate of alive nodes.

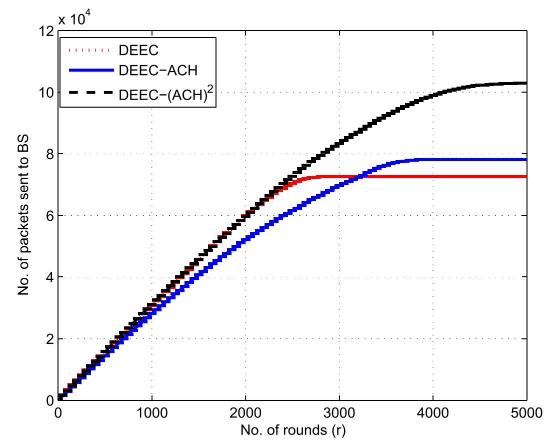


Fig. 18. Transmitter side.

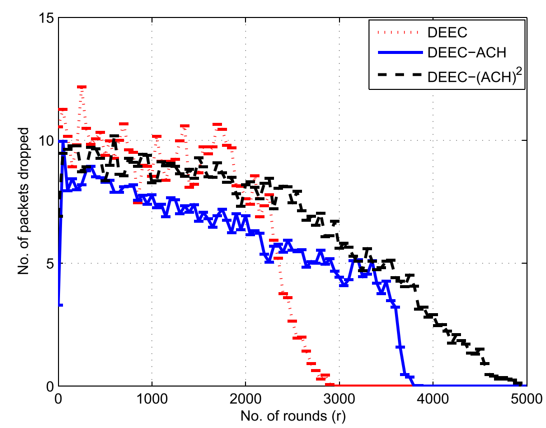


Fig. 19. Packets dropped.

purpose, we set the probability of a link to be in bad status as 30% ($p_{bad} = 0.3$) and that of a link in good status as 70% ($p_{good} = 0.7$).

In subject to system performance, the following metrics are used for evaluation purpose.

1) **Stability period:** Time duration from the establishment of the network till the death of first node.
2) **Un-stability period:** Time duration from the death of first node till the death of last node in the network.
3) **Network lifetime:** Time duration from the establishment of the network till its end.
4) **Number of packets sent to BS:** Number of packets sent directly to BS.
5) **Number of packets dropped:** Packets dropped due to bad status of link.
6) **Throughput:** Number of packets successfully received at the BS per unit time.
7) **Node density:** The number of nodes in a given network area.

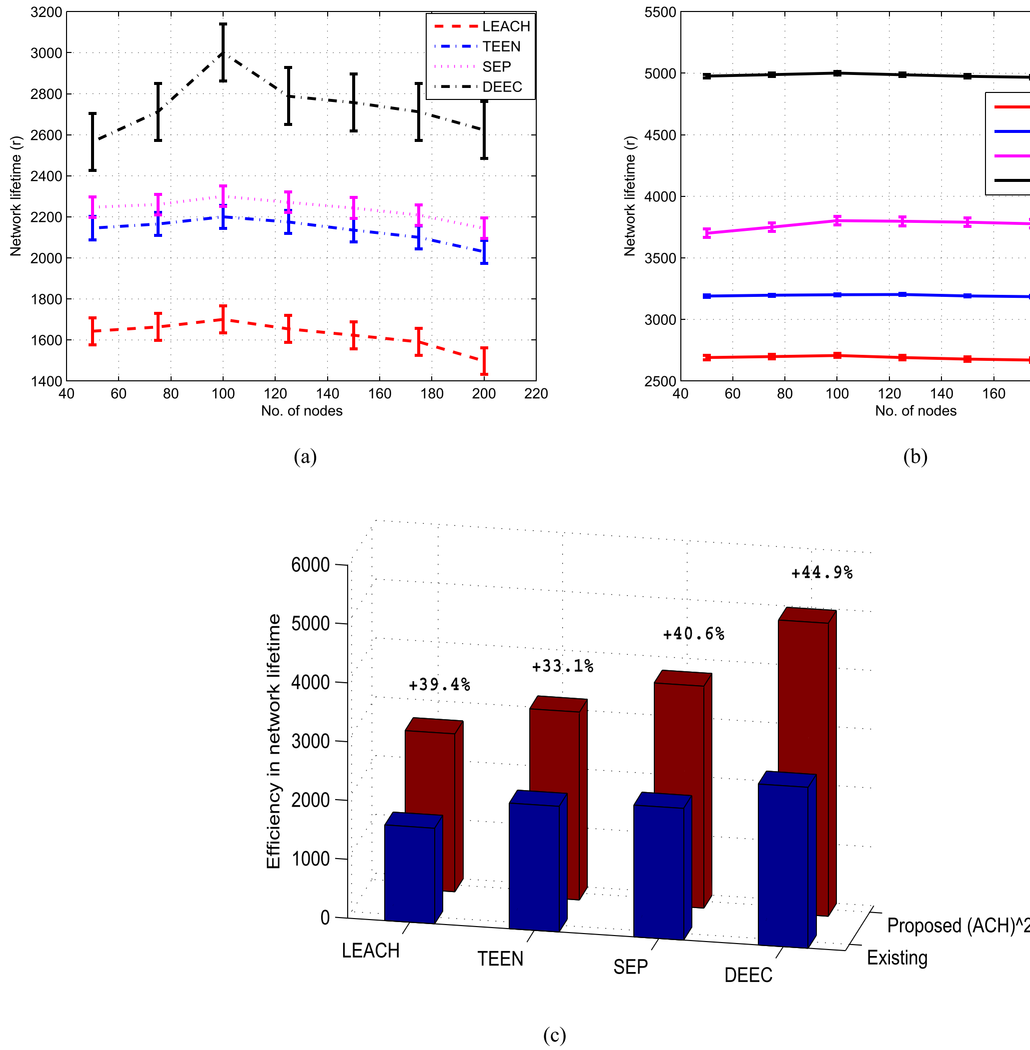


Fig. 20. Network lifetime with varying number of nodes: existing and newly proposed protocols. (a) Existing. (b) Proposed. (c) Existing versus Proposed.

8) **Transmission delay (per packet):** Duration from the beginning un till the last bit of the packet has left the transmitting node.

In the upcoming subsections, we implement $(ACH)^2$ in the selected simulation environments.

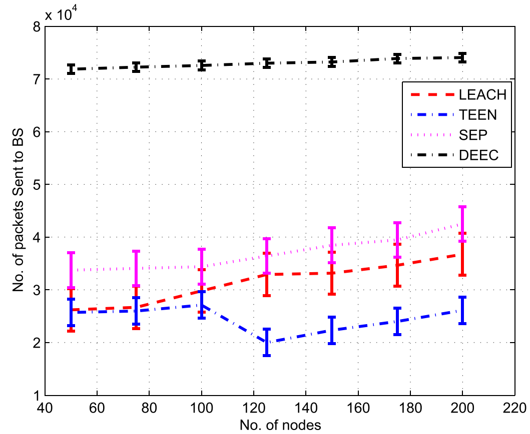
A. Implementation of $(ACH)^2$ in Proactive Homogeneous Environment

LEACH, being a routing protocol for homogenous WSNs, assumes all nodes with same initial energy. Therefore, the initial energy of each node is set at $0.5J$. Fig. 8 shows the average number of nodes that remain alive during simulation for LEACH, LEACH-ACH, and LEACH-(ACH^2). Regarding stability period and network lifetime, LEACH-$(ACH)^2$ represents the most in comparison to LEACH and LEACH-ACH. LEACH-ACH, with the capability to remove away CHs, extends the stability period and network lifetime of LEACH by 40.1% and 21.6%, respectively. While, LEACH-$(ACH)^2$ prolongs the stability period further due to balanced clusters, back transmissions removal and direct communication of nearer nodes to BS. The stability period and network lifetime of LEACH-$(ACH)^2$ is increased by 21.9% and 26.4% from LEACH-ACH, and 53.6% and 41.7% from LEACH in the order given.

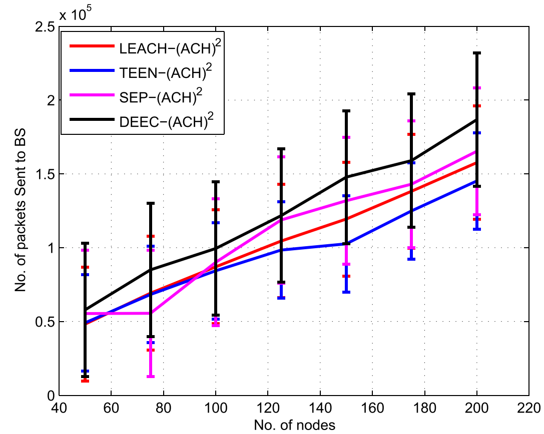
It is clear from fig. 9 that due to enhanced network lifetime, LEACH-$(ACH)^2$ sends 26.3% and 66.5% more packets to BS as compared to LEACH-ACH and LEACH. As the probability of packet drops is directly related to the number of packets sent to BS, that is why LEACH-$(ACH)^2$ performs the least in comparison the other two protocols shown in fig. 10. Thus, we conclude that our scheme extends the stability period of LEACH and LEACH-ACH.

B. Implementation of $(ACH)^2$ in Reactive Homogeneous Environment

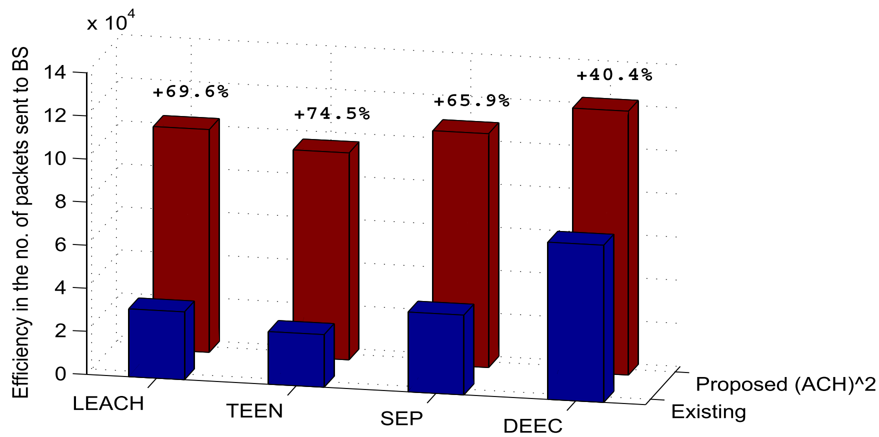
Being the first protocol for reactive homogenous WSNs, TEEN uses hard and soft thresholds. In our experiments, the value of soft threshold is set at $2F$ and that of hard threshold at $100F$ (refer [13] for the values of hard and soft thresholds). From fig. 11 and 12, it is clear that our proposed scheme performs superior to TEEN and TEEN-ACH. Regarding first node's death, last node's death, and number of packets sent to



(a)



(b)



(c)

Fig. 21. Number of packet sent to BS with varying number of nodes: existing and newly proposed protocols. (a) Existing. (b) Proposed. (c) Existing versus Proposed.

BS; the proposed TEEN-$(ACH)^2$ is 45.5%, 29.4% and 69.3% better than TEEN, while, 23.3%, 10.1% and 10.4% better than TEEN-ACH, respectively.

Fig. 13 depicts that in terms of packets dropped TEEN-ACH performs the least relative to the other two protocols. Minimized number of transmissions in TEEN is the major cause of its enhanced network lifetime as compared to LEACH. TEEN-ACH further extends the network lifetime and throughput by introducing away CHs selection scheme. Moreover, in the case of TEEN-$(ACH)^2$ energy of the network is further conserved by changing the association mechanism, and optimal number of CHs selection technique.

C. Implementation of $(ACH)^2$ in Two Level Proactive Heterogenous Environment

SEP is a heterogeneity-aware routing protocol for WSNs. The nodes in SEP are initially supplied with two levels of energy. Here, we assume a heterogenous WSN with $m = 0.1$ and $\alpha = 1$ (refer [14] for the values of m and α). Based on the lifetime of nodes and number of packet sent to BS, SEP, SEP-ACH and SEP-$(ACH)^2$ are compared in fig. 14 and 15, respectively. In SEP, the introduction of advanced nodes helps to increase the network lifetime as well as the rate at which packets are sent to BS, and this effect is clearly reflected in fig. 14. While keeping the overall network alive, SEP-$(ACH)^2$ takes 30.3% and 40.5% more rounds than SEP-ACH and SEP, per order. fig. 13 also shows that 10% of the total nodes die at a much slower rate as compared to the other 90% which justify the value of m. In SEP-$(ACH)^2$, the rate at which packets are dropped is more as compared to SEP and SEP-ACH as illustrated in fig. 16. The reason is straight forward i.e., the nature of the adopted packet drop model assumes that greater packet sending rate is directly related to the rate at which packets are dropped.

D. Implementation of $(ACH)^2$ in Multi Level Proactive Heterogeneous Environment

Whenever multilevel heterogeneity of nodes is in question, DEEC seems to be an appropriate choice. For experimental testing, the initial energy of nodes is randomly distributed from E_0 to $4E_0$ ($E_0 = 0.5J$). In Fig. 17, detail views of the behavior of DEEC-$(ACH)^2$, DEEC-ACH, and DEEC are illustrated.

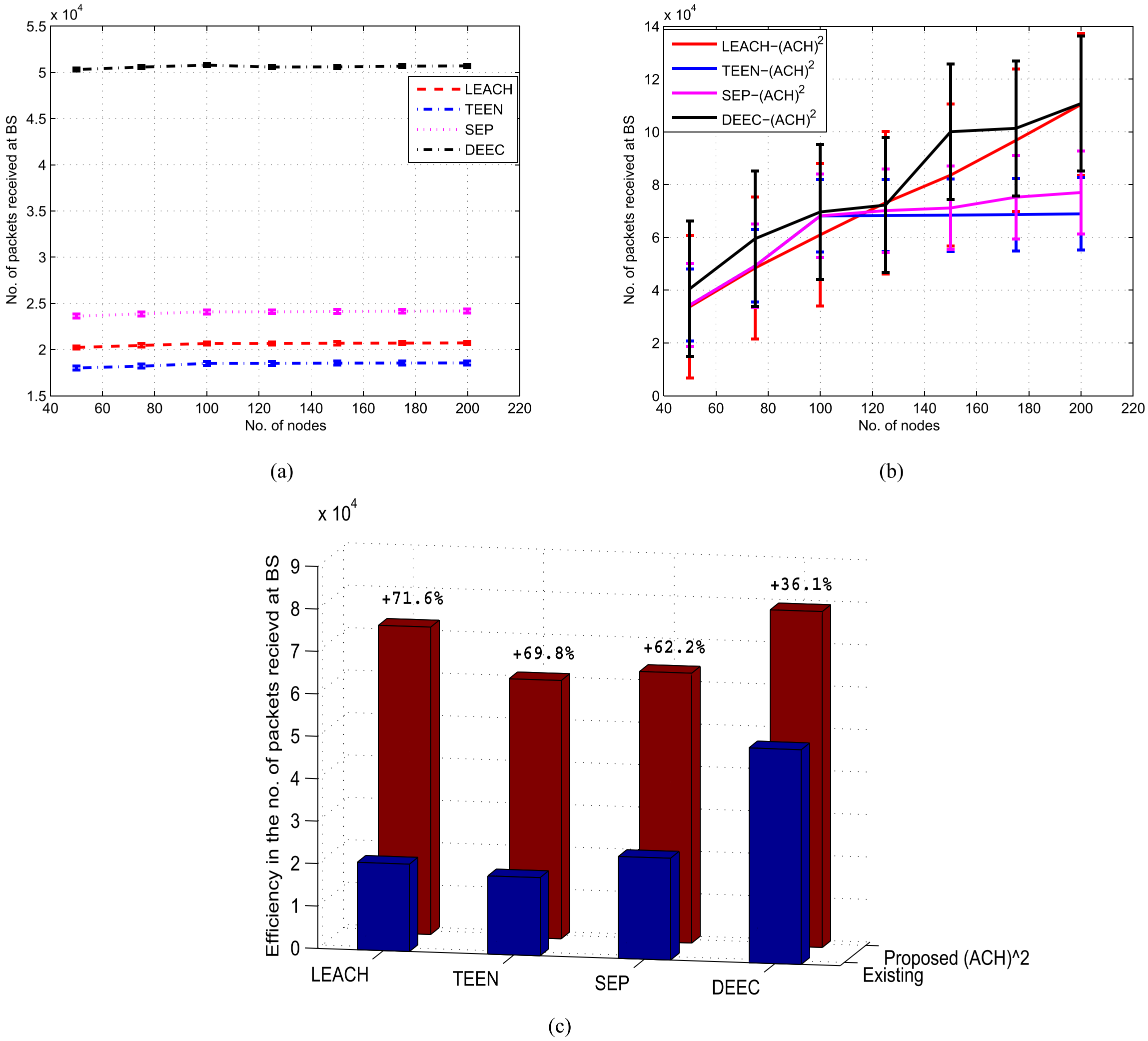


Fig. 22. Number of packet received at BS with varying number of nodes: existing and newly proposed protocols. (a) Existing. (b) Proposed. (c) Existing versus Proposed.

We observe that DEEC-$(ACH)^2$ shows 21.6% and 62.1% extension in network lifetime as compared to DEEC-ACH and DEEC, respectively. On the other hand, fig. 18 illustrates that 25.1% more packets are sent to BS in DEEC-$(ACH)^2$ relative to DEEC-ACH, and 30.6% relative to DEEC. As CHs are one of the major sources of high energy consumption, energy is conserved in DEEC-$(ACH)^2$ because the CHs nearer than $10m$ are treated as normal nodes. Moreover, the communication distance is minimized by our proposed free association mechanism which facilitates high packet sending rate and longevity in the lifetime of the network. In fig. 19, three protocols are compared in which DEEC is witnessed with highest packet drop rate. As the cluster size of each cluster is different from that of the other clusters in DEEC, so some CHs are severely contended; thereby leading to more packets being dropped. DEEC-$(ACH)^2$ solves this problem by selecting away CHs.

E. Impact of Node Density

Fig. 20(a, b) shows the impact of varying node density on network lifetime in the existing and newly proposed protocols. The network lifetime first increases and then decreases whenever the number of nodes in LEACH, TEEN, SEP, and DEEC are varied (refer fig. 20(a)). Initially (for less than 100 nodes), downsizing the network in terms of the number of nodes results in decreased network lifetime. This is obvious; the network area is $100m \times 100m$, so less number of nodes communicate at relatively greater distances thereby consuming more energy (decreased network lifetime). On the other hand up to two fold increase in node density above 100 also leads to decreased network lifetime. In this case, the network becomes congested (the cluster size increases) which means that the load on CHs is increased i.e., the CHs now forward relatively more data to BS. Thus, the CHs consume surplus energy causing the network lifetime to decrease. The proposed $(ACH)^2$, on the other hand, balances the energy consumption in cases where the number of nodes are either increased or decreased from 100 (refer fig. 20(b)). This balanced energy consumption, in case of the proposed $(ACH)^2$, is obvious due to its adaptive approach for selecting optimal number of CHs as well as removal of back transmissions (free association). Fig. 20(c) shows relative efficiency of the proposed protocols with respect to

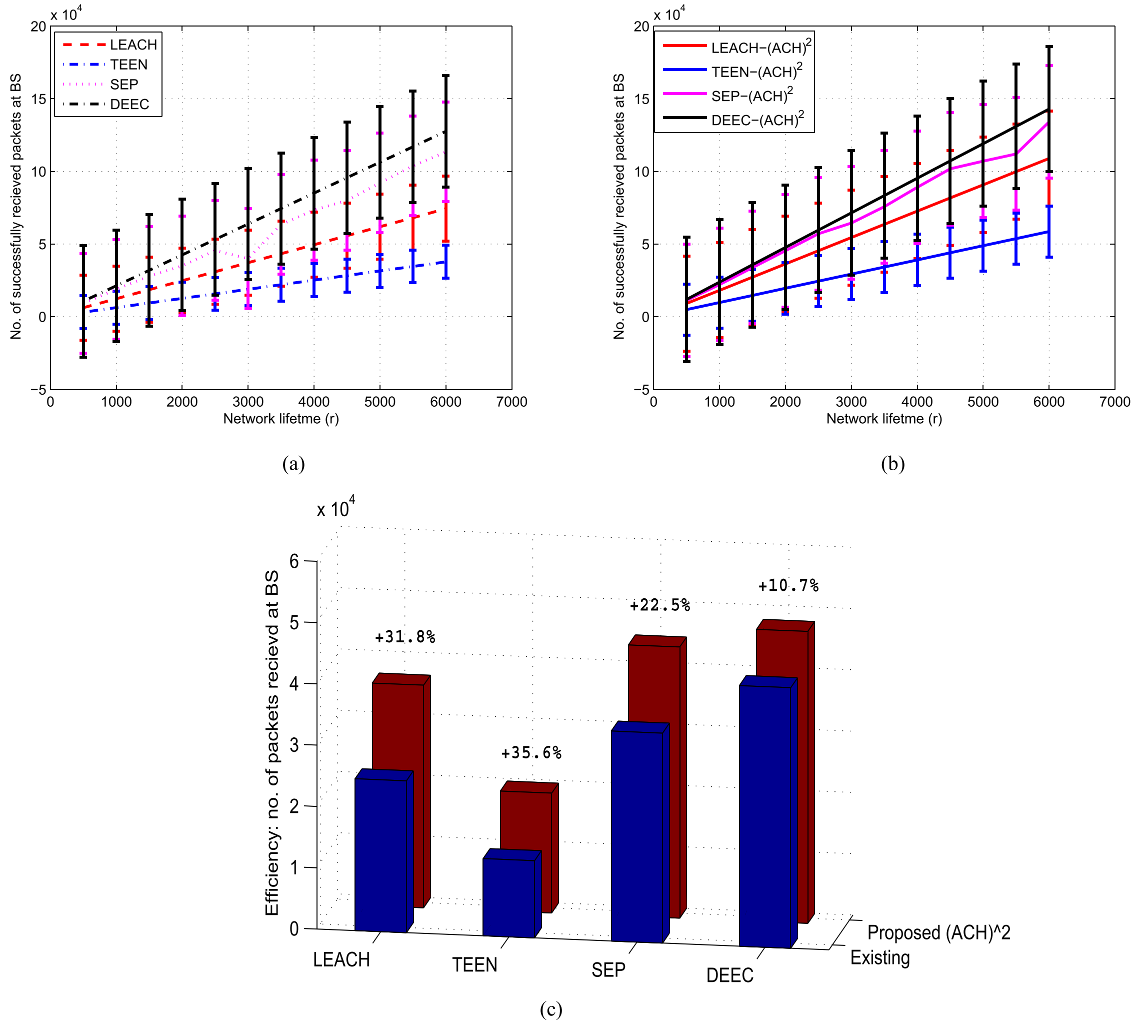


Fig. 23. Number of packet received at BS with varying network lifetime: existing and newly proposed protocols. (a) Existing. (b) Proposed. (c) Existing versus Proposed.

the existing ones. In this regard; LEACH-$(ACH)^2$, TEEN-$(ACH)^2$, SEP-$(ACH)^2$ and DEEC-$(ACH)^2$ are 39.4%, 33.1%, 40.6% and 44.9% better than LEACH, TEEN, SEP and DEEC, respectively. The overall efficiency order of the proposed protocols is; DEEC-$(ACH)^2$>SEP-$(ACH)^2$>TEEN-$(ACH)^2$>LEACH-$(ACH)^2$.

The effect of varying node density on the number of packets sent to BS are shown in fig. 21(a, b). The packet sending rate, at first, slowly increases then decreases and then again shows somewhat increase incase of the existing TEEN protocol. The hard and soft threshold values cause this un-predictable packet sending rate. Referring fig. 21(a), the packet sending rate increases very slowly (with respect to the order in which the number of nodes are increased) for LEACH, SEP and DEEC, respectively. This is due to the fact that in these protocols CHs are the only responsible entities for data forwarding towards BS and incase of congested cluster size(s) the packets are slowly sent to BS. On the other hand, fig. 21(b) shows relatively faster packet sending rate for the newly proposed protocols as compared to the existing ones due to two reasons; (i) the clusters are no more congested (away CHs selection) and (ii) nodes are allowed to communicate with BS on individual basis. Relative efficiency of the newly proposed protocols in comparison to the existing ones is shown in fig. 21(c). LEACH-$(ACH)^2$, TEEN-$(ACH)^2$, SEP-$(ACH)^2$ and DEEC-$(ACH)^2$ are 69.6.4%, 74.5%, 65.9% and 40.4% better than their respective existing versions. The overall efficiency order of the proposed protocols is; TEEN-$(ACH)^2$>LEACH−$(ACH)^2$>SEP-$(ACH)^2$>DEEC-$(ACH)^2$.

Fig. 22(a, b) depicts that the rate at which packets are received at BS do not show noticeable increase (existing protocols) as compared to the the newly proposed $(ACH)^2$ versions of the same protocols. Unbalanced cluster size, in the existing protocols, means that the contending nodes for channel access are increased (chances of collision are increased) thereby leading to increased packet drop rate (refer fig. 22(a)). The $(ACH)^2$ with balanced cluster sizes reduces the chances of collision between the contending nodes for channel access thereby positively impacting the packet reception rate (refer fig. 22(b)). Relatively, the newly proposed protocols are 71.6%, 69.8%, 62.2% and 36.1% more efficient than their respective existing versions. Overall, the proposed protocols

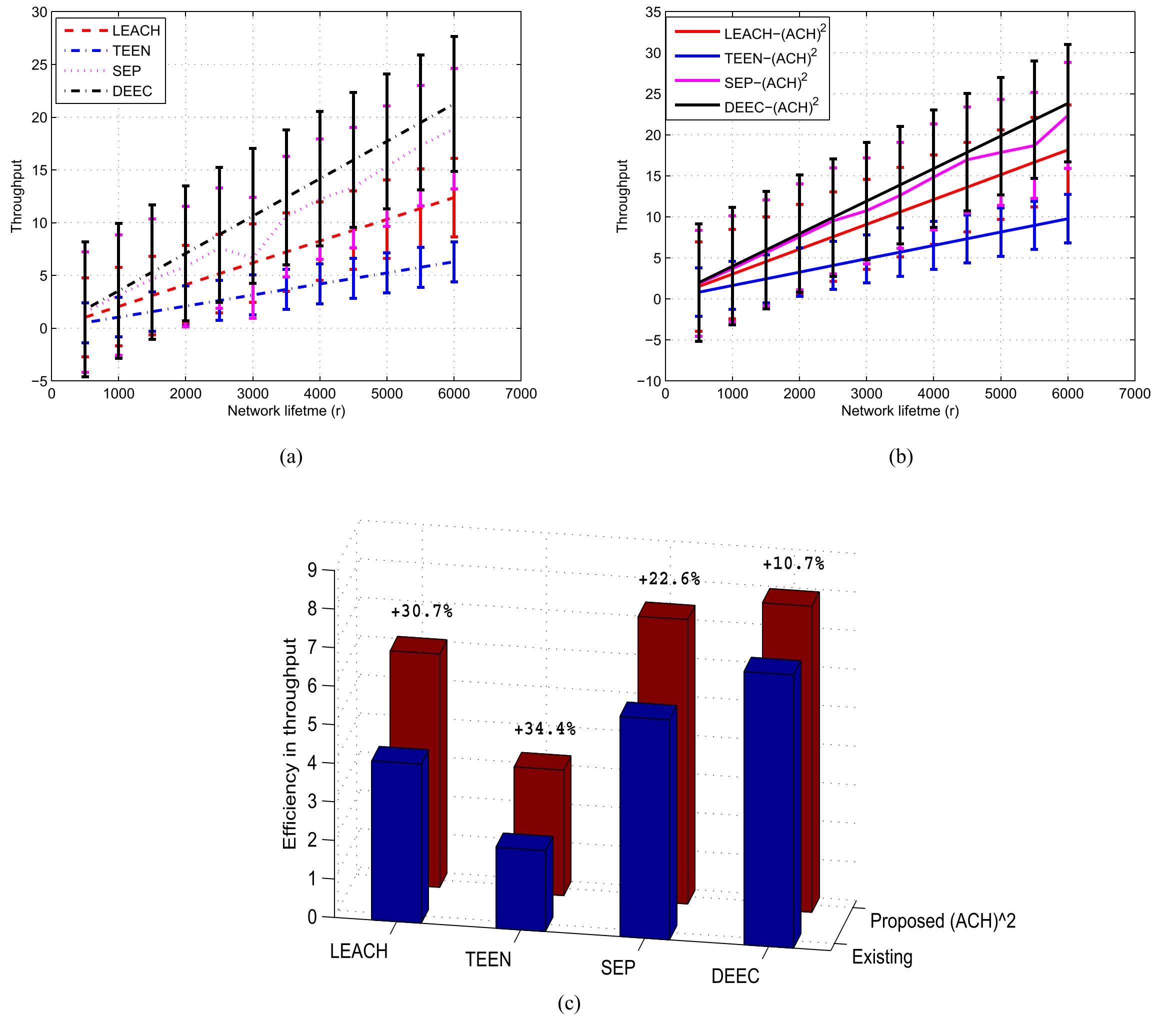


Fig. 24. Throughput with varying network lifetime: existing and newly proposed protocols. (a) Existing. (b) Proposed. (c) Existing versus Proposed.

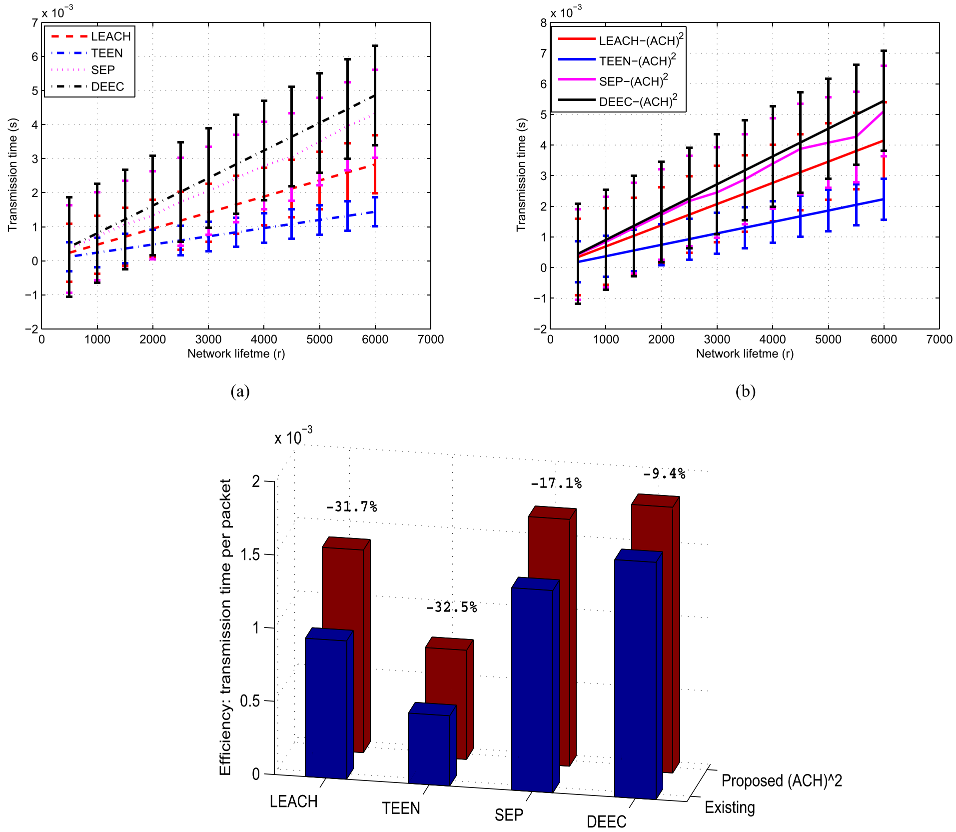
are efficient in the following order: LEACH-$(ACH)^2$>TEEN-$(ACH)^2$>SEP-$(ACH)^2$>DEEC-$(ACH)^2$.

F. Impact of Network Lifetime (Initial Energy)

When the varied network lifetime (initial energy) is plotted versus the number of successfully received packets at BS, for the newly proposed as well as the existing protocols, the obtained results are shown in fig. 23(a, b) with relative efficiency in fig. 23(c). These results are obtained by keeping constant node density ($N = 100$). Furthermore, these results show that packets are received at a faster rate for the newly proposed protocols as compared to the existing ones due to; (i) balanced load on the selected CHs, and (ii) communication of individual nodes with BS. In contrast to fig. 22(a), fig. 23(a) shows faster packet reception rate. Reason for this interesting result is obvious i.e., nodes which remain alive for a longer duration transmit for a longer duration too (refer fig. 23(a)) whereas more number of contending nodes increases the chances of collisions between packets (refer fig. 22(a)). Relatively, the newly proposed protocols are 31.8%, 35.6%, 22.5% and 10.7% more efficient than their respective existing versions. The overall efficiency order of the proposed protocols is; TEEN-$(ACH)^2$>LEACH-$(ACH)^2$>SEP-$(ACH)^2$>DEEC-$(ACH)^2$. Reasons, similar to that for fig. 23(a, b) also account for the results shown in fig. 24(a,b). The relative throughput efficiency of the newly proposed protocols in comparison to their existing respective versions is also show in fig. 24(c).

Besides providing the interesting simulation discussions regarding the response of each protocol i.e., to increase network lifetime as well as throughput efficiency, these protocols have to pay some cost. In this regard, fig. 25(a, b) shows increased transmission delay for the proposed protocols as compared to their existing versions. More packet sending rate of the newly proposed protocols causes the average per packet transmission delay to increase as compared to LEACH, TEEN, SEP and DEEC, respectively. The newly proposed protocols (LEACH-$(ACH)^2$, TEEN-$(ACH)^2$, SEP-$(ACH)^2$ and DEEC-$(ACH)^2$) are 31.7%, 32.5%, 17.5% and 9.1% less efficient than their respective existing versions (LEACH, TEEN, SEP and DEC).

Therefore, for achieving increased throughput and enhanced network lifetime, the proposed $(ACH)^2$ pays the cost of transmission delay.



(c)

Fig. 25. Transmission time with varying network lifetime: existing and newly proposed protocols. (a) Existing. (b) Proposed. (c) Existing versus Proposed.

VII. Conclusion

The ongoing research work, with reference to network lifetime extension and throughput maximization, leads us to investigate its current body. We found that many protocols are proposed, however, these protocols are applicable under specific constraints. For example, LEACH works in proactive homogeneous environment, TEEN in reactive homogeneous environment, SEP switches to two level heterogeneity, and DEEC introduces multi energy levels by using a proactive approach. These classical protocols have a common problem i.e., the selected CHs are not optimal in number which causes non uniform load on them. Moreover, their association mechanism increases the overall length of the path used for the transmission of locally compressed data to BS. Our proposed scheme introduces natural selection of CHs mechanism, which chooses the CHs to be distant and optimal in number. Moreover, our free association mechanism reduces the overall communication distance. Thus, balanced load on CHs and length of communication path reduction result in efficient energy utilization. More importantly, linear programming based solution for throughput maximization with mixed-bias bandwidth allocation scheme further facilitate the desired objectives. From simulation results, we conclude that $(ACH)^2$ prolongs the network lifetime and maximizes the throughput of homogeneous, heterogeneous, proactive and reactive protocols in all of the selected node densities and as well network lifetimes (initial energies).

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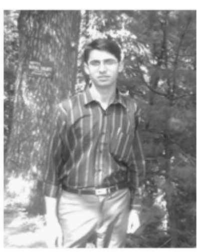

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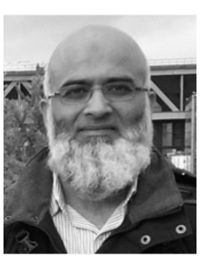

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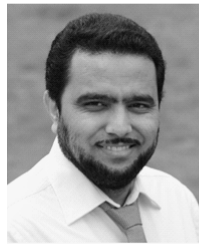

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