Review on Energy Efficient Clustering Protocols in Wireless Sensor Network

Manisha Jaisinghani[1] Ranjan Bala Jain[2]
[1]M.E Student [2]Professor
[1,2]Department of Electronics & Telecommunication Engineering
[1,2]Vivekanad Education Society Institute of Technology, Chembur

Abstract— In recent time's Wireless Sensor Networks (WSN) have grown enormously and become progressively attractive in wide variety of applications because of their low cost, low power, small in size and self-organizing behavior in harsh environments. Clustering is the process where sensing area is divided in groups to balance the energy level of sensor nodes known as clusters. It is used to prolong the lifetime of the wireless sensor networks. An Optimal Clustering technique can reduce the energy consumption in WSN and the lifetime of the network. In this paper we present the study of different clustering based energy efficient routing protocols in WSN and compared them on their parameters such as Cluster Head selection, data aggregation, scalability, complexity and energy efficiency and it is found that improved TEEN ensures creditability of nodes which leads to better lifetime of network.

Key words: WSN, Energy Efficient Clustering Protocols

I. INTRODUCTION

WSN is made up of a large number of sensors and at least one Base Station (BS). The sensors are autonomous small devices with several constraints like the battery power, computation capacity, communication range and memory. A sensor node has one or more sensors, a general purpose processor of limited computing power, memory, and a radio transceiver operating on battery. By deploying sensor nodes in an area, information on the behavior, condition, and position of the entities can be collected remotely. The basic components of a sensor node are sensing unit, processing unit, radio unit, and power unit [1]. The data collected by the sensor nodes are sent to the BS through wireless communication. The BS summarizes the collected data and presents them to the user or sends them to the remote host [2]. Sensor networks differ from traditional networks in power computation and memory. The lifetime of WSN is limited by energy of deployed sensor nodes as they carry irreplaceable power sources due to small in size. Therefore is a need of energy efficient routing protocol which can increase the life of WSN. Cluster-based routing protocol is the routing protocol proposed for the WSN to minimize the consumption of the energy of the sensors. In this sensor nodes are grouped together to form clusters. Each cluster has a head node called Cluster Head (CH) as shown in "Fig 1". The CH gathers the data periodically from sensor nodes and transmits to the BS wirelessly.

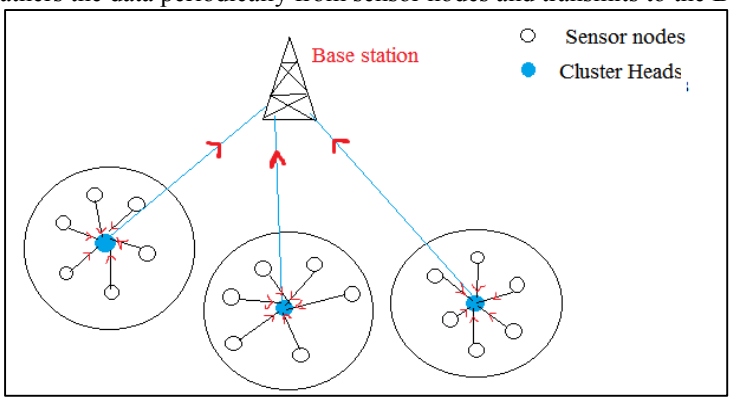

Fig. 1: Clustering pattern in WSN

In Section II first order radio model is studied, which is used for various protocols. In section III, we present study of various energy efficient protocols and in section IV comparison of different protocols on their various parameters.

II. FIRST ORDER RADIO MODEL

In this section, we describe about first order radio model used in routing protocols. Let d be the distance between transmitter and receiver is the amount of bits to be transmitter, E_{elec} be the amount of energy dissipated in running transmitter and receiver and $\mathcal{E}_{amp}$ be the amount of energy to amplify the signal to achieve an acceptable Signal to noise ratio (SNR) as shown in "Fig 2".

For transmission, radio expends

$$E_{Tx}(k,d) = E_{elec*}k + \mathcal{E}_{amp}* k* d^2 \qquad (1.1)$$

For reception, radio expends

$$E_{Rx}(k)=E_{elec}*k \qquad (1.2)$$

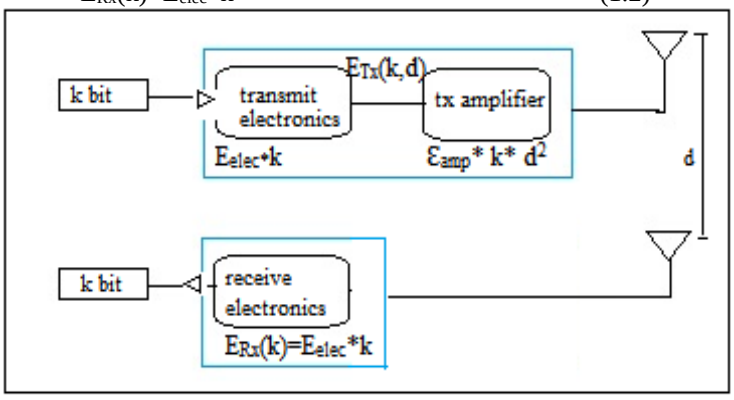

Fig. 2: Radio model

III. EXISTING PROTOCOLS

There were various protocol based on clustering has been developed from many years. We introduce some of them including LEACH protocol. Some of protocols based on clustering are as follows,

A. LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) was proposed by W. Heinzelman [3]. It was first clustering approach introduce for WSN. It is for homogeneous and dense sensor network. It is Time Division Multiple Access (TDMA) based Media Access Control (MAC) protocol integrated with clustering and uses simple routing. Leach is a cyclical algorithm; it provides a conception of round. It runs with several rounds. LEACH operations can be divided into two phases:-

- Setup phase
- Steady phase

In the setup phase, the clusters are formed and a cluster-head is chosen for each cluster. While in the steady phase, data is sensed and sent to the central base station. The steady phase is longer than the setup phase as shown in "Fig 3". This is done in order to minimize the overhead cost.

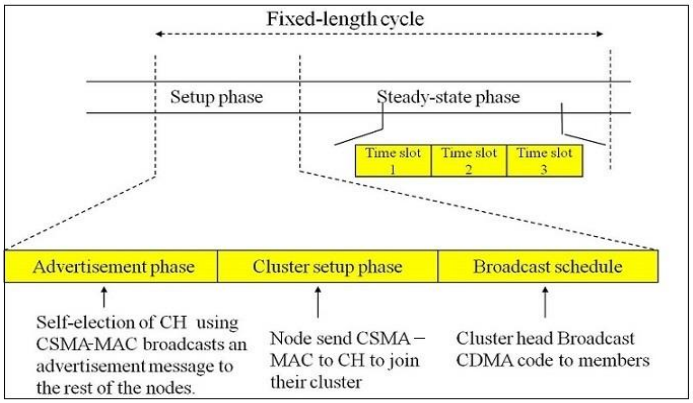

Fig. 3: Phase description of LEACH

In advertisement phase, when clusters are being created, each node decides whether or not to become CH for the current round. This decision is based on the suggested percentage of CHs for the network and the number of times the node has been a cluster-head so far. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold, the node becomes a cluster-head for the current round. The threshold is set as:

$$T(n) = \frac{P}{1-P\times\left(r \bmod \frac{1}{P}\right)} \text{ ; if } n \in G \qquad (3.1)$$

$$T(n) = 0; \quad \text{otherwise.} \qquad (3.2)$$

Here, P is the desired percentage of CHs (e.g. is like 3% or 4%), r is that the current round, and G is that the set of nodes that haven't been selected as CHs within the last 1/P rounds. By considering this threshold, each node can become the CH at some point with 1/P rounds. Nodes that are CHs cannot become CH for the second-time for (1/P)-1 rounds. Therefore, every node has a 1/P probability to be selected as a CH in every round.

In cluster setup, phase each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the cluster. Each node transmits this information back to the cluster-head again using a (Carrier Sense Multiple Access) CSMA-MAC protocol. During this phase, all cluster-head nodes must keep their receivers on.

In broadcast schedule phase, cluster-head node creates a TDMA schedule telling each node when it can transmit using (Code Division Multiple Access) CDMA codes. This schedule is broadcast back to the nodes in the cluster.

Limitation of LEACH is, after number of rounds, the node containing greater remaining energy and the node with smaller remaining energy has same probability to be chosen as CH. If the node with smaller remaining energy is chosen as

CH, it will run out of the energy and die quickly, due to which network's robustness can be affected and lifetime of the network becomes short.[3]

B. Optimum LEACH

Optimal LEACH is proposed by Y.Haiming and B.Sikdar in 2007 [11]. There were several problems in LEACH [3], which makes the LEACH energy inefficient. Since CHs spend more energy than leaf nodes (non CH nodes), it is quite important to reselect CHs after equal interval. If this probability is set high, more nodes will become CHs and the rate of energy consumption becomes high; if this probability is low, the size of each cluster becomes larger and the average distance between leaf nodes and their CH increases in order to maintain balanced energy consumption, It suggests that each node probabilistically become a CH. To reduce the energy consumption and to avoid synchronization of TDMA, sleep-wake up based decentralized MAC protocol to LEACH is applied. The operation of MAC is divided into rounds. A round is defined as the period of CH selection to the next CH reselection. Each round consists of several cycles and each cycle consists of a setup phase, an intra cluster communication phase and an inter cluster communication phase as shown in "Fig 4". In each setup phase, the nodes may either exchange messages to select a new CH or exchange network setup and maintenance messages if there is no need to reselect a new CH. The CH selection is repeated once several cycles. During the intra cluster communication phase, CHs exchange data with the leaf nodes in their cluster and compress these data into a single message. After the intra cluster communication phase, the cycle comes to the inter cluster communication phase and only the CHs keep the radio on to transmit the compressed data to the sink. During this period, each CH accesses the channel in distributed manner by using CSMA/ (Collision avoidance) CA. The CHs stay awake at all times while the leaf nodes may sleep during the inter cluster communications to save energy. Since CSMA/CA is used for both the intra and inter cluster communication, the distr protocol reduces the complexity and improves the capability of system as the number of nodes increases.

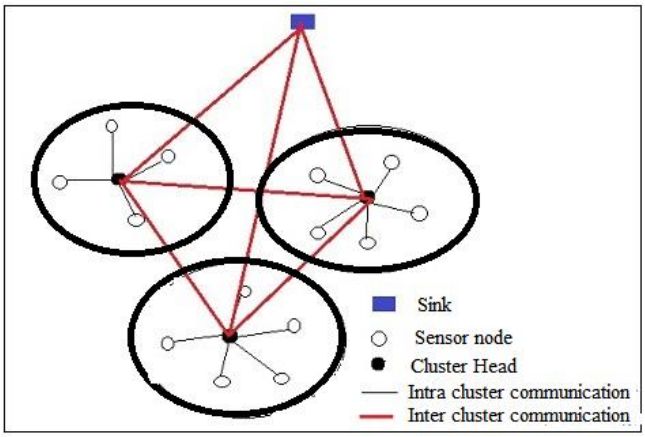

Fig. 4: Inter and Intra cluster communication

C. Comparative LEACH

It was proposed by Ramesh.K and Dr.K. Somasundaram in 2011 [8]. Different communication protocols and algorithms are investigated to find ways to reduce power consumption. Comparison of their costs of CH selection in different rounds, transmission method and other effects like cluster formation, distribution of CHs and creation of clusters shows a need of a combined strategy for better results. While improving the limitations of LEACH [3], many clustering proposals for increasing network lifetime are reported suggesting different strategies of CH selection and its role rotation among the sensor nodes, using different parameters. Based on these parameters, these strategies of CH selection may broadly be categorized as deterministic, adaptive and combined metric (hybrid) as shown in "Table 1". In deterministic schemes special attributes of the sensor node such as their identification number (Node ID), number of neighbors they have (Node degree) also in adaptive schemes the resource information like remnant energy, energy dissipated during last round , initial energy of the nodes are used to decide their role during different data gathering rounds. In Fixed strategy fixed no. of CHs are choosen and Fixed percentage of CHs also and Hybrid adapts combination of both i.e deterministic and adaptive.

Deterministic	**Adaptive**	**Fixed**	**Hybrid**
Node ID,Node degree	Energy dissipation during last round, initial energy	Fixed no. of CHs and round number	Unequal Cluster-based Routing (UCR)
Broadcast declares CH	CH elected by BS or nodes	Fixed percentage of CH	Elects CH based on Residual energy
CH receive joining request & distributes TDMA slots	No. Of CH =Residual energy/sum of square distance concerned node to sensor node and square distance to base station	A random number between 0 and 1 and if this number is less than the evaluated adaptive threshold, selects itself as CH for the current round.	CH closer to the BS have smaller cluster sizes than those farther from the BS

Table 1: Comparison of CH selection strategies

D. EEE LEACH

It was proposed by Sharma, Meenakshi, and Kalpana Sharma in 2012. Energy Efficient Extended LEACH (EEE LEACH) [10] is new version of LEACH [3]. This protocol establishes multilevel clustering approach to minimize communication distance

between nodes and introduces Master CHs along with CHs. It involves two layers of clusters formation. In the first layer CHs are formed where the nodes transmit their own data to their respective CH and by using the data aggregation energy technique, CHs aggregate the received data. Again in the second layer Master Cluster Heads (MCHs) are formed as shown in "Fig 5". After the formation of MCHs, the CHs search the nearest MCHs by calculating the distance between them and transmit their aggregate data to the respective MCHs. In the similar way, the MCHs receives data from their nearest CHs, aggregate all received data by using their master data aggregation energy technique, transform them into a compress format and forward them to the base station (BS). The key idea of introducing both CHs and MCHs in our new version of LEACH protocol is to minimizes the control overhead on CHs and distribute the load equally among the MCHs while finally forward data to BS. This will overcome the situation of node failure when nodes suffer from extra overhead.

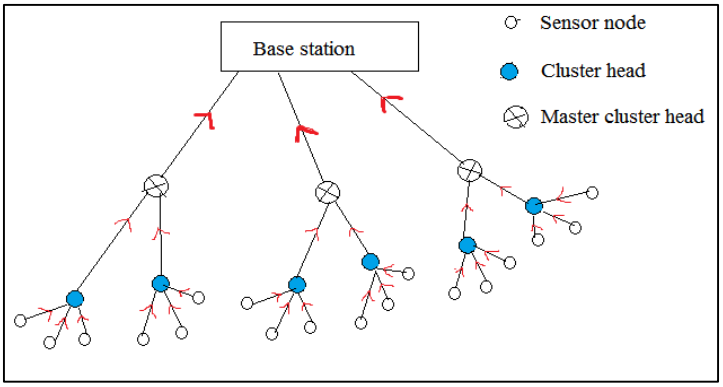

Fig. 5: Cluster organization in EEE LEACH

E. TEEN

Threshold sensitive Energy Efficient sensor Network (TEEN) protocol is proposed by A. Manjeshwar and D. P. Agarwal in 2001 [6]. It was developed for reactive networks. In this protocol, nodes sense the medium continuously, but the data transmission is done less frequently. The network consists of simple nodes, First-level CHs and second-level CHs as shown in "Fig 6". TEEN uses LEACH strategy to form cluster, First level CHs are formed away from the BS and second level CHs are formed near to the BS.

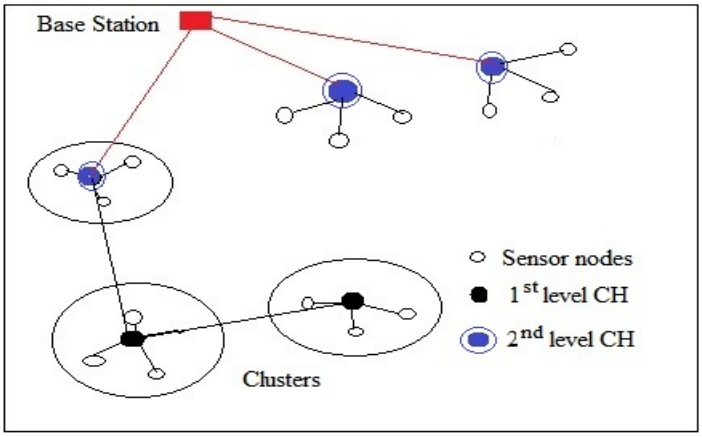

Fig. 6: Cluster organization in TEEN

A CH sends two types of data to its neighbors one is the hard threshold (HT) and other is soft threshold (ST). In the hard threshold, the nodes transmit data if the sensed attribute is in the range of interest and thus it reduces the number of transmissions. On the other hand, in soft threshold mode, any small change in the value of the sensed attribute is transmitted. The nodes sense their environment continuously and store the sensed value for transmission. Thereafter the node transmits the sensed value if one of the following conditions satisfied:

- Sensed value > Hard threshold (HT).
- Sensed value ~ HT ≥ Soft threshold (ST)

Limitation in TEEN protocol is, a node may wait for their time slot for data transmission. Again time slot may be wasted if a node has no data for transmission. Also CHs always wait for data from nodes by keeping its transmitter on.

F. APTEEN

Adaptive Periodic Threshold sensitive Energy Efficient sensor Network (TEEN) [7] protocol is proposed by A. Manjeshwar and D. P. Agarwal in 2002. APTEEN is an improved version of TEEN [6] which has all the features of TEEN. It is developed for hybrid networks and captures both periodic data collection and reacts to time critical events.

APTEEN supports queries like:

1) Historical analysis of past data values
2) A snapshot of the current network view.
3) Persistent monitoring of an event for a period of time.

In each round, after deciding the CH, the CH broadcasts the following parameters: Attributes (interested physical parameters), Thresholds (hard threshold value and soft threshold value), time schedule (time slot using TDMA) and Count time (maximum time period between two successive reports sent by a node). It allows the user to set threshold values and also a count time interval. If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data thus maintaining energy consumption. Since it is a hybrid protocol, it can emulate a proactive network or a reactive network depending on the count time and threshold value. It has the disadvantage that additional complexity is required to implement the threshold function and count time features.

G. Improved TEEN

It was proposed by Wang Junwei and Fang Xiaoyi in 2015[4]. As we know WSN node is physically captured or damage easily and network may lead network vulnerable by all kinds of interference and attacks. The core idea of TEEN protocol is that the CH is chosen periodically, probability and randomly. The other node joins the cluster just because the CH is nearest to it. This can reduce the energy consumption and prolong the network lifetime. Energy adaptive CH selection mechanism is adopted. In CH selection phase, not only candidate nodes energy consumption and residual energy of each round is considered, but also the trustworthy concept of node is taken into account. In phase transmission phase multiple hop routing is designed between CH and sink node in TEEN_TQ algorithm. Thus CH selection strategy and routing strategies are also improved to ensure the energy efficiency of the network.

Therefore, the routing security is particularly important. Based on the in-depth analysis of WSN protocol–TEEN [6] protocol, combined with the trustworthy evaluation mechanism, an improved TEEN based trust routing algorithm in wireless sensor networks is put forward. A dynamic trust management mode is designed to ensure the credibility of node. The CH selection strategy and routing strategy of TEEN are improved to ensure the energy efficiency of the network, and the periodic data collection mechanism is introduced to determine the survival state of node.

H. PEGASIS

It was proposed by Lindsey, Stephanie, and Cauligi S. Raghavendra in 2002, Power Efficient GAthering in Sensor Information System (PEGASIS) [5] is a near optimal chain-based power efficient protocol based on LEACH [3]. PEGASIS assumes that all the sensor nodes have the same level of energy and they are likely to die at the same time. Since all nodes are immobile and have global knowledge of the network, the chain can be constructed easily by using greedy algorithm. Chain creation is started at a node far from BS as shown in "Fig 7". Each node transmits and receives data from only one closest node of its neighbors. To locate the closest neighbor node, each node uses the signal strength to measure the distance from the neighbors and then adjusts the signal strength so the only one node is heard. Node passes token through the chain to leader from both sides. Each node fuses the received data with their own data at the time of constructing the chain. In each round, a randomly chosen node (leader) from the chain will transmit the aggregated data to the BS. The chain consists of those nodes that are closest to each other and form a path to the base station. The aggregated data is sent to the BS by the leader. The drawback of this protocol is, any time it can be collected from the network and a long link communication which leads to early death of node.

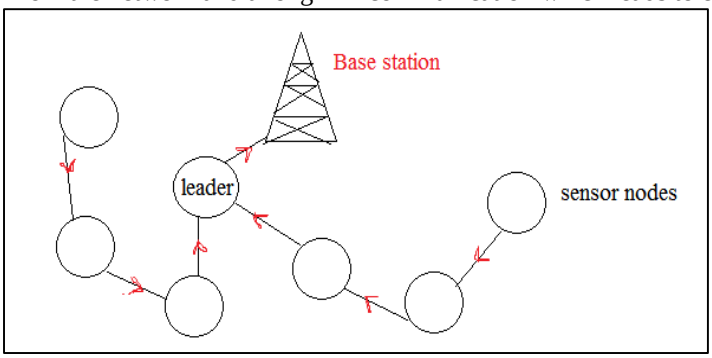

Fig. 7: Chain creation in PEGASIS

I. EECB

Energy Efficient Chain Based (EECB) [12] is proposed by Yu, Yongchang, and Yichang Song in 2010. PEGASIS can be improved slightly by applying a threshold adaptive to the remaining energy levels in nodes; there is still some room to distribute the energy load further even among the sensor nodes. EECB adopts distances between nodes and the BS and remaining energy levels of nodes to decide which node will be the leader EECB operates in three phases like PEGASIS [5]:

- Chain construction phase: In this phase a threshold distance is calculated it the distance between the two link nodes is less than threshold then it is not LL otherwise it is LL
- Leader election phase: In this phase leader is selected on the basis of residual energy of node.
- Data transmission phase: In the phase re-election of leader takes place depending upon the residual energy and avoiding the LL leads to the improvement of life time of network.

J. IEEPB

Improved Energy Efficient PEGASIS Based protocol (IEEPB) [9] was proposed by Sen, Feng, Qi Bing, and Tang Liangrui in 2011. IEEPB[9]. IEEPB adopts new method to build chain, and uses 'weighting method' when selecting the leader node, that is assigning each node a weight so as to represent its appropriate level of being a leader which considers residual energy of

nodes and distance between a node and BS as main parameter. EEPB adopts threshold when constructing chain to decrease the formation of LL, selects the Leader by considering both the residual energy of nodes and the distance between node and BS, and adjusts the reselection frequency of leader according to remaining nodes in the network. EEPB [6] overcomes several problems over PEGASIS [5]. The chain construction process and avoids the formation of LL. In leader selection phase, IEEPB uses weighting method which considers the node energy and distance between node and BS as parameters to select more suitable leader and keep energy consumption balanced. But still has deficiencies as follows:

1) When EEPB builds a chain, the threshold adopted is uncertain and complex to determine, which causes the inevitability of LL if valued inappropriately.
2) When EEPB selects the leader, it ignores the suitable proportion of nodes energy and distance between node and BS which optimizes the leader selection according to various application environments.

IV. CONCLUSION

LEACH and its improved variants, TEEN, APTEEN are cluster based routing protocols, whereas PEGASIS is a chain-based protocol. The performance of APTEEN lies between TEEN and LEACH with respect to energy consumption and longevity of the network. TEEN only transmits time-critical data, while APTEEN performs periodic data transmissions. In this respect APTEEN is also better than LEACH because APTEEN transmits data based on threshold value whereas LEACH transmits data continuously. PEGASIS increases network lifetime compared to the LEACH protocol. Because of greedy algorithm data transmission will produce time-delay in PEAGASIS. Also the method of choosing the CH is not suitable for load balance. EEPB protocol tries to overcome the drawbacks of PEGASIS by using a distance threshold Whereas Improved TEEN proves to be better among other protocols having dynamic trust management which includes creditability of nodes. Finally it is conclude from study that still it is needed more scalable, energy efficient and stable clustering method, for data gathering in wireless sensor networks. Summary of all the protocols is shown in "Table 2".

Protocol	Classification	CH Selection	Data Aggregation	Scalability	Algorithm Complexity	Energy Efficiency
LEACH	Clustering	Distributive (self-election)	Yes	Very low	Low	Very poor
OPTIMUM LEACH	Clustering	Distributive(based on energy)	Yes	High	Low	Medium
EEE LEACH	Clustering	Distributive(node near to BS)	Yes	Very high	Very high	High
TEEN	Reactive/clustering	Distributive (self-election)	Yes	Low	High	Very high
APTEEN	Hybrid	Centralized (by BS)	Yes	Low	Very high	Medium
IMPROVED TEEN	TEEN+Trustworthy evaluation mechanism	Distributive (based on behavior interaction)	Yes	High	Very high	Very high
PEGASIS	Chain based	Distributive (by BS)	No	Very low	High	Poor
EECB	Improved chain based	Distributive(based on energy)	No	High	High	Medium
IEEPN	Chain based on weighting	Distributive (using threshold)	No	Very high	Very high	High

Table 2: Comparison of Various Protocols

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