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A New Energy Efficient Communication Protocol (NEEP) for Wireless Sensor Networks

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Abstract: In recent years, Wireless Sensor Networks (WSNs) is one of the most important technologies because they have the ability to monitor and control the physical environment from the remote locations. The major advantage of the networked sensors is the ability to continue its function accurately even if few sensors in a network fail and lose a piece of crucial information. This is possible because other sensors come for rescue by providing the missing data. Hence, the WSNs have exciting new applications, such as, real-time remote monitoring using networked sensors, personal medical monitoring, home networking of everyday appliances, forest fire detection, moisture control in agricultural lands, habitat monitoring, natural disaster management, defence applications and so on. These applications demand high performance from the network. But, they suffer from certain severe resource constraints. In particular, wireless spectrum is scarce, often limiting the bandwidth available to applications and making the channel error prone. Furthermore, the sensor nodes are battery operated, thus limiting available energy. These restrictions require innovative communication techniques to increase the amount of bandwidth per user and also the life time of the total network. These are the major concern while designing the network because these networks are unattended after deployment. The primary objective of this paper is to design a New Energy Efficient Protocol (NEEP) and to compare this with few existing energy efficient communication protocols which prolong the total network lifetime.

Key words: Wireless Sensor Networks · Energy efficiency · Clustering protocol · Network lifetime

INTRODUCTION

Depending upon specific research objectives, sensor components have evolved to build more powerful applications with less cost and this is possible because of the recent developments in Micro-electro-mechanical system (MEMS) technology [1]. Hundreds to thousands of nodes are deployed in a remote environment to monitor and control the environment. These nodes coordinate, collaborate and communicate among themselves to form the network called wireless sensor networks. A micro–controller, a radio transceiver and an energy source are comprised in the sensor. The three essential functions of a sensor network are sensing, communicating and computation. These functions are implemented using the corresponding basic components hardware, software and algorithms. All the three functions require energy, in which communication requires more energy when compared to the other two functions. Authors Pottie and Kaiser [2] showed that the energy consumed for transmission is much higher than that for data processing.

It is necessary to implement a power conscious approach while designing the sensor network algorithms and protocols and also it is necessary that the energy usage is scaled in accordance with the given quality specifications [4, 5]. Thus, by reviewing many related works, it is observed that WSNs will be more energy-efficient by employing proper clustering and data-aggregation techniques [3]. That is, the nodes send the sensed raw data to the Cluster Head (CH) first. After processing the data locally in the CH, the CH transmits the processed data to the Base Station (BS) or Data Processing Centre (DPC).

In one of the existing models, the authors, Seema Bandyopadhyay and Edward 2003 [6] only considered the energy consumption used for the data transmission without taking the data-receiving energy consumption

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into account. Normally, the CH uses more energy than the cluster member. If the data-receiving energy is ignored, the energy consumed by the CH will be lower than the actual. This degrades the accuracy of results significantly. Hence, to assure the energy efficiency of NEEP, the energy expended for both the data transmission and the data-reception is taken into consideration.

Many protocols have been designed with these mentioned constraints to maximize the network lifetime. Some of these works are reviewed for better understanding of the concept so that new protocol architecture can be developed. The observations made during the review process are discussed next.

The existing energy efficient protocols can be classified into three classes. The first type protocols control the transmission power level at each node to increase network life time while keeping the network connected and the second type decides routing method based on power optimization goals. The third type of protocols control the network topology by determining which nodes to be awake to participate in the network operation and which nodes to remain asleep [8]. In certain cases particular modules of the sensor's hardware are turned off when not required [7].

The main objective of proposed NEEP architecture is to minimize the energy consumption and there by maximize the network lifetime. Key assumptions that are considered while designing the NEEP are as follows. The Base Station (BS) to which the nodes must send the information is very far away from the WSN and is immobile. The network deployment is in random fashion and the sensor nodes are immobile. All nodes present in the network are homogeneous and energy constrained. All nodes make use of symmetrical propagation channel for communication with other nodes and the BS. Nodes know about their geographic locations.

Classification of Protocols: Based on the above assumptions (either all of them or some of them), certain protocols have been designed and 1. Conventional protocols, 2. Iterative protocols, 3. Probabilistic and hierarchical protocols. The proposed NEEP architecture is based on the iterative process. Before, looking into the proposed architecture, some of the existing protocols are discussed below.

Conventional Protocols: In this survey, few protocols other than conventional protocols like time-division multiple access (TDMA) [9], frequency-division multiple access (FDMA) etc [10], for transmitting data from the sensor nodes to the Base Station (BS), are reviewed. TDMA based protocols are not adaptive. They cannot support a large number of nodes because latency increases significantly with the number of nodes. Contention-based protocols are basically Carrier Sense Multiple Access (CSMA) [11] protocols. In CSMA, wireless nodes are able to sense the communication medium and defer their transmission while the channel is busy. CSMA protocols can easily accommodate newly added nodes (adaptive), do not require strict synchronization among nodes and can support a large number of sensor nodes (scalable).

As per Direct Communication Protocol (DCP) [4], all the sensor nodes directly communicate with the base station, which by assumption is located far away. As a result, the nodes that are very far away lose their energy very quickly because of longer range. This leads to reduction in total network life time.

In Minimum Transmission Energy (MTE) routing, the author performs the selection of routes from each node to the base station such that each node's next–hop neighbour is the closest node that is in the direction of the base station [4, 12]. In order to determine its next–hop neighbour, every node requires 100 nJ. The transmit power of the nodes are adjusted to the minimum necessary to reach their next – hop neighbour, by which the interference with other node during transmissions and also the node's energy dissipation is reduced.

Existing MAC protocols with some trade-offs can be made use in WSN [13]. But from MAC's perspective energy is lost in the form of collision, idle listening and overhearing and control packet overhead [14]. All these lead to the deployment of Sensor-MAC (S-MAC) which is a MAC protocol specifically designed for WSN [27]. S-MAC strives to retain the flexibility of contention-based protocol but at the same time it includes approaches to reduce energy consumption. These were standardized as 802.15.4 mainly for applications of low power and wireless communication Protocols such as CLUSTERPOW and MINIPOW. There are some Link Layer optimizations which were done on the network layer Vikas Kawadia and Kumar [16] in their work on Power Control and Clustering in Ad-hoc networks.

In Static Clustering Architecture, clusters are formed statically at the time of network deployment, where the size of a cluster, the area it covers and the members it possesses, are static. Fixed membership is not robust from the perspective of fault tolerance. When a CH dies of energy constraint, all the sensors attached to this CH become useless. In such case the network may not have sufficient sensors to carry out its tracking tasks in this location.

Iterative Protocols: In iterative clustering techniques, a node waits for a specific event to occur or certain nodes to decide their role (e.g., a node to become CHs) before making a decision. For example, in the Distributed Clustering Algorithm (DCA), before making a decision, a node waits for all its neighbours with higher weights to decide to be cluster heads (CHs) or join existing clusters [18]. Nodes possessing the highest weights in their one-hop neighbourhoods are elected as CHs.. The problem with most iterative approaches is that their convergence speed is dependent on the network diameter. The performance of iterative techniques is also highly sensitive to packet losses.

To ameliorate the above problems, some protocols enforce a bound on the number of iterations for each node. For example, in ACE when a node finishes executing a number of iterations, it makes a decision based on the available information [17]. These iterations are enough to achieve a stable average cluster size.

Probabilistic and Hierarchical Protocols: The probabilistic approach for node clustering ensures rapid convergence while achieving balanced cluster sizes. It enables every node to independently decide on its role in the clustered network while keeping the message overhead low. LEACH (Low Energy Adaptive Clustering Hierarchy) is most popular probabilistic and hierarchical algorithm and is energy efficient [5]. In order to determine the Cluster Head (CH), LEACH uses randomization technique. In this algorithm, after each cycle or after certain time interval, sensors elect themselves to be local CHs, with a certain probability. Subsequently, each sensor node determines to which cluster it wants to belong by selecting the CH for which minimum communication energy is required. It uses TDMA model for data aggregation.

For communication between nodes and CH and between CHs and BS, radio model is used. The energy necessary for transmission from CH to BS is more due to the fact that the BS is far away from the sensors deployed. Nonetheless, only a small number of nodes are affected as there are only a few CHs. To form a cluster, the position of the sensors is not essential.

In the initial stage of LEACH-C (LEACH-CENTRALIZED) algorithm, each node sends information to the base station about current location and energy level of that node [27]. An optimization algorithm is run by the base station to determine the clusters for that round. This necessitates a global positioning system (GPS). In order to determine the best nodes to be cluster heads for the next round and the associated clusters, the base station uses the remaining nodes as possible cluster heads and runs an algorithm known as simulated annealing algorithm.

According to LEACH-F, the clusters are fixed and only the cluster heads are rotated [27]. In this case, when another cluster's CH is nearer, large amount of power is required by a node to communicate with its cluster head. LEACH-F also employs the same annealing algorithm for initial cluster formation. When compared to LEACH-C, this algorithm is more energy efficient. However, due to the reason that this LEACH-F algorithm does not allow new nodes to be added to the system and does not adjust its behaviour based on nodes–dying and high interference of signals, this algorithm cannot be implemented in practical real time systems. In addition, node mobility is not handled by LEACH-F.

A simple energy-efficient cluster formation algorithm for the wireless multi hop sensor network AROS has been presented which demonstrates that using a minimum separation distance between cluster heads improves energy efficiency [19]. The energy efficiency is measured by the number of messages received at the base station. A comparison of employing the minimum separation between the cluster heads with not employing the minimum separation between the cluster heads is performed, in which it is illustrated that the performance of employing the minimum separation between the cluster heads is better up to 150%.

Unlike LEACH, Energy Efficient Hierarchical Clustering (EEHC) algorithm extends the cluster architecture to multiple hops [6]. It is distributed, probabilistic and hierarchical *k*-hop clustering algorithm, which maximize the network life time. Initially, each sensor node is elected as a CH with probability '*p*'. Considering the overall performance of EEHC, the energy consumption for network operations (data gathering, aggregation, transmission to the BS, etc.) clearly depends on the parameters *p* and *k* of the algorithm. The authors derive mathematical expression for the values of *p* and *k* that achieve minimal energy consumption and they show via simulation results that by using the optimal parameter values energy consumption in the network can be reduced significantly.

A distributed, energy-efficient, hierarchical clustering approach for ad-hoc sensor networks has been presented by Ossama Younis and Sonia Fahmy [8]. In this HEED (Hybrid, Energy-Efficient and Distributed) protocol, to increase energy efficiency and prolong the network lifetime, the authors consider both intra-cluster communication and inter-cluster communication. Based on the residual energy, the CHs are selected probabilistically which is the primary parameter for inter-cluster communication. The secondary clustering parameter is the function of cluster size and whether or not variable power levels are permissible for intra-cluster communication. The power level used for intra-cluster announcement and formation of the cluster is termed as cluster power level which is set to one of the lower power levels of a node, to increase the spatial reuse. The higher power levels are used for inter-cluster communication and ensure the inter-cluster overlay connectivity.

The discussed approach is hybrid: the selection of cluster heads are made probabilistically based on their residual energy and nodes join clusters such that communication cost is minimized. Here, the authors assumed the quasi-stationary networks (nodes are location-unaware and having equal significance). The authors also compare the HEED protocol with the generic weight-based clustering protocols such as DCA [26, 18] and WCA-Weighted clustering algorithm [21, 22] which are quasi-stationary ad hoc networks and they use the residual energy as real-valued weight for generic clustering. This protocol is independent of network diameter and terminates in a constant number of iterations.

PEGASIS (Power-Efficient Gathering in Sensor Information Systems) is a greedy chain protocol that is near optimal for a data-gathering problem in sensor networks [24]. PEGASIS eliminates the overhead of dynamic cluster formation, minimizes the distance non leader-nodes must transmit, limits the number of transmissions and receives among all nodes and uses only one transmission to the BS per round. Due to the above features, PEGASIS outperforms LEACH. The fused data are transmitted by the nodes (in turns) to balance the energy depletion in the network and robustness of the sensor web is preserved as nodes die at random locations. The lifetime and quality of the network are increased by distributing the energy load among the nodes. The simulations illustrates that PEGASIS performs better than LEACH by about 100 to 300% when 1%, 20%, 50% and 100% of nodes die for different network sizes and topologies. The performance of PEGASIS improves further with increase in the size of the network.

A novel, distributed energy efficient and load balanced clustering scheme has been presented in [20] intended for periodical data gathering. An Energy Efficient Clustering Scheme (EECS) produces a uniform distribution of cluster heads across the network through localized communication with little overhead. Additionally, the authors discuss a novel approach that distributes the energy consumption among the sensors in the cluster formation phase. It can be observed from the simulation results that EECS prolongs the network lifetime as much as 135% of LEACH and the consumption of total energy is efficient.

The authors, Hang Su and Xi Zhang [23] have derived the optimized parameter, the number of clusters, for (energy-threshold-driven based BC clustering Algorithm) BCCA by extending the existing analytical model and its correctness is illustrated by simulations. The authors' claim that the original analytical model underestimates the optimal number of clusters and thus necessitates modification is revealed by the analysis performed. The analysis is verified by the simulation results, which illustrate the modified model is more accurate in deriving the optimal number of clusters to maximize the lifetime of wireless sensor networks.

The authors, Handy *et al* [10] have discussed two modifications of LEACH's CH selection algorithm, which accomplishes a 30 % increase of lifetime of micro sensor networks. Despite the modifications, an important quality of a LEACH network is sustained in addition, which is the necessity of only local information rather than global information for the deterministic selection of cluster-heads. The determination whether nodes become CHs is performed by the nodes itself, which does not require the communication with the base station or an arbiter-node. In addition, they have presented the metrics FND (First Node Die), HNA (Half of the Nodes Alive) and LND (Last Node Die) which describe the lifetime of a micro sensor network.

All the above protocols concentrate on minimizing the energy consumption and there by maximizing the network lifetime. Most of the discussed algorithms minimizes energy consumption either in the cluster formation stage or during inter cluster communication or during intra cluster communication. But, it is possible to increase the network lifetime even by selecting a proper cluster heads during cluster setup phase so that it can withstand the overload in terms of energy consumption due to additional responsibilities such as intra cluster communication, data aggregation and communication to the BS. Hence, it is decided to design a new cluster formation protocol by name NEEP which introduces better cluster head selection for maximizing the network lifetime.

Proposed Neep Protocol: Due to the intended miniaturization process as the major design goal for micro sensors, the energy supply of the sensors becomes a main constraint in WSNs [25]. In most of the applications, the exact location of a particular phenomenon is unknown. Almost in all cases, the environment to be monitored does not have an existing infrastructure for either energy or communication. It becomes imperative for sensor nodes to survive on small, finite sources of energy and communicate through a wireless communication channel where communication is a major consumer of energy.

In WSNs, the nodes which are sensing can collaborate locally to reduce the data to be transmitted to the end-user. Correlation is the strongest among data signals from nodes that are close to each other. Therefore, the formation of a clustering infrastructure becomes necessary to allow the nodes which are close to share data. Thus, the objective of this work is to design a communication protocol, which employs a new type of clustering architecture for processing raw data received from sensing nodes and communicating this data to the BS. This facilitates the achievement of low energy dissipation.

Before creating a totally new algorithm, few of the existing algorithms like DCP, Static Clustering are simulated and analyzed. Later a totally New Energy Efficient Protocol (NEEP) is proposed. From the results, it is illustrated that the NEEP maximizes the system lifetime in WSNs.

The protocols are analyzed for system life time first. The lifetime of the network is observed based on the number of the nodes alive in the network. Therefore, a WSN is constructed using simulation technique and then, the energy spent by the nodes for communication purpose is calculated based on the simple first order RF radio model [4.5]. It is assumed that the radio dissipates E_{elec} = 50 nJ / bit to run the transmitter or receiver circuitry and ϵ_{amp}= 100 pJ / bit /m ^{2} for the transmit amplifier (Table -1) to achieve an acceptable Signal to Noise Ratio (SNR). These parameters are slightly better than the current state of the art in radio design. It also assumed that the energy loss due to channel transmission is proportional to r^2. Thus, to transmit a k-bit message a distance d m using the given radio model, the radio expends:

$$E_{Tx}(k,d) = E_{Tx} - elec(k) + E_{Tx-amp}(k,d)$$

$$E_{Tx}(k,d) = E_{elec} \times k + \epsilon_{amp} \times k \times d^2 \quad (1)$$

Table 1: Radio characteristics

Operation	Energy Dissipated
Transmitter Electronics ($E_{Tx-elec}$) Receiver Electronics ($E_{Rx-elec}$) ($E_{tx-elec} = E_{rx-elec} = E_{elec}$)	50 nJ / bit
Transmit Amplifier ϵ_{amp}	100 pJ / bit / m^2

To receive this message, the radio expends:

$$E_{Rx}(k,d) = E_{Rx-elec}(k)$$

$$Erx\ (k) = E\text{elec} \times k \quad (2)$$

The transmission and reception of a k-bit message is an expensive operation. Hence, it is necessary that the protocols attempt to minimize both the transmit distances and the number of transmit and receive operations for each message. It is assumed that the radio channel is symmetric such that the energy required for transmitting a message from node A to node B is the same as the energy required for transmitting a message from node B to node A for a given SNR (Signal to Noise Ratio). For this experiment, all sensors are assumed to be sensing the environment at a fixed rate and thus always have data to send to the end-user.

Simulation Parameters: A 100 node network is deployed randomly in an area of 100x100m^2. The BS is assumed to be situated at (50,200) away from the above specified area. Also, it is assumed that 5% of nodes are considered as CHs for the entire cycles. Thus, 5 clusters are formed for five cluster heads as per our network size. The first set of CHs is selected randomly by the BS by sending a “hand shake” signal to those 5% nodes. The initial energy of all the nodes assumed as 0.5 joules.

In this simulation, the channel capacity of nodes is set to 2 Mbps. The distributed coordination function (DCF) of IEEE 802.11 for wireless LANs (Local Area Networks) is used as the MAC layer protocol. The simulated traffic is FTP (File Transfer Protocol) with TCP (Transmission Control Protocol) source and sink. All experimental results presented in this section are averages of five runs on different randomly chosen scenarios. The Table-2 summarizes the simulation parameters used and the consecutive Fig. 1 represents the simulated WSN using these parameters.

Simulation Results: As mentioned earlier, the several random 100 node networks are simulated to evaluate the network life time for the existing protocols like DCP, Static

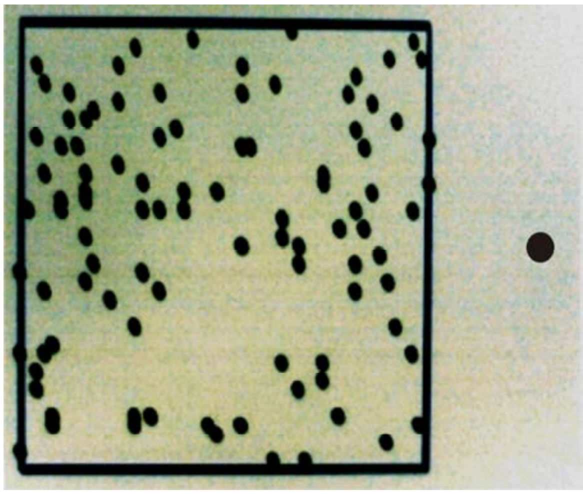

Fig. 1: The simulated WSN with 50×50 m^2 area

Table 2: Simulation Parameters

Name of the parameter	Quantity
No. of Nodes	100
Area Size	50 x 50, 100 x 100
MAC	802.11
Simulation Time	50 sec
Traffic Source	FTP
Packet Size	512
Transmit Power	0.360 w
Receiving Power	0.395 w
Idle Power	0.335 w
Initial Energy	0.25J,0.5J,1J
Transmission Range	100m
Base Station Location	50,200
Data size	2000 bits

Table 3: Lifetimes using different amounts of Initial energy for the sensors in 50×50m^2 area

Energy J/Node	Type of Protocol	Round first node dies	Round last node dies
0.25	DCP	53	117
	MTE	5	221
	Static clustering	54	77
	LEACH	394	665
	PEGASIS	788	1096
	NEEP	853	866
0.5	DCP	107	236
	MTE	8	429
	Static clustering	113	166
	LEACH	932	1312
	PEGASIS	1578	2192
	NEEP	1683	1698
1	DCP	216	465
	MTE	15	843
	Static clustering	247	449
	LEACH	1848	2608
	PEGASIS	3159	4379
	NEEP	3370	3384

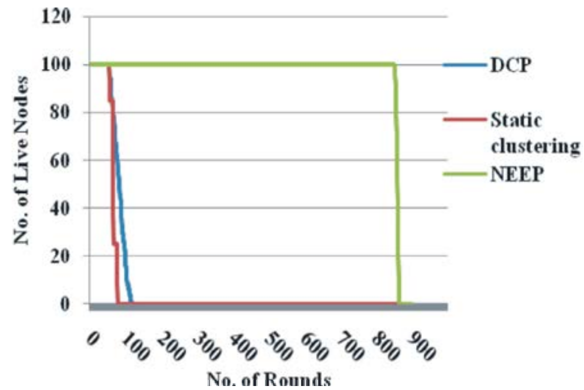

Fig. 2: The life times of the NEEP with initial energies of all nodes are 0.25 J

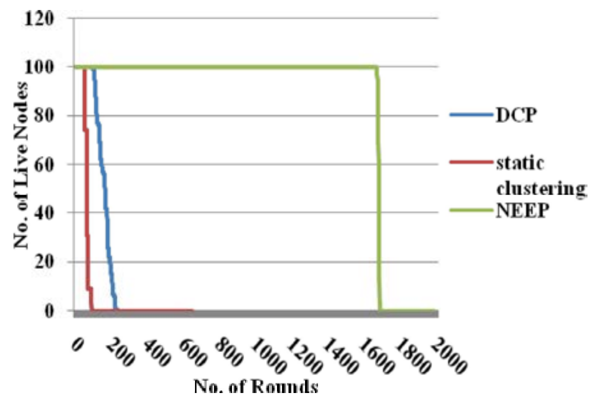

Fig. 3: The life time of the NEEP with the initial energies of all nodes are 0.5 J

Clustering. Using the equations 1 and 2, the network lifetime is calculated. Also, for the evaluation of life of the network, three different energy levels namely 0.25J, 0.5J and 1.0J are assumed as initial energy for all nodes and for all protocols. Then, the network lifetime is compared among DCP and MTE routing protocols, static clustering, LEACH, PEGASIS and NEEP protocols.

The number of rounds at which the first node die and the lost node die for different data reporting models/protocols for the above three battery energy levels are tabulated in Table-3. For the discussions, the results obtained for 50×50 m^2 range network is considered first. This Table-3 clearly indicates that compare to other protocols, the NEEP improves the network life time in many folds. This is because in NEEP architecture, for every round of communication, during cluster setup phase, the nodes with the highest residual energy are selected as cluster heads. The effect of network lifetime, that is, the graph between the numbers of nodes alive versus number of cycles completed for Static clustering, DCP and NEEP protocols for 0.25J, 0.5J and 1J are plotted and shown in Fig. 2, 3 and 5 respectively. Fig. 4 represents

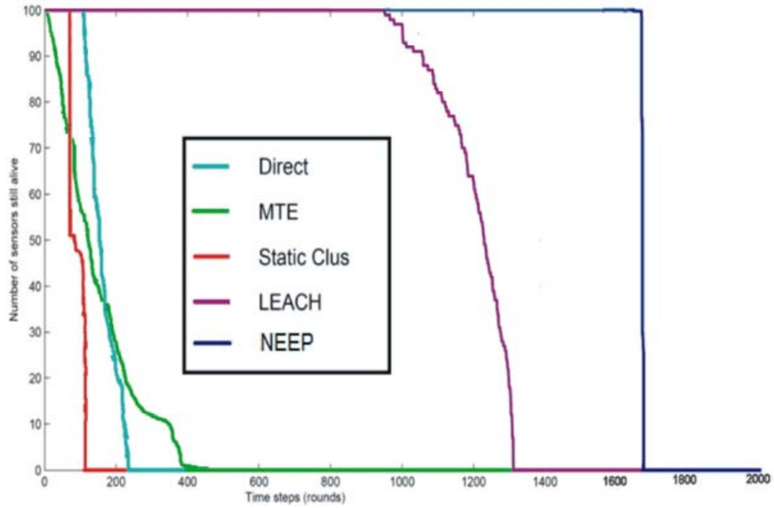

Fig. 4: The life time comparison with LEACH architecture for 0.5J of node energy (Wendi Rabiner Heinzelman 2000)

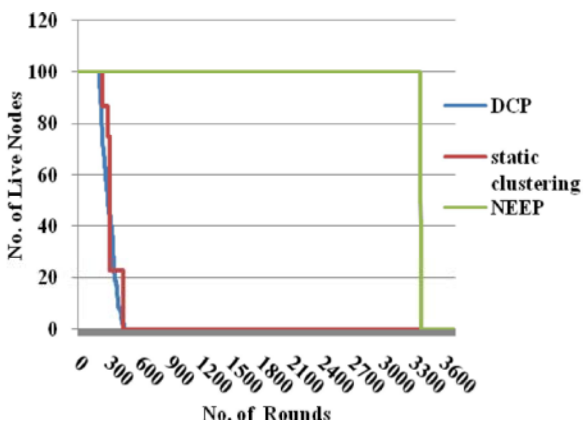

Fig. 5: The life time of the NEEP with the initial energies of all nodes are 1 J

the comparison of LEACH protocol with the other protocols assuming 0.5J as the initial energy of the individual nodes.

RESULTS AND DISCUSSION

Use of the wireless channel is growing at an amazing speed. Advances in energy – efficient design have created new portable devices that enable exciting applications for the wireless channel. Specifically, the wireless channel is bandwidth limited and the portable devices that use the wireless channel are typically battery operated and hence energy – constrained. The work described in this project has demonstrated the advantages of generic approach protocol architectures by designing and evaluating protocol architectures for two different application spaces: large scale and distributed micro sensor networks. Also, this architecture is energy efficient cluster formation architecture. By the selection of proper cluster head and by forming energy efficient clusters, this protocol architecture maximizes the system life time by 180% of LEACH (Low Energy Adaptive Clustering Hierarchy) when 1% node die. The author of HEED architecture mentions that the original LEACH outperforms HEED when based on the same assumptions as that of LEACH. EECS architecture also has the same assumptions as HEED. Since, NEEP architecture outperforms LEACH by 180% of life time maximization, this architecture outperforms the HEED as well as EECS architectures.

PEGASIS introduces a greedy chain protocol in which network lifetime will be reduced because of the data reception, data fusion and data transmission to neighbouring cluster head. Hence, NEEP architecture maximizes total life of the network by 106% of PEGASIS (Power-Efficient Gathering in Sensor Information Systems).

Further, AROS concentrates only in communicating maximum number of messages to the base station than saving the life of the network. The number of messages communicates to the base station require more energy because BS is far away from the network. Hence, the energy consumption of NEEP is lesser than these AROS architectures.

CONCLUSION

Specifically, the WSNs are bandwidth limited and the portable devices that use the wireless channel are typically battery operated and hence energy – constrained. In addition, the wireless channel is error prone and time – varying.

Hence, there is still much work to be done in the area designing of protocols for WSNs. The protocols developed in this research are for scenarios where the sensors have correlated data. However, there are important applications of micro sensor networks where this is not the case. For example, sensor networks for medical monitoring applications may have different sensors located on and / or in the body to monitor vital signs. These networks may not be as large scale as the discussed WSN, but they need similar requirements as per the earlier discussions, which mean that these types of sensor networks also require long system lifetime, low latency data transfers and high quality data. These networks will most likely focus on maximizing quality above all parameters, because loss of information will not be acceptable.

Therefore, the secondary objective in designing NEEP protocol is to achieve the maximum network lifetime without sacrificing the Quality of Service (QoS) of the network. In the second phase of this work, the network parameters such as average energy consumption, throughput and latency will be compared with respect to cluster size, time and source variation. This will be done in three stages with different protocols to verify whether the proposed NEEP does not sacrifice the QoS at the cost of extending the lifetime.

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