Sencars – The robust recharger of WSN: NDN Approach

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Abstract—*Sencars are the mobile nodes which could be a robot or a moving vehicle or any movable object that could act as a robust energy recharger, of those nodes in a wireless sensor networks which are really in need of energy. Sencars would move to the sensor node of the network whose battery backup is below the threshold value. The threshold value is set prior, to all the sensor nodes, based upon their data transmissions or according to the purpose of the network. Sencars move along in its defined path, from the Base station and travel from clusters to clusters in a WSN (Wireless Sensor network).This paper suggests NDN (Named Data Networking) based approach, a novel concept which is under research and development, that could bring a solution for the efficient recharging mechanism, through Sencars. This paper attended a WSN with static sensor nodes and few mobile nodes called Sencars. The problems that we could come across would be, the Sencar must meet the energy depleted sensor nodes before it fully gets exhausted. So, while travelling along the WSN, Sencars must formulate the recharge optimisation problem into Multiple Traveling Salesman Problem with Deadlines (m-TSP with Deadlines), which is NP-hard. The focus must be on the increased scalability of the network, meeting the energy starvation of a sensor node, as it requires on time. Our simulation results, focuses on the recharging of energy depleted sensor nodes as the Sencars move along its path by NDN approach.*

Keywords-Wireless Sensor Networks, Named Data Networking, Energy depletion, Mobile vehicle – Sencars.

I. INTRODUCTION

The mobile charging vehicles called Sencars are equipped with charging sources or devices and move along a wireless sensor network. The way the Sencar attends the energy depleted nodes, the order by which it meets the sensor nodes would have an impact on the life time and efficiency of a network.

Many papers and researchers have tried attending, the recharging of nodes at certain intervals and in periodic manner. Assuming that the recharged node will prolong with the energy gained, for a certain period, the Sencar would come and meet the already recharged node, quite a while after some prescribed time intervals. This is unpredictable, that the energy level of the node might get depleted at any point, based upon its transmission of data along the network. This paper proposes, a well-defined solution called NDN approach, which would meet the requirement of the thirsty nodes whenever it is needed.

II. PRELIMINARIES

A wireless sensor network is divided into clusters with the following network components.

A. Network Components

- Sensor nodes:

These are the nodes in a network which are capable of transmitting the data or receiving the data in its range of transmission in a wireless sensor network.

- Head Nodes:

These are the nodes which have the maximum energy backup when compared with the other nodes in a cluster. Head nodes are capable of gathering the information from the normal sensor nodes below its level, in the cluster and send the information back to the proxy nodes or Sencars. It also spreads or propagates the information to the normal sensor nodes which is transmitted by the Sencars or the other head nodes in WSN or the proxy nodes. The Head node selection will be changing as per their energy back up, from time to time.

- Proxy Nodes:

The top level head nodes are the proxy nodes. Whenever there is an emergency, the proxy node collects the emergency node situations having the energy back up less than the threshold value, to the Sencars, urging them to meet the requirements of recharging the sensor nodes which are energy depleted.

- Normal Nodes:

The sensor nodes other than the Head nodes and the proxy nodes, are the normal nodes. The normal sensor nodes send the energy status to head nodes or even to the proxy nodes at emergency situations.

- Base Station or Service Station:

The base station controls the entire network. The communication of the network is controlled and monitored by an administrator in the base station. The Base station controls the movement of the Sencars.

- Sencars:

Sencars are the mobile nodes which would collect the information from the head nodes, about the energy status of the normal nodes and recharge them with energy needed for them to prolong its life in the sensor network. Whenever the energy of the battery backup of the Sencar is found to be low, it moves to the Base station and gets energised.

B. General Delineations in the sensor network

- The Sencar knows the position of itself and every Sensor node in its range of communication.
- The position of every sensor node is noted as co-ordinates, even at the time of network initialisation itself.
- Sensor nodes are stationary and they know their positions in the geographical area of the network.
- The network area is divided into sub areas, and each node is denoted by its area name and its id, for the Sencar to reach it by their area name.
- Whenever any request is raised on recharging the sensor nodes, the Sencar would locate its position and the requested node’s position, by its area name and id. It would then trace the shortest path to reach the energy depleted node to get recharged.

- Sencars are equipped with very powerful antennas to communicate with themselves and to the Base station, over a wide range of communication technologies.

III. PROTOCOL SCENARIO

A. LEACH Protocols - Head Node Selection

In a newly formed network, the energy level of all the sensor nodes will be the same. After clustering, among the individual clusters, any one node will act as a head node. The following protocols were referred by various researchers in their papers as suitable for cluster head selection. So, this paper also finds LEACH protocol as its best find for cluster head selection.

LEACH stands for Low-Energy Adaptive Clustering Hierarchy. There is no longer the life of a sensor node, if its energy level falls back and dies below the threshold value which affects the life time of the entire network. This protocol allows us to space out the lifespan of the nodes, allowing it to do only the minimum work it needs to transmit data. LEACH is dynamic and the role of the cluster head rotates. LEACH works with two phases. (I)The Set up Phase and (II) The Steady State Phase. In Set up Phase Cluster heads are chosen whereas in the Steady Phase the cluster Heads are maintained and the data being transferred between the nodes.These cluster heads change randomly over time in order to balance the energy of the network. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. In LEACH, the Cluster Heads compress data arriving from member nodes and send an aggregated packet to the Base station in order to reduce the amount of information that must be transmitted to the Base station. In order to reduce inter & intra cluster interference LEACH uses a Time Division Multiple Access (TDMA) / Code-Division Multiple Access (CDMA) MAC. This is done by choosing a random number between 0 and 1. The node is selected as a cluster head for the current round if the random number is less than the threshold value T (n), which is given by

$$T(n)=\begin{cases} \dfrac{p}{1-p^{*}(r \bmod 1/p)} & \text{if } n \quad G \\ 0 & \text{otherwise} \end{cases}$$

Here ‘n’ is a random number between 0 and 1, ‘p’ is the cluster head probability and ‘G’ is the set of nodes that are involved in the CH election. In steady state phase, the actual data is transferred to the Base station. To minimize the overhead the duration of the steady state phase should be longer than the duration of the set up phase. The CH node after receiving all the data from its member nodes, performs aggregation before sending it to Base station. After certain time period, the set up phase is restarted and new CH is selected. This LEACH protocol is very prompt and easy applicable for those networks which can be assumed that all the energy levels of nodes are same ie Homogeneous networks.

To be in short, Using LEACH protocol, every node in the cluster will become cluster head at-least once.Many such improved LEACH protocols are suggested in order to elect a Head Node or Cluster head. Few improved LEACH protocols include E- LEACH, TL- LEACH, LEACH –C, V-LEACH, etc. The appropriate Protocol must be chosen according to the execution and performance of the network.

Among the improved LEACH protocols, since our paper is suggesting a solution towards energy recharge of sensor nodes, it would be probable to go with either E-LEACH or LEACH – C protocol. The brief description of it is as follows.

- E-LEACH Protocol

Energy-LEACH protocol improves the CH selection procedure. It makes residual energy of node as the main metric which decides whether the nodes turn into CH or not after the first round. Same as LEACH protocol, E-LEACH is divided into rounds, in the first round, every node has the same probability to turn into CH, that mean nodes are randomly selected as CHs, in the next rounds, the residual energy of each node is different after one round communication and taken into account for the selection of the CHs. That mean nodes have more energy will become a CHs rather than nodes with less energy.

- LEACH-C Protocol

Leach-C protocol can produce better performance by dispersing the cluster heads throughout the network. During the set-up phase of LEACH-C, each node sends information about its current location (possibly determined using GPS) and residual energy level to the sink. In addition to determine good clusters, the sink needs to ensure that the energy load is evenly distributed among all the nodes. To do this, sink computes the average node energy, and determines which nodes have energy below this average. Once the cluster heads and associated clusters are found, the sink broadcasts a message that obtains the cluster head ID for each node. If a cluster head ID matches its own ID, the node is a cluster head; otherwise the node determines its TDMA slot for data transmission and goes sleep until it’s time to transmit data. The steady-state phase of LEACH-C is identical to that of the LEACH protocol.

In LEACH-C, the threshold value T(n) is based on the energy status of the nodes.

$$T(n) = \frac{p \qquad E_{n\_current}}{1-p^{*}(r \bmod p^{-1}) \quad E_{n\_max}}$$

where $E_{n\_current}$ is the current amount of energy and E_{n_max} is the initial amount of energy.The Head node will be selected whether or not it had already been the cluster head.

Since this paper deals with the recharging of the sensor nodes using Sencars, before the network initialisation itself, we must set, in which way the cluster heads are going to be chosen. It would be probable to choose the Cluster Head or the Head Node of a cluster using **E- LEACH Protocol** or **LEACH-C Protocol**.

B. Named Data Networking

Named Data Networking is a novel approach that has been recently introduced for internet. Usually, in a network the importance would lie on the end to end connectivity i.e., the connectivity established between the nodes. Most of the architectures that were proposed showed their importance on the connection establishment between the nodes. NDN is a different approach and an emerging protocol that would bang the Internet Architecture one day for its uniqueness and exclusiveness. We can define its individuality as it roots on content-centric networking, content-based networking, data-oriented networking or information-centric networking. NDN focuses its importance on the data content rather than the connection between the nodes. It is not like that the connectivity is not important, but the weightage of the data that is been transferred between the nodes are very important. Recently, NDN has extended its hands towards internet and a little on mobile computing, but whether it is possible towards WSN is still unexplored. This paper is still an effort to bring out the ideas of NDN in WSN.

Let us have an overlook of NDN architecture.

- The NDN Architecture:

Communication in NDN is driven by the receiving end, i.e., the data consumer. To receive data, a consumer sends out an Interest packet, which carries the name that identifies the desired data. A router remembers the interface from which the request comes in, and then forwards the interest packet by looking up the names in the Forwarding Information Base (FIB), which is populated by a name-based routing protocol. Once the Interest reaches a node that has the requested data, a Data packet is sent back, which carries both the name and the content of the data, together with the signature by the producer's key. This Data Packet traces in the reverse path created by the Interest packet back to the consumer. We must note that here there is no involvement of any host or other interface addresses i.e., IP addresses. NDN routers keep the Interest and Data for a certain period of time. When multiple Interests are received for the same data, then the router stores the Interest in the Pending Interest Table (PIT). When Data packets arrives, the router finds matching in the PIT and caches the Data in the Content Store, the buffer memory of the router.

NDN Packet is a meaningful packet, independent of where it comes from or where it may be forwarded to, thus the router can cache it to satisfy potential future requests. This enables NDN various functionality without extra infrastructure, including content distribution (many users requesting the same data at different times), multicast (many users requesting the same data at the same time), mobility (users requesting from different locations) and delay tolerant networking (users having intermittent connectivity).

NDN names are opaque and are not globally defined. It may be independent of the network.

Interest Packet

Content Name
Selector (order Preference, Scope,Publisher Filter….)
Nonce

Data Packet

Content Name
Signature (digest Algorithm, witness,….)
Signed Info (publisher info, Key Locator, Stale time,….)
Data

Figure 1. The packets in NDN Architecture

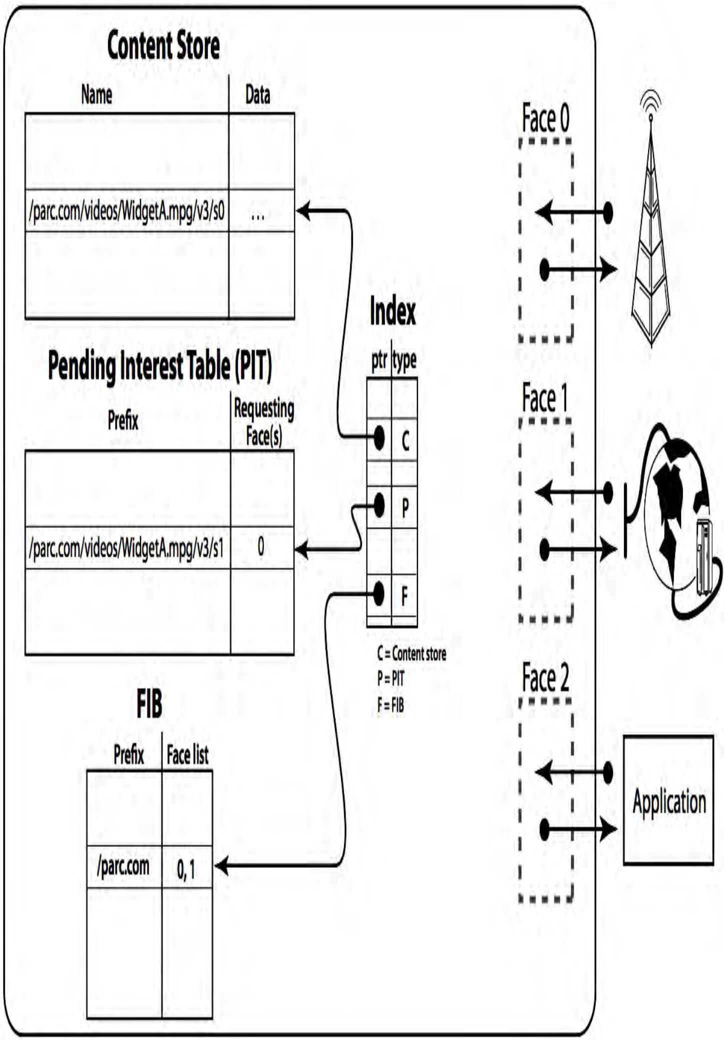


Figure 2. The forwarding process at an NDN Node

The figures, Figure 1 and Figure 2 represents the packets in the NDN architecture and the forwarding process at an NDN Node respectively. The above details are still under research and development. Even then,.

Even then the above NDN Approach is under Research and development, this paper's idea and interest to implement NDN on recharge mechanism boomed when surfing the above NDN details from the internet. This paper made an effort to bring out the significance of NDN concept to be applied in recharge mechanism of sensor nodes by Sencars in WSN. This will be discussed in the latter portions of this paper

IV. ALGORITHM USED

A. Shortest Path Algorithm

After the minimum energy node is identified, the Sencar would make a move towards the energy depleted node below its threshold value by implementing the shortest path algorithm.

As the preliminary set up of the network, the nodes in a network are noted down by its location as represented in (X,Y) co-ordinates.(can be positioned by GPS also). Every node in the network knows its location and the location of the other nodes in a network. The distance between the adjacent nodes say having the location co-ordinates as (X1, Y1) and (X2, Y2) can be found using the formula,

Distance between the nodes = Sqrt $((X2-X1)^2 + (Y2-Y1)^2)$

The weight of the node is the distance between the adjacent nodes. Sencar would reach the sensor node which is to be recharged by taking the path through minimum weights.

B. Minimum Weighted Sum Heuristic Algorithm – to meet emergency situations

This paper tries to schedule and coordinate the Sencars to recharge the nodes within their residual lifetimes while minimizing the cost of Sencars, called the Emergency Recharge Optimization with Multiple Sencars

(EROMS). EROMS are NP hard problem. To overcome the EROMS problems, we would suggest an algorithm which attends the Multiple Travelling Salesman Problem with Deadlines or Time Windows (m-TSPTW).

In EROMS emergencies may appear at any time and residual node lifetimes also vary due to ongoing sensing activities. We present a heuristic algorithm that schedules recharge assignments among Sencars.

At times of emergencies, it is not only important to focus on the shortest path, but also the node which should be attended first, whether it is on the basis of shortest path or on the basis of the residual energy of the node.Whenever any Sencar sends an energy interest message, the cluster heads around its transmission range would respond. The Sencar must prioritise the nodes at that point with their residual energy status i.e, their energy left over status in order to overcome the emergency situation which would lead even to the death of the node, affecting the life time of the network.

One of the related research papers define, Residual Lifetime is the information about how long the node can last. It is calculated by taking a weighted sum of the estimated residual lifetime in previous time slots. The estimated lifetime L_i at time slot i is obtained by dividing the current energy consumption rate from residual energy. The residual lifetime can be calculated as the weighted average of previous lifetime at n slots:

$$L_i = \frac{L_{i-n} + L_{i-n+1}}{2^n} + \frac{L_{i-n+2}}{2^{n-1}} + \ldots\ldots + \frac{L_i}{2}$$

If node j has a small L_j such that it would be dead if a Sencar recharges node i first, node j should be visited first.We use a weighted sum w_{ij} of traveling time from the current node i to next node j and the residual lifetime of node j,

$$w_{ij} = \alpha t_{ij} + (1 - \alpha) L_j$$

w_{ij} is used to decide which node j to recharge next. A sensor node with a smaller weighted value should be visited at a higher priority. When $\alpha = 1$, the algorithm reduces to nearest node selection that the Sencars always recharge the closest node first regardless of battery deadlines. When $\alpha = 0$, it picks the node with the earliest battery deadline first regardless of the traveling distance.

The above methodology is followed in one of the related research papers, suggesting the way to overcome the emergency situations. The value of α would determine the node to be recharged by the Sencars.

We could also propose an idea that at emergency situations in which the energy depleted nodes are unattended, those nodes can send voluntary messages to the head nodes and the head nodes in turn could propagate to the base station through the proxy nodes. Then the base station administrator can find the nearest idle or moving Sencar and alarm the Sencar, to meet the requirements following the shortest path algorithm to reach the energy depleted node.

V. NDN IMPLMENTATION

A wireless sensor network is divided into different clusters. Sencars move along the sensor network from clusters to clusters. Each cluster has a cluster head which receives as well as transmits data to the node below its hierarchy. There are also proxy nodes which are the top level head nodes, which could directly communicate with the base station at the time of emergencies. The cluster heads communicate with the base station through the proxy nodes.

As the Sencars travel along the WSN, it propagates the Energy Interest Message. The cluster heads around its transmission range would forward it to the lower nodes under its levels. The following FIB (Forward Information Base) entries would flow till it reaches all the nodes in the cluster.

The names given to the nodes of different clusters are opaque and are not global. Assume, that the clusters are named by their area names, say a, b, c, etc., and the individual nodes are also represented by cluster name / it's ID. (e.g.) a/1 may represent the 'node 1' of the cluster 'a'. Likewise the nodes along the network need not be specified by their IP addresses, instead they can be denoted by some names as initialised by the administrator of the network.

Soon the interest messages are received by the nodes in the clusters, within the transmission range of the Sencars, the individual nodes would send the data bearing their names (a/1), energy status of their battery backup, their residual lifetime details as Data Packets to the cluster heads. The cluster heads forward the data to the Sencars. The Sencar would locate the nodes with minimum energy backup (below the threshold value needed for the data transmission of the nodes) and less residual lifetime, by following the shortest path and recharge them with the sufficient energy. After finishing the recharge of any of the sensor nodes or the emergency nodes, the Sencars would again propagate an interest message to make sure that any recharge of nodes are needed. In the meanwhile, the intermediate nodes also maintains the Pending Interest Table to go in order to meet the recharge mechanism. If these intermediate nodes find that the node entry was already recharged, it would delete the previous entry which was already recharged by the Sencar.

VI OVERALL DESIGN

The overall design of the proposed concept is given as follows:

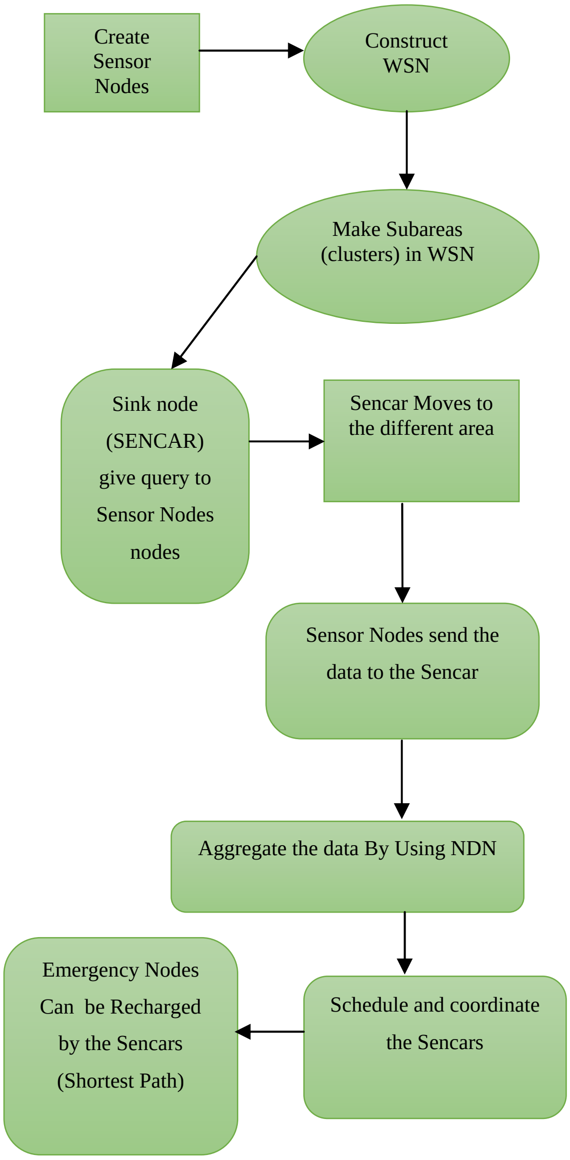


Figure 3.The Overall Design

Figure 3 explains the overall design of the proposed NDN approach to recharge the nodes in WSN.

VII PERFORMANCE ANALYSIS

A. Comparison with the existing Networks

Usually in a WSN, the mobile recharging nodes called Sencars would have a definite path to move along the network. It starts from a point, travels along the network, and recharge the nodes in periodic time intervals. The existing system does not meet the emergency situations when the sensor nodes are really in need of energy to get recharged. It was not an advisable methodology which even affected the life time of the network. There were many issues that the existing system suffered. For an instance, the Sencar recharges a node at the 0'th hour. It takes 1 hour to recharge it. Thereafter it moves to the next node as scheduled and recharges it at the 2'nd hour. Meanwhile, due to the data transmission over the network, suppose the node which was recharged by the Sencar at the 0'th hour got its energy depleted, there is no chance for the Sencars to meet the energy requirement of that node. Instead it would come and attend the energy depleted node only at the next schedule when the node has to be recharged again. This would entirely affect the lifetime of the network because, by the time the Sencar would come for recharging, the node would have already been dead.

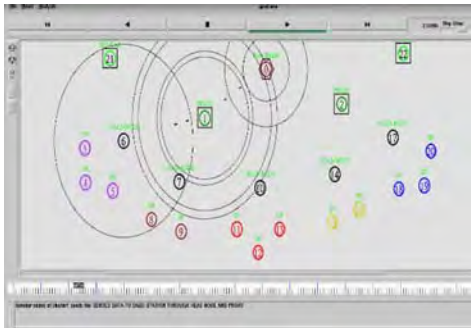
To overcome all these issues, the proposed system suggested the NDN approach to meet the energy requirement of the nodes as its energy falls below the threshold value. The reliability and the scalability of the network is increased. The lifetime of the network is enormously improved since the emergency situations are handled to some extent. The existing system’s scheduled recharge fashion is overcome to some extent by attending the energy depleted nodes at the time it requires for recharge by implementing a novel idea called NDN.

B. Simulation Results

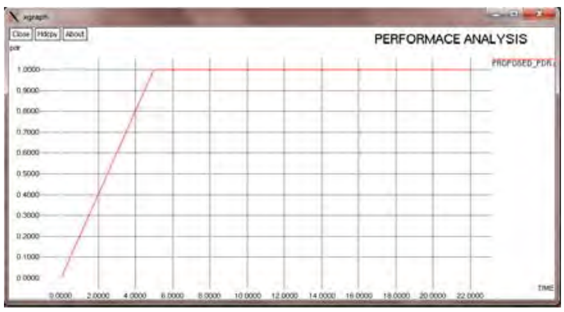
The above proposed system which suggested the implementation of NDN was simulated through Network Simulator-2 and the performance analysis was done.

The following are the few screenshots of the simulated WSN through Network Simulator-2, where the Sencars recharge the energy depleted nodes by NDN approach.

- Screenshots:

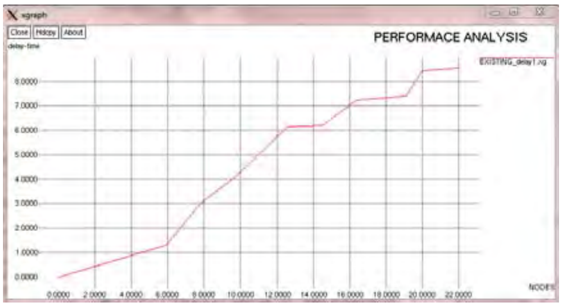


- Graph Analysis

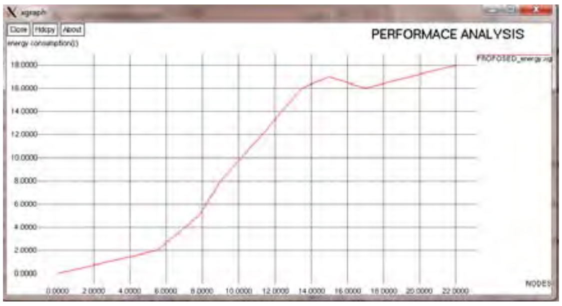


The above graph explains the packet delivery ratio of our system. The packet delivery ratio is estimated as 1.0b rate which is 95-100% packets are delivered with respect to time.

The above graph explains the throughput rate of our system. The throughput rate is estimated as 95 kbps with respect to time.



The above graph explains the delay time of our system, the delay time is estimated as 8.5 s with respect to nodes.



The above graph explains the energy consumption of our system, the energy consumed by nodes is 18 joules with respect to nodes density

The simulation was done only for a very small network setup with 23 nodes. The results showed the appropriate movement of Sencars from clusters to clusters meeting the requirement of energy depleted nodes increasing the life time of the network. The various graphs are shown above.

The recharging energy transmission rate was calculated as 95 to 100% with respect to time. The loss of energy during transmission was minimised. The throughput was increased and the delay time is reduced, whereas the energy consumption of the network was reasonable. These were general analysis that we would go for any sort of network to conclude that the functionality of a network is better.

The simulation was done by moving the Sencars from clusters to clusters, generating the interest messages, to which the head nodes responded as discussed in the paper. The requirements we proposed were met.

Few related research papers have analysed even the Sencars movement, the number of Sencars and the cost estimation factors etc. This paper proposed a new idea of NDN for Sencar recharge mechanism and analysed the performance of the network.

VIII CONCLUSION AND FUTURE WORKS

The paper totally relied on the recharge mechanism through NDN approach by Sencars. Cluster Head selection Protocols were analysed. Various algorithms like Shortest Path Algorithm and Minimum Weighted Sum Heuristic Algorithm to meet the emergency situations were also discussed. Named Data Networking concept was studied thoroughly and tried a better implementation in recharging the nodes of WSN.

Named Data Networking which is an emerging Internet Architecture has its significance in maintaining a better performing network setup. This would bang the network developments, one day with its own valid standards. This paper made an effort to bring out a small outline of NDN concept in recharge mechanism and succeeded as proposed.

In Future, the concept of NDN must spread its wings in all aspects of network. This paper has focussed only on recharging the energy depleted nodes by mobile Sencars. Efforts have to be taken to minimise the number of Sencars used and to make Sencars take decisions of its own dynamically. Also, we could suggest, when the most emergency situations are met, even the Cluster heads or the proxy nodes would have the mechanism to recharge the nodes. If any node is undergoing maximum transmission, losing its energy thereby, we could even suggest on the load distribution concept, thereby increasing the energy backup time at least prolonged for few more hours/days. The coordination among the Sencars that moves in the network is very important. Also the recharge capacity of the Sencars and its energy depletion factors has to be studied and worked on, in the future to develop an efficient WSN.

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