A Cluster based Multipath Routing Scheme for Power Efficiency in Wireless Sensor Networks

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Abstract - Wireless sensor networks consist of some nodes that have limited processing capability, small memory and low energy source. These nodes are deployed randomly and often densely in the environment. In monitoring applications, sensor nodes sense data from the environment periodically and then transmit them to a base station which is called sink node. Thereby data transmission consumes node's energy based on transmission distance. In most wireless sensor networks, the energy source of the node is limited and cannot be minimized. Here, we have proposed the cluster based multipath routing scheme for power efficiency for minimizing the power consumption in WSNs. It consists of three phases. These phases are the cluster topology and selection of cluster head, energy based multipath route and Power utilization procedure. The proposed scheme attains the balance between power efficiency, load balancing and network lifetime in WSNs. By simulation results, the proposed CMRP achieves better data delivery ratio, improved network lifetime, less end to delay and energy consumption in terms of mobility, time, throughput, packet interval and number of nodes than EEMCRP and FAF-EBRP.
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I. Introduction

A. Wireless Sensor Networks (WSNs)

Wireless sensor networks (WSN's) have attracted a great deal of research attention due to their wide-range of potential applications. Applications of WSN include battlefield surveillance, biological detection, medical monitoring, home security and inventory tracking. This type of network consists of a group of nodes and each node has limited battery power. There may be many possible routes available between two nodes over which data can flow. Assume that each node generated some information and this information needs to be delivered to a destination node. Any node in the network can easily transmit their data packet to a distance node, if it has enough battery power. If any node is far from its neighbour node then large amount of transmission energy is required to transmit the data to distance node. After every transmission, remaining energy of this node decreases and some a counts of data transmission this node will be eliminated from the network because of empty battery power and in similar situation there will be a condition that no node is available for data transmission and overall lifetime of network will decreases.

B. Design goals of Wireless Sensor Networks WSNs)

Based on the application, different architecture, goals and constraints have been considered for WSNs. As discussed in [1], the following design goals are given.

a. Energy Efficiency

Sensor network is normally deployed in unattended environment, and it is distributed in nature. With few of WSN application cases, its deployment is once and not be able to replace or monitor the nodes physically on regular basis, especially in the case of Military battle field and chemical industrial deployment. As sensor node is cost effective and less in size with very low computational and memory capability power along with its battery life, sensor node's life depends upon its battery. Most of the times as these nodes remain unattended and normally draining their batteries continuous on regular basis, it is too hard to replace these batteries. So energy is the most important constraint for the WSN type's networks. In last decade a significant amount of research has been done in the field of WSN, and most of the part was focusing about the energy concern. There are couple of different reasons for energy loss with the node including, un efficient routing, mixed traffic, run time change network topology, mobility, deployment of the nodes and distance from the sink. Dealing with real-time requires all the nodes live and in contact with the sink, if any node from the loop is just died just because of energy reason then the complete real-time communication will be dropped. Past recent work shows more attention on this critical issue and, about designing different energy efficient routing protocols with different energy efficient mechanism, but even, it still requires more significant attention.

b. Node deployment

Topology or node deployment is also a one reason to drain node energy of sensor network. Topology concept is entirely different from existing ad hoc networks, with sensor network it is not possible to follow any existing standard of topology, because this special characteristic network have very unique infrastructure. Topologies normally varies from application to application with sensor network, but even each topology is changeable at run time, as with sensor network connection path with sink established several times (when any active node dies, resulting of power drain) again and again to avoid that up to a certain limit, densely nodes network deployment is suggested. In this situation network topology also changes it status randomly, in all situations it affects routing activities.

Energy consumption without losing accuracy

Sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime. In a multihop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

c. Fault Tolerance

Fault tolerance can be defined as the ability of sensor

network to sustain network functionalities in case of any un desired conditions occurred and may be few nodes not working properly. Sensor nodes may fail or be blocked due to lack of power, have physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the sensor network. This is the reliability or fault tolerance issue.

II. Related Work

In this paper [1], it is investigated that how to secure route discovery of the Multicast Ad-hoc on Demand Distance Vector (MAODV) protocol for Sensor Networks. Compared to Ad hoc Networks, some secure routing protocols cannot be directly applied to energy constrained WSNs. In this research work, it was focused on secure route discovery of MAODV based on one way hash function. Here there is no signature generation proposed.

In this paper [2], authors presented an authentication scheme that uses public-key cryptographic scheme for authentication with an acceleration method for the signature verification in order to gain a high security level while preserving the limited resources in sensor networks. In this work, the distributed authentication model was proposed.

In this paper [3], a secure group communication scheme was proposed that allows sensor nodes belonging to the same group to communicate securely. It was composed of two main components: the group membership management and the group key management. First component defines in a secure manner the group creation, the group join and the group leave processes. The construction of a logical neighbor tree helps sharing the task of rekeying messages distribution among group members. This scheme eliminates the necessity of a powerful group controller and so that can fit resource-constrained sensor nodes.

In this paper [4], an efficient and secure geographical routing was presented against a series of attacks. This secure routing requires associative one-way hash function and security mechanism for security. It also makes use of the broadcast nature of wireless channel and forwards packets based on the opportunistic approach. Including this, one more routing metric is combined with this routing to defend against packet tempering and dropping incurred by the Sybil attack, wormhole attack, black hole attack, and so forth.

In this research work [5], it was given an overview of existing multicast protocols and investigate the performance of these protocols with respect to Qos metrics. The power multicast routing is also proposed and analysed with routing protocols.

Lee et.al [6] proposed a cluster-based energy-aware routing protocol without location information of the sensor nodes for sensor networks. In this protocol, the focus was placed on the fact that all sensor nodes do not necessarily know their own position. Moreover, to send information on their position every cluster construction phase may cause unnecessary overheads. However, it is desirable to send their information with their sensing data in order to construct optimal clusters. Therefore, the proposed protocol constructs clusters without inefficient sensor-node-broadcasts to notify the base station of the information of each sensor node. In addition, the proposed protocol changes the desirable number of cluster-heads when composing optimum clusters.

Ghosh et, al [7] presented a cluster based routing algorithm. This algorithm makes the best use of node with low number of cluster head know as super node. Here it divided the full region in four equal zones and the center area of the region is used to select for super node. Each zone is considered separately and the zone may be or not divided further that's depending upon the density of nodes in that zone and capability of the super node. This algorithm forms multilayer communication. The number of layer depends on the network current load and statistics.

In this paper [8], it is examined that the optimization of the lifetime and energy consumption of Wireless Sensor Networks (WSNs). These two competing objectives have a deep influence over the service qualification of networks and according to recent studies, cluster formation is an appropriate solution for their achievement. To transmit aggregated data to the Base Station (BS), logical nodes called Cluster Heads (CHs) are required to relay data from the fixed-range sensing nodes located in the ground to high altitude aircraft. This study investigates the Genetic Algorithm (GA) as a dynamic technique to find optimum states.

Golam et.al [9] developed a two layer hierarchical routing protocol called Cluster Based Hierarchical Routing Protocol (CBHRP). It is introduced a new concept called head-set, consists of one active cluster head and some other associate cluster heads within a cluster. The head-set members are responsible for control and management of the network.

S. Barani and Dr. C. Gomathy [10] introduced energy aware routing algorithm for wireless sensor networks. Protocol is based on fuzzy logic computation reduces power consumption by the ratio of 10 when compared to classical routing protocol. Proposed protocol is implemented in two phases, first phase being computation of neighbor node and updating of routing table and route establishment is done in second phase. Consumption of energy is considerably reduced on properly designed protocol.

Zhenhua Yu et.al [11] introduced the a knowledge-based inference approach using fuzzy Petri nets which is employed to select cluster heads and then the fuzzy reasoning mechanism is used to compute the degree of reliability in the route sprouting tree from cluster heads to the base station. Finally, the most reliable route among the cluster heads can be constructed. The algorithm is not only balanced the energy load of each node but also provided the global reliability for the whole network. The proposed algorithm effectively prolonged the network lifetime and reduces the energy consumption.

Yuping Dong et.al [12] proposed energy efficient routing algorithm for WSN. In this algorithm, they have divided the sensor nodes into several scheduling sets and let them work alternatively. In this way, the sensors do not have to be active all the time which saves a lot of energy. When choosing the next sensor to forward the information to, they considered both the distance from the base station to the sensor and its current energy level. So the network power consumption will be distributed among the sensors. When the network does not have enough sensors that have sufficient energy to run, it generates new scheduling sets automatically.

Sasmita Sahoo and Biswa Mohan Acharya [13] proposed the energy efficient routing protocol in Wireless Sensor Network. Routing is a serious issue in WSN due to the use of computationally-constrained and resource constrained micro-sensors. Once the sensor nodes are deployed replacement is not feasible. Hence, energy efficiency is a key design issue to improve the life span of the network. Since the network consists of low-cost nodes with limited battery power, it is a challenging task to design an efficient routing scheme that can offer good performance in energy efficiency, and long network lifetimes.

Imanishimwe Jean de Dieu et.al [14] explored a new energy efficient secure path algorithm for wireless sensor networks to ensure the secure sensed data in a balanced energy network backbone. The proposed algorithm overcomes the limitations caused by the symmetric cryptographic algorithms for securing data in sensor networks. They have achieved the authenticity and integrity on the actual sensed data within the energy efficient infrastructure. The key contribution is to ensure secure transmission which results prolonging network lifetime via a suboptimal energy-efficient and balancing routing algorithm.

In this paper [16], an energy-balanced routing method was proposed based on forward-aware factor (FAF-EBRM) is proposed in this paper. In this method, the next-hop node is selected according to the awareness of link weight and forward energy density. Including this, a spontaneous reconstruction mechanism for local topology is designed additionally. Nodes can vary transmission power according to the distance to its receiver. The sink node can broadcast message to all sensor nodes in the sensing field. The distance between the signal source and receiver can be computed based on the received signal strength. Regional central nodes are not selected at the beginning on the contrary.

The paper is organized as follows. The Section 1 describes introduction about WSNs, energy consumption and design goals of WSNs. Section 2 deals with the previous work which is related to the Power consumption models. Section 3 is devoted for the implementation of proposed algorithm. Section 4 describes the performance analysis and the last section concludes the work.

III. Implementation Of Proposed Algorithm

In this proposed protocol, there are three phases involved. Initially the cluster topology is discovered and cluster head will be chosen based on energy dissipation. Here Time Division Multiple Analysis and Gaussian Elimination algorithm are used to determine the eligibility of cluster head. In next phase, multipath routing is implemented in the cluster region to provide load balancing. In order to ensure the minimum energy consumption among the sensor nodes, power consumption model was developed. Based on simulation analysis, the proposed protocol achieves high performance in terms of QoS parameters.

A. Cluster topology discovery and selection of cluster head procedure

Steps for creating cluster topology and selecting cluster head:

1 A Time Division Multiple Access (TDMA) schedule is created by base station and advertise the message to all the sensor nodes.

2. All the sensor nodes broadcast a message to advertise its power consumption level and location to its neighbors.

Based on this information, each sensor node sets up a neighbour information table that records the power level and the positions of its neighbours and sends this table to its neighbours. It is repeated until the information of all the nodes in the network is sent to the bases station. In this step, all the nodes are cluster head nominators, and each node has a unique ID that is also included in the information table.

3. Once the node information is advertised, the base station runs the Gaussian algorithm and determines the number of rounds at which every node can be a cluster head, in order to maximize the network lifetime.

4. Process of election of cluster head is categorized in to two stages. In the first step of the cluster head election, the base station selects the nodes closest to itself to be the high stage cluster heads. If any direct advertisement message is not received by any node, it is considered to be low stage cluster heads.

5. The base station broadcasts the unique IDs of the newly selected cluster heads, and their cluster members and the nodes use this information to form and enter a cluster. Therefore, each sensor node has the awareness of the number of times that it can be a cluster head and the number of times that it cannot be a cluster head.

6. The lower stage cluster heads do not transmit directly to the base station. It uses the upper stage cluster heads as intermediate repeaters of their data.

7. Every cluster head generates a TDMA schedule and broadcasts this schedule to the nodes in its cluster, in order to inform each sensor node of the timeslot that it can transmit. Including this, the radio component of each node is allowed to be turned off at all time periods, except during its transmission time. Therefore, the energy dissipation of every individual sensor is considerably reduced.

8. Then, the data transmission resumes. The sensor nodes, based on the allocated transmission time, send the data concerning the sensed events to their cluster head. The transmission power of every node is adjusted according to the minimum level that should reach its next hop neighbour. In this way, both the interference with other transmissions and the energy dissipation are reduced.

9. Every lower stage cluster head aggregates the data and then transmits the compressed data to the upper stage cluster heads until the data reaches the base station. A round of data transmission has been completed, and the protocol continues from step 5 for the next round.

10. In case that there is a change in the network topology, due to either a change in a node position or in the total dissipation of a node residual energy, the Base station will use the Gaussian elimination algorithm and power consumption model to determine the appropriate cluster head election

11. The execution of the protocol is finished as soon as all the nodes in the network run out of power.

B. Energy based Multipath Routing

In the proposed multipath routing, primary three paths are used and the best path is chosen for transmission. The goal is to deliver data along this primary path. To recover from failure of this primary path, it is constructed and maintains a small number of alternative paths. Specifically, when the primary path is set up, the network also sets up multipath along which data is sent at a low-rate. This low-rate data represents the energy expended for maintaining multipath. The maintenance overhead is introduced in multipath routing to denote this energy. The low-rate data thus constitutes "propagate" on the alternate paths. As soon as a failure is detected on the primary path, nodes can quickly reinforce an alternate path without the need for network wide flooding to initiate discovery. However, there may be relatively rare occasions when the primary path and all alternate paths simultaneously fail. In that event, the source or sink must resort to network wide flooding of data to re-establish the multipath. One measure of the resilience of proposed protocol is how frequently there is a complete failure of the multipath.

The steps for achieving load distribution through the multipath routing is follows.

Step 1: Calculate the ℓ , a set of disjoint path from source to destination. The path is considered as a loop less path.

Step 2: Find the path χ from ℓ based on the bandwidth and (least hop) shortest path distance i.e.

$LB(p_m) = LB(p_k)$ and the distance $S_d(m) = S_d(l)$.

Step 3: If (Path failure occurs)

{

Choose the alternative backup path form the set ℓ {P_l, P_m, ……..P_n} with least hop distance. If the source is *l* and the destination *n*.

}

else

{

Stop the transfer of the data form source to destination.

}

Step 4:

Select the path from the maximum number of edge disjoint paths which satisfies the bandwidth and delay requirements

$LB(p_l) + LB(p_m) + \ldots\ldots LB(p_k) = LB_t(P_T)$

$PF(p_l) + PF(p_m) + \ldots\ldots PF(p_k) = PF_t(P_T)$

Step 5:

Establishing the multipath routing among all the mobile nodes in the network.

Step 6:

Achieving the load balancing to improve the throughput and network connectivity.

C. Power utilization Procedure

In wireless communication, the signal attenuation is not linear. In this model, it is considered as a wireless propagation model whereby the received signal power attenuates $d^{-\phi}$. Where d is the distance between transmitting antenna and receiving antenna. ϕ depends on the characteristics of communication medium. It is constant throughout the medium because the uniform medium we have chosen. The required power to support the wireless link at a specified data rate between node p and q is given by,

$$P_{p,q} = d_{p,q}^{\varphi} \quad (1)$$

Where $d_{p,q}$ denotes the distance between node p and q. If the transmitting power of p is greater than or equal to $d_{p,q}^{\varphi}$, node p can reach q suddenly. Each node can add or remove links by adjusting its transmitting power levels, hence the network topology totally depends on the transmitting range of each node. Let the cluster member nodes transmit data packets to cluster heads simultaneously. The required power is determined by

$$P_{broadcast} = \max(d_{r_1,a}^{\varphi}, d_{r_2,a}^{\varphi} \ldots\ldots d_{r_n,a}^{\varphi}) \quad (2)$$

The power required for a transmitting node to directly reach a set of destination nodes that is determined by the maximum required power to reach the farthest node, and other nodes essentially get the transmission for "free". The received signal from a transmitting node is combined in the sense that signals from those transmitting nodes arrive in phase at the receiving node with coordination. The condition for minimum power consumption for cooperative transmission is given by

$$P_{Coop} = \frac{1}{\sum_{p=1}^{n} \frac{1}{d_{a_p,r}^{\varphi}}} \quad (3)$$

The required power of each of the transmitting sensor node in cooperative transmission is given by,

$$P_r = \frac{d_{a_p,r}^{-\varphi}}{\sum_{q=1}^{k} \frac{1}{d_{a_q,r}^{\varphi}}} \times \frac{1}{\sum_{q=1}^{k} \frac{1}{d_{a_p,r}^{\varphi}}} \quad (4)$$

Step 1: Transmit power is recorded in the data packet by every node lying along the route from source to destination and it is forwarded to the next node.

Step 2: When the next node receives that data packet at power P_{recv}, it reads the transmit power P_{tx} from the packet, and recalculates the minimum required transmit power P_{min}, for the precursor node.

$$P_{min} = (P_{tx} - P_{recv}) + P_{mar} + P_{wast} \quad (5)$$

To overcome the problem of unstable links due to channel fluctuations, a margin P_{margin} is included. Because the transmit power is monitored packet by packet, in our work, we maintain a margin of 10dB.

Step 3: The recalculated minimum required transmission power, P_{min} is sent to the precursor node through acknowledgement (ACK) packet. This packet contains the source, destination id, transmission and reception power.

Step 4: This ACK packet is received by the precursor node, it records the modified transmit power in the power table and transmits the remaining packets with P_{min}.

Step 5: When a node cannot find a record in the power table for a particular node, which will be the case when two nodes never exchanged packet before, it transmits with default power level 300 db.

IV. Performance Analysis

We use Network Simulator (NS3) to simulate our proposed algorithm. Network Simulator-3 (NS3) is used in this work for simulation.NS2 is one of the best simulation tools available for Wireless sensor Networks. We can easily implement the designed protocols either by using the otcl coding or by writing the C++ Program. In either way, the tool helps to prove our theory analytically.

In our simulation, 250 mobile nodes move in a 1600 meter x 1600 meter square region for 60 seconds simulation time. All nodes have the same transmission range of 250 meters. Our simulation settings and parameters are summarized in table 1.

Table 1. Simulation Settings and parameters of CMRP

No. of Nodes	250
Area Size	1600 X 1600
Mac	802.11
Radio Range	250m
Simulation Time	60 sec
Traffic Source	CBR
Packet Size	512 bytes
Mobility Model	Random Way Point
Transmitter Amplifier	150 pJ/bit/m^2
Package rate	5 pkt/s
Protocol	AODV

Performance Metrics

We evaluate mainly the performance according to the following metrics.

End-to-end delay:

The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

Packet Delivery Ratio:

It is the ratio of packet received to packet sent successfully. This metric indicates both the loss ratio of the routing protocol and the effort required to receive data. In the ideal scenario the ratio should be equal to 1. If the ratio falls significantly below the ideal ratio, then it could be an indication of some faults in the protocol design. However, if the ratio is higher than the ideal ratio, then it is an indication that the sink receives a data packet more than once. It is not desirable because reception of duplicate packets consumes the network's valuable resources. The relative number of duplicates received by the sink is also important because based on that number the sink, can possibly take an appropriate action to reduce the redundancy.

Throughput:

It is defined as the number of packets received successfully.

The simulation results are presented in the next part. We compare our proposed algorithm CMRP with EEMCRP and FAF-EBRM in presence of energy consumption.

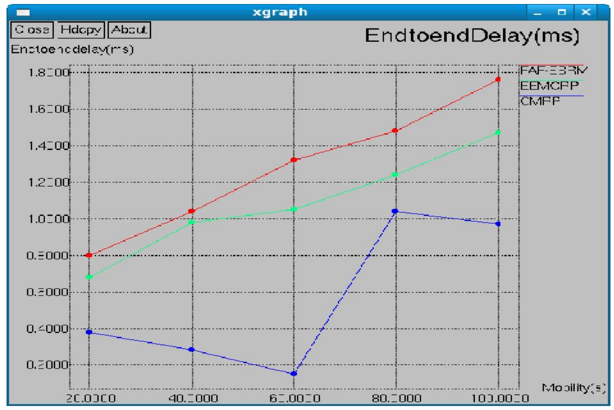

Fig. 1. Mobility Vs End to end Delay

Figure 1 shows the results of average end-to-end delay for varying the mobility from 20 to 100. From the results, we can see that CMRP scheme has slightly lower delay than our previous work EEMCRP and FAF-EBRM [16] scheme because of stable routing.

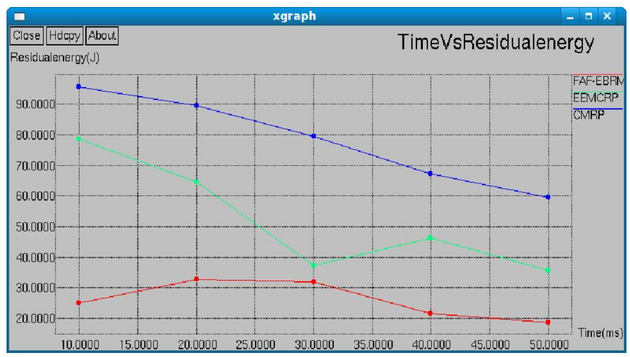

Fig. 2. Time Vs Residual Energy

Figure 2, presents the residual energy while varying the time. The Comparison of CMRP, FAF-EBRM and EEMCRP energy consumption is shown. It is clearly seen that energy consumed by CMRP is less compared to FAF-EBRM and EEMCRP.

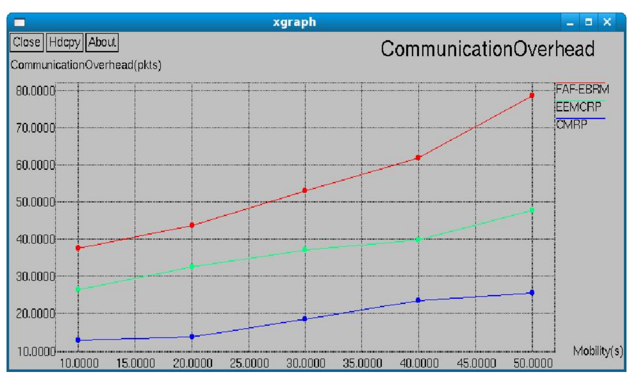

Fig. 3. Mobility Vs Communication Overhead

Fig. 3 presents the comparison of communication overhead. It is clearly shown that the overhead of

CMRP has low overhead than EEMCRP and FAF-EBRM scheme.

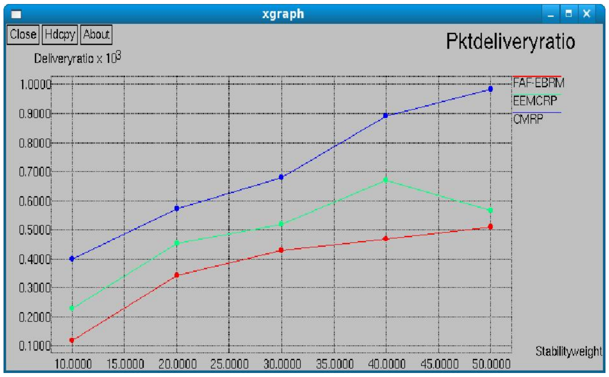

Fig. 4. Stability Vs Packet Delivery Ratio

Figure 4 shows the results of average packet delivery ratio for the stability weight 10, 20…50 for the 100 nodes scenario. Clearly our CMRP scheme achieves more delivery ratio than the EEMCRP and FAF-EBRM scheme since it has both reliability and stability features.

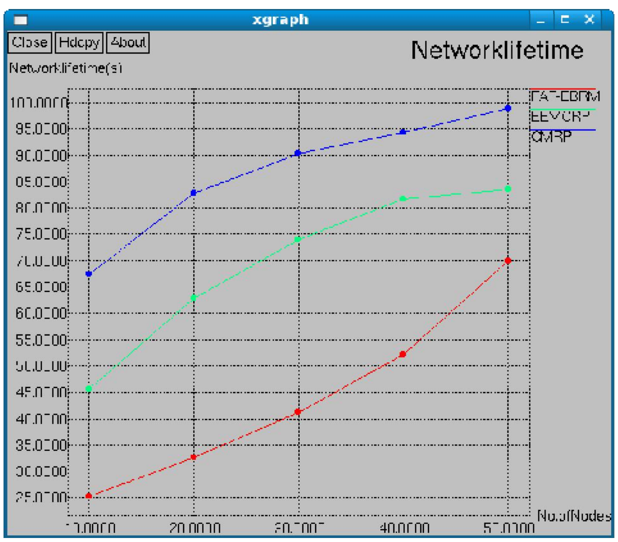

Fig.5. No.of Nodes Vs Network Lifetime

Figure 5 show the results of average network lifetime for the nodes from 10 to 50. Clearly our CMRP scheme achieves more network lifetime than the EEMCRP and FAF-EBRM scheme since it has more residual energy.

V. Conclusion

In this paper, we have developed a cluster based Multipath Routing Approach which attains load balancing and Power consumption model to make a balance between network life time, energy consumption and throughput, route redundancy, minimum cost to the sensor nodes. In the first phase of the scheme, cluster topology and selection of cluster head are proposed. In second phase, construction of multipath routing tree is implemented based on energy and path failure In third phase, average power consumption is minimized. It uses following factors minimum cost, route redundancy to favour packet forwarding and reduce the effect of node and link failures by maintaining high residual energy consumption for each node. We have demonstrated the node energy consumption of each node. By simulation results we have shown that the CMRP achieves good throughput, high network lifetime, low energy consumption, good delivery ratio while attaining low delay, energy consumption than the existing schemes EEMCRP and FAF-EBRP while varying the number of nodes, time, throughput and packet interval.

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