ENERGY EFFICIENT DISTRIBUTED MULTI-PARENT ROUTING FOR WIRELESS SENSOR NETWORKS

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Abstract

Increasing the lifetime of energy constraint Wireless Sensor Network (WSN) is one of most critical and challenging requirement. In this paper, an Energy Efficient Distributed Multi-Parent (EEDMP) heuristic routing algorithm is proposed to maximize the minimum lifetime of WSN and enhance its reliability. In EEDMP, WSN is considered as a broadcast tree routed to the base station where a sensor node has to select more than one of its neighbor nodes as next hop (parent) to forward the data and distributes its total load among them in such a way that the lifetime of the network is maximized. Each stage of algorithm is analyzed to show the stability of EEDMP routing. Simulation results show that the EEDMP routing algorithm is very stable, requires less routing overhead, gives high packet delivery ratio and provides lifetime of network near to optimum.

Keywords - Multi-Parent, Multi-Path, Distributed, Wireless Sensor Network, Energy Efficient Routing.

1 INTRODUCTION

A Wireless Sensor Networks (WSN) consist of a large number of small and low cost sensor nodes powered by small battery and equipped with various sensing devices. WSN are usually deployed in extreme conditions such as mountain regions, forest regions, disaster affected areas etc. and are left unattended to function for long time. The major constraint of WSN is that, the battery of sensor node cannot be charged or replaced, the lifetime of the WSN depends critically on the energy conservation mechanism, a survey of energy conservation in wireless sensor networks is given in [1][17]. It has been shown that transmitting one bit may consume as much power as in process of a few thousand instructions [6][15]. Therefore, trade off between power consumed in transmission by a node and power consumed in processing at a node can be made to conserve the energy of the node. The remaining energy of a node dictates the lifetime of the WSN. In order to prolong the network lifetime, it is necessary to minimize the consumption of energy by individual nodes. The precise definition of lifetime of wireless sensor networks (WSN) depends upon the applications [8].

In this paper, an Energy Efficient Distributed Multi-parent (EEDMP) reliable routing algorithm using multi-parent and multi-path is proposed to maximize the minimum lifetime of WSNs. In the EEDMP routing algorithm node distributes its total load (internal and external) among its parents by assigning weights to the parents depending upon the potentiality to bear the load.

The rest of the paper is organized as follows, Section 2 describe related wok, Section 3 explains proposed Energy Efficient Multi-parent Distributed (EEDMP) routing algorithm and in section 4, experimental results showing performance of EEDMP routing algorithm and it comparison with existing energy efficient algorithms are discussed. Section 5 contains conclusion and future scope.

2 RELATED WORK

Plenty of energy efficient routing protocols for WSN have already been proposed to prolong the lifetime of network. Most routing algorithms in sensor network focuses mainly on conserving battery power of nodes to enhance the lifetime of the network.
Heinzelman, et.al, 2000, proposed LEACH (Low-Energy, Adaptive Clustering Hierarchy) [7]. LEACH is a cluster-based protocol that utilizes data fusion and randomized rotation of cluster-heads to evenly distribute the energy among the sensors in the network. Hsu and Liang, 2005, extend LEACH stochastic cluster-head selection algorithm by a deterministic component to reduce energy consumption [9]. In LEACH, selection of cluster heads is completely stochastic, each node has the same probability to become cluster-head in each round even though the battery capacities in some nodes are very low. In, 2009, Matrouk and Landfeldt modifie LEACH by considering sensor residual energies directly on routing parameter decision [12]. Aslam M. et.al [19] focus on how these extended protocols work in order to increase the life time and how quality routing protocol are improved for WSNs, also they highlights some of the issues faced by LEACH and also explains how these issues are tackled by extended versions of LEACH.
MEAODV (Multi-path Energy Aware AODV) routing [2] is another cluster based energy efficient routing algorithm. MEAODV utilizes the topology of network and divides the network into one or more logical clusters, restricting the flooding of route request outside the cluster. The main limitation of cluster based routing is the time taken or amount of computation required for forming the cluster. The single path with minimum energy is selected but frequent use of single path overuse the energy of nodes in the path, thus it required selection of new routes after regular interval of time.
Most of the routing protocols are based on energy aware techniques. Some routing protocols tried to optimize network lifetime with the help of linear programming, in which objective function is to maximize the minimum lifetime of each node in WSN and they are described below.
J.H Chang and L. Tassiulas, (1999), [10] introduced first model of maximum system lifetime routing algorithm as a linear programming problem for single destination. They proposed Flow Redirection algorithm (FR) and Maximum Residual Energy Path (MREP) heuristic routing protocols. The FR is a redirection based algorithm where small amount of flow is redirected in such a way that the resulting flow to the destination will eventually have the same lifetime in all paths hence the minimum lifetime over all the nodes will increase. In MREP algorithm, the idea was to augment the flow on the path whose minimum residual energy after the flow augmentation will be longest. Simulation result of [10] is compared with Minimum Total Energy (MTE) [7]. MTE selects the path with minimum transmission energy consumption. Simulation result shows that FR and MREP routing algorithms are close to optimum. They also proposed Flow Augmentation algorithm (FA) for the multi commodity case [11]. FR and FA algorithms provide optimal flow rates based on knowledge of complete topology and packet generation rate at each node. To further extend the lifetime of network also considered energy consumption at the receivers. The main limitation of [10][11] is complexity in solving linear programming complex and it not appreciable in a resource constraint network.
Q. Li, j. Aslam, and D. Rus (2001) proposed two algorithm Max-Min zPmin and Zone Based Routing algorithms [13]. The max-min zPmin algorithm combines the benefits of selecting the path with the minimum power consumption and the path that maximize the minimal residual power in the nodes of the networks. This algorithm requires accurate power information of all the node at all the time, knowing accurate power information introduces processing complexity in resource constraint WSN. In zone based routing the network is divided into small number of zones. The optimal path for each message across the zone is determined and the best path among these optimal paths for the message within each zone is selected, proposed algorithm requires information about the power level of each node in the network.
C. Pandana and K. J. Ray Liu, (2005) [4] proposed Keep Connect (KC), Minimum Total Energy Keep Connect (MTE-KC) and Flow Augmentation-Keep Connect (FA-KC) algorithms. The KC algorithm finds the weight of node based on number of components are connected with this node. MTE-KC algorithm finds the minimum total energy path with edge cost e_{ij} .w(i), where e_{ij} is the energy required to guarantee successful transmission from node i to node j and w(i) is the weight of node i. In FA-KC the minimum total energy path using flow augmentation algorithm with w(i) is determined and if any node die then recomputed the remaining nodes weight and the energy efficient path using KC and FA algorithm respectively. The main limitation of these algorithms is if any node dies because of low battery power, then algorithm recomputed the remaining nodes weight and also recomputed the minimum total energy path and thus increases processing complexity.

Ok, et.al, (Aug 2009), have proposed Distributed Energy Balance Routing (DEBR) [5]. DEBR algorithm calculates the energy cost (EC) of all paths and selects a path having minimum EC for balancing the energy. EC defines as the ratio of energy required for transmission to available energy of the node. The idea is to select a path that will give minimum EC , either by transmitting data directly to the base station or forward it to any of its neighbors which will give the minimum EC. DEBR assume that one of its neighbors must send data to the base station. In DEBR every node calculates EC of its own and its neighbor after transmission of each data packet by any node to the base station and thus creates a large routing overhead. DEBR is computationally simple, heuristics and distributive but it suffers from large routing overhead due to frequent EC calculation which is undesirable for dense network and network with heavy data transmission.
Thanh Dinh Ngoc et.al proposed Congestion-aware energy-efficient routing in wireless sensor networks[18]. They suggest that congestion is one of the main factors to provoke energy consumption in constrained environments of WSN. [18] considers the congestion and energy levels of nodes together to increase the network lifetime while maintaining the network throughput.
In this paper an Energy Efficient Distributed Multi-parent (EEDMP) routing is proposed in which multipath for data forwarding are selected in round robin fashion such that lifetime is balanced among the nodes of that path. A modification is proposed to increase lifetime among nodes belonging to the same level by balancing the load among these nodes, instead of making lifetime equal for all nodes as considered in [7][9][10][11] [12].

3 ENERGY EFFICIENT DISTRIBUTED MULTIPARENT ROUTING ALGORITHM (EEDMP)

In EEDMP routing protocol, node selects multiple parents as its next hop and distributes its total load among its multiple parents in such way that their remaining energy or battery dies out nearly at the same time and hence maximizes the lifetime of the network. The topology and network model for EEDMP routing is described in subsection 3.1. The load distribution of a given node among the multiple parents depends upon the potentiality of the parents to bear the load. The potentiality of the parents is determined by its remaining energy and data flow through it. Multiple paths can provide more reliability and more load balancing in energy constraint WSN by distributing the load among them. To keep track of multiple routes, each sensor node maintains a small potential parent vector table (PPVT) along with the weight of the parents. This is explained in subsection 3.2.

3.1 Network Model of EEDMP routing

A WSN consists of *n* number of nodes distributed as a broadcast tree routed at the base station. The topology of wireless sensor network is static as shown in Fig.1. The neighboring distance is defined as distance from the node at which a packet can be successfully received. Each sensor node placed at level *l* forwards data packet to its neighboring node placed at level (l−1), where *l* is the level of the node from the base station starting from 0 to *h* (height of the tree). S_i is set of potential parents of node *i.* The various notation used for explaining the protocol and deriving the mathematical model are listed in Table I.
In EEDMP routing protocol, node selects multiple path by selecting multiple parents and thus try to minimize the difference of lifetime of nodes belonging to same level by the distributing the flow among them. The various definitions of lifetime used in model are defined as follows

Definition 3.1: The *Lifetime* of node L_i is defined as the time until the battery of the node *i* is drained out. The lifetime of a node *i* depend upon its residual energy E_i and the total packets forwarded by node *i,* (f_i is the number of packet generated by node *i* and packets given by its neighbors). Lifetime of a node in terms of E_i and f_i can be expressed as

$$L_i = \frac{E_i}{e * f_i} \quad ,\forall i : i \in n \quad (1)$$

Where *e* is the amount of energy consumed in transmitting a packet and $E_i \geq e^*f_i$.

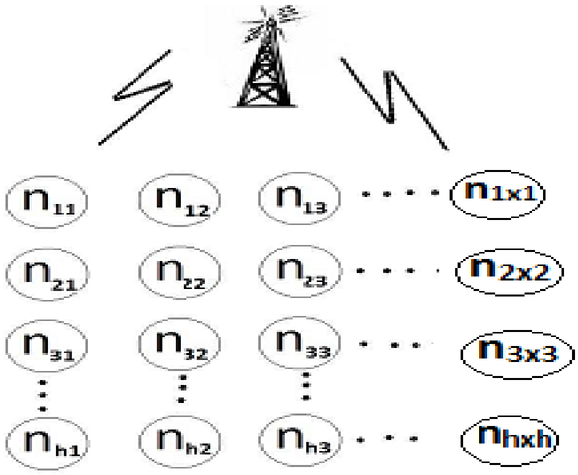

Fig.1. An Example Network

TABLE- I Notation

L	Lifetime of Network
L_i	Lifetime of a node *i*
L^l	Lifetime of Level *l*
S_i	Set of potential parents of node *i*
n	Number of nodes in the network
λ_i	Packet generating rate at node *i*
R_i	Packet receiving rate at node *i*
f_i	Packet forwarding rate ($f_i = \lambda_i + R_i$)
P^l	Total load at level *l*
F	Total load of network ($F = \sum_{i=1}^{n} f_i$)
H	Height of the tree
E_i	Residual energy of node *i*
n_{hxh}	xh^{th} node in h^{th} level

Definition 3.2: The *Lifetime of Level* L^l is defined as minimum time until battery of any node at level *l* is drained out. Lifetime of a level *l* in terms of L_i can be expressed as

$$L^l = \min (L_i) \qquad , \forall i : i \in l \qquad (2)$$

Definition 3.3: The *Lifetime of Network L* is defined as the time until battery of any node in the network is drained out. It can be written in terms of lifetime of nodes *i* in the network

$$L = \min(L_i) \quad ,\forall i : i \in n \tag{3}$$

or, in terms of lifetime of all the levels *l* in the network

$$L = \min(L^l) \quad ,\forall l : l \le h \tag{4}$$

Following definition provides the sufficient conditions to maximize *L* in terms of lifetime of individual nodes.

Definition 3.4: For a given λ_i, and E_i the lifetime of the network is maximum when the lifetime of nodes L_i are equal for all nodes.

Definition 3.4 ensures the maximum lifetime of the network but it is practically not achievable, as it is not possible all the time to adjust f_i in such a manner so that the lifetime of all the nodes becomes equal. The nodes at lower level or near base station will have higher f_i because they have to carry the accumulative flows coming from the higher layers. Also node at level *l* can forward data only to the nodes located at level (*l* – 1). Therefore the load distribution is only possible between the nodes at the same level.
In order to maximize the *L*, some criterion is needed in addition to definition 3.4 which is sufficient and feasible to achieve for a given network. Following definition provides another sufficient condition to maximize *L* in terms of lifetime of individual levels.

Definition 3.5 For a given λ_i and E_i the lifetime of the network is maximum when the lifetime of each level is maximized. The lifetime of each level can be maximized when lifetime of all the nodes belonging to same level are same.
Let P^l is the total load at level *l* i.e. summation of f_i at level *l*, then

$$P^l = P^{(l+1)} + \sum_{i=1}^{xl} \lambda_{l,i} \tag{5}$$

$$= \sum_{l=1}^{h} \sum_{i=1}^{xl} l * \lambda_i$$

So, P^l is the summation of λ_i for all the nodes up to that level and is constant. The P^l does not depend upon flow distribution among the nodes above level *l*. So, for given λ_i, distribution P^l is constant and therefore by the definition 3.4 the lifetime of a level will be maximized when lifetimes of all the nodes belonging to a level are same. The lifetime of network can be maximized when lifetime of all the levels are maximized. Note that maximizing the lifetime of a level does not affect the lifetime of other levels because the total load at a given level *l* is always constant.
To maximize the lifetime of network, definition 3.5 allows to individually maximizing the lifetime of each level by making lifetime equal for all nodes belonging to that level. Since from equation(4), it is not useful to further maximize the lifetime of any level *l* if L^l is not minimum among all the levels. In this case increasing the lifetime of level *l* will not affect the lifetime of the network. Hence preference is given to level which will give minimum L^l among all the levels.
In the presence of above mentioned constraints it is only possible to maximize the lifetime of the network up to a certain value. Let $(L_i - L_j)$ is the difference of lifetimes of two nodes *i* and *j* in a level. Thus objective is to minimize this difference in all the levels.

$$max(L)=min(L_i^{\,l} - L_j^{\,l}) \;,\; \forall\, i,j: i,j \in n \text{ and } l \leq h \qquad (6)$$

The above maximization problem can be considered as Linear Programming Problem (LPP) along with the constraint given above. Although running an algorithm to solve LPP is not feasible for resource constraint wireless sensor nodes. Following section discusses the developed algorithm to maximize the lifetime of network by distributing the load among the nodes of a level based on their current lifetimes.

3.2 Description of Energy Efficient Distributed Multi-parent routing (EEDMP)

The proposed multi-parent algorithm tries to maximize network lifetime by minimizing equation (6). This is achieved by distributing flow from a node among all of its potential parents. The two main data structures used in EEDMP routing are one hop advertised message (ADV) and potential parent vector table (PPVT).

ADV message will contain lifetime of node *i* (ADV_{Li}) , level or depth of node *i* (ADV_{Di}) and node address $(ADV_{nodeIDi})$. Each node *i* broadcast one hop path length advertisement message (*ADV*) to its entire neighbors in a periodic manner. The periodicity of the *ADV* message can vary as per the energy requirement of the application. The idea of broadcasting lifetime by using *ADV* message is to declare its potentiality to bear an external load.

In wireless sensor network all the data packets are forwarded to the base station therefore developed routing protocol maintains the depth of the node (N_D) in terms of minimum hop path length. The different functions performed by a node with current depth (N_D) on receipt of ADV message with depth (ADV_D) by its neighbor are

(i) If $N_D = 0$ then it means N_D is not defined. Set N_D equal to ($ADV_D + 1$) where ADV_D is the depth of node from which first *ADV* message received.

(ii) If $(ADV_D) > (N_D - 1)$ then node simply drops the *ADV* message to avoid longer paths to the base stations and hence save the energy per packet transmission by intermediate node

(iii) If $(ADV_D) < (N_D - 1)$ then there exist a path of lesser hop path length to the base station in comparison to the path which is currently set by the node. The new depth (N_D) of the node will be set to $(ADV_D + 1)$. The reason of removing all previous entries is to ensure the smallest hop path length towards the base station.

(iv) $(ADV_D) = (N_D - 1)$ then it means received ADV message is from the node having same depth as the currently defined parent's depth. Search the entry corresponding to receive ADV message in the PPVT (using function *PPVT.Find)*. If entry is found then update the entry else insert new entry in PPVT. Hence multiple parents are registered to a node for forwarding data packets.

Each node also maintains the information related to its potential parents in PPVT as a circular linked list with their respective weights normalized between 0 and 1. PPVT contain lifetime of parents' $(PPVT_L)$, depth of parents' $(PPVT_D)$, parents' address $(PPVT_{nodeID})$ and parents' weights to bear the load $(PPVT_w)$. The PPVT table contains the list of only those parents having equal $PPVT_D$.

EEDMP routing keeps track of a node which will give the minimum lifetime of a network in a level for all the levels, variable *netLT* is used in algorithm to track the minimum lifetime of network. On receipt of ADV message by a node, node compares ADV_L with *netLT*, if *netLT* is greater than to ADV_L the variable *netLT* set its value equal to ADV_L.

A node assigns weight to each of its parents placed at same level based on current lifetimes of all the parents. The weight for a parent is defined as the fraction of total incoming data flow at node forwarded in the direction of the parents. These weights are used to distribute total load flowing from a node among its potential parents according to their remaining energy (E_i) and the number of packets flow from it (f_i). The summation of weight of all parents is equal to one. On receipt of *ADV* message from the parents, weights of parents are adjusted according to the new *ADV* message. This weight adjustment is done for all the nodes for reception of each *ADV* message ensuring the summation of weights of all parents always remains equal to one $(\sum w_i = 1, \forall i : i \in S_i)$ where S_i is set of potential parents of ***i*.**

The above method of re-balancing the load among potential parents balances the lifetime of all the parents and ultimately stable to a value where the difference between the lifetimes becomes minimal. To enhance lifetime of a network it is required to adjust the difference of lifetime among all nodes in a level. This can be achieved by distributing the flow among them. Distribution of flow among nodes in a level is done according to the weights assigned to them. This desirable minimization of difference is as small as possible

The algorithm is converged if the difference in new weight and previous weight of all the potential parents is minimizing to a very small value ε instead of zero. If the difference is less than a defined value ε, indicates that the weight of the parents is already balanced up to the desired level and no further readjustment of weight is needed. The value of ε depends upon the network lifetime requirement and sensor node battery capability. The difference between the weight of a node, ε, is calculated as follows.

$$difference = \sqrt{\sum_{i \in S_i} (W_{i_{new}} - W_{i_{old}})^2} \qquad (7)$$

Variable $minLT_l$ is used in the algorithm to define the minimum lifetime of a node in a level. This $minLT_l$ is determined for all the levels. Since it is not useful to further maximize the lifetime of any level L^l, if L^l is not minimum among all the levels (i.e $minLT_l$ is greater than $netLT$). In this case increasing the lifetime of level L^l will not affect the lifetime of the network *L.* Consider only those levels which will give minimum L^l among all the levels.

4 SIMULATION RESULT

In this section, experimental results are provided to validate the effectiveness of EEMDP routing. EEDMP routing is also simulated in Qualnet 5.0.2 over IEEE 802.15.4 MAC/PHY module. The performance of EEDMP routing is compared with two existing routing algorithm standard MANET AODV routing [3] and MEAODV (Multi-path Energy Aware AODV routing) [2]. Three performance metrics are used to evaluate EEDMP routing (i) routing overhead and (ii) remaining energy of nodes (iii) packet delivery ratio. Qualnet simulation setup is given Table II. The simulation is carried out for different values of K

Table – II : Qualnet Simulation Setup

Parameter	Default value
Network Area	50 X 50 m square
Number of sensor nodes	50
Transmitting Range	10 meter
Remote Site	1 Base Station
Mobility	none
Network Setup time	15 seconds
Simulation Duration	500 seconds
Application type	256 byte CBR(Constant bit rate)
Queue type	Drop tail
Queue length	10 packets
Data rate of node	1 Kbps
Receiver & Transmitter power	0.3m W
Destination node	Base station
Propagation Model	Two ray ground

4.1 Routing overhead

The total number of packets transmitting during initialization and route discovery phase in the routing process is defined as the routing overhead. In MEAODV and AODV routing there is always some routing overhead during route discovery process. Therefore comparison is done until EEDMP achieve stability. Fig.2 compares the routing overhead of AODV, MEAODV and EEDMP. It is observed that as the number of nodes increases in the network routing overhead also increases. In EEDMP routing this is due to large number of parents participate to distribute the load. Another observation in EEDMP routing is when k = 0.5 then the routing overhead is more, this is because the balancing done by one node is destructed by the another node therefore it is highly recommended to use small value of K even though it requires more time to balance the load.

4.2 Remaining Node Energy

Energy consumption is defined as the amount of energy consumed by MICAZ mote devices during the periods of transmitting and receiving the packets. The unit of energy consumption used in the simulation is m Joule. The remaining node energy is the amount of energy of all sensors at the end of simulation. Fig.3 shows that EEDMP has distributed load over the entire sensor node in a more balanced way thus remaining energy of all the node is uniform whereas the load distribution is non-uniform in MEAODV and AODV routing(as noted in node 5 and node 7). Experimental results shows that all the sensor nodes in a level die nearly at the same time, thus improves the lifetime of the network.

4.3 Packet Delivery ratio

The ratio of data packets delivered to the base station and the data packets generated by the CBR sources are taken as packet delivery ratio(PDR). If packet delivery ratio is more than retransmission probability is less hence maximize the lifetime of the network. Fig. 4 shows that EEDMP routing delivers above 90% of the packet to the base station. In EEDMP routing PDR is more due to less congestion by distributing load among its multiple parents.

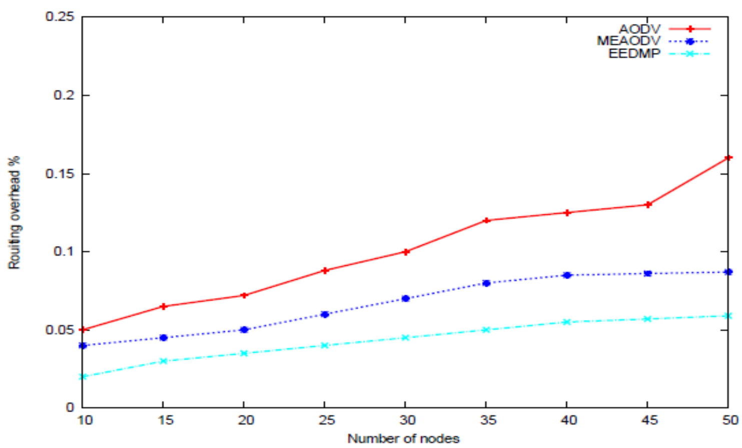

Fig.2. Percentage of routing overhead for different numbers of nodes

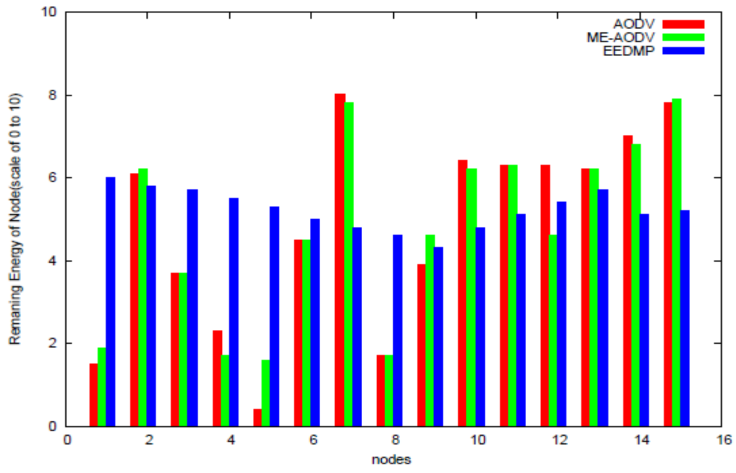

Fig.3. Remaining Node Energy

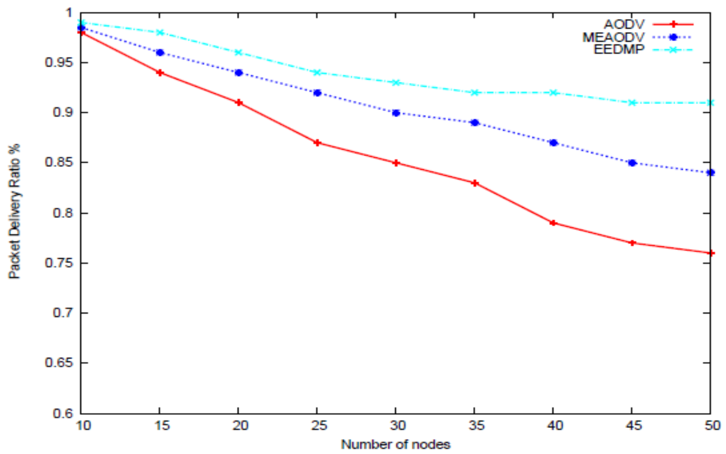

Fig 4. Percentage of packet delivery ratio for different numbers of nodes

5 CONCLUSION & FUTURE WORK

Increasing the lifetime of WSN is a challenging requirement. In this paper an Energy Efficient Distributed Multi-Parent routing algorithm (EEDMP) is proposed to maximize the lifetime of WSN by distributing the load among multiple parents of the node. It is observed that the maximum lifetime of the network can be achieved, if the lifetimes of all nodes are equal. Most of time, it is not feasible to have equal lifetime of all nodes in a network, hence the developed multi-parent algorithm tries to maximize the lifetime of the network by minimizing the difference between the lifetime of nodes in a level. The developed heuristic routing algorithm is distributed and iterative. After few iterations the weights of parents tends to get stable to the point where the lifetime of the network is maximum. Experimental results show that the EEDMP routing algorithm having less routing overhead and more packet delivery ratio than in comparison to existing energy efficient routing algorithm like AODV and MEAODV.

The EEDMP routing algorithm is for static network, where sensor nodes are not mobile. To use EEDMP routing for mobile nodes it is required to consider additional parameters like dynamic topology, mobility speed etc. In future EEDMP routing algorithm can be modified to cater the need of mobile wireless sensor network.

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