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Energy Efficient Broadcasting and Forward Node Selection Using Network Coding In Mobile Wireless Sensor Networks (MWSN)

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Abstract

In mobile wireless sensor networks (MWSN), broadcasting and forward node selection scheme may result in redundancy, collision, congestion, performance degradation, broadcast storm problem and so on. In order to overcome these issues, in this paper, we propose an energy efficient broadcasting and forward node selection using network coding in (MWSN). In this technique, the number of nodes involved in broadcasting operation is reduced by eliminating the nodes using minimum connected dominating set algorithm. Then the rebroadcast redundancy is minimized by selecting the forwarders using fuzzy logic based on the parameters such as delay, residual energy and distance. To minimize rebroadcasts, each node rebroadcast only when its coverage degree is above a threshold value. By simulation results, we show that the proposed technique minimizes the energy consumption and redundancy.

Keywords: Mobile wireless sensor networks (MWSN),

Introduction

Mobile Wireless Sensor Networks

A mobile wireless sensor network is comprised of tiny sensor nodes with three basic components: a sensing subsystem to enable data acquisition from the physical surroundings, a processing subsystem to enable local data processing and storage, a wireless communication subsystem allowing data transmission. The sensor nodes are either equipped with mobilizers, springs and wheels or attached to transporters such as vehicles, animals, robots etc to ensure mobility of these nodes. The path breakage occurs often due to node movement raising the need of mobility in wireless sensor network.

A mobile node's frequent location updates results in excessive drain of sensor node's battery supply and raises collisions. Also the sensor network life relies on energy supply. Hence energy efficient routing protocol is required [1].

Broadcasting and Forward Node Selection In MWSN

Broadcasting, a fundamental communication operation is the process of sending a message from a node to all other nodes in the network. Several ad hoc network protocols accept broadcasting as a basic mechanism. Broadcasting was deployed in many routing protocols as in ad hoc on-demand routing protocols in their route discovery phase. Broadcasting is utilized for topology updates, network maintenance, for reliable multicast in fast moving MANETs or just to send a control or warning message.

Efficient broadcasting in a MANET chooses a small forward node set by simultaneously ensuring broadcast coverage. Broadcasting enables each node to decide its forwarding status according to given neighborhood information, and the respective broadcast protocol is called self-pruning. Broadcasting adopts its simpler form in flooding where each node broadcasts the message on its first time reception of it. With full network coverage guarantee, flooding assures transmitting broadcast packet to every node in the network and provide static and connected network. MAC layer of the communication channel is error-free while broadcasting. Flooding enable each node to receive the message from all its neighbors in a collision-free network. Blind flooding enables each node to forward the packets exactly once [2, 3, 4].

In general, efficient broadcasting requires constructing a network backbone to avoid the broadcast storm problem due to simple blind flooding; in which only selected nodes namely forwarding nodes forms the virtual backbone, forward data to the entire network. The forwarding node set for broadcasting in MANETs are generally chosen a localized manner so as to enable each node to determines its own status of forwarding or non forwarding based on local information or the status of a node is designated by its neighbors. A smaller-sized forwarding node set is believed as more efficient because of the limited transmissions in the network, so as to alleviate interference and conservation of energy. Hence the total number of transmission sectors of the forwarding nodes in the network is reduced so as to reduce interference and energy consumption [7].

Flooding as well as blind flooding generates many redundant transmissions which increase on increasing average number of neighbors. Higher broadcast leads to high power and bandwidth consumption in the network. Also it raises packet collisions, resulting in additional transmissions. As a result, severe network congestion or significant performance degradation, namely the broadcast storm problem occurs [2, 3]. Furthermore, the existing static network broadcast schemes has poor performance in terms of delivery ratio while nodes are mobile. Message delivery failure is due to collision and mobility of nodes [3, 5].

Problem Identification

There are many works on broadcasting selection based on forward node selection can be done in many works as [2], [6], [7], [8], [9] etc. However there are many drawbacks in these existing works as decreased delivery ratio [2] [7], less forwarding ratio [4] [9], reduced rebroadcast ratio [10], increased delay [8] [11] and packet loss [12] etc. In general broadcasting and forward node selection scheme faces issues like increased redundancy, collision, congestion, performance degradation, broadcast storm problem etc.

Hence our objective is to develop a broadcasting and forward node selection in mobile wireless sensor networks with minimized redundancy, higher delivery ratio, high forwarding ratio, high rebroadcast ratio, reduced delay and packet loss. In addition the scheme should be free from collision, congestion, broadcast storm problem etc.

To accomplish the above objective, a broadcasting algorithm was deployed by minimizing rebroadcast redundancy [10]. In general the forward nodes rebroadcasts but when hearing this rebroadcasts, neighbor nodes starts to rebroadcast called as induced forwarders. To reduce the induced forwarders, we set it as 2 by choosing only the nearby nodes satisfying residual energy. Redundant rebroadcast can be further reduced by tracking its coverage degree which determines the node's rebroadcast efficiency. The lifetime of WSN can be maximized by reducing redundant rebroadcast and balancing energy consumption by utilizing node's self delay.

However there will be still redundancy and increased energy consumption.

Literature Review

Majid Khabbazian and Vijay K. Bhargava [2] proposed a forwarding node selection algorithm with fewer broadcasts in the network and an efficient receiver-based algorithm. The constant approximation to the optimal solution (minimum CDS) can be assured by 2-hop-based receiver-based algorithm. However the average delivery ratio was decreased.

Marimuthu Murugesan and Ammasai Krishnan [4] proposed a reliable and efficient broadcasting algorithm using minimized forward node list algorithm using 2-hop neighborhood information for reducing redundant transmissions in asymmetric Mobile Ad hoc networks which assure full delivery. However it has low forwarding ratio.

Jailani Kadir et al [6] proposed a probability based node selection method to detect the intermediate node with optimum stored energy throughout the connection duration. Thereby the highest probability node consumes the lowest energy. This can reduce interruption as well as enhance the network lifetime due to the lowest possible consumption of energy for a given communication.

Anchal Garg and Mohit Garg [7] proposed a scheme using a directional antenna to forward chosen locally need to transmit broadcast messages, only to the restricted sectors, so as to enhance the increased performance on transmit and receive and interference from unwanted sources. The directional antenna usage was combined with network coding based broadcasting which could support each forwarding node to combine some of the messages it receives before transmission. This could minimize the number of transmissions of each forwarding node in the message broadcast application. However delivery ratio was decreased on increased node movement.

Naixue Xiong et al [8] proposed an Efficient Minimum CDS algorithm (EMCDS) using an ordered sequence list without considering itself with node energy resulting in sometimes failure of broadcast operations if relay nodes are out of energy. Then a Minimum Energy-consumption Broadcast Scheme (MEBS) with a modified version of EMCDS was proposed to provide an efficient scheduling scheme with maximized network lifetime. However there is a possibility of link failure or delay.

M.Murugesan and A.Krishnan [9] proposed a localized forward node list selection algorithm with 2-hop neighborhood information in directed graphs with different transmission range for each node. A set of nodes were only chosen among the nodes within the sender's transmission range, to retransmit the broadcast message. However, forward ratio got decreased with increasing number of nodes.

Ruiqin Zhao et al [10] proposed a broadcast algorithm with least redundancy (BALR) for WSN establishing a weighted sum model with detection of the optimized number of induce forwarders as 2 and by considering rebroadcast efficiency and residual energy as a new metric for self delay computing of nodes before rebroadcasting. However rebroadcast ratio of BALR decreases with increasing node density.

Wei Lou and Jie Wu [11] proposed a simple broadcast algorithm namely double-covered broadcast (DCB) utilizing broadcast redundancy so as to enhance the delivery ratio in high transmission error rate environment. Few chosen forwarding nodes only retransmit the message among the 1-hop neighbors of the sender. Here forwarding nodes were chosen so that it covered the sender's 2-hop neighbors are covered and at least two forwarding neighbors cover the sender's 1-hop neighbors are either forwarding nodes or non forwarding nodes. The sender receives the retransmissions of the forwarding nodes as the packet reception confirmation. However delay was increased.

Basavaraj S.Mathapati and Dr.V.D.Mytri [12] proposed an Adaptive Energy Efficient Forwarding Protocol (AEEFP) to reduce the energy consumption with high reliability. The data forwarding probability was adaptively determined according to the measured loss conditions. The network lifetime was maximized by reducing energy consumption. However packet loss was increased.

Proposed Solution

Overview

In this paper, we propose to design an energy efficient broadcasting algorithm based on network coding. Network coding allows the intermediate nodes to combine packets before forwarding. Hence it can be used for efficient broadcasting by reducing the total number of transmissions. In this algorithm, the number of nodes involved in broadcasting operation is reduced by eliminating the nodes using Minimum

Connected Dominating Set (MCDS) algorithm. Then the rebroadcast redundancy is minimized by selecting the forwarders using Fuzzy logic. Fuzzy logic takes the input parameters delay, residual energy and distance and gives the forward node selection probability as output. To minimize rebroadcasts, each node rebroadcast only when its coverage degree is above a threshold value.

Estimation of Metrics

Node Delay

The node delay is estimated using the following equation (1)

$$\delta(i) = \delta_{\max}(w_1.\frac{d(i,t)}{r} + w_2\frac{[E_{\max} - e(i,t)]}{E_{\max} - E_{th}}) \quad (1)$$

where $\delta_{\max}$ = maximum allowed delay

d (i, t) = distance from node N_i to the nearer ideal location at time t

E_{max} = initial maximum energy of each node

E_{th} = threshold value of energy that helps in preventing node expiry with little energy level

w_1 and w_2 are the relative weights values of significant location and residual energy of the node respectively.

i.e. $w_1 + w_2 = 1$, $0 \leq w_1 \leq 1$, $0 \leq w_2 \leq 1$

Residual Energy

The total energy spent by the transmitter for transmitting x bits message through distance d is given using Eq. (2)

$$E_{tx} = E_e.x + E_a.x.d^2 \quad (2)$$

where E_e = electronics energy

E_a = amplifier energy

The total energy consumed by the receiver is given using Eq. (3)

$$E_{rx} = E_e.x \quad (3)$$

The residual energy of each node (E_{res}) following one data communication is estimated using Eq (4) [10]

$$E_{res} = [E_i - (E_{tx} + E_{rx})] \quad (4)$$

where E_i = initial energy of the node

Distance

The distance between two nodes can be estimated as follows

$$d = \begin{cases} r, & 0 \leq \tau < z^2 \\ z\sqrt{\frac{r^2}{\tau}}, & z^2 \leq \tau \end{cases} \quad (5)$$

where τ = node density.

r = region

$\sqrt{\frac{r^2}{\tau}}$, = smallest distance between two neighbor nodes.

z = constant

Note: The node density τ is defined as the average number of nodes per region of $r \times r$.

Energy Efficient Broadcasting Using Network Coding

Network coding allows the intermediate nodes to combine packets before forwarding. Hence it can be used for efficient broadcasting by reducing the total number of transmissions. In this algorithm, the number of nodes involved in broadcasting operation is reduced by eliminating the nodes using Minimum Connected Dominating Set (MCDS) algorithm. The steps involved in this algorithm are as follows.

Let the C = {V, E} be the wireless sensor network

where V = set of sensor nodes,

E = set of edges among the nodes

Let Source $S \in V$

Let L = L_0, L_1, $L_2 \ldots L_n$ are layers of the node.

Let X be the layer list for nodes according to their distance to the source.

Let Y be the ordered sequence list.

Let Z be the set for the maximal independent set.

Let M be the list of children for N_i.

Let H_i be the list of parent nodes for N_i.

Let MA be the marked status of the node

Let UM denote the unmarked status i.e. the nodes are initialized with this status in general.

Let IN be the independent status of the node where the node is included as a member of the independent set.

Let CO be the covered status where the node is connected to the node in the independent set.

Let CD be the connected dominating set

Let CN and UC be the connected and unconnected status

1. Once the nodes are deployed in the network, a breadth first search algorithm is applied with S as the root.
2. Based on the distance of the node from S, the node layer is obtained.
3. S is located in layer L_0 and sequence of nodes in increasing order of the layer is updated in node list X.
4. The nodes from L_0 to L_n are verified and order in decreasing order of the node degree and stored in the list Y. The nodes in the lists are assigned with different status as follows:
   - All the nodes in Y is assigned with UM status.
   - S is assigned with IN status and added into list Z.
   - All the neighbor nodes of S is set with status CO.

Note: The nodes in the network are sequenced with prior information which is a combination of the layer and node degree.

1. For each node N_i in X and Y,
   If status of N_i = UM
   Then
   UM is changed to IN and added into Z
   End if
   If the initial value of N_i = UM
   Then
   Neighbors of N_i is changed to CO
   Neighbor nodes are added to M
   End if
2. After all nodes in the network are marked, the final maximum independent set is obtained as list Z.
3. For each $N_i \in Y$, $N_j \in Y$ is visited as per the prior information of node degree and layer (as per step 4). N_j is added to H_i, if N_j is adjacent to N_i and nearer to S in the similar layer.
4. All the nodes in Z is inserted into CD in the same order as mentioned in previous step. Here,
   - S is set as CN
   - Remaining nodes are set as UC
5. For each $N_i \in Y$ except S,
   If status of N_i = UC
   Then
   UC is changed to CN and H_i is verified as follows
   If $N_j \in H_i \cap CD$,
   Then
   N_j is selected as the connect node N_i
   N_i is added into M_j
   Else
   First node N_{1st} in H_i is selected as the connected node
   N_i is added into M_{1st}.
   End if
6. If state of all nodes in Z is CN, then all the leaf nodes are removed from the tree of set CD. Otherwise, repeat step 9. The status of all nodes in CD is set as UM.
7. For each $N_i \in CD$ excluding S,
   If status of N_i = UM
   Then
   UM is changed to MA
   If there are some parent node in same layer of N_j,
   Then
   N_i is removed from the CD.
   M_i is updated.
   End if

Fuzzy Based Forward Node Selection

The forward nodes (FN) are selected using fuzzy logic technique. The parameters delay, residual energy and distance are taken as input for the fuzzy membership functions and based on the fuzzy rules, the forward node selection probability (P_{FN}) is estimated as output.

The steps that determine the fuzzy rule based interference are as follows.

- **Fuzzification:** This involves obtaining the crisp inputs from the selected input variables and estimating the degree to which the inputs belong to each of the suitable fuzzy set.
- **Rule Evaluation:** The fuzzified inputs are taken and applied to the antecedents of the fuzzy rules. It is then applied to the consequent membership function.
- **Aggregation of the rule outputs:** This involves merging of the output of all rules.
- **Defuzzification:** The merged output of the aggregate output fuzzy set is the input for the defuzzification process and a single crisp number is obtained as output.

The fuzzy inference system is illustrated using fig 1.

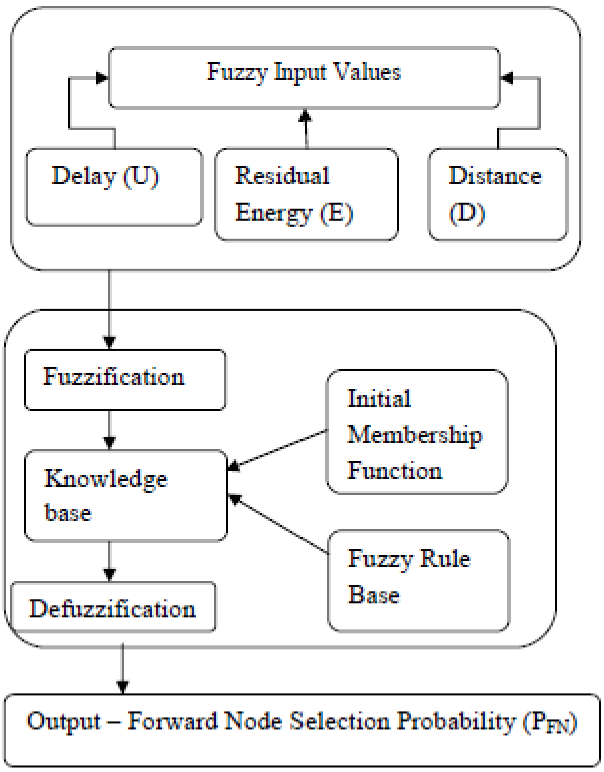

Figure 1: Fuzzy Interference System

Fuzzification

This involves fuzzification of input variables such as delay (U), residual energy (E) and distance (D) (Estimated in sections 3.2.1-3.2.3) and these inputs are given a degree to appropriate fuzzy sets. The crisp inputs are combination of U, E and D. We take two possibilities, high and low for U, E and D.

Figure 2, 3, 4, 5 and 6 shows the membership function for the input and output variables. Due to the computational efficiency and uncomplicated formulas, the triangulation functions are utilized which are widely utilized in real-time applications. Also a positive impact is offered by this design of membership function.

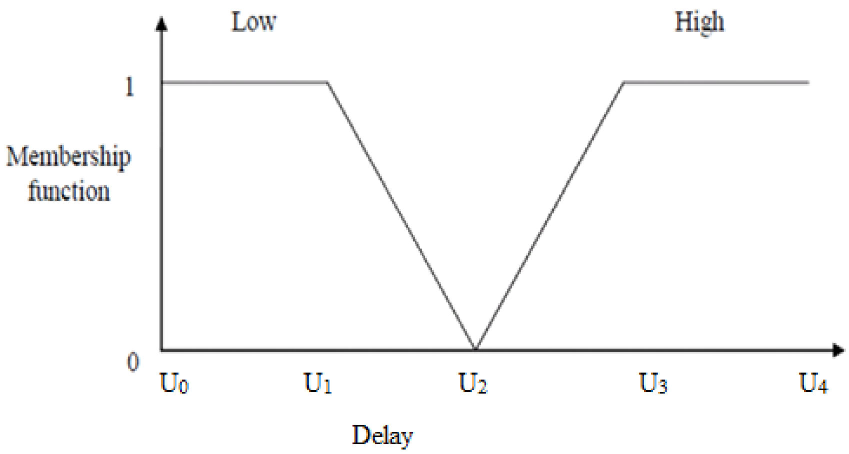

Figure 2: Membership Function of Delay

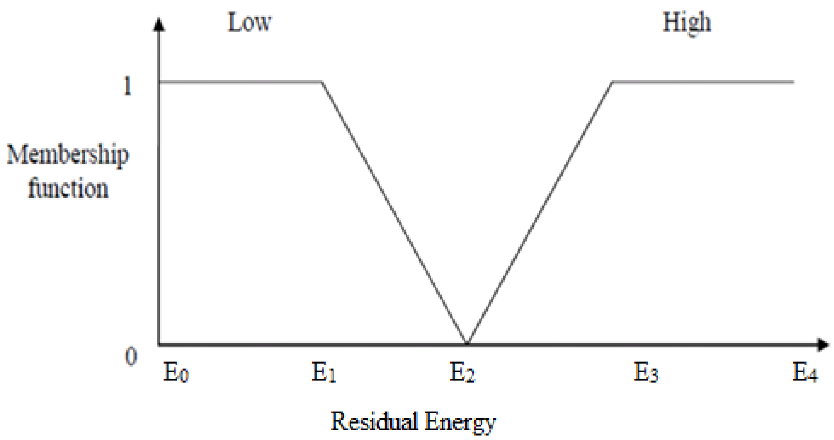

Figure 3: Membership Function of Residual Energy

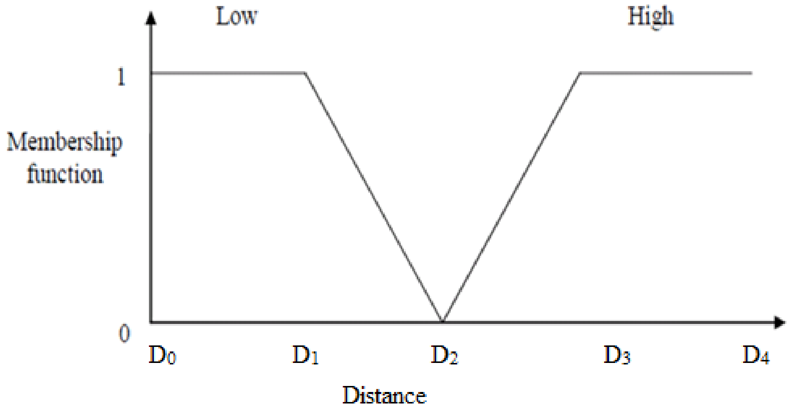

Figure 4: Membership Function of Distance

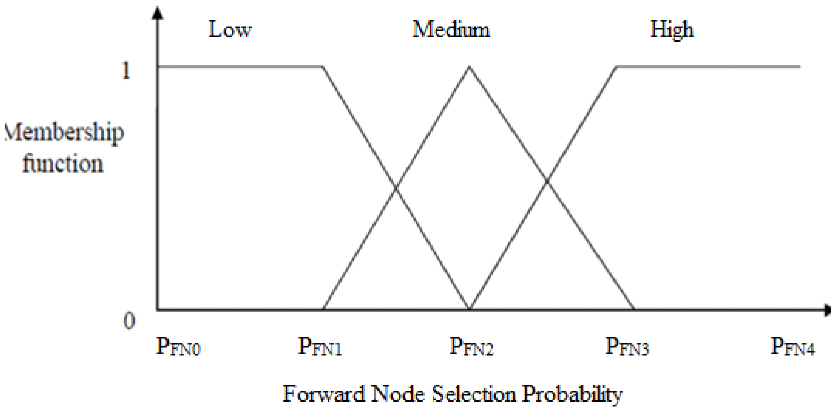

Figure 5: Membership Function of Forward Node Selection Probability

In table 1, U, E and D are given as inputs and the output represents the forward node selection probability. The fuzzy sets are defined with the combinations presented in table 2.

S.No	Delay (U)	Residual Energy (E)	Distance (D)	Forward Node Selection Probability (P_{FN})
1	Low	Low	Low	Low
2	Low	Low	High	Low
3	Low	High	Low	High
4	Low	High	High	Medium
5	High	Low	Low	Low
6	High	Low	High	Low
7	High	High	Low	Medium
8	High	High	High	Low

Table 2 demonstrates the designed fuzzy inference system. This illustrates the function of the inference engine and method by which the outputs of each rule are combined to generate the fuzzy decision.

For example

Let us consider Rule 15.

If (U&D = low, E = High)

Then

P_{FN} = high

End if

i.e To minimize rebroadcasts, each node rebroadcast only when its coverage degree is above a threshold value.

Defuzzification

Defuzzification is used for extracting a crisp value from a fuzzy set as a representation value. We consider the centroid of area strategy for defuzzification.

$$F_{QoS} = \frac{\int_f \eta_{agg}(F)_{fdf}}{\eta_{agg}(F)_{df}} \qquad (3)$$

Where $\eta_{agg}(F)$ = aggregated output of membership function

Simulation Results

Simulation Model and Parameters

The Network Simulator (NS2) [13], is used to simulate the proposed architecture. In the simulation, the mobile nodes move in a 900 meter x 900 meter region for 50 seconds of simulation time. All nodes have the same transmission range of 250 meters. The simulated traffic is Constant Bit Rate (CBR).

The simulation settings and parameters are summarized in table.

No. of Nodes	20,40,60,80 and 100
Area Size	900 X 900
Mac	IEEE 802.11
Transmission Range	250m
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512
Rate	250kb
Initial Energy	10.1J
Transmission Power	0.660
Receiving Power	0.395
Speed	10,20,30,40 and 50m/s

Performance Metrics

The proposed Energy Efficient Broadcasting and Forward Node Selection Using Network Coding (EEBFNS) is compared with the BALR technique [ ]. The performance is evaluated mainly, according to the following metrics.

- **Packet Delivery Ratio:** It is the ratio between the number of packets received and the number of packets sent.
- **Packet Drop**: It refers the average number of packets dropped during the transmission
- **Energy Consumption**: It is the amount of energy consumed by the nodes to transmit the data packets to the receiver.
- **Delay**: It is the amount of time taken by the nodes to transmit the data packets.

Results

1) Based on Nodes

In our first experiment we vary the number of nodes as 20,40,60,80 and 100.

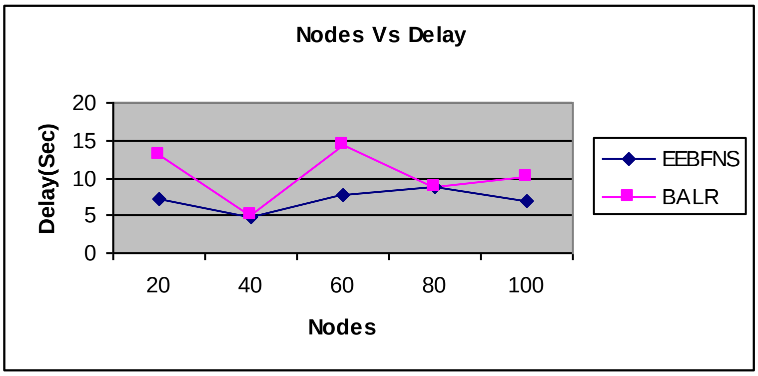

Figure 6: Nodes Vs Delay

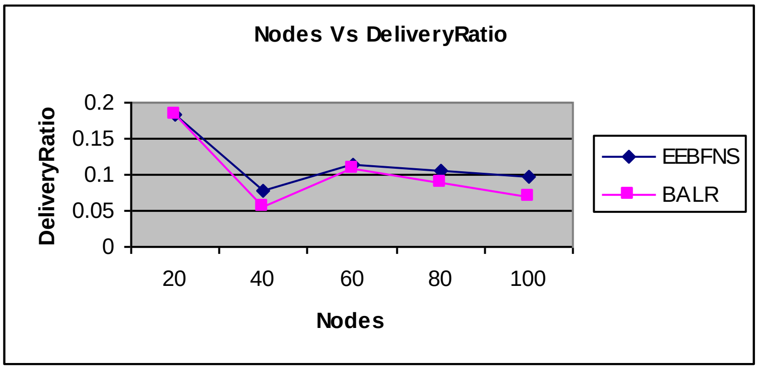

Figure 7: Nodes Vs Delivery Ratio

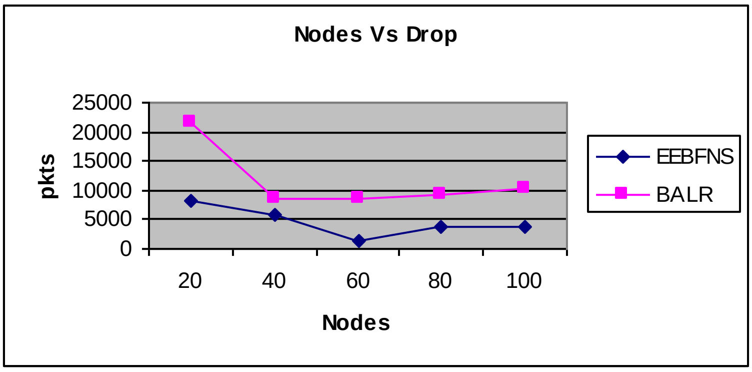

Figure 8: Nodes Vs Drop

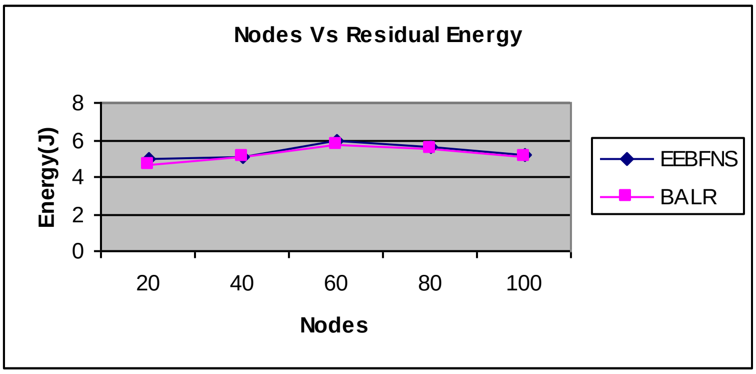

Figure 9: Nodes VS Residual Energy

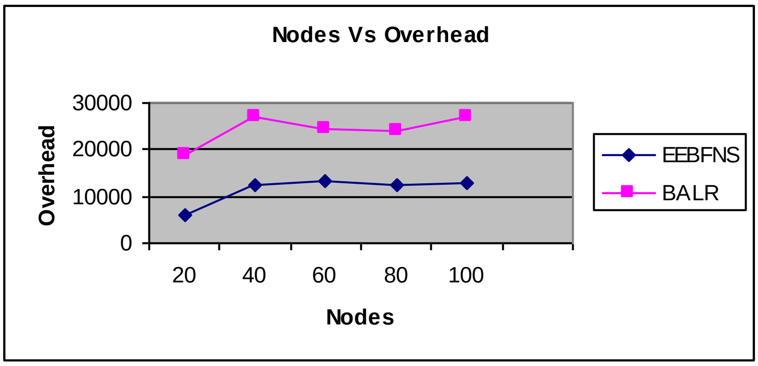

Figure 10: Nodes VS Overhead

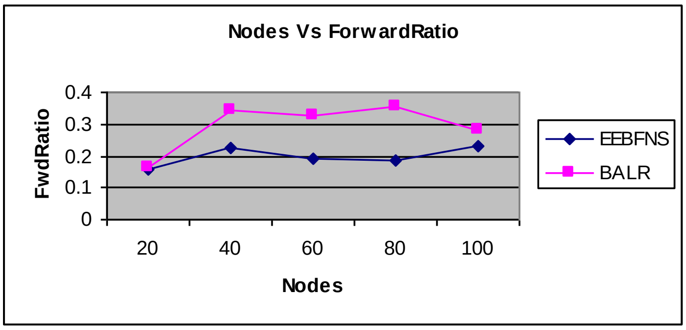

Figure 11: Nodes Vs Forward Ratio

Figure 6 shows the delay of EEBFNS and BALR techniques for different number of nodes scenario. We can conclude that the delay of our proposed EEBFNS approach has 26% of less than BALR approach.

Figure 7 shows the delivery ratio of EEBFNS and BALR techniques for different number of nodes scenario. We can conclude that the delivery ratio of our proposed EEBFNS approach has 16% of higher than BALR approach.

Figure 8 shows the drop of EEBFNS and BALR techniques for different number of nodes scenario. We can conclude that the drop of our proposed EEBFNS approach has 59% of less than BALR approach.

Figure 9 shows the residual energy of EEBFNS and BALR techniques for different number of nodes scenario. We can conclude that the delay of our proposed EEBFNS approach has 3% of higher than BALR approach.

Figure 10 shows the overhead of EEBFNS and BALR techniques for different number of nodes scenario. We can conclude that the overhead of our proposed EEBFNS approach has 54% of less than BALR approach.

Figure 11 shows the forwarding ratio of EEBFNS and BALR techniques for different number of nodes scenario. We can conclude that the forwarding ratio of our proposed EEBFNS approach has 29% of less than BALR approach.

2) Based on Speed

In our second experiment we vary the mobile speed as 10,20,30,40 and 50m/s.

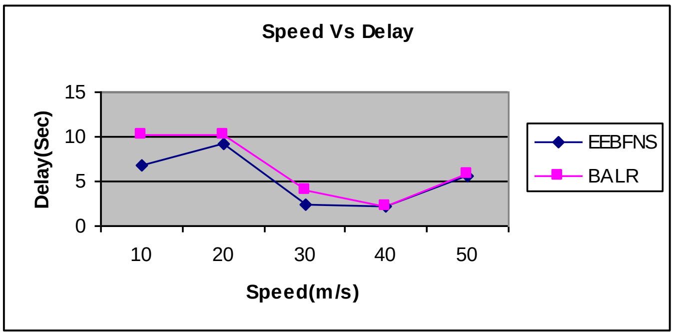

Figure 12: Speed Vs Delay

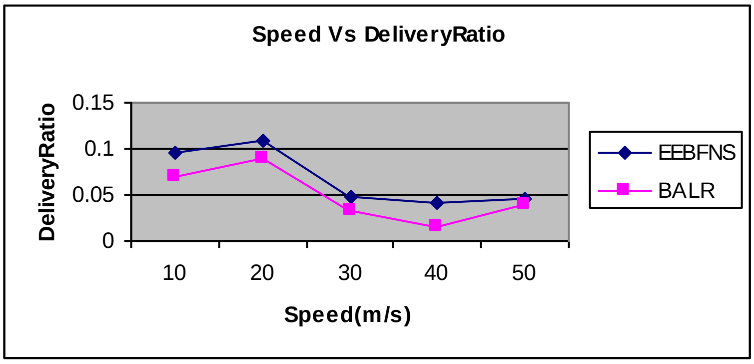

Figure 13: Speed Vs Delivery Ratio

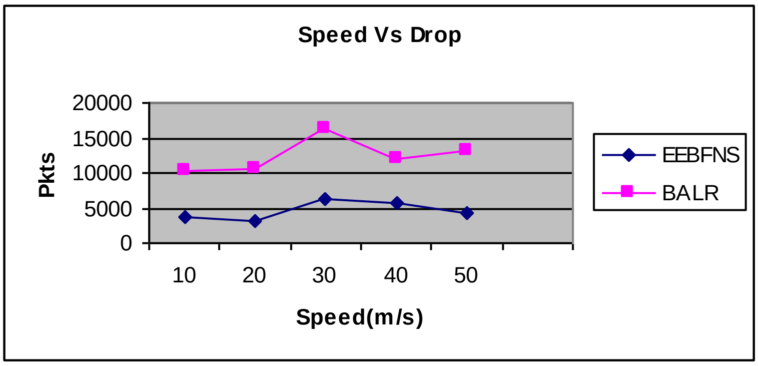

Figure 14: Speed Vs Drop

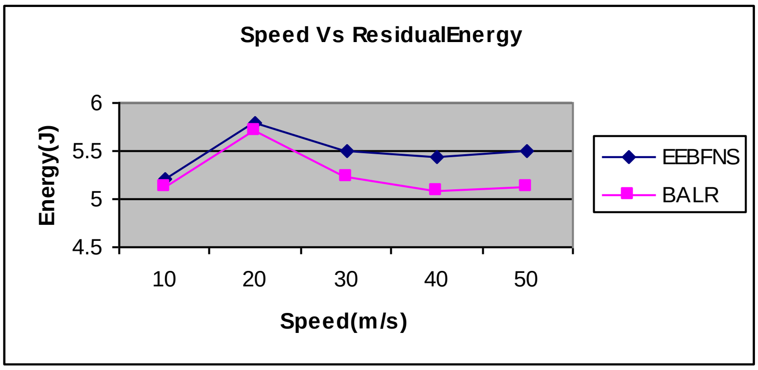

Figure 15: Speed Vs Residual Energy

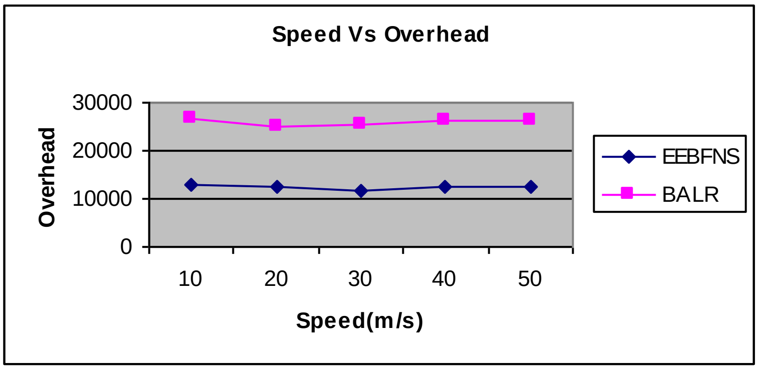

Figure 16: Speed Vs Overhead

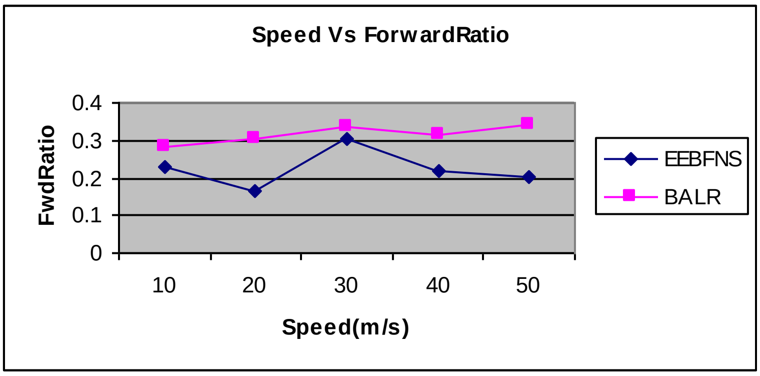

Figure 17: Speed Vs Forwarding Ratio

Figure 12 shows the delay of EEBFNS and BALR techniques for different speed scenario. We can conclude that the delay of our proposed EEBFNS approach has 19% of less than BALR approach.

Figure 13 shows the delivery ratio of EEBFNS and BALR techniques for different speed scenario. We can conclude that the delivery ratio of our proposed EEBFNS approach has 32% of higher than BALR approach.

Figure 14 shows the drop of EEBFNS and BALR techniques for different speed scenario. We can conclude that the drop of our proposed EEBFNS approach has 63% of less than BALR approach.

Figure 15 shows the residual energy of EEBFNS and BALR techniques for different speed scenario. We can conclude that the delay of our proposed EEBFNS approach has 4% of higher than BALR approach.

Figure 16 shows the overhead of EEBFNS and BALR techniques for different speed scenario. We can conclude that the overhead of our proposed EEBFNS approach has 52% of less than BALR approach.

Figure 17 shows the forwarding ratio of EEBFNS and BALR techniques for different speed scenario. We can conclude that the forwarding ratio of our proposed EEBFNS approach has 29% of less than BALR approach.

Conclusion

In this paper, we have proposed an energy efficient broadcasting and forward node selection using network coding in (MWSN). In this technique, the number of nodes involved in broadcasting operation is reduced by eliminating the nodes using minimum connected dominating set algorithm. Then the rebroadcast redundancy is minimized by selecting the forwarders using Fuzzy logic based on the parameters such as delay, residual energy and distance. To minimize rebroadcasts, each node rebroadcast only when its coverage degree is above a threshold value. By simulation results, we have shown that the proposed technique minimizes the energy consumption and redundancy.

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