distance between neighbouring nodes can be estimated based on incoming signal strengths. Therefore, we propose here a reliable path discovery mechanism to avoid the path breakages. Finding the reliable path for the data transfer results in good packet delivery ratio, throughput, and it reduces the number of route discoveries in DSR thus by reducing the energy consumption.

Transmit power control algorithms will result in energy saving. A detailed explanation was given in [12] and [21] for the effect of transmission power control on the consumed energy. Network capacity [13] and [18] can also be increased by reducing the transmission power of nodes. In the proposed framework, path discovery includes transmit power control and the discovery is done by considering the two parameters such as RSS and residual energy. RSS value is taken first for finding whether the nodes are moved away or not due to mobility. Then the residual energy of the node is validated based on a threshold and the broadcasting decision is carried out. So, in a MANET, distance based on RSS has to be updated quite often in order to improve the liveliness of the network. When the mobility is high, there will be a maximum number of link breakages, causing the network flooded with more Route Requests (RREQs) [24] and [26] which leads to more routing overheads, low received signal strength, resulting in low throughput and high packet failure ratio. In order to enhance the throughput and lifetime, we introduce path selection.

The DSR based proposed design concentrates on the RSS for predicting the closeness of the nodes and the path with minimum energy consumption and hop count for extending the lifetime. Most common property of the reactive routing protocols is that they discover routes using broadcast flooding by transmitting at maximum power in order to minimize the number of relay nodes between source and destination. The authors [11] proved that the inefficiency of the routing in MANET is due to broadcast flooding. They pointed out that the generation of many signaling packets at lower transmission power is the main reason for flooding. The intermediate forwarding nodes in the discovered routes were also high. So, to enhance the working of network in an efficient manner, cross layer framework is chosen. The system is designed in such a way that the number of paths discovered is always more than the number of selected paths for transmission. In this paper, a biobjective-optimized method is proposed for path selection for energy efficient routing that finds a path with minimum energy consumption and reduced number of hops. Many authors [7], [8], [22] and [25] have discussed the process of optimizing multi objectives. They found it as a difficult task. Therefore, we combine the two objectives into one objective by using two variables.

Many researchers proposed different methods for increasing the lifetime of mobile ad-hoc networks by minimizing energy consumption. However, most of them concentrate on minimizing the energy consumption for transmission and reception. In all these techniques, the minimum energy path will quickly deplete and this results in link failure. The proposed work is the dual approach for extending the lifetime of the network. Some of the existing works, namely, the on-demand routing protocol Dynamic Source Routing, Power - Aware Multi-path Routing (PAMP) and Signal Strength Based Routing (SSBR) is outlined in the following paragraphs.

2 Related Works

The DSR is specifically for multi-hop mobile ad-hoc networks. Due to the mobility of the nodes, topology is changing quite often. It does not use periodic 'hello' messages. DSR operate in promiscuous listening mode. In DSR, Route Discovery and Route Maintenance each operate entirely "on demand.” Overhearing improves the network performance. However, it could make the situation even worse by generating more RREP packets for a route discovery to offer alternative routes in addition to the primary one. The primary route is checked for its validity during the communication between the source and the destination and the alternative routes may remain in route cache unchecked even after they become stale. DSR is found to be a good reactive protocol under low mobility conditions. Under high mobility, performance degrades because of the stale route problem.

In PAMP [29], authors progressed based on the assumption that the source node knows the amount of power consumed in transmitting a data. Path discovery process is based on the remaining power of nodes recorded in the RREQ packet, which is the amount of power available for data transmission. After receiving the first RREQ, the power availability in the path is found and based on this the amount of data transmitted is calculated. If the power availability is insufficient to complete data transmission, then the destination node waits for the later route requests to determine the path that has adequate power for the data transmission. After receiving the entire RREQs, the destination node sends back the RREPs for all recorded paths to the source node. PAMP concentrates on path breakages also. One problem arises in this during high mobility is that the transmission bandwidth of the alternative paths may be reduced and this causes more power to be consumed. PAMP was applicable to the situation in which data transmission cannot be completed with only one path. They have evaluated the remaining powers of all paths to construct multiple paths to complete the data transmission.

In SSBR [6], the authors concentrated on the transmission bandwidth between two nodes for decreasing the power consumption and increasing network lifetime. They measured the distance between two nodes based on the received signal strength, without using a Global Positioning System (GPS). Transmission bandwidth is determined by using the dB-to-bandwidth table. The RSS variations are used to predict the possible amount of data that can be transmitted via a link. They used this prediction to find the remaining power of nodes in the path after the data transmission is over. The average transmission bandwidth, the number of rerouting paths, the path lifetime, and the power consumed when a byte is transmitted, number of rerouting paths and the network lifetime are considered for comparison with the earlier works.

3 Proposed Routing Methodology

The focus of our design is to reduce the energy consumption during route discovery by avoiding the nodes based on the predicted RSS. The reason for adopting both path discovery and selection is due to dynamic change in topology. During the path discovery process, transmit power required is adjusted based on the transmission range between one hop neighbours. Connectivity changes are found out using the value of RSS of the selected links. RSS is used here as the distance predicting factor. Path selection is done with respect to a biobjective model.

3.1 Network Model

For designing EE-BPS, the topology of the MANET is represented as a graph G= (V, E) containing the set of nodes (V) and the links (E) in the network. 'V' is assumed here as 'TN'. The set TN contains set of nodes that takes part in rebroadcast (TN_R) and set of non-rebroadcasting nodes (TN_{NR}). It is denoted here as $TN = (TN_R \cup TN_{NR})$. Proposed Path discovery mechanism is designed in such a way that the ratio of reliable nodes (TN_R) to total number of one hop neighbour nodes (N) is always greater than zero. So, at least one path will exist. Probability of path discovery can be found out if ($N>TN_R$) using the following formula.

$$P_{PD} = {(N - TN_R)}\big/{N} \qquad (1)$$

Where N - Total number of one hop neighbours;
TN_R –No.of neighbours forwarded the RREQ;
TN - Total nodes in the network;

It is evident that from the Eq. (1), that the existence of a link depends on number of neighbours. The routing protocol of the network model is based on DSR. For a node with three neighbours, if there is at least one reliable node, based on Eq. (1), PPD is 0.66… ≈ 0.7. This ensures definitely, there is a path for the destination.

3.2 Transmit Power Control

The transmit power level is adjusted in order to reduce the power wasted for transmitting the data to the nearest neighbour nodes. This power reduction leads to energy saving. This is done based on the parameter called Transmission Range maximum (TR_{max}). TR_{max} is defined here as the maximum distance between any two nodes. This value is calculated based on the following equation.

$$TR_{\max} = \frac{R}{10 \times TN}\sqrt{\frac{\log N}{N^2}} \qquad (2)$$

The value $\sqrt{\log N}$ gives assurance that there exists at least one neighbour. i.e., If the value of N goes to 0 also, the value is greater than 0. TR_{max} can become a zero or a defined transmission range value. Eq. (2) will hold good and give optimum results only if the following conditions are satisfied.

$$TN \ge (R)^{1/3} \;;\; TR \ge \frac{\sqrt{R}}{4} \;\text{ and }\; N \ge 3 \;;$$

Where R - Area of the network;
TN - Total number of nodes;

N - Number of one hop neighbours;
TR - Defined Transmission Range;

The transmit power (P_t) required for the transmission is updated as follows,

$$P_{t\_adj} = f(N, TR_{\max}, TR, P_t) \quad (3)$$

$$P_{t\_adj} = \frac{N + TR_{\max} \times P_t}{TR} \quad (4)$$

Transmit power adjustement *(P_{t_adj})* is done mainly to reduce the energy consumption based on one hop neighbours as per the Eq. (4).

3.3 Energy Consumption Model

The proposed EE-BPS computes the energy consumption as follows and it is updated in the EC_{SD} field of RREQ. Eq. (5) denotes the energy consumption from the source node to the destination (SD pair) for all the *(M-1)* links. *M* represents the number of nodes in the path.

$$EC_{SD} = \sum_{m=1}^{M-1} EC_{TP_m} \quad (5)$$

The energy consumed for transmitting the entire data in the link ij is denoted as EC_{TP} and it is computed as in Eq. (6).

$$EC_{TP} = \sum_{s=1}^{p} EC_{ij_s} \quad (6)$$

No. of packets $p = \frac{Datasize}{Packetsize}$

Energy consumption of the individual link between a pair of nodes i and j is given in Eq. (7) as EC_{ij}.

$$EC_{ij} = EC_{txi} + EC_{rxj} + EC_{sleepj} + EC_{transj} \quad (7)$$

Where
EC_{txi} - Energy spent for the transmission of data by node i;
EC_{rxj} - Energy spent for receiving data by the node j;
EC_{sleepj} - Energy spent in the sleep state j and
EC_{transj} - Energy spent for the transition from awake to sleep for node j.

The proposed work utilizes the power saving mode of IEEE 802.11 to reduce the energy costs of the idle state, but it exhibits poor latency performance in multi-hop infrastructure less environments. The source node buffers packets for the destination node that is in the doze/sleep state, and these buffered packets are announced during a subsequent ATIM window. When a node has sent an ATIM frame to another node, it remains awake for the entire beacon interval. A node that has no packets to be transmitted can go into the doze state at the end of the ATIM window if it does not receive an ATIM frame. All dozing nodes again wake up in PSM at the start of the next beacon interval. Nodes in the PS mode are expected to synchronize among themselves in a distributed way [14]. For the simulation, Monarch version [10] is used for the 802.11 power management in ad-hoc networks.

3.4 Path Discovery Process

The source node broadcasts a single RREQ message to discover a route to all the nodes currently within the transmission range of the source. Path discovery after adjusting the power level is done based on RSS and remaining energy of the node. By using RSS value, the nearest node can be selected for forwarding the data. Second remaining energy is checked for determining the node lifetime. The main aim is that in route discovery phase, a mobile node has to choose a neighbour with highest RSS value to improve the lifetime of the path. Based on Friis transmission formula [30], the *RSS* in dBm for free space propagation of the links is computed using the Eq. (8) as,

$$RSS = \frac{P_t G_t G_r}{L} \left(\frac{\lambda}{4\pi d} \right)^n \quad (8)$$

In this, P_t is transmitting signal strength in dBm, G_t and G_r are the unity gain of the transmitting and receiving antennas, λ is wavelength in meters, d is the distance between transmitter and receiver in meters, n is path loss coefficient and takes a value of 2 to 4 and L is path loss component (L=1). Usually value '2' is free space model and '4' for two-ray ground propagation model. The noise and fading are not considered for the design. From the Eq. (8), it can be seen that if *RSS* value is more, link quality will be good, otherwise link is likely to be broken soon. The RREQ of DSR is modified by appending the fields such as RSS and Energy Consumption from Source to Destination (EC_{SD}).

The algorithmic steps for forwarding the RREQ based on RSS value and remaining energy is as follows :

Step 1 Select the source and destination node.
Step 2 Broadcast the RREQ.
Step 3 Compare received RSS value (RSS_{rec}) with the RSS values received from other nodes in the table.
Step 4 If the present received value is higher, then compute the residual energy as given in Eq.(9).
Step 5 Check whether the current node's residual energy is above the threshold as in Eq.(10).
Step 6 If it is TRUE – then node is eligible for data transfer. Go to Step 8. If it is FALSE – Go to step 7.
Step 7 Drop the RREQ.
Step 8 Find whether the current node is the destination.
Step 8 If it is not TRUE, then rebroadcast RREP. If it is TRUE – Go to step 10.
Step 9 Repeat the process until the destination node is reached.
Step 10 Path selection at the destination based on biobjective model.

Initially, source node will carry the transmit power level as the RSS and it is broadcasted to the neighbour node. The neighbour node maintains a table containing the RSS values received from other nodes. When a node which is not the destination receives the RREQ, it checks whether the current received signal strength of RREQ is greater than or equal to the previously stored RSS values of other nodes RREQ in the routing table. The current node after predicting its closeness makes a final decision based on its residual energy of the node for forwarding / rebroadcast RREQ. Otherwise, the current node drops the forwarding job. When a node receives a RREQ, it compares current RSS_{rec} with the *RSS* already recorded in the routing table. After comparing *RSS* of the neighbours RREQ, the current node decides whether it is eligible. If it is the destination, then instead of rebroadcasting, it sends a unicast RREP to the source node. If the residual energy of the nodes has not been taken into account, there are chances that the discovered paths may have link nodes with insufficient energy to relay data. Initially the residual energy value is kept as initial energy. Residual Energy of the current node j ($ResE_{j\_current}$) is calculated based on Eq. (9).

$$\mathrm{Re}\,sE_{j\_current} = \mathrm{Re}\,sE_j - EC_{ij} \tag{9}$$

$ResE_j$ is residual energy at the node 'j' and EC_{ij} is calculated based on Eq. (7). Then we validated it with the set threshold given in Eq. (9).

$$\mathrm{Re}\,sE_{j\_current} \geq \frac{IE}{5} \tag{9}$$

In Eq. (9), *IE* is the initial energy of the node. It is assumed constant for all the nodes. This is done to find the node whether they can participate or not in the data transmission by forwarding the RREQ to the neighbour. The path discovery process is shown below schematically with an example in Fig. 1.

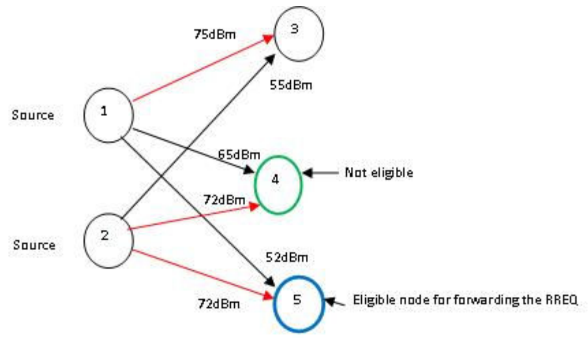


Fig. 1 Node Eligibility Selection in Path Discovery Process

Based on the algorithmic steps, the source node selects the node for forwarding the RREQ. In the above Fig.1, node number 1 and 2 are taken as source nodes. Source node 2 broadcasts RREQ to node 3, 4 and 5. All the three validates the RSS_{rec}. Node 3 is dropped out because of less signal strength. Node 4 and 5 tests its residual energy and it is found that node 5 is the only eligible node based on both RSS and residual energy.

Thus, by reducing the number of RREQ's and by utilizing variable transmit power in the path discovery process, energy conservation can be obtained. The path discovery results in the reduction of number of RREQs flooding the network. This kind of filtering at each node helps in reducing the routing overhead.

4 Mathematical Model for Biobjective Path Selection

Path selection after discovering the reliable paths for the data transfer is carried out based on reduced energy consumption and number of hops. The focus is to reduce path breakage and to increase the network lifetime. The energy consumption is calculated based on the Eq. (5) and it is updated in the RREQ field. Once the RREQ reaches the destination, the destination takes a decision based on the updated energy consumption and hop count for all the collected paths (*P*). A single objective model is proposed as given in the following Eq. (10). Objective function is defined by keeping in mind equal weight to both the energy and hop. This is because; minimization of energy without taking the hops may lead to a path selection having increased number of hops. Minimization of hops without minimum energy path may reduce the lifetime of the network or may select a path, which consumes more energy. So, our design goal is to minimize both. The mathematical model for biobjective based Path Selection (PS_b) is defined as follows,

$$PS_b = \min(EH(P)) \qquad (10)$$

Where

$$EH(P) = \alpha \frac{EC_{SD}(P)}{\beta} + (1-\alpha)H(P) \qquad (11)$$

EH(P) – Single objective function for path selection
H(P) – Hop count
α – Adjustable parameter varying from 0 to 1
β – Normalizing coefficient

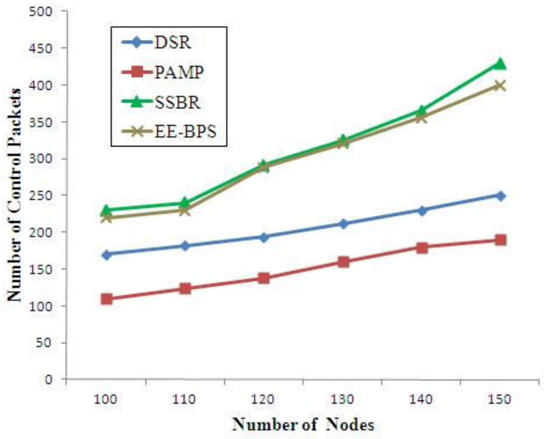
Based on the above Eq. we can find the desired path that will consume the least amount of energy with reduced number of hops. The destination will give a RREP to the source node for data transfer after validating based on the above. Here in Eq. (11), if α is zero, then path selection is purely depends on the hop count. If α is 1, then it depends on energy consumption. Therefore, the selection of α value is such that it minimizes the energy and hop count in making a decision in path selection. Normalizing coefficient β is introduced in order to maintain a balance between the energy and hop count. This is purely a dependent factor on the maximum energy consumed for a single hop in the selected path. If the energy is in J, then the value of β is also in J. For example, the energy consumption of a path $EC_{SD}(P)$ is 2.5J and *H(P)* is 3, then the β value is chosen as 0.9Jx3 = 2.7J. The optimal decision can be either energy based or hop based or minimal of energy and hop based on the objective function.

5 Results and Discussion

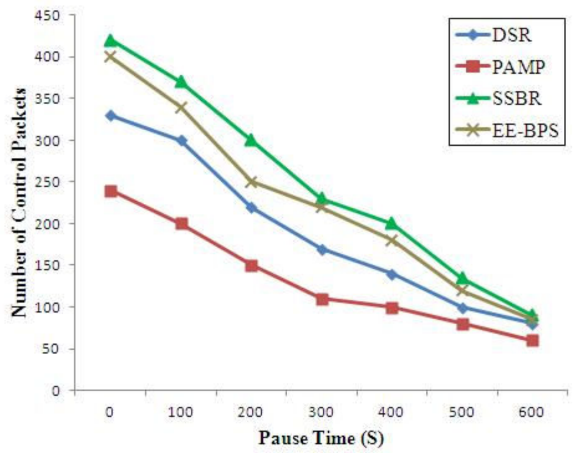
The simulation of the proposed design is developed using the Linux based network simulator [28]. Mobility model chosen is Random Way Point (RWP) model [2]. Simulation time is 900 seconds and the results are taken after 10 runs to obtain steady state value. Network size is 1000 x 1000 m^2. Total number of nodes for the design is varied from 100 to 150. Transmission range is set as 250m. Maximum node speed is 5m/s. The packets are injected into the network from 1-5 packets / sec. The initial energy of the node is kept at 180J. Pause time is varied from 0 – 600s. The data size is taken as 5MB and the packet size is 256bytes. The parameters considered for the analysis are control packets and energy consumption in path discovery process and packet delivery ratio, overall energy consumption, number of path breakages and network lifetime.

The analysis for the number of RREQ packets used for discovering the path by varying the number of nodes and pause time is plotted in the following Fig. 2a and 2b. Fig. 2a is drawn by keeping the pause time as 300s. Fig. 2b is by considering 100 nodes in the network. The analysis reveals that the number of control packets for the proposed routing method is lesser compared to the SSBR because of the restriction of RREQ broadcasting based on RSS. The reason for more number of control packets in the proposed compared to DSR and PAMP are due to the finding of reliable paths based on RSS. So, the number of RREQs for setting up the path becomes more.

The number of control packets in DSR is almost twice that of PAMP. In PAMP, the destination node after receiving all RREQs, records and decides by giving RREPs to the source node in order to construct multiple paths. Therefore, overhead is lesser for PAMP. SSBR selects the routes after predicting the amount of data transmitted and the remaining power of nodes. The overhead of SSBR is little higher compared to the proposed EE-BPS. If the pause time is 600s, almost all the methods converge to a point because of the static nature of the network.

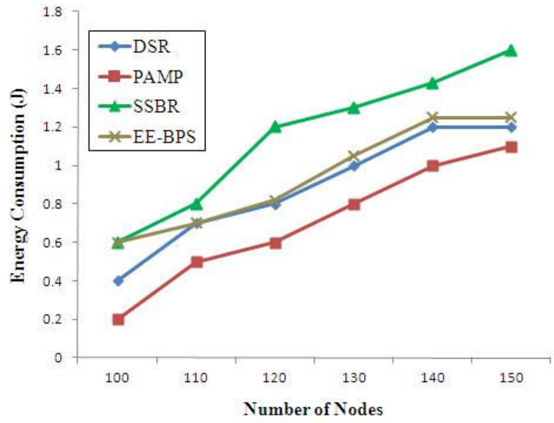


a. Number of Nodes

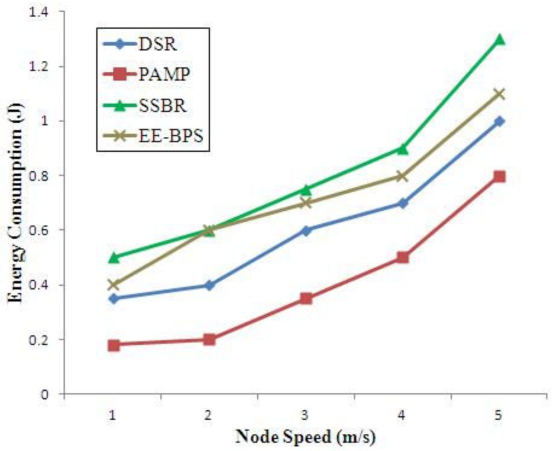


b. Pause Time

Fig. 2 Overhead Analysis



a. Number of Nodes



b. Node Speed

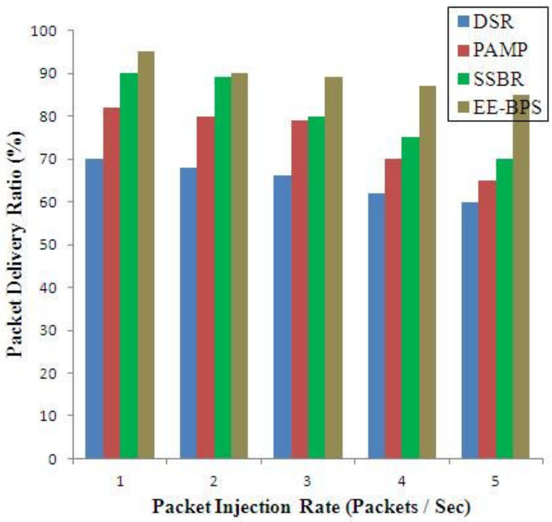
Fig. 3 Energy Consumption (J) in path discovery process

Analysis for the energy consumption in the path discovery process is plotted in Fig. 3. Energy consumption in path discovery is purely dependent on the overheads and transmission range maximum value. Fig. 3a is drawn by varying the number of nodes and keeping the node speed as constant at a value of 2 m/s. Fig. 3b is by varying the node speed and keeping the nodes as 100.

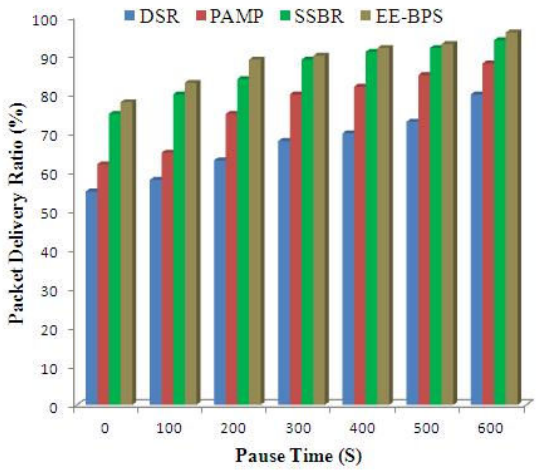
It is evident from the following Fig. that more energy is spent for finding the reliable paths in path discovery process in the proposed work. Though SSBR and EE-BPS are proceeding almost with the same approach, EE-BPS energy consumption in path discovery is lesser compared to SSBR. The reason for this is that EE-BPS is using transmit power control. EE-BPS energy consumption is higher compared to DSR and PAMP is that it initiates large number of control packets for the path discovery.

Packet Delivery Ratio (PDR) is plotted in Fig. 4a. by varying the packet injected rate in network from 1 to 5 packets / second and keeping the total number of nodes as 100. Fig. 4b represents the packet delivery ratio for different pause times from 0-600s by keeping the packet-injected rate at 2 packets / second for the same number of nodes in the network.

Packet delivery ratio is higher in proposed system. This is due to the reason that the EE-BPS finds reliable paths for data transfer by path discovery and it selects minimum energy paths with reduced number of hops. Therefore, the chances for path breakage due to node failure are very less. SSBR also achieves nearly the same PDR as that of the EE-BPS. PAMP and SSBR lies below this. SSBR predicts the possible amount of data that can be transmitted before transmission by considering the RSS variation and the bandwidth.



a. Packet Injection Rate (Packets/Sec)



b. Pause Time (S)

Fig. 4 Packet Delivery Ratio

Number of path breakage is plotted in Fig. 5 for all the methods. EE-BPS has an average of 30 path breakages for the varying network sizes of 100 to 150 nodes compared to the remaining methods like DSR, PAMP, and SSBR. Reduced number of path breakages in EE-BPS is due the residual energy consideration in path discovery. In PAMP, the path selection is multiple in numbers and depends on the data and power available. It does not consider, whether the nodes are nearer or far for the transmission. The chances of path breakage are more.

SSBR selects the path based on the following two factors. It checks first whether the receiver lies within the transmission range and the remaining power for data transmission. This is the reason for the minimization of rerouting paths in SSBR. In addition, SSBR considers the remaining power, and there are a lesser number of node failures. This results in reduced number of path breakages.

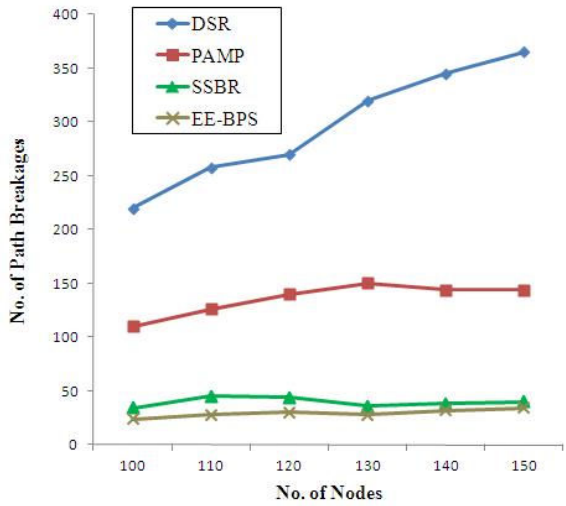


Fig. 5 Number of path breakages

Energy consumption analysis for the pause time of 300s and for the number of neighbours of 5 is diagrammatically shown in the Fig. 6. The energy consumed is plotted for one byte of information. It is seen that the proposed achieves a very less energy consumption compared to all the other methods.

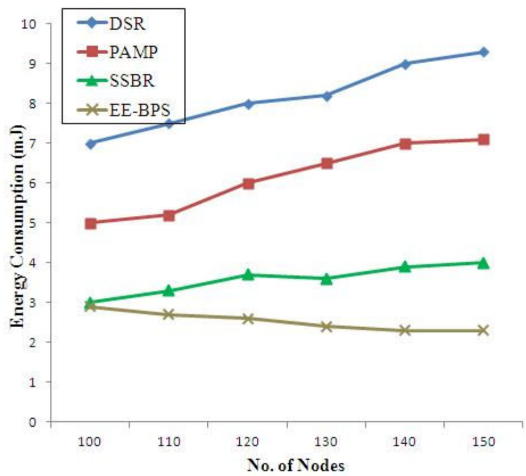


Fig. 6 Energy Consumption vs. Number of Nodes

It is due to the reason that the design utilizes the transmit power control and it selects the path with minimum energy and hop for the data transfer.

Network lifetime in seconds is shown in Fig. 7 for the selected path. We assume here the network lifetime as a purely dependent parameter on the residual energy of the path. Therefore, if the energy is more, then the network lifetime is also going to be more.

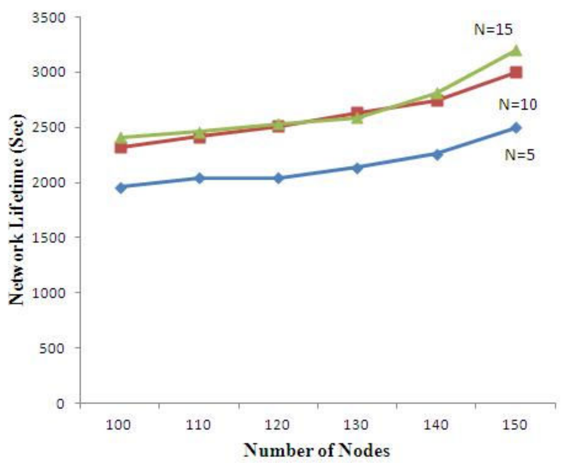


Fig. 7 Network Lifetime

The graph is drawn by varying the number of neighbours for the different sizes of the network. It is seen clearly that as the neighbours are in direct proportion to the selected path lifetime. However, for the neighbours of size 10 and 15, the lifetime shows a similar pattern. Therefore, we conclude that from the above results, optimum lifetime can be achieved for the network if it contains the neighbour ratio as 1/10th of the total nodes. Table 1 shows the energy consumption analysis by varying the pause time from 0 sec. to 600 sec.

Table 1 Mobility based Energy Consumption Analysis

Total nodes	Energy Consumption (mJ)						
	Pause Time (sec.)						
	0	100	200	300	400	500	600
100	14.4	11.7	5.5	2.5	2.4	2.2	1.7
110	14.2	11.2	5.2	2.4	2.3	2.1	1.7
120	13.5	10.6	5.1	2.4	2.2	2.1	1.6
130	13.1	10.2	4.7	2.3	2.1	1.9	1.5
140	12.2	9.5	4.3	2.2	2.1	1.8	1.3
150	12	9.1	3.2	2	2	1.6	1.1

Diagrammatic representation of this is given in Fig. 8. It can be seen that below the pause time of 300 seconds, the energy consumption is being increased. It can be concluded that the proposed system achieves good energy consumption for the pause time from 300 seconds to 600 seconds.

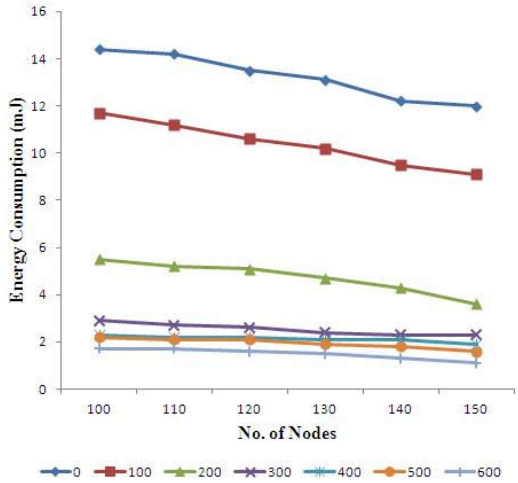


Fig. 8 Energy Consumption Analysis for different values of Pause Time

So, it can be inferred from the simulation results that the system is best suited for medium mobility condition.

A numerical example for the path selection model based on the defined objective function given in Eq. (11) is tabulated in Table 2.

Table 2 Path Selection EH(P) for different sets of Energy and Hop

$EC_{SD}(P)$ (mJ)	H(P)	α					
		0	0.2	0.4	0.6	0.8	1
2.5	3	3	2.6	2.2	1.8	1.5	0.9
2	4	4	3.4	2.7	2.1	1.5	0.8
2.8	2	2	1.8	1.6	1.4	1.1	0.9

The tabulated values are presented as a graph in Fig. 9 as follows. Three sets of energy consumption and hop are taken and it is plotted by varying α parameter from zero to one.

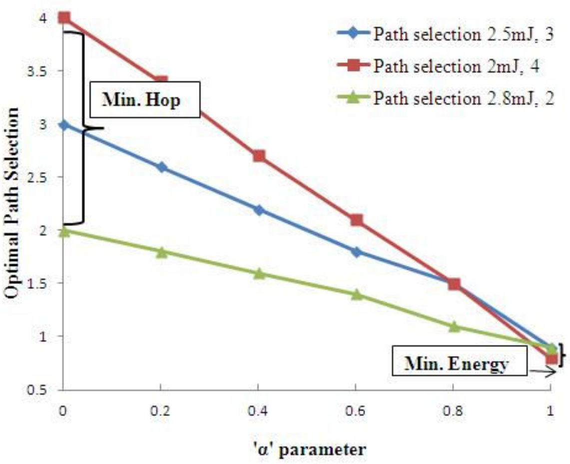


Fig. 9 Path Selection EH(P) for different combinations of Energy and Hop

From the graph, it is understood that the value of α = 0 gives us minimum hop selection and α = 1 leads to minimum energy. Thus, the minimum optimal path EH (P) is chosen as the lower plot having the representation as path selection with 2.8mJ of Energy and 2 as the Hop count.

6 Conclusion

The proposed EE-BPS is used to select the path based on a biobjective decision making function. This function depends on minimum energy consumption and reduced number of hops. Discovery of the path is done with respect to RSS and residual energy and adjusting the transmit power based on maximum transmission range. Path selection is found to be reliable, because of the reduced number of path breakages in the proposed system compared to other methods. Selection of the path that consumes less energy and number of hops will definitely extend the network lifetime. From the simulation results, it is noted that the control packets and energy consumption for the path discovery process is appreciably increased compared to the DSR, PAMP and decreased compared to SSBR. Reason is that the proposed selects reliable paths for data transfer. The factors like path breakages and overall energy consumption are very much lesser. Packet delivery ratio is very much increased. The system gives an optimum performance for the network of 100 nodes with pause time of 300 sec., and packet injection rate of 2 packets / sec,.

As a future work, we thought of extending this for network lifetime improvement by reducing the sharing of nodes in path selection with the help of node disjoint paths.

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