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A Proposed System Using Genetic Algorithm for Energy Efficiency in Wireless Mesh Networks

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Abstract

Support of mobility is catalyst factor for use of wireless mesh networks (WMNs). They are intended to replace wired backbone for making communication truly wireless. With growing interest in WMNs, it can play significant contribution in achieving objective of energy efficient communication. With need of meeting acceptable qualities, networks are planned to support peak traffic demands. But during low traffic periods many of resources are not utilized up to their full capacity. A genetic algorithm based traffic consolidation approach has been designed for WMN. Given traffic demands redundant nodes are identified and allowed to sleep to minimize energy consumption. Tradeoff in saving by switching off underutilized nodes and transmission or reception energy has been considered. Results prove that significant energy can be saved by traffic consolidation.

1. INTRODUCTION

With increasing access to digital equipment, the Internet is playing a significant role in everyday life. During last 15 years there is increase of 39% in internet users, and mobile users by 73% worldwide [1]. With internet revolution, demand of mobility support is prevalent in today culture. This is leading to expansion in wireless technologies and hence energy expenditure. With coverage expansion, direct one hop wireless communication from each client user to gateway node for internet connectivity is not practicable. There should be relay nodes to support multi hop communication from user to gateway nodes and vice versa. This requirement fed escalation towards development of wireless mesh network (WMN).

Eventual goal of WMN is to provide high bandwidth Internet access to users. Fixed relay nodes at backbone gives it more stable topology and capacity. Data is collected from client's nodes at respective wireless mesh access points (MAP) and forwarded to Internet gateway via intermediate mesh routers (MR's) in multi-hop fashion and vice versa. This is contrasting to ad hoc network where sink and source can be in any pairs of node. WMN works on principle that by breaking long distance signal into shorter one, intermediate nodes can preserve signal strength. It helps to achieve important feature of WMN i.e. support for extended coverage, enhanced quality of service and reliable communication. Wireless backhaul part represent significant portion of energy expenditure. WMN is progressively popular access network, so this paper addresses the energy efficiency objective in WMN.

Energy efficient approaches can be broadly categorized in two ways. Firstly, when network nodes are not constrained by electricity supply then objective of energy efficiency becomes minimizing overall network energy cost. Secondly, in scenarios where electricity supply is a scarce resources network node needs to be battery operated. The rate of energy consumption of nodes determines network connectivity and hence duration of network survival. So, network survivability becomes most valuable metric.

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Approach based on power down of nodes comes under first category while, load distribution approach comes under second one.

WMN is usually not constrained by energy at backhaul part. So by minimizing overall energy consumption, objective of energy efficiency can be achieved. Networks are designed to meet peak traffic demand. Network resources in backhaul like MR's are over provisioned during low traffic period and opens scope for minimizing energy consumption. During low traffic period a wireless node spends most of its time in idle mode. When traffic follows a pattern on periodical basis the resources can be dynamically adjusted according to current traffic level and hence can play significant role in reducing energy consumption. Research work for utilization of low traffic periodtowards energy saving is not being addressed adequately. Unlike previous works like [2-7,11], our approach favors utilization of active network resources to their full capacity. Traffic over few nodes is consolidated by considering tradeoff in saving by switching off underutilized nodes and communication energy. With assumption of predetermined traffic demands redundant nodes are identified and allowed to sleep to cut down idle energy cost of underutilized nodes. Such kind of system can be incorporated for WMNs, to allow integrated and distant control of all mesh devices and to alter of their configuration as per requirement.

The remaining of text is structured as follows. After related area of work, a detailed model for measurement of energy consumption has been given. After discussing traffic model, problem is formulated and presented in mathematical form. Furtherto identify redundant nodes for doze state, a genetic algorithm for minimum energy consumption has been designed.Simulation and analysis reveals that presented approach can save significant energy.

2. RELATED WORKS

Mhlanga et al., [2] have considered battery operated network. As IEEE 802.11s routing protocol does not give main concern to energy conservation, so authors have proposed energy aware optimized path selection algorithm. Chen et al., [3] have explored tradeoff between energy consumption and quality of video content. Energy aware routing algorithm works onremaining energy level, communication distance and traffic load. For static mesh routers, 22.9% energy saving but 9.65% increases in packet loss has been observed. While, Li et al. [4] targets energy efficient throughput optimization problem for renewable energy nodes in disaster area under assumption of known traffic demands. Yu, et al. [5] have designed an energy-efficient routing protocol in wireless networks to defer the emergence of the first energy exhausted node. The routing protocol adopted hop penalty and flooding delaying strategy to enhance the conventional method for better load balancing, and hence to reduce the number of energy exhausted nodes. While, in [6] authors address energy efficient routing by considering the channel fading dynamics. As impact of fading cannot be ignored in real word scenarios, proposed algorithm utilize information about the nodes location and their channel condition. Similarly to [2-5], research works of [7] also focuses on network with battery operated node and are not suitable to cover the network with sufficient energy supply. For prolong operation of network, objective in energy efficiency shift towards fare use of available battery among all network nodes and overall energy minimization. Capone et al. [8] and Mamechaoui et al. [9] addressed energy conservation in WMN, where energy is not a constraint at backhaul part. Capone et al. [8] formulated the problem asamixed integer linear programming (MILP) for network management to reduce underutilized mesh nodes and hence operational energy requirement by considering daily variations of the traffic demand. But communication energy has been ignored. Similarly, Mamechaoui et al. [9] has also designed the problem as MILP. But solving MILP based solution may not be suitable in practical scenario. So research work has further proposed sleep mechanism to switch off a mesh node by considering their traffic load and solar energy. Li-yong Yuan et al. [10] reduces idle listening by using the wake/sleep schedule information of two-hop neighbor nodes. But mechanism in [9-10] does not consider any traffic consolidation. Whereas, Akhtar et al. [11] determines the minimum energy route from source to destination node. Cooperation based transmission accounts the circuit power consumption, but algorithm does not reduce the number of used Dener et al. [12] have proposed energy efficient hierarchical routing protocol. The proposed protocol found to outperform LEACH, PEGASIS, TEEN and APTEEN in energy efficiency and number of surviving nodes. Authors in [13] have emphasized opportunities of energy savings at the MAC layer. Attributes like energy efficiency, latency, throughput, security should be considered while designing MAC protocol. Research work to ensure energy awareness in WMN needs more attention by considering communication energy and traffic consolidation. Keeping in view of above constraints this paper focus on providing heuristics based algorithm forpredetermined traffic profile.

3. MATHEMATICAL MODEL FOR ENERGY EXPENDITURE

Energy consumption model is a foundation for development and analysis of energy efficient network. Energy aware design depends upon knowledge of energy expenditure model of wireless devices of network and protocol. This requires more detail insight into hardware of wireless device and working of protocol. Energy consumption has complex relationship over multiple factors. Accuracy of designed mechanism and analysis of results enhances with accurate model of energy measurement. The overall energy consumed by the network over a segment of time is given by idle listening, receiving packets, transition among states, transmitting packets etc.

Energy consumption of network mainly comes from three factors:

- Active mode: This is a state of node when transceivers are active and communicating with neighbor node. Apart from constant energy consumption, communication energy i.e. energy consumed in transmitting or receiving data packets or control packets needs to be considered. Due to noise packets at receiver end may fail to pass error check e.g. cyclic redundancy check (CRC). A corrupted packet needs retransmission, which adds on to energy consumption.
- Idle mode: Here transceivers are ready but node is not participating in any active communication. Nodes keep listening to probable packets intended for them, but is not sent. In this stage node consumes unnecessary energy. Energy at this part can be reduced by letting nodes in sleep. Most transceivers running in idle state have energy expenditure about equal to the energy expenses in receive mode.
- Sleep mode: Energy spent in sleep state which is due to leakage current and represents lowest power consumption.

In this section efforts will be devoted to develop more accurate energy consumption model. Detailed block circuit of transmission circuit to produce the required output power for transmitting over media and receiving circuit [14] for processing of received signal are given in Figure 1 and Figure 2 respectively.

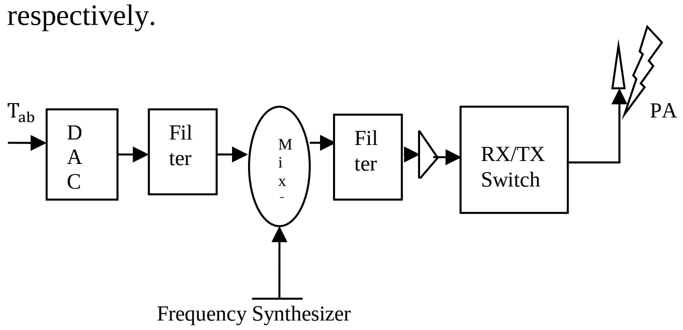


***Figure 1**. Transmission end*

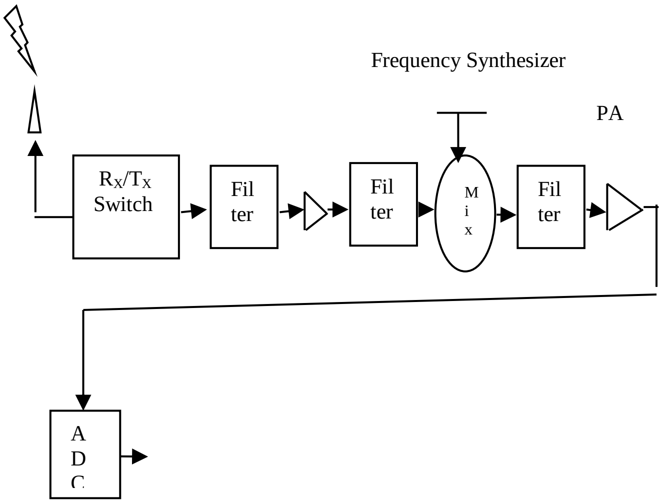


Figure 2. *Reception end*

3.1. Transmission Power Model (E_t)

Total energy in transmitting a packet over a link connecting two nodes is given by circuit power consumption (P_{ct}) and transmission signal power measured per unit of time as in equation (1). P_{ct} is contributed mainly by energy consumption due to DAC(P_{DAC}), filter (P_{filter}), mixer (P_{mixer}) and frequency synthesizer (P_{synth}).

$$E_t = (\text{circuit power} + \text{transmission power}) \times \text{duration} \quad (1)$$

$$E_t = \left(P_{ct} + \frac{T_{ab}}{F} \right) \times \text{Hor}\left(P_{ct} + \frac{T_{ab}}{F} \right) \times \left(\frac{S}{r}\right) \quad (2)$$

$$P_{ct} = P_{DAC} + P_{filter} + P_{mixer} + P_{synth} \quad (3)$$

Where, T_{ab} is power level used by transmitting node. T_{ab} can range from T_{min} to T_{max} as per power control scheme. F ∈ (0, 1] is efficiency of power amplifier. H is time required to transmit a packet of size S with data rate r.

3.2. Receiving Power Model (E_r)

Power received at receiving node $R_{a,b}$ decays with distance between transmitter and receiving node. Level of $T_{a,b}$ should be kept such that received signal is above a threshold value for successful decoding.

$$R_{a,b} = \frac{T_{a,b}}{|x_a - x_b|^{\alpha}} + N_o \quad (4)$$

Where, α is path loss exponent, $|x_a - x_b|$ is a distance between two nodes (a, b) and N_o is background signal.

From (2) and (4) energy consumption is directly related to transmission power. For path loss exponent α=2, reducing transmission range in half cuts required output power by $(\frac{1}{4})$. This means that by choosing shorter hops to cover same distance, the total required transmission power can be reduced ($\frac{1}{4}+\frac{1}{4}<1$) depending up on P_t and P_r value. ACK frame have negligible length so energy consumption due to them can be ignored and it is assumed that ACK are received without fail. Energy consumed in receiving a packet over a link connecting two nodes is given by receiving circuit (P_{cr}) as in equation (5).

$$E_R = P_{cr} \times H \tag{5}$$

$$E_R = P_{cr} \times \frac{S}{r} \tag{6}$$

$$P_{cr} = P_{ADC} + P_{filter} + P_{mixer} + P_{synth} + P_{LNA} + P_{IFA} \tag{7}$$

Where, P_{cr} is energy used by receiving circuit per unit time to receive, decode, and processing data packets. $P_{cr}$is dominated by energy consumption due to ADC, filter, mixer, frequency synthesizer, LNA, and IFA. To receive packet of size S with data rate r, E_R can be rewritten as (6).

3.3. Idle Power State Model (E_{idle})

This is a constant energy component consumed by hardware of a node, in spite of any communication going on. This can be assumed typically same as energy used by receiving circuit.

$$E_{idle} = P_{cr} \tag{8}$$

3.4. Reliable Transmission Modes

Reliable transmission modes can be broadly categorized in End to End Retransmission (EER) and Hop by Hop Retransmission (HHR). In the EER (CSMA, MACA) mode, in-between nodes along a path do not offer any retransmission by layer-2. If source node doesn't receive the acknowledgement from the destination within some pretended period, then it will resend the packet. In the HHR (802.11) mode, the source node and all in-between nodes provide layer-2 retransmissions. This work considers HHR mode. If e_{l_i} is probability of corruption of packet on a link l_1, then expected transmission attempts for successful transmission is given by $\frac{1}{1-e_{l_i}}$. So, net energy consumption due to transmission and reception becomes as below:

$$E_t = \frac{1}{1-e_{l_i}} \times \left(P_{ct} + \frac{T_{ab}}{F}\right) \times \frac{S}{r} \tag{9}$$

$$E_r = \frac{1}{1-e_{l_i}} \times P_{cr} \times \frac{S}{r} \tag{10}$$

Total energy consumption at wireless node i over a period of time can be given by (11).

$$E_i^T = E_t \times T_t + E_r \times T_r + E_{idle} \times T_{idle} \tag{11}$$

Where, T_t, T_r and T_{idle} are duration of transmitter staying in transmission, receiving and idle state respectively.

4. TRAFFIC MODEL

Traffic can be divided into two types: Inter cluster traffic and Intra-cluster traffic. In first case all traffic between mobile clients (MC) to other node outside of WMN or nodes of other cluster goes to-fro via gateway node. It is assumed that inter-cluster traffic is from the MCs to the gateway. While in second case both source and sink are within WMN. Client should communicate directly via MR, while bypassing gateway node. In case if such traffic is to be allowed from gateway then this will add-on to degradation of network performance as the capacity is constrained by that of gateways. Allowing ad hoc routing in the backend part requires MR with full knowledge of network, and increases MR overhead excessively. Keeping this in view WMN forms multi cluster collections of nodes, where each cluster is in-charged by one unique gateway to route traffic. So, this paper focuses on all traffic via gateway nodes. Authors in [8] have divided whole day into eight periods of duration of three hours each and reproduced here in Figure 3. Traffic profile probability is in respect to peak load.

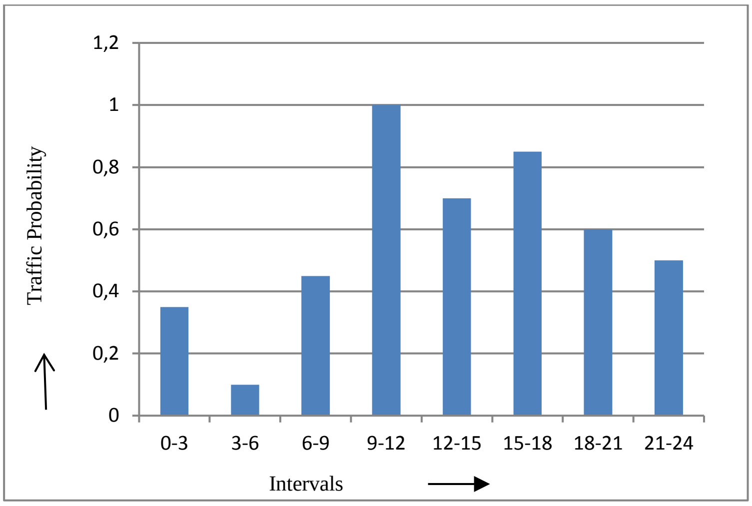


Figure 3*. Day division in eight time intervals with traffic probability*

Following assumptions have been followed:
1) MR'snodes are assumed to be fixed and bidirectional links can be setup.
2) Two nodes can communicate if they have direct mesh link between them. So if nodes don't fall within cover range of each other they have to follow a multi hop route.
3) Nodes have hierarchical relation; Client nodes request is collected at MAP and forwarded to gateway nodes via router nodes.
4) Mesh nodes are operational with several network interfaces each equipped with, so it can be concluded that the flow in a certain link does not influence that of nearer links. So, by appropriate frequency assignment interference, collision and overhearing can be minimized and their impact may be ignored.
5) Each link among two mesh nodes has a preset capacity.

5. PROBLEM FORMULATION

In this section, Linear Programming Problem (LPP) has been designed to find out optimal set of mesh routers to be switched off. Both communication and idle energy has been considered. Backhaul nodes are connected with fixed power source. Consider a WMN with set of MAP, MR, gateway nodes denoted by A, K, G respectively and set of edge denoted by E. Total set of nodes N in WMN is given below.

$$N = A + K + G \tag{12}$$

Objective Function Formulation:

$$\mathrm{Min}\left(\sum_{i\in N} E_i^T - \sum_{f_{i,j}\,\mathrm{or}\,f_{j,i}=0,\,i,j\,\in N} E_{idle}^i\right) \times \Delta T \tag{13}$$

Where, ΔT is duration of traffic profile interval. E_i^T is energy consumption of node i as given by (11). First factor take care of energy consumption of nodes involved in communication. Second factor accounts of nodes without any load and hence can be turned off.

Constraints Formulation:

If $f_{i,j}$ denotes flow through a link (i,j), then according to network flow constraint inflow is equal to outflow at a node. For an MR node flow constraint becomes as below:

$$\sum_{j\in k} f_{i,j} - \sum_{j\in k} f_{j,i} = 0 \forall i \in K \quad (14)$$

As MAP collects traffic from client and forwards same towards gateways node and vice versa. MAP i also acts as traffic collection point from client nodes and hence generator of traffict_i. They also forward data of neighbor mesh points, towards gateway nodes.

$$\sum_{j\in A,K} f_{i,j} - \sum_{j\in A,K} f_{j,i} = t_i \ \forall\ i \in A \quad (15)$$

All traffic generated at MAP is received by gateway node. For a gateway node i, constraint is given by (16). It simultaneously ensures existence of path between MAP and gateway node.

$$\sum_{i\in G} \sum_{j\in (k+A)} f_{j,i} = \sum_{i\in A} t_i \quad (16)$$

$$\sum_{i\in G} \sum_{j\in (k+A)} f_{i,j} = 0 \quad (17)$$

Link capacity is amount of data that can be transmitted by a link in each direction. Then for bidirectional link having capacity$L_{capacity}$, constraint becomes as below.

$$\sum_{(i,j)\in E} f_{i,j} \le L_{capacity} \forall\ i \in N \quad (18)$$

As problem space increases, number of variables and constraints becomes large. Solving LPP involves large computation. Hence may not be feasible [15] in practical scenario due to complexity. Hence, in next section a genetic algorithm based heuristics approach has been proposed.

6. ENERGY MINIMIZATION USING GENETIC ALGORITHM

In this section genetic algorithm based approach to identify and switch off underutilized mesh nodes will be designed. The contributions of proposed algorithm are the following:

1. To consolidate traffic over few active nodes so that chances for sleep for other nodes can be increased to minimize overall energy consumption of network.
2. Approach accounts idle energy, communication energy, link error rate, and link load.
3. Quality of service is maintained by bypassing traffic from congested nodes as determined by link capacity.
4. As multi path routing may lead to transmission of packets out of order, single path routing is achieved.

Let's denote path p by ordered set of nodes and p' as ordered set of links. Let flow $f_{S,D}$ to be transferred from source S to destination D. Equation (19) presents an energy aware path metric (EAM) to be used by genetic algorithm based approach proposed in algorithm 1.

$$EAM = \sum_{i \in p} S_i^E + \sum_{l_i \in p'} \frac{1}{1-e_{l_i}} \times \left(\left(\frac{\left(\frac{T_{ab}}{F} + P_{ct}\right) S}{r} \right) + P_{cr} \frac{S}{r} \right) + L_{available}^{l_i} \text{ HIGH\_ENERGY} \quad (19)$$

Where, first factor considers static energy consumption; S_i^E accounts for traffic consolidation as below in (20). Second factor gives energy consumption for actual transmission or reception of a packet successfully. The link quality determines expected number of transmission required. While third one avoids choosing paths having insufficient capacity to accommodate new flow $f_{S,D}$. $L_{available}^{i}$ is a boolean variable to track availability of link capacity.

$$S_i^E = \left(\frac{E_{idle}}{load_{n_i} + traffictotransmit} \right) \left(1 - L_{available}^{l_i} \right) \quad (20)$$

$$\text{If} \left(L_{capacity} - L_{available}^{l_i} \right) \geq f_{S,D} \Rightarrow L_{available}^{l_i} = 0 \text{ else} L_{available}^{l_i} = 1 \quad (21)$$

where,

e_{l_i}= Error rate on link l_i
S = Size of packet
r = Data rate
P_{ct}= Energy consumption transmitting circuit per unit time
P_{cr}= Energy used by receiving circuit per unit time
T_{ab}= Transmission power level
F = Efficiency of power amplifier
E_{idle} = Idle energy consumption of node

Towards effort of traffic consolidation (19) helps to decide upon which MR should be turned off during a given time interval. But relative order of path selection by MAP impact best path chosen by other MAP. So there must be an optimal order where overall energy consumed by network can be maximized. Algorithm 1 based on Genetic Algorithm [16] finds optimal order and hence minimizes network energy consumption. The visual presentation of algorithm is given in flowchart at figure 4. The encoding of chromosome and genetic operators are given next in section (6.1) and section (6.2) respectively. In algorithm 1 termination condition can be determined by maximum generations allowed.

Algorithm 1. Energy Optimization in Wireless Mesh Network

Genetic_Algorithm

1. Initialize population as per permutation encoding for n MAP in section 6.1;
2. While termination condition not satisfied do 2.1 to 2.4
2.1 Evaluate current population using Evaluate_Individual();
2.2 Select parents using tournament selection;
2.3 Apply genetic operators (crossover and mutation) to parents to create children as in section 6.2;
2.4 Set current population equal to be the new child population;
3. Switch off nodes having zero loads;

Evaluate_Individual (Individual $ind_{n,2}$)

1. Initialize $load_i$=0 $i \in 1..N$;
2. For i=1 to N
Find all possible routing paths from source node (ind_{i1}) to destination node ($ind_{I,2}$), using depth first search algorithm[17];

3. Evaluates path using (19), and choose minimum value path as best path;
4. Update load of nodes on chosen best path;
5. Set chromosome fitness to energy consumption of whole network after switching off nodes with zero loads;

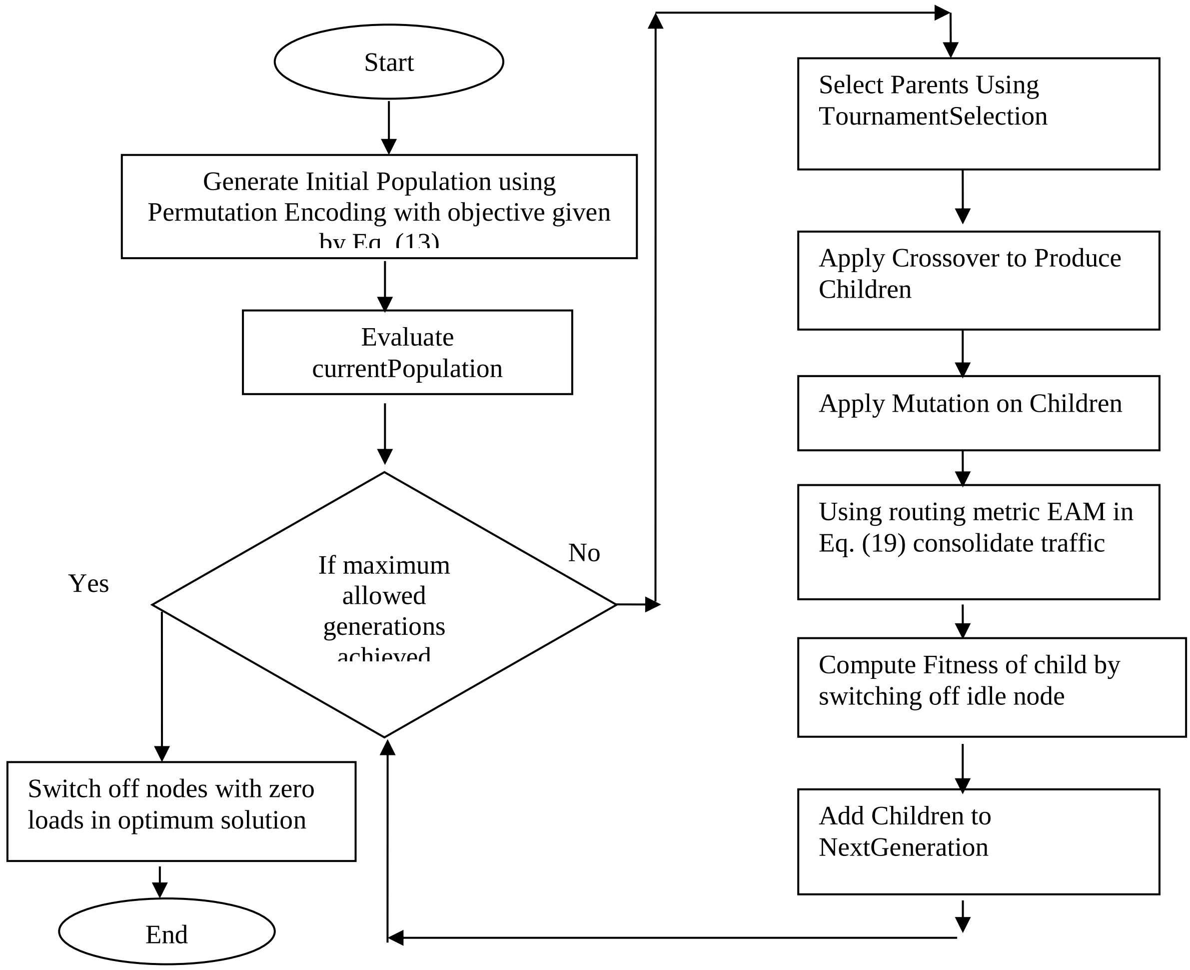


Figure 4. *Energy optimization in wireless mesh network*

6.1. Encoding Chromosome

A chromosome is a possible solution for the network and represented as ordered sequence of MAP. The permutation encoding, which is best suitable for our problem space is adopted. For network with n MAP numbered from 1 to n, G gateways numbered from 1 to g gives n! × g! possible search space. Size of chromosome is determined by number of MAP. For n=10,g=3 candidate solution is illustrated below in figure 5. First row identifies ordered sequence of MAP and second row reflects selected gateway for routing the flow of MAP.

3	8	5	1	10	2	4	6	7	9
1	3	1	2	2	1	3	2	1	1

Figure 5. *Sample candidate chromosome*

6.2. Operators

Single point crossover: Crossover is similar to reproduction process. A child is formed by taking attributes from multiple parents. Here two parents and a crossover point is selected as in Figure 6(a), Figure 6(b) using tournament selection. The genes are copied to first child from the first parent up to crossover point, then the second parent is searched for gene from left to right which are not yet added to child. If not added yet then add to next available position in first child as in Figure 6(c). Similarly second child is formulated as shown in Figure 6(d).

Mutation: It is an operator to maintain, genetic diversity and performed with very low probability. In our problem space, two positions in parent are randomly selected as in Figure 6(c) and Figure 6(d) with given mutation probability and gene values are exchanged as in Figure 6(e) and Figure 6(f).

3	8	5	1	10	2	4	6	7	9
1	3	1	2	2	1	3	2	1	1

Crossover Point

(a)

10	1	5	3	2	9	6	4	7	8
3	1	2	3	2	2	1	2	2	2

Crossover Point

(b)

3	8	5	1	10	2	9	6	4	7
1	3	1	2	3	2	2	1	2	2

Mutation Site Mutation Site

(c)

10	1	5	3	8	2	4	6	7	9
3	1	2	3	3	1	3	2	1	1

Mutation Site Mutation Site

(d)

3	8	9	1	10	2	5	6	4	7
1	3	2	2	3	2	1	1	2	2

(e)

10	1	5	6	8	2	4	3	7	9
3	1	2	2	3	1	3	3	1	1

(f)

***Figure 6**. a) Parent 1 b) Parent 2 c) Child 1: after crossover operation d) Child 2: after crossover operation e) Child 1: after mutation operation f) Child 2: after mutation operation*

7. SIMULATION AND ANALYSIS

Algorithm has been implemented in Visual C++. Analysis for topology in Figure 7, Figure 10 and Figure 11 with increasing number to nodes 10, 25, 133 respectively have been performed using parameters in Table 1, Table 2 and Table 3. The topology in Figure 7, Figure 10 and Figure 11 corresponds to a small topology, gridtopologyand hypothetical wireless mesh network of south campus of Panjab University, Chandigarh respectively. The small topology network is considered for mean of ease in analysis. Grid topology network is widely used for example topology is suitable to cover area near train track, roads etc. While hypothetical wireless mesh network of south campus of Panjab University, Chandigarh is used to consider a realistic example. The simulations were performed for 10 times for each instance. Optimal solutions were found repeated. Solution quality is measured by energy saved and number nodes that can be put in sleep mode.

For each topology two cases have been considered. Case A denotes when all links have equal link capacity, while in case B congestion near to gateway node has been relaxed by increasing the capacity of links joining the gateway nodes. Simulated results for topology in Figure 7, Figure 10 and Figure 11 are given in Table 4, Table 5 and Table 6 respectively. Heading C, D, E, F, G in Table 4, Table 5 and Table 6 implies as follows.

Column C denotes interval number corresponding to Figure 3, column D gives number of sleeping nodes after running proposed algorithm. While column E is energy consumption of whole network before implementation of proposed algorithm measured in joules i.e. traffic consolidation is not performed and traffic is routed via Ad hoc On-Demand Distance Vector Routing (AODV). Column F represents energy consumption of whole network after implementation of proposed algorithm measured in joules. Column G gives energy saved in joules given by difference of before and after implementation of algorithm.

Table 1. *Parameter setting of GA*

GA parameter	Value	Description
Length of Chromosome	Fixed length(N)	Given by number of mesh access points
Encoding Chromosome	Permutation Encoding	A possible solution for the network
Maximum iterations	20	The successive generations no longer produce better results
Population size	30	Number of chromosomes in a population
Selection strategy	Tournament Selection	Method used to select the best chromosome
Crossover operator	Variation of Single point crossover	Crossover is similar to reproduction process. A child is formed by taking attributes from multiple parents
Crossover rate	0.8	Should be high
Mutation rate	0.01	To maintain genetic diversity, Gene values are exchanged with very low probability

Table 2. *List of parameters values*

Parameters	Value	Parameters	Value
HIGH_ENERGY	100	P_{LNA}	20.0 mW
Transmission power (T_{ab})	26.6 mW	P_{syn}	50 mW
N_o, background signal	Null	P_{IFA}	3 mW
Size of packet	1024 bytes	P^{t}_{filter}	2.5 mW
Bandwidth (r)	5 Mbps	P^{r}_{filter}	2.5 mW
Amplifier Efficiency (F)	0.75	P_{DAC}	15.4 mW
Path loss exponent (α)	2	P_{ADC}	14 mW
P_{mix}	30.3mW	P_{idle}	119.8 mW

Table 3. *Derived parameters*

Parameters	**Value**	**Parameters**	**Value**
P_{ct}	98.2 mW	Energy used in transmitting a packet	3.1 mJ
P_{cr}	119.8 mW	Energy used in receiving a packet	0.2 mJ

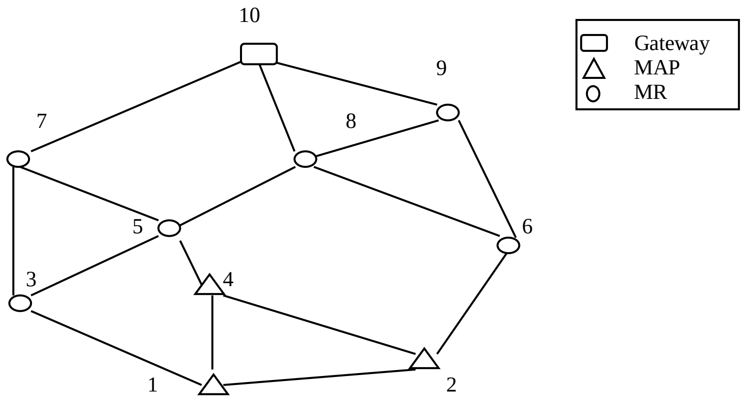


Figure 7. *Small topology network*

Results of small topology network (Figure 7) in Table 4, shows that for both Case A and B, during second interval (minimum load) (Figure 3) of a day, our approach consolidates the traffic over nodes (1, 2, 4, 6, 9, 10) and allow nodes (3, 5, 7, 8) to sleep. But without proposed GA algorithm, AODV still requires all nodes to be in active mode to route same traffic of MAP (1, 2, 4). Whereas for Case A, interval four (maximum load) (Figure 3) requires all nodes in active state, due to heavy traffic. While in Case B one node can be allowed in sleep mode. Figure 8 gives trade off in increase in communication energy and saving in ideal energy for small topology network in Case B. Traffic consolidation is possible only if saving in ideal energy outperform increase in communication energy. Screen shot of optimum chromosome result is given in Figure 9.

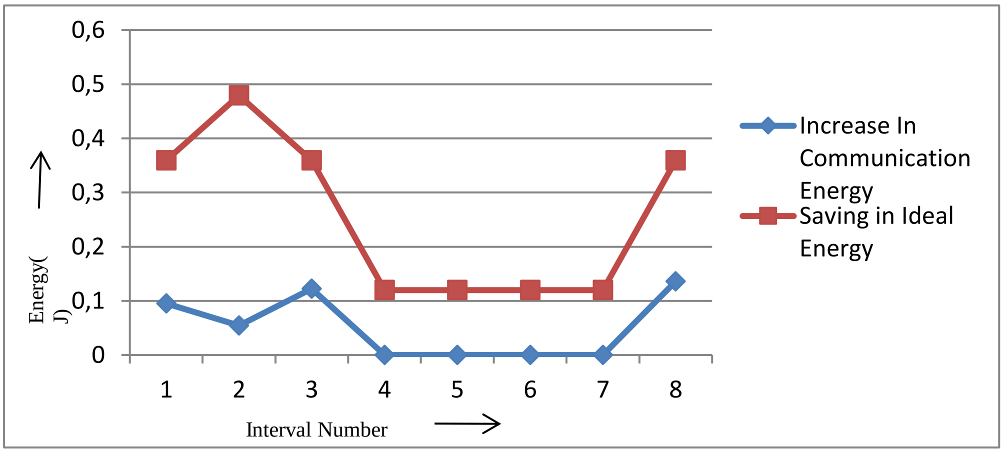


Figure 8. *Comparison of increase in communication and saving in ideal energy in small topology network for case B*

Table 4.*Results of small topology, number of nodes =10 (mesh access point=3, gateway= 1)*

C	Case A				Case B			
	D	**E**	**F**	**G**	**D**	**E**	**F**	**G**
1	2	22194.45	20520	1674.45	3	19880.45	17027.38	2853.06
2	4	15582.99	10800	4782.99	4	14921.84	10334.16	4587.68
3	2	24839.03	23544	1295.03	3	21863.89	19304.67	2559.21
4	0	39384.25	39384.25	0	1	32772.82	31478.97	1293.84
5	0	31450.47	31450.46	0	1	26822.49	25528.60	1293.88
6	0	35417.37	35417.37	0	1	29797.65	28503.79	1293.87
7	0	28805.91	28805.9	0	1	24839.05	23544	1295.05
8	2	26161.33	26161.33	0	3	22855.61	20443.32	2412.29

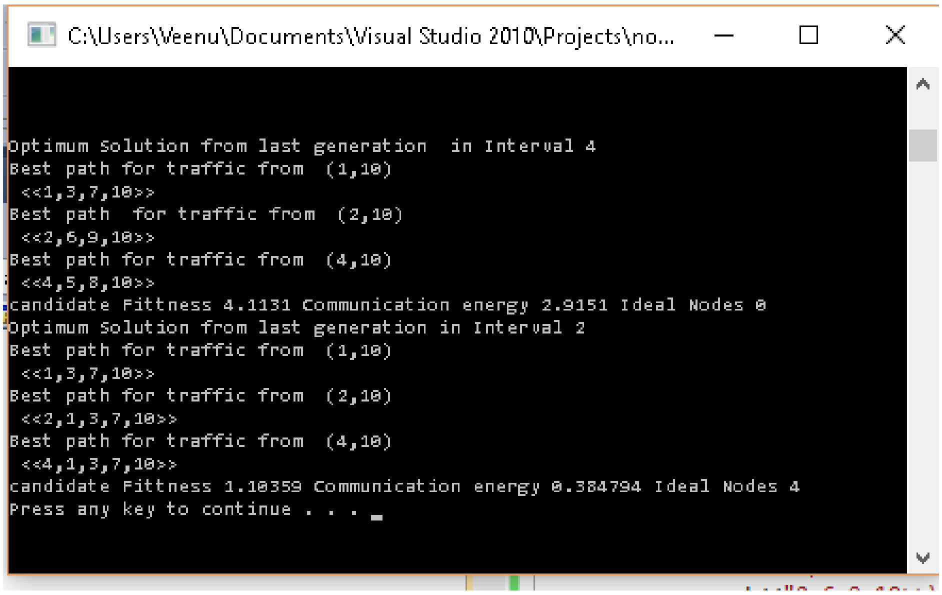


Figure 9. *Screen shot in small topology network*

Similarly, results of grid topology network (Figure 10), as in Table 5, reveals that during second interval, sleeping nodes are maximum. For Case A, due to congestion near gateway, nodes cannot be put in sleep mode during interval 4, 5, 6, and 7. But by allowing more bandwidth for links connecting gateway nodes more traffic consolidation can be achieved. As shown in Case B, energy efficiency increases by relaxing congestion near gateway nodes.

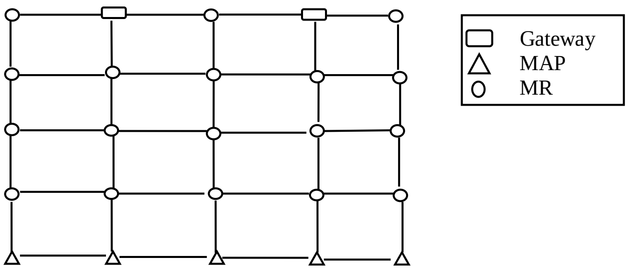


Figure 10. *Grid topology network*

Table 5. *Results of grid topology, number of nodes =25 (mesh access point=5, gateway= 2)*

C	Case A				Case B			
	D	**E**	**F**	**G**	**D**	**E**	**F**	**G**
1	8	56054.34	51820.24	4234.1	9	52195.86	46669.72	5526.14
2	13	39158.38	24635.23	14523.15	13	38055.96	23533.31	14522.66
3	8	62812.71	60341.76	2471	9	57851.82	54000	3851.82
4	0	99983.81	99983.81	0	3	88959.6	85029.16	3930.45
5	0	79708.67	79654.64	54.02	3	71991.72	68040	3951.72
6	0	89846.24	89846.24	0	3	80475.66	76464	4011.66
7	0	72950.28	72950.28	0	3	66335.76	62402.4	3933.36
8	8	66191.904	64602.468	1589.436	9	60679.8	57798.36	2881.44

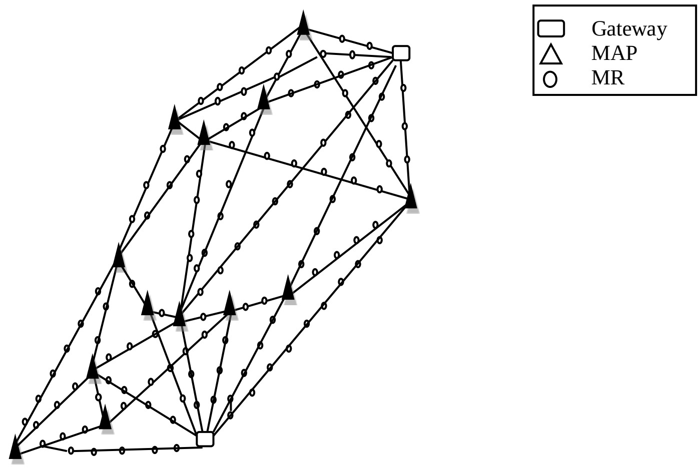


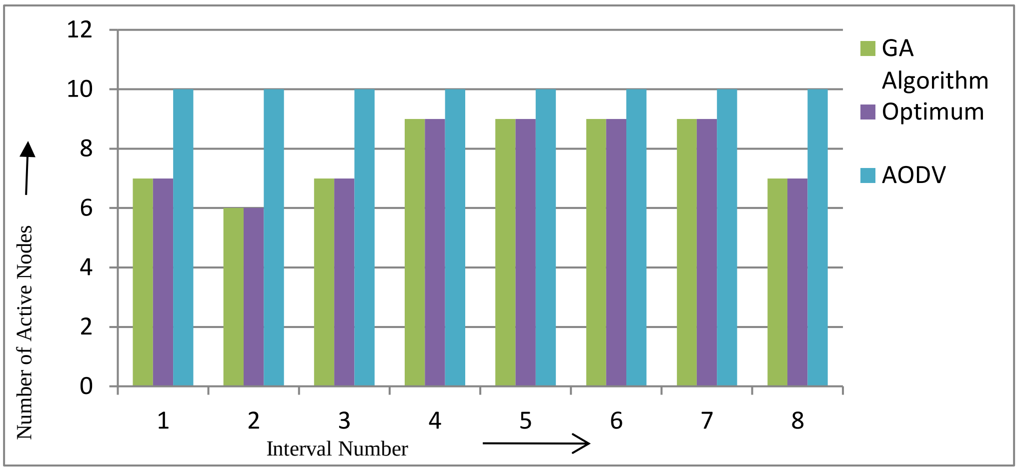
Figure 11. *Hypothetical network*

Results of hypothetical wireless mesh network of south campus of Panjab University, Chandigarh (figure 11), in Table 6, reveals that as traffic load decreases more traffic can be consolidated to fewer nodes and hence rest of idle nodes can be allowed to switch off. The numbers of sleeping nodes are same in interval 1, 3, and 8 due to adopted single path routing. By relaxing single path routing and allowing multi path routing more idle nodes and hence more energy saving can be achieved.

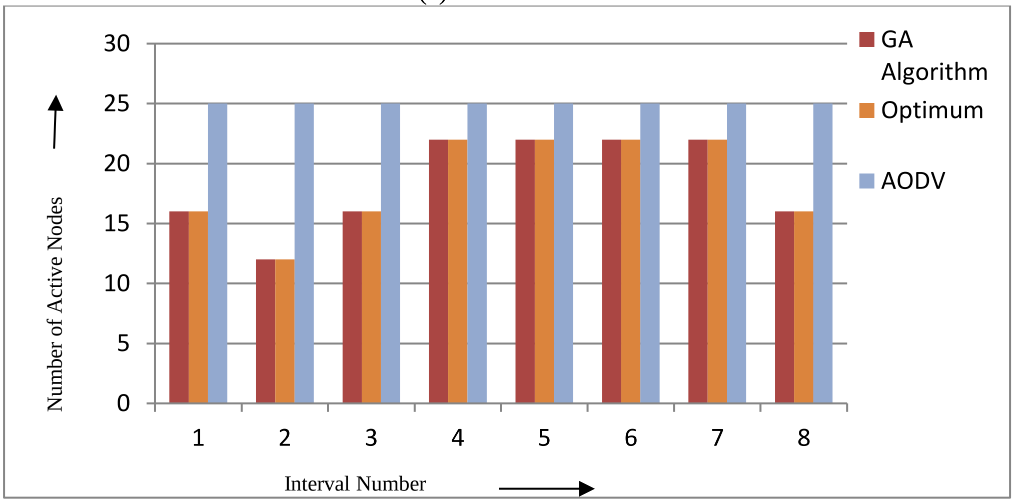
Table 6. *Results of hypothetical wireless mesh network of south campus of panjab university, chandigarh, number of nodes =133 (mesh access point=13, gateway= 2)*

C	Case A				Case B			
	D	**E**	**F**	**G**	**D**	**E**	**F**	**G**
1	78	301357.8	154465.92	146891.9	81	201339.46	120759.12	80580.33
2	87	209530.8	95904	113626.8	87	180954.13	80085.56	100868.6
3	78	338088.6	178266.96	159821.6	81	209493.58	136038.96	73454.62
4	35	540108	494098.92	46009.08	79	254341.3	151408.44	102932.9
5	35	429915.6	383908.68	46006.92	77	229878.91	153702.36	76176.55
6	35	485011.8	439020	45991.8	79	242110.10	139177.3	102932.7
7	35	393184.8	347176.8	46008	77	221724.78	142095.6	79629.18
8	78	356454	190166.4	166287.6	81	213570.65	143678.9	69891.77

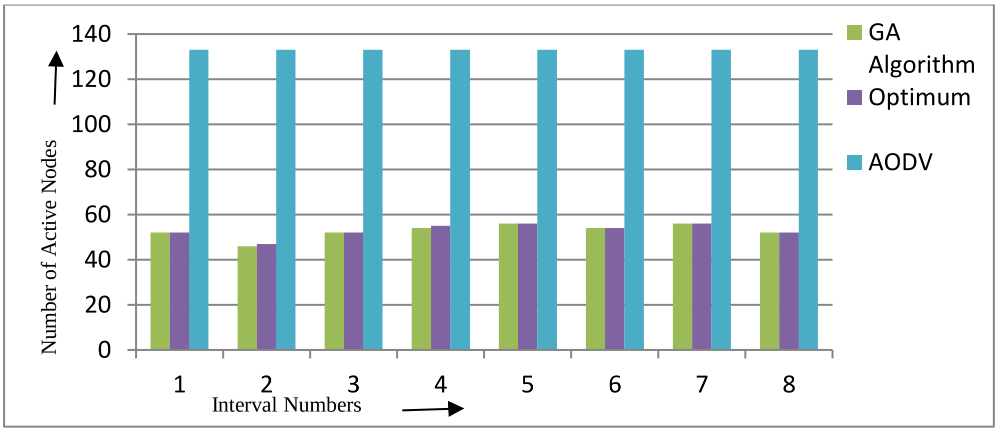
Further, Figure 12 gives comparison of proposed genetic algorithm with respect to AODV and optimum in term of number of active nodes needed. Results are found much close to that of optimum one and better than when no traffic consolidation is performed and traffic is routed with AODV. A brief comparison with existing work is given in Table 7.



(a)



(b)



(c)

Figure 12. *Number of active nodes with respect to traffic profile during eight interval of a day a) small topology b) grid topology c) hypothetical network*

Table 7. *Comparison with existing work*

Parameters	Paper [2-7]	Paper [8]	Paper[9]	Paper[11]	Our Approach
Suitable for network with nodes having no power constraint	No	yes	Yes	No	Yes
Transmission Energy Considered	No	No	No	No	Yes
Reception Energy Considered	No	No	No	No	Yes
MILP Proposed	No	Yes	Yes	No	Yes
Traffic Consolidation routing	No	No	No	No	Yes
Heuristic Based optimization	No	No	No	No	Yes
Link Quality Considered	No (except [6])	No	No	Yes	Yes
No of active nodes Reduced	No	Yes	Yes	No	Yes

8. CONCLUSIONS AND FUTURE WORK

In this research work genetic algorithm based traffic consolidation approach has been proposed. With assumption of predetermined traffic profile, underutilized nodes are identified and allowed to sleep. Unlike [8-9], our approachfavors utilization of active network resources to their full capacity by considering communication energy and traffic consolidation. Trade-off in saving by switching off underutilized nodes and transmission or reception energy cost has been considered. Results prove that significant energy can be saved by traffic consolidation. Such kind of resource management can be incorporated for WMNs, to allow integrated and distant control of all mesh devices and to alter of their configuration as per requirement (in hours). Nodes are assumed with multiple network interfaces. Work can be easily extended for network with omni directional antenna by considering interference of links as well.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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