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تقييم أداء التشكيلة التفاضلية القائمة على التطور التفاضلي في شبكات الشبكات اللاسلكية

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الخلاصة

حققت شبكات الشبكات اللاسلكية (WMNs) اهتماما أكبر في مجال الاتصالات اللاسلكية. نشر العقدة التقليدية يسمح التوزيع العشوائي للموجهات شبكة مما يزيد من عدد من أجهزة التوجيه شبكة وبالتالي زيادة تكلفة التصميم أيضا. من أجل الحصول على الموضع الأمثل لعقد شبكة، تعتبر مشكلة وضع العقدة مشكلة الأمثل. هنا يتم صياغة المشكلة كمشكلة موقع المرفق. ويقترح نهج التفاضلية غامض (FDE) جنبا إلى جنب مع طريقة تخصيص الوزن (TW) طريقة التعيين الأمثل وضع العقد شبكة وتخصيص البوابات. تكلفة التصميم (DC) وتكلفة الإرسال (TC) هما هدفان إلى أدنى حد يتم حلهما باستخدام الطريقة المقترحة. وتبين نتائج المحاكاة أنه في المتوسط، يتم تقليل (DC) باستخدام نهج (FDE) إلى الحد الأدنى 10 ٪ مقارنة مع خوارزمية (2.8٪، TC) من (1.2٪ SA) من طرق (DE). ويخفض مقياس أداء الشبكة المسمى معدل الفشل (FR) وهدف (TC) بدرجة كبيرة باستخدام الموضع القائم على (FDE). ويتم تقييم أداء الشبكة بتدفقات بمعدلات ثابتة (CBR) متعددة وتظهر نتائج المحاكاة زيادة بنسبة 10 ٪ إلى 5 ٪ في معدل الإنتاجية ومعدل تسليم الرزم مقارنة بالطرق الحالية.

Performance evaluation of fuzzy DE based node placement in WMN

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ABSTRACT

Wireless Mesh Networks (WMNs) have received a greater attention in wireless communication field. The conventional node deployment allows random distribution of mesh routers, which increases the number of mesh routers, and hence the design cost also increases. In order to have an optimal placement of mesh nodes, the node placement problem is considered as an optimization problem. Here, the problem is formulated as a facility location problem. A Fuzzy Differential Evolution (FDE) approach is proposed along with a traffic weight (TW) assignment method for optimal placement of mesh nodes and allotting gateways. Design Cost (DC) and Transmission Cost (TC) are the two minimization objectives, which are solved using the proposed method. The simulation results show that, on average, the DC using FDE approach is minimized 10% compared to TW algorithm, 2.8% less than SA, and 1.2% less than DE methods. A network performance metric called failure rate (FR) and the TC objective are considerably reduced using the FDE based placement. The performance of the network is evaluated with multiple CBR flows, and the simulation results show 10% to 5% increase in the throughput and packet delivery rate compared to the existing approaches.

Keywords: WMN, Differential Evolution; Fuzzy DE; simulated annealing, traffic weight, Transmission Cost; design cost; failure rate.

INTRODUCTION

Wireless Mesh Networks (WMNs) are an attractive and upcoming technology with improved scalability, reliability, and throughput for industry and academic communities. WMN provides the capacity to interconnect multiple homogenous or heterogeneous networks. Homogeneous networks are of identical platform nodes. Heterogeneous networks are different types of nodes. Mesh nodes are able to self-organize by themselves. They provide the interconnections among all networked nodes where each node sends and receives data. WMNs are able to reconfigure themselves when the nodes are added or removed from networks. They automatically discover topology change and self-adaptively modify the routing for more efficient data transmission. Generally, a wireless mesh network consists of three kinds of nodes: the mesh router, mesh gateway, and mesh client (Akyildiz *et al.*, 2005; Sheeba *et al.*, 2012b) as shown in Figure 1. Mesh routers have powerful capacities in forwarding data with low mobility. They form the backbone network that automatically sets and maintains the connection even if there is any failure in nodes. Ernst & Brown (2013) have discussed that the mesh routers near the gateways aim to prioritize and can handle their own traffic. The mobile clients forward the data to the neighborhood nodes. In conventional networks the wireless devices get connected first with the access points. But in this type of architecture the nodes may directly communicate with the neighboring nodes. WMN uses long distance transmission protocol 802.11, and specifically for WLAN mesh networks 802.11s are used. The 802.11s WLAN mesh Networking integrates mesh networking services and protocols with 802.11 at the MAC Layer (Younis *et al.*, 2008). The mesh gateway supports both protocols. The gateways and routers automatically interconnect with each other to form a mesh network. Multiple gateway deployment is one of the challenging issues. Increasing the number of gateways reduces the average number of hops and avoids single failures in the network. The mesh routers are normal routers but have additional features of mesh networking. Wireless mesh networking is becoming one of the important networking infrastructures due to their low cost and maintenance. Placement of mesh nodes plays a vital role in achieving good performance such as throughput, reliability, stability, and packet delivery. Node placement problems are computationally hard to solve for optimality. Random node placements give less QOS performance. Placement strategies can be classified as dynamic and static depending on the implementation of optimization at the time of deployment or when the system is in operation. The clients can be stationary or mobile. Here stationary clients are considered for applications such as facility locations, logistics, and services (Xhafa *et al.*, 2015; Dhivya & Sheeba 2016a).

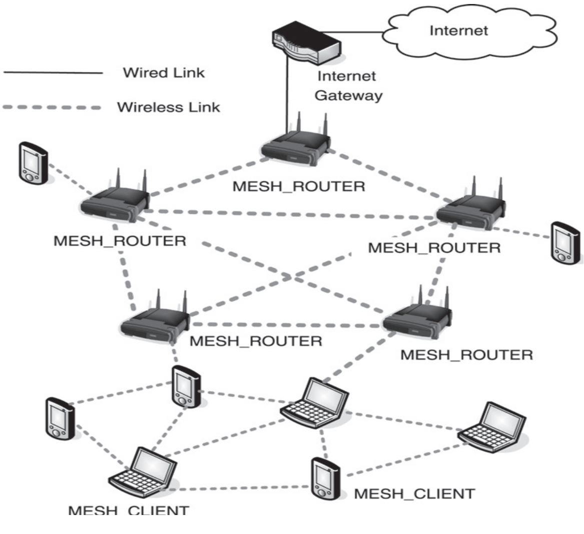


Figure 1. Architecture of Wireless Mesh Networks.

Related Works

Given the number of routers to deploy and their positions, an optimization problem is formulated to place the routers with increased connectivity and coverage. Considering the router placement problem as facility location problem with the assumption that the mesh routers are the facilities, which gives services such as Internet to the client nodes, Xhafa *et al.* (2015) have experimentally implemented and evaluated the Tabu search algorithm for optimizing various instances of the giant component to maximize the connectivity of the network. Sanni *et al.* (2012) has sketched out an Internet gateway (IGW) optimization problem for optimizing the placement of gateways. The authors have not experimentally evaluated the problem with any of the conventional methods or evolutionary computations.

Wu *et al.* (2010) formulated a Cost Effective Node Placement (CENP) problem and experimentally evaluated the optimization problem to minimize the cost using MSC-based coverage algorithm, weighted clustering algorithm, and gateway rooted tree pruning algorithm to determine the positions of mesh nodes. Barolli *et al.* (2015) developed a web interface of WMN-GA system and have evaluated the system using NS3 simulator. The algorithm tries to optimize the network objectives such as connectivity and coverage. For various generations the network performance parameters such as throughput, packet delivery, and jitter are observed. Xhafa *et al.* (2011) selected two indispensable objectives such as connectivity and user coverage. As the optimization problem is computationally hard to solve for optimality heuristic approach, simulated annealing algorithm is evaluated for various instances of grid sizes. The search algorithm explores the neighborhood using four different movements like random, radius, swap, and combination. The authors have experimentally evaluated the algorithm for router placements based on facility location problem for varied instances of network size and capturing the topological placements of the client nodes. Benyamina *et al.* (2015) formulated three planning models, that is, (a) load balanced model, (b) interference model, and (c) flow capacity model. The authors have simultaneously optimized the deployment cost and network throughput. Many experiments have been conducted where results show that the load balanced model generates broader set of non-dominated solutions for cheaper planning of networks. Using a network simulator the models are evaluated and the results concluded that the load balanced model provides better throughput.

Mikhaylov & Tervonen (2012) have presented the idea of using energy harvesters in sensor node batteries. The available and the identified power sources are utilized to save the batteries from draining. The proposed Energy Aware Data-centric (EAD) routing protocol improves the life time of the sensor networks. Yerra & Rajalakshmi (2014) have discussed the importance of transmission power without increasing the interference between the routers. Low power sensor nodes would increase the number of hops and, thereby, the reason to increase the delay in the network.

The remainder of the paper is structured as follows. We present the system model and problem formulation in Section 3. The existing traffic weight based placement method is discussed in Section 4. In Section 5 the proposed evolutionary method fuzzy DE is explained. Simulation results and performance comparison are given in Sections 6 and 7 concluding the paper.

System Configuration

System model

The system can be defined as follows:

- A set of candidate positions to be selected, say T.
- A set of mesh nodes, say U.
- Let V be the set of all nodes in the network (mesh routers, gateways, and client nodes) represented as $V \leftarrow U \cup \mathrm{T}$.
- The network graph with edges E is represented as $G(V, E)$.

Let Cj be the set of nodes in the coverage range or communication range of node i.

$$C_j = \{ j \varepsilon V, j \neq i, d(i,j) \leq R \} \forall i \varepsilon U \tag{1}$$

where $d(i,j)$ represents the Euclidean distance between the node i and j. R denotes the maximum communication range of node.

Let the edges E be the set of all possible links

$$E = \{e(i,j); i\varepsilon\, \mathrm{U}, \mathrm{j}\,\varepsilon\, \mathrm{C_j}\} \tag{2}$$

A grid of $n \times n$ is considered and divided into small cells. The mesh routers are evenly placed in each cell and the clients are distributed randomly. In this proposed work rechargeable routers are considered for energy efficient placement.

Problem formulation

A rough assumption is done that the mesh routers synchronize with the client nodes in each time slot. The energy charging and discharging model of mesh router is incurred from the paper of Huan et.al. (2015). An optimization model is formulated to minimize the cost. Due to insufficient supply of stored energy any client may get disconnected temporarily with the mesh router, which is frequently referred to as node failure. Essentially there are two models in a multi-objective optimization, hierarchical and simultaneous model. Here a bi-objective hierarchical optimization model is used to formulate an objective function to minimize design cost (DC) and Transmission Cost (TC) with sustainability constraints. Hence for a problem with two objectives one is selected as the primary objective and the other as secondary one. Here DC is considered as the primary one and TC as the secondary.

The objective function is given by

$$Minimize \sum_{\mathrm{i,j=1}}^{\mathrm{n}} (\mathrm{C_{pi}\, M_{ri} + C_{pj} M_{gj}}) \tag{3}$$

where $\mathrm{Cpi, Cpj}$ are the placement cost of mesh routers and gateways. *Mri* is the ith mesh router and *Mrj* is the jth mesh gateway which is defined as

$$Mri = \begin{Bmatrix} 1 & \text{if the mesh router is active} \\ 0 & \text{otherwise} \end{Bmatrix} \tag{4}$$

$$Mrj = \begin{Bmatrix} 1 & \text{if the mesh gateway is active} \\ 0 & \text{otherwise} \end{Bmatrix} \tag{5}$$

Subjected to the constraints.

The Euclidean distance between the gateway nodes is expressed as

$$d(i,j) \geq G_r \tag{6}$$

where *Gr* is the gateway radius (communication range).

Traffic flow constraint

Let *lij* is a binary variable denoting the total flow link between the mesh nodes

$$lij \in (0,1)\ v \in V, mr \in MR \tag{7}$$

Energy consumption and sustainability constraint

$$(e_{mrj} + e_{gj}) \leq \mathrm{E}_{mrj} + \mathrm{E}_{gj}\ \forall mr, g \in MR \tag{8}$$

where e_{mrj} is the energy consumed by the mesh routers and e_{gj} is the energy consumed by the gateways for uplink and downlink. E_{mrj} and E_{gj} indicate the harvested energy for routers and gateways.

$$(e_{mrj} + e_{gj}) = P' \times T \tag{9}$$

$$\mathrm{E}_{mrj} + \mathrm{E}_{\mathrm{gj}} = P \oplus \times T \tag{10}$$

where P' and $P \oplus$ are the discharging rate and charging rate of the mesh routers. The failure rate (FR) is checked with a threshold condition as given in Eq. (11).

$$FR \leq \text{FR threshold} \tag{11}$$

The constraints are discussed in brief as follows. Eq. (6) indicates that the gateway radius, that is, the communication range, should be less than the Euclidean distance between the gateways to avoid interference between the gateways. The constraint specified in Eq. (7) ensures that one minimum link exists between the gateway and the end user through the routers. One of the indispensable characteristics in WMN is its self-healing feature. Even if one router fails the packet is forwarded to another alternative route to avoid transmission delay. In Eq. (8) the energy consumed by the node must be less than the harvested energy. Average discharging and charging rates of the rechargeable routers are given in Eq. (9) and (10). The FR condition specified in Eq (11) is expressed as

$$FR = \sum_{k \in K} \sum_{i \in S} (1 - \sum_{j \in T} x_{ij}(k)) \Big/ |S| * |K \tag{12}$$

where $x_{\mathrm{ij}}(\mathrm{k}) = \begin{Bmatrix} 1 \text{ if a node is associated with the MR} \\ 0 \text{ otherwise} \end{Bmatrix}$, $|S|$ stands for the total number of clients and $|K|$ denotes the time slots. The rechargeable routers are equipped with battery storage. Let us divide the continuous time line of energy stored into consecutive slots of ‘t’. Failure rate indicates the ratio of number of connection failures to the number of attempts done by the mesh clients. As the mesh clients move far away from the mesh routers they try to consume more energy; hence they get disconnected due to insufficient harvested energy. The energy charging and discharging of a router is defined with a discrete time energy model as

$$E(t) = E(t-1) + H(t) - C(t) \tag{13}$$

where $E(t)$ is the residual energy of the router after the t^{th} slot. If t=0, $E(0)$ is the initial stored energy in the router. Let the harvested energy be $H(t)$, the energy consumed be $C(t)$ and the maximum charging power of rechargeable routers be 100mW. Here two cases can be fitted:

Case (1): If $H(t) > C(t)$ and $E(t) = 1$ failure rate is less (14)

Case (2): If $H(t) < C(t)$ and $E(t) = 0$ failure rate is more (15)

The simulation period is set as 12 hours, that is, half a day, which is divided into 108 consecutive slots each with time duration of 400 seconds. The algorithms implemented for node placement check the failure rate, which is considered as one of the network performance measures. We repeat the simulations for 1000 generations and calculate the failure rate percentage after each generation.

Materials And Methods

Traffic weight based node placement

Each mesh router is placed evenly in each cell of the grid area of interest. Here we have selected a 5x5 grid region. The client nodes are distributed unevenly in each cell as shown in Figure 2. The *Gr* is determined using the number of routers and gateways to avoid interference between the gateways.

$$G_r = round\,\frac{\sqrt{N_r}}{2\sqrt{N_g}} \tag{16}$$

where *Nr* represent the number of mesh routers and *Ng* represent the number of gateways. The traffic demand on each mesh router is calculated from the number of nodes connected to the router. The algorithm calculates the traffic weight $TW(i)$ (Zhou *et al.*, 2010; Sheeba & Nachiappan, 2015) using the demand $D(i)$ of the ith router.

$TW(i)$ calculation is given as

$$\begin{aligned} TW(i) &= (G_{r+1})D(i) + G_r\,(\text{Traffic demand of 1-hop neighbour of } M_{ri}) + \\ &(G_{r-1})(\mathit{Traffic}\text{ demand of 2-hop neighbour of } M_{ri}) + \ldots\ldots\ldots\ldots \end{aligned} \tag{17}$$

The traffic weight is calculated using Eq. (17) in each cell, and the gateway positions are located depending on the traffic demand. they are Optimal placement of gateways is important and challenging. In large scale networks if the demand increases, the number of gateways also increases.

12	6	10	8	5
3	6	6	8	9
9	10	7	8	11
10	9	5	9	9
8	8	8	4	10

(a) Distribution of client nodes

159	202	215	210	162
201	261	284	266	218
222	293	312	302	237
212	265	293	275	217
160	206	212	202	165

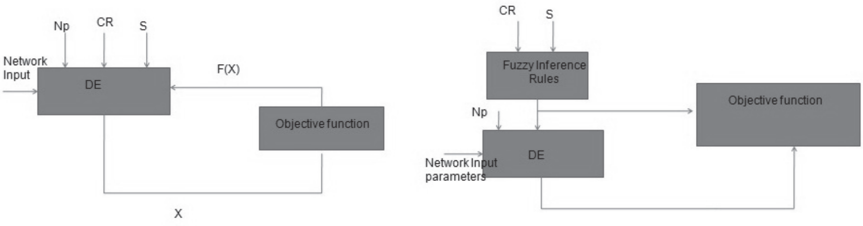
(b) Traffic weight calculation

Figure 2. Distribution of mesh clients with the corresponding Traffic Weight calculation.

Transmission cost is related to the energy consumption of the nodes. Green networking is achieving tremendous growth; hence minimizing the energy consumption is utmost important. Natural energy harvesters like solar, hydro, wind, and so on help in reducing the failure rates of remote and rural located nodes. The harvested energy is stored as a backup source for the mesh routers and increases the sustainability and lifetime. Solar powered networking components are undergoing intensive research. The harvested energy from solar cells are dynamic in nature due to unstable environmental conditions.

Fuzzy differential evolution

Differential Evolution (DE) is an elegant and simple population based approach for finding the global optima (Sheeba & Nachiappan, 2014; Das *et al.*, 2011). According to DE the crossover constant (CR) and scaling factor (S) are kept constant throughout the optimization process. Using the trial and error methodology the best parameters can be found out. But the proposed Fuzzy Differential Evolution (FDE) is a knowledge based system, which dynamically selects the best from the fuzzy set (Sheeba & Nachiappan, 2016b). The flow diagrams representing DE and FDE are shown in Figure 3(a), (b). The fuzzy system is classified as (a) fuzzification of inputs and outputs, (b) fuzzy rules, and (c) defuzzification. The fuzzy system makes the control parameters adaptive for the minimization process and finds the values for its parameters. The output function value is adapted based on the d1 (CR) and d2(S). The Mamdani fuzzy inference method is used to map the output function. The output of each rule is a fuzzy set and the output fuzzy set is the aggregation of all the sets (Jinila *et al.*, 2014; Boopathi *et al.*, 2015).

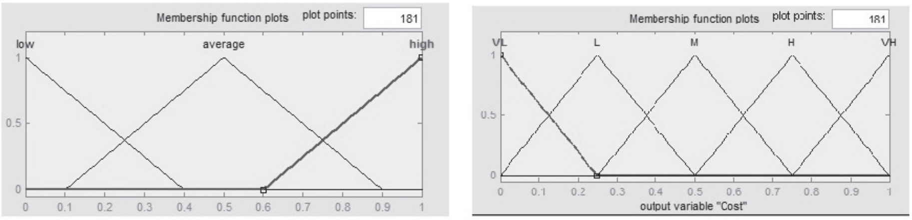


(a) Differential Evolution (DE) (b) Fuzzy Differential Evolution (FDE)

Figure 3. Flow diagrams showing DE and FDE algorithms.

Fuzzification of inputs and outputs

The control parameters CR and S are the two input variables selected for fuzzification. The linguistic variables for the input are "low", "average", and "high" and for the output, "very low", "low", "medium", "high", and "very high". These variables are used for both cost and energy consumption objectives. An example of membership plot of cost using triangular membership function is shown in Figures 4(a) and 4(b).



(a) Input variables CR and S (b) Output variable Cost

Figure 4. Fuzzy Membership Function of input and output.

Knowledge base fuzzy rules

The fuzzy rules follow the IF THEN structure. The objective functions are cost and energy consumption. A total number of possible fuzzy inference rules will be 9(3*3); hence there are two linguistic states. The rules are tabulated in Table 1.

Table 1. Fuzzy rules

Input		**Output**
CR(d1)	S(d2)	f(x)
low	low	very low
low	average	low
low	high	medium
average	average	medium
average	high	medium
average	low	low
high	high	very high
high	low	medium
high	average	high

Defuzzification

Defuzzification is used to get the crisp values from the fuzzy inference rules. The input fuzzy set μ is defuzzified into crisp value 'c' using centroid technique. For example, the linguistic values of CR (low=0.3, average=0.5, high=0.9) and S (low=0.1, average=0.6, high=0.9) of the crisp output can be calculated by

$$C=\sum xi\,\mu(\mathrm{xi})/\sum \mu(xi) \qquad (16)$$

where xi is the CR or S selection and $\mu(xi)$ is the linguistic value.

Algorithm 1: Node placement with cost minimization using FDE

```
1. Set iteration iter=0;Select a population size $P$
2. Randomly generate $P$ number of vectors in the search space
3. Generate the vectors for the network inputs Nr , Nc   // Nr-number of mesh router, Nc-number of clients//
4.Specify the limits Min<Nr<max ;min< Nc< max
5. Determine the traffic weights of the scenario and decide the gateway placement
6. $P=[Y_1(g)\ldots\ldots Y_n(g)]$ and $Y_i(g)=[X_{1i}(g)\ldots\ldots X_{ni}(g)]$
7. Fuzzify the DE input parameters S and CR
8. Randomly pick three population vectors from $Y_{i(g)}$ such that $xi1 \neq xi2 \neq xi3$
9. Generate a random integer for 'S' scaling factor or Mutation factor.
10. Calculate the trail vector $Y_{m(g)}= Y_{a(g)}+S[Y_{b(g)}-Y_{c(g)}]$
11. Generate a random integer for CR say $0<\eta<1$
12. The candidate vector is obtained from CR involving the vectors $Y_{m(g)}$ and $Y_{i(g)}$
```

13. The crossover operation is defined by

$$Y_c(g) = \left\{ \begin{matrix} Y_m(g) \text{ if } \eta \leq CR \\ Y_i(g) \quad \text{otherwise} \end{matrix} \right\}$$

14. The selection process involves the replacement of the candidate vector with the original parameter vector, depending on the objective value is minimum or maximum.

15. More number of generations is iterated until a stopping criterion is met

Results And Discussions

The proposed fuzzy DE scheme is implemented for a real time campus model of Sathyabama University shown in Figure 5. Using Xml coding the backend deployment terrain is developed in Qualnet 7. The proposed FDE method is compared with the traffic weight based placement method and other evolutionary schemes such as Simulated Annealing and DE. The design cost involves the deployment cost and the service cost when the router or the gateway is active. With a population size of 500 and 1000 generations the schemes are compared for optimum fitness. The network simulation settings and evolutionary computation settings of the schemes are tabulated in Tables 2 and 3. In a 1000m x 1000m area the mesh routers are deployed optimally. The stationary clients are distributed randomly. After calculating the TW the gateway is fixed in the cell with highest weightage.

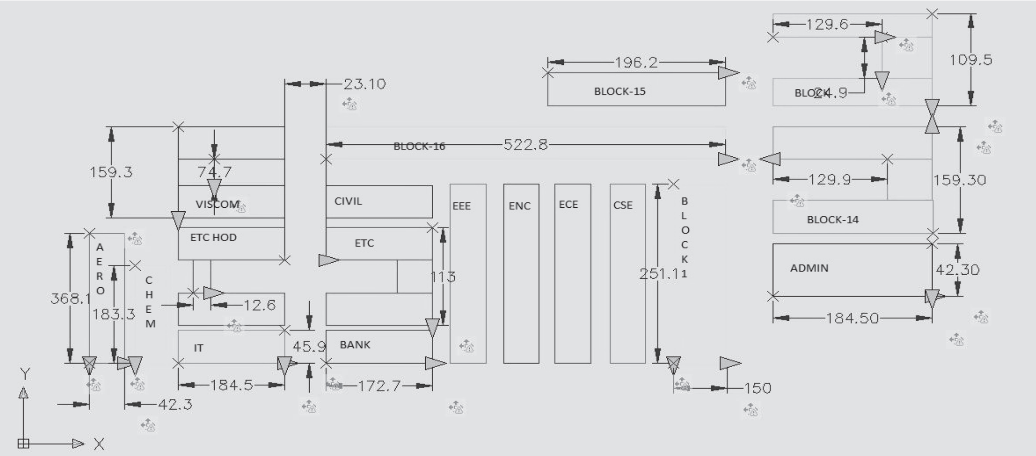


Figure 5. Campus Terrain Model.

The simulation results shown in Figures 6 and 7 significantly indicate that the convergence of FDE and DE is faster than that of the other conventional methods. The optimal values for 10 benchmark instances are tabulated in Table 4. The optimal values of DC and TC are achieved when the fuzzy linguistic control parameter values are set to CR=0.9 and S=0.8. The design cost shows 10% decrease using FDE compared to TW, 2.8% less than SA, and 1.2% less than DE methods. The cost function is evaluated for 1000 generations and the result demonstrates clearly that FDE and DE methods achieve convergence at 500th generation compared to the other algorithms. The transmission cost is related to the energy consumed by the nodes in the network. Applying the energy model function specified in Eq. (13) the residual energy consumption is calculated for each generation. Also, the failure rate of the nodes is evaluated for each generation shown in Figure 8.

Table 2. Simulation parameters.

Parameters	Values
Area Size	1000m X 1000m
MAC	802.11s
No. of mesh routers	36
No. of mesh clients	100
Application Type	CBR
Packet Size	1024 bytes

Table 3. Simulation settings-optimization methods.

Parameters	SA	DE	FDE
Placement of nodes	random	random	random
Population size	500	500	500
CR	Probabilistic	0.5	Fuzzy rule based
S	selection	0.6	selection

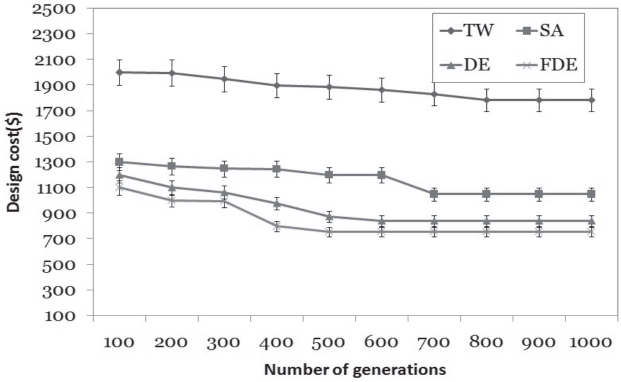


Figure 6. Comparative analysis of the deployment cost of using TW method, SA, DE, and FDE.

Table 4: Comparison of SA, DE, and FDE approaches.

Bench mark Instance	SA			DE			FDE			Gap (DE-FDE)	
	DC (units)	TC (Joules)	CPU time (secs)	DC (units)	TC (Joules)	CPU time (secs)	DC (units)	TC (Joules)	CPU time (secs)	DC%	TC%
1	1300	100	80	1200	99	50	1111	99	44	.89	0
2	1267	100	86	1100	99	54	1065	99	44	0.35	0
3	1250	100	87	1065	98.9	56	1010	98.76	43	0.55	0.001
4	1246	100	90	978	98.5	56	875	97.6	43	1.03	0.009
5	1200	99.7	98	876	97.45	57	856	96.8	43	0.2	0.006
6	1198	99.7	97	843	96.12	57	765	95.4	42	0.78	0.007
7	1050	99.7	98	843	96.12	57	765	95.4	42	0.78	0.007
8	1050	99.6	98	843	96.12	57	765	95.4	41	0.78	0.007
9	1050	99.6	98	843	96.12	57	765	95.4	41	0.78	0.007
10	1050	99.6	98	843	96.12	58	765	95.4	41	0.78	0.007

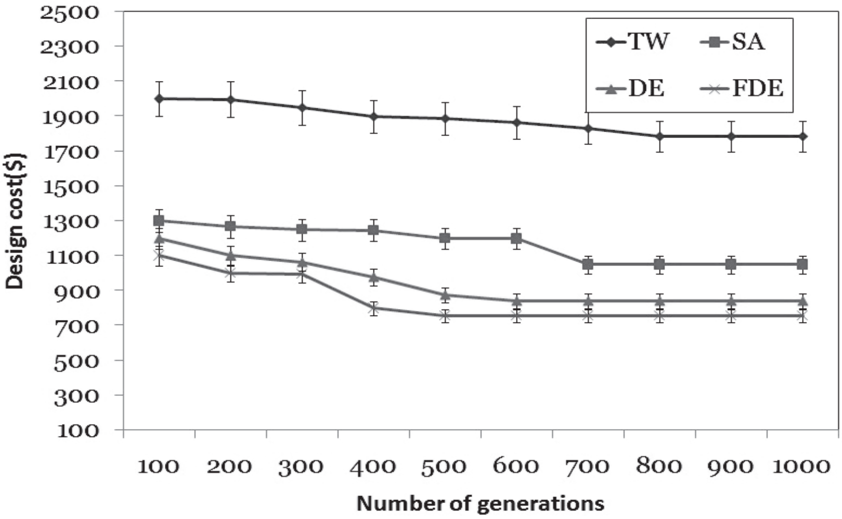


Figure 7. Energy consumption of mesh nodes.

The network performance is evaluated through metrics such as throughput and packet delivery ratio (PDR). Throughput refers to how much data can be transferred from one location to another in a given amount of time. PDR is defined as the ratio between the successfully received packets in the destination to the number of data packets sent from the source node. A comparison is performed with our previous work of random placement of mesh nodes (Sheeba and Nachiappan 2012a), that is, the conventional method. The comparison graphs are shown in Figures 9 and 10. The traffic flow application constant bit rate (CBR) is simulated. The evolutionary method of placement shows about 5% to 10% performance improvement compared to the conventional method of placing the nodes randomly in the grid area.

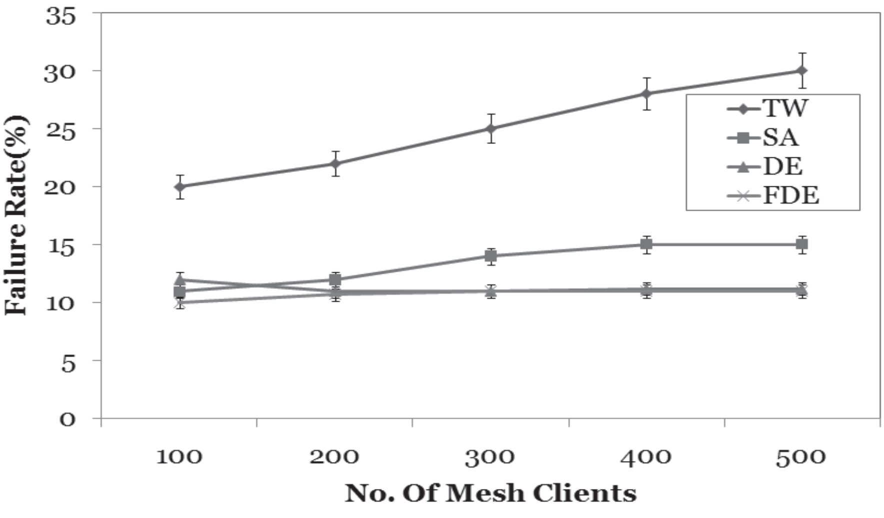


Figure 8. Failure rate of mesh nodes with increasing demand.

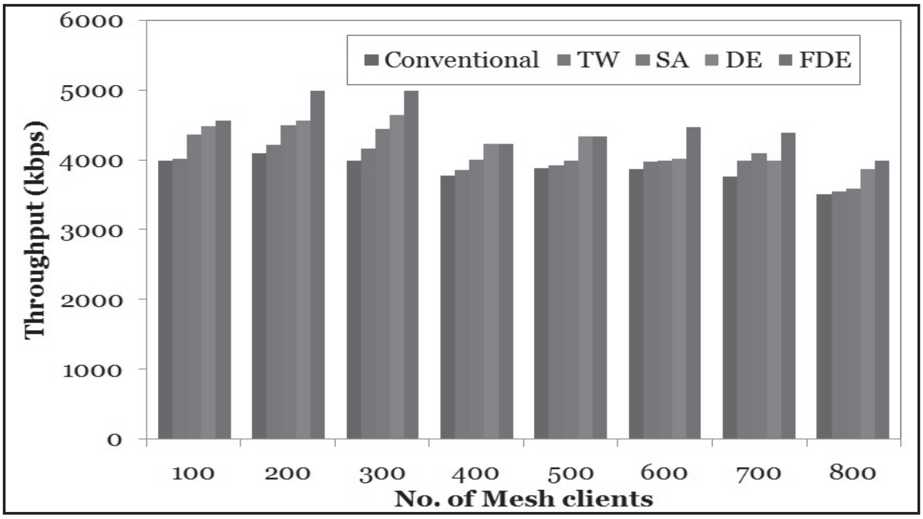


Figure 9. Comparison of network throughput using conventional, TW, SA, DE, and FDE schemes.

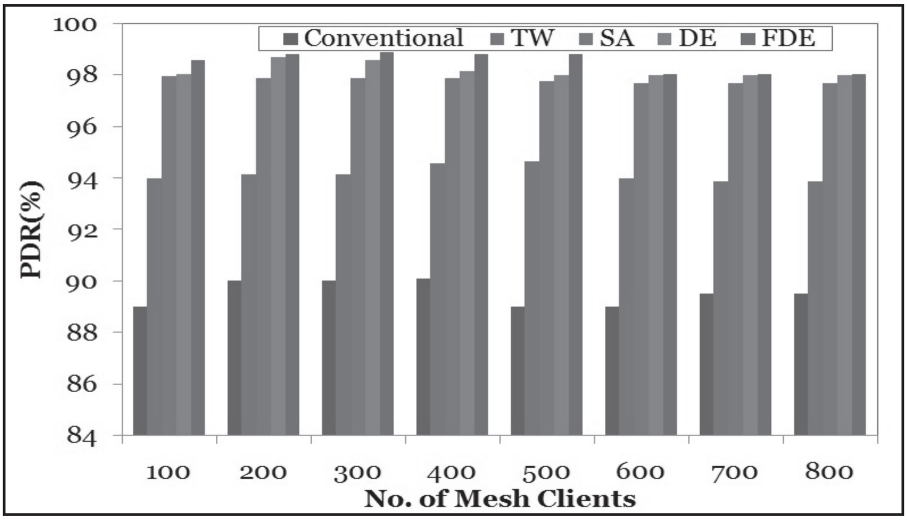


Figure 10. Comparison of PDR using conventional, TW, SA, DE, and FDE schemes.

Conclusion

Node placement, which is a NP hard problem, can be solved using heuristic methods. The FDE algorithm significantly shows less design cost and transmission cost than SA and DE methods. Energy consumption and failure rate are considerably reduced using the evolutionary methods compared to the conventional placements. The performance metrics such as throughput and PDR are evaluated using the evolutionary methods and conventional ones. FDE improves the WMN system with 10% increase in throughput and PDR compared to the conventional and existing methods. The work can be further extended using client distribution models and evaluating the DE based WMN system for improved performance.

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