# Using Imperialist Competitive Algorithms in Clustering of Wireless Mesh Networks

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**ABSTRACT:**
Load balancing can be used to extend the lifetime of a Mesh Network and thus reducing the traffic congestion and improving the network performance. Various approaches have been proposed for load balancing in WMN .This study takes a closer look at existing solutions with the application of clustering techniques to solve routing and congestion control problems because it offers scalability and enhances the availability of network and reduced overheads. The nature of the problem of clustering is NP-hard and using meta-heuristic and evolutionary algorithms can build stable and relatively efficient clusters. This paper proposes a new clustering algorithm method in WMN networks and divide the network into k clusters to manage the load in small scale and hence to reduce the overall load of WMNs. This algorithm is a centralized method and it is designed on the basis of an imperialist competitive algorithm (ICA). A WMN is divided into multiple clusters for load control and each gateway served even number of node. A cluster head estimates traffic load in its cluster. As the estimated load gets higher, the cluster head increases the routing metrics of the routes passing through the cluster. The simulation results show that the performance of the WMNs is improved with the proposed clustering method.

**KEYWORDS:** Wireless Mesh Networks ,Clustering ,imperialist competitive algorithm, Congestion Control, Load Balancing Introduction

## 1. INTRODUCTION

A key technology, wireless mesh networks (WMNs), has emerged recently for future broadband wireless access.WMNs are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad-hoc network and maintaining the mesh connectivity.

WMNs comprise of mesh routers and mesh clients, in which mesh routers form the mesh backbone of the infrastructure and can either be stationary or semi-mobile. Some mesh routers may have gateway functionality and provide connectivity to other networks, such as the Internet and other wireless networks.The most traffic in WMNs is exchanged with the Internet through the gateways.Mesh clients (e.g., PDAs, laptops) use mesh routers as relay nodes to access the Internet, as shown in Fig 1.In the WMN, a great portion of users intends to communicate with outside networks via the wired gateways.In such environment, the wireless links around the gateways are likely to be a bottleneck of the network [1] . The term load balancing refers to optimization of usage of network resources by transferring traffic from congested links to less loaded parts of the network based on knowledge of network state.There are many factors that can easily cause load imbalance, such as heterogeneous traffic demands, time-varying traffic and uneven number of nodes served by gateways.(motivated for example by unplanned gateway placement, or user behavior)[2].

In a WMN network, the formation of a clustered network equivalent to finding a topology plays a crucial role to effectively utilize the resources and improve the network performance. In other words, a well-organized scalable network structure increases the efficiency of routing algorithms, power control mechanisms. Various clustering algorithms have been developed to form an optimal clustered network structure. They mostly aim at improving network performance in terms of scalability, stability and communication control overheads. Forming a stable clustered topology that each gateway served even number of node can prevent from bottleneck and congestion [1], [3]. Using a graph theoretic approach to solve this problem and selecting a set of nodes to take the role as cluster heads has been defined as an dominating set in the corresponding

graph . This problem has been proved as an NP-hard problem that can be effectively solved by applying meta-heuristic algorithms such as genetic algorithms (GAs), ant colony optimization methods to form the clustered structure.This paper proposes a new clustering algorithm method in WMN networks. This algorithm is a centralized method and it is designed on the basis of an imperialist competitive algorithm (ICA). This paper is organized as follows :in Section 2 we review related work and various clustering algorithm techniques Section 3 briefly describe the advantages of clustered structure. The imperialist competitive algorithm (ICA) is illustrated in Section 4. proposed algorithm is investigated in Section 5.finally in section 6 some simulation results are presented.

## 2. RELATED STUDIES IN CLUSTER FORMATION

Simple clustering methods are 'identity based clustering algorithms (e.g. Lowest-ID and Max-min d-cluster algorithms), which select the cluster heads on the basis of the node identities. These algorithms aim at reducing the control communication overheads in the network and maximizing the stability of the clusters in terms of prolonging the lifetime of cluster heads. Another simple clustering algorithm is the highest connectivity clustering (HCC) algorithm, which is a type of 'connectivity-based clustering' algorithm. The HCC has a similar objective as Lowest-ID ; however, it uses the nodes' degree  to form the clusters [1],[4]. Another clustering method is the combined weight based clustering method. In this method, a weight, which is defined as a summation of several metrics, is assigned to each node. The node with maximum weight is more desirable to select as the cluster head (WCA).The aim of this method is to minimize the number of clusters and the control communication overheads. In addition to the mentioned clustering algorithms, other algorithms such as power-aware, load balanced clustering and low cost of maintenance clustering algorithms have also been proposed. In addition to the above methods, meta-heuristic algorithms e.g., genetic algorithms (GAs), and ant colony optimization methods have also been examined to form the clustered structure [5]. Good examples are GA-based algorithms that have been applied to modify the performance of a weighted clustering algorithm (WCA).The suggested algorithm forms a clustered topology with a minimum number of clusters while maximizing the connectivity, a distributed genetic-based algorithm has been proposed to improve the performance of WCA in selecting cluster heads .

## 3. ADVANTAGES OF CLUSTERING NETWORKS

A clustering algorithm partitions the network into a set of connected clusters covering all nodes in the wireless mesh network. A clustered structure causes an increase in the manageability and scalability of the network; thus, numerous clustering algorithms have been developed to provide clustered structure networks. Clustering schemes have been developed to improve scalability in large wireless networks. The use of clustering has some advantages, since it allows a smaller and more stable structure to be produced. In this scenario, if a mesh router fails, only the routers that are in the corresponding cluster need to update their information. As a result, local changes do not need to spread out and be updated across the entire network, which reduces the amount of information processed. Clustering of wireless network nodes into groups with proper cluster head (CH) selection will impose a regular structure in the network and makes it possible to guarantee basic levels of system performance such as throughput and delay, even in the presence of mobility, energy resources and a large number of mobile nodes.
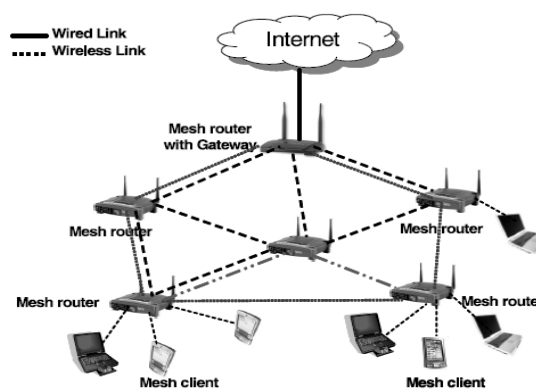


**Fig. 1.** Typical Wireless Mesh networks

However, mobility and energy resources are not major issues in infrastructure WMNs. Cluster algorithms may be used in improving database access and network performance. The network performance metrics such as routing delay, bandwidth consumption, energy consumption, throughput, and scalability are highly improved with appropriate clustering techniques. Efficient clustering protocols rely on different design goals, depending on the application they are designed for [1].In this study we achieve load balancing in wireless mesh networks through clustering algorithms methods. Where CHs or GW perform data processing or significant intra-cluster administration tasks an even node distribution among the clusters is often desirable in order for the CHs to have a balanced the load. Load balancing is a particular issue for WMN and the establishment of equally sized clusters offers energy savings and thus prolongs the network lifetime rather than employing a subset of high rate GW that could

expire too early. Even node distribution can also influence data delay [3].

## 4. BASIC THEORY OF IMPERIALIST COMPETITIVE ALGORITHM

ICA is a population-based stochastic search algorithm. It has been introduced by Atashpaz and Lucas, recently The algorithm is inspired by imperialistic competition. It attempts to present the social policy of imperialism to control more countries and use their sources when colonies are dominated by some rules. If one empire loses its power, the rest of them will compete to take its possession. In ICA, this process is simulated by individuals that are known as countries. This algorithm starts with a randomly initial population and objective function which is computed for them. The most powerful countries are selected as imperialists and the others are colonies of these imperialists .Then the competition between imperialists take place to get more colonies .The best imperialist has more chance to possess more colonies. Then one imperialist with its colonies makes an empire. After dividing colonies between imperialists, these colonies approach their related imperialist countries [6], [7]. Based on this concept each colony moves toward the imperialist by a units and reaches its new position. If after this movement one of the colonies possesses more power than its relevant imperialist, they will exchange their positions. To begin the competition between empires, total objective function of each empire should be calculated. It depends on objective function of both an imperialist and its colonies. Then the competition starts, the weakest empire loses its possession and powerful ones try to gain it. The empire that has lost all its colonies will collapse. At last the most powerful empire will take the possession of other empires and wins the competition .To apply the ICA for clustering, the following steps have to be taken [8].

### A. Generating Initial Empires
The goal of optimization is to find an optimal solution in terms of the variables of the problem. Form an array of variables values to be optimized. In GA terminology, this array is called "chromosome", but here the term "country"  is used for this array .In an $N_{var}$-dimensional optimization problem ,a country is a $N_{var}$ array .This array is defined by

$$Country = [p_1, p_2, p_3, \ldots, p_{N_{var}}] \qquad (1)$$

The cost of a country is found by evaluating the cost function $f$ at the variables $(p_1, p_2, p_3, \ldots, p_{N_{var}})$. Then

$$cost_i = f(country_i) = f(p_1, p_2, p_3, \ldots, p_{N_{var}})$$
(2)

To form the initial empires, divide the colonies among imperialists based on their power. That is the initial number  of colonies of an empire should be directly proportionate to its power . To divide the colonies

among imperialists proportionally .define the normalized cost of an imperialist by

$$C_n = \max_i\{c_i\} - c_n$$
(3)

Where $c_n$ is the cost of $n$th imperialist and $C_n$ is its normalized cost .The normalized power of each imperialist is defined by

$$P_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right|$$
(4)

$P_n$ is the power of $n$th imperialist. The normalized power of $n$th imperialist is the number of colonies that are possessed by that imperialist, calculated by:

$$N.C._n = round\{p_n.(N_{col})\}$$
(5)

where, $N.C._n$ is the number of initial colonies possessed by the $n$th imperialist $N_{col}$ is the total number of colonies in the initial population,and round is a function that gives the nearest integer of a fractional number.

### B. moving colonies toward imperialist
Imperialists countries started to improve their colonies .The colony moves $x$ distance along with $d$ direction toward its imperialist. The moving distance $x$ is a random number generated by random distribution within interval $[0, \beta \times d]$

$$x \in U(0, \beta \times d)$$

Where, the value of $\beta$ falls between 1 and 2. Setting $\beta > 1$ causes the colony to move toward the imperialist direction. To
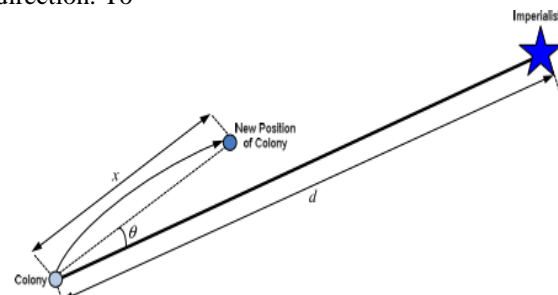


**Fig. 2.** Moving colonies toward their relevant imperialist in a randomly deviated direction

search different points around the imperialist was add a random amount of deviation of movement .fig 2 shows the new direction .In this figure $\theta$ is a random number with uniform (or any proper)distribution .Then

$$\theta \in U(-\gamma, \gamma)$$

Where $\gamma$ is a parameter that adjusts the deviation from the original direction?

### C. Exchanging the positions of a colony and an imperialist

Once assimilation and revolution operations are performed on colonies of an empire, the cost functions of new position of colonies are then compared with cost function of position of imperialist. If we find any colony whose cost function is less than cost function of imperialist, then we swap imperialist with that colony.

**D. Total power of an empire**
The power of an empire is computed based on the power of its imperialist and a fraction of the power of its colonies.

$$T.C._n = Cost(imperialist_n) + £ * mean\{Cost(colonies\ of\ emprie_n)\}$$
(6)

Where $T.C._n$ is the total cost of $n$ th empire, and $£$ is a positive number between 0 and 1, usually close to zero. A small value of $\varepsilon$ emphasizes a greater influence of imperialist power in determining the total power of empire, while a large value of $£$ indicates the influence of the mean power of colonies in determining the total power of the empire.

**E. imperialist competition**
During competition among imperialist countries, weaker empires will be collapsed gradually. This means that the weaker empires will lose their colonies over time, while stronger empires will possess the colonies of weaker empires, thereby increasing their power. Therefore, one or some of the weakest colonies belonging to the weakest empire will be given to a different empire based on competition that occurs among all empires. Stronger empires have a greater chance to possess the weakest colony. In order to model the competition process among the empires, we need to compute the normalized total cost of empire by

$$N.T.C._n = \max_i\{T.C._i\} - T.C._n \qquad (7)$$

Where $T.C._n$ is the total cost of $n$th empire, and $N.T.C._n$ is the normalized total cost of corresponding $n$ th empire. Then, the probability of possessing a colony is computed by,

$$P_{P_n} = \left| \frac{N.T.C._n}{\sum_{i=1}^{N_{imp}} N.T.C._i} \right| \qquad (8)$$

There is a need for a mechanism similar to the Roulette Wheel in GA to distribute the weakest colonies among the empires based on their possession probabilities. The ICA introduces a new distribution mechanism requiring less computation than the Roulette Wheel in GA, which requires a fairly heavy computation for Cumulative Distribution Function (CDF). The mechanism in the ICA only requires a Probability Density Function (PDF), addressed below:Vector P with the size of $1 * N_{imp}$ contains the possession probability of a colony by empires as follows:

$$P = \left[ p_{p_1}, p_{p_2}, p_{p_3}, \ldots\ldots, p_{p_{N_{imp}}} \right]$$
(9)

Then, vector $R$ with the same size of $P$ is formed in which its elements are generated using uniform distribution within interval of [0,1] as follows:

$$[r_1, r_2, r_3, \ldots\ldots, r_{N_{imp}}]$$
(10)

$$r_1, r_2, r_3, \ldots\ldots, r_{N_{imp}} \epsilon \cup (o, 1)$$

Next, vector $D$ is defined as

$$D = P - R = \left[ D_1, D_2, D_3, \ldots., D_{N_{imp}} \right]$$
(11)

$$= \left[ p_{p_1} - r_1, p_{p_2} - r_2, p_{p_3} - r_3, \ldots., p_{p_{N_{imp}}} - r_{N_{imp}} \right]$$

Once vector $D$ is calculated, the weakest colony is assigned to the empire with the larger index. The absence of CDF computation will speed up the distribution process of ICA in comparison to the Roulette Wheel in GA.

**F. Collapsing the weaker empires**
Weaker empires lose their colonies gradually to stronger empires, which in turn grow more powerful and cause the weaker empires to collapse over time.

**G. Convergence**
Similar to other evolutionary algorithms, ICA continues until stopping criteria are met, such as predefined running time or a certain number of iterations.

**5.   THE PROPOSED LOAD BALANCING SCHEME**
**5.1.. Clustering networks through ICA approach**
We use ICA to clustering WMN by observing two conditions: High intra cluster similarity; distribution balance nodes in clusters so that even number of nodes served by gateways
The characteristics of ICA as a clustering algorithm metods can be explained as follows:

**A. Encoding and Initialization of Population**
Let us assume that the cluster formation problem has been proposed in WMN with $N_{network-size}$ nodes that have assigned unique IDs. In order to encode this problem, the solution must be represented by the integer numbers that determine the nodes' IDs as equation.

$$Country = [n_i, n_j, n_k, \ldots., n_{N_{var}}]$$

The parameters $i, j, k$ are numbers between 1 and $N_{network-size}$ The node's identity of $i^{th}$is represented by $n_i$.

**B. Fitness Function**

In our algorithm, we aim to find the gateway set which can build up the load balanced cluster structure .Our primary criterion of solution quality is the standard deviation of the gateway degrees. To quantitatively measure how well balanced the gateways are, we use a parameter called load balancing factor (LBF) as defined in [9], [10]. The load handled by a gateway or clusterhead is essentially the number of nodes supported by it. A clusterhead, apart from supporting its members with the radio resources, has also to route messages for other nodes belonging to different clusters. It is difficult to maintain a perfectly load balanced system at all times due to frequent detachment and attachment of the nodes from and to the clusterheads. As the load of a clusterhead can be represented by the cardinality of its cluster size, the variance of the cardinalities will signify the load distribution. We define the LBF as the inverse of the variance of the cardinality of the clusters. Thus

$$\mathbf{LBF} = \frac{n_c}{\sum(X_i - \mu)^2}$$

(12)

Where $n_c$ is the number of clusterheads, $X_i$ is the cardinality of cluster $i$ and

$$\mu = \frac{N - n_c}{nc}$$

is the average number of neighbors of a clusterhead, N being the total number of nodes in the system.Clearly, a higher value of LBF signifies a better load distribution and it tends to infinity for a perfectly balanced system. We use inverse of LBF factor in our objective function. Therefore, among a set of candidate solutions, we choose the one with the least standard deviation.

The another goal is to find the clustering which minimizes the sum of the distances between each nodes and the centroid of the cluster to which it is assigned .The most intuitive and frequently used criterion function is the Sum of Squared Error (SSE) given by Eq 13.

$$\boldsymbol{SSE} = \sum_{j=1}^{k}\sum_{i=1}^{n}\left\|x_i - c_j\right\|^2$$

(13)

A multi-objective function as equation is defined .it is defined as a weighted combination of Eq.12,13 .

$$\boldsymbol{Cost} = \boldsymbol{\alpha} * \sum_{j=1}^{k}\sum_{i=1}^{n}\left\|x_i - c_j\right\|^2 + (\mathbf{1} - \boldsymbol{\alpha})\frac{\sum(x_i-\mu)^2}{n_c}$$ (14)

**C. Select the best node as clusterhead**
A large WMN can be partitioned into multiple disjointed local networks, each of which consists of one IGW and a group of MRs that are attached to the IGW by single hop or multi-hop path. The size of each local network is restricted by IGW's capacity. In the proposed routing scheme,the ICA approach divides the mesh network into k multiple clusters, where $k$ is the number of clusters decided by the user and thus performs the load balancing at IGWs to gain better network performance .After clustering, the cluster head is chosen on the basis of value, which is calculated by the Eq.15. The $W_n$ value has been chosen to select the most appropriate gateway as the cluster head based on some important parameters, which reflects the status of the network with respect to that gateway.Wrong selection of gateway can affect the network performance which results in degradation of network performance because a failing gateway causes accumulation data in a cluster and then increasing workload ascendant.

$$W_n = \frac{w_1.BW + w_2.N_{degree} + w_3.Power_{supply} + w_4.T_{Ql}}{w_5.D(x,c_i) + w_6.|Ql_{Averag} - Ql_{value}|}$$     (15)

In above equation use this parameters:
.
- BW: Total bandwidth terminate to each node.Bandwidth capacity means how many nodes can be connected to the node at the same time.
- $N_{degree}$: degree of node especially the diversity of the neighborhood of each node.
- $Power_{Supply}$ : node with highest energy is suitable to be chosen as GW as it consumes more energy during traffic consumption and have longer lifetime as compared to other nodes.
- $T_{Ql}$ : Total queue capacity of the gateway.
- $D(x, c_i)$ : Distance from center.
- $Ql_{Average}$ : Average queue length of the gateway.
- $Ql_{Value}$ : Preset service requests that are available in the gateway's queue.

In Eq.15    $w_1, w_2, w_3, w_4, w_5, w_6$ are the weighting factors that
$$w_1 + w_2 + w_3 + w_4 = 1 , w_5 + w_6 = 1$$

A cluster head takes role of controlling the traffic load on the wireless links in its cluster. The cluster head periodically estimates the total traffic load on the cluster and increases the "link costs" of the links in the cluster, if the estimated load is too high. In this scheme, each user chooses the route that has the minimum sum of the link costs on it.

**5. EXPERIMENTAL RESULTS**
This section describes the model of wireless mesh network and implementation of the proposed ICA clustering algorithm and also analyzes the results of the experiments. The proposed algorithm is simulated with MATLAB .The simulation results have been analyzed with four different performance metrics.
The experiment has been designed by varying the total number of nodes and holding all other parameters constant to compare with respect to the different

performance metrics. The results of the proposed method, i.e. WMN with ICA clustering approach, have been compared with the simple WMN scenario,i.e. WMN without cluster.

**A.  Network model of wireless mesh network**
A WMN can be considered as an infrastructure-based wireless
network,which is represented by an undirected graph $G(V, E)$ called connectivity graph. $V = (v_1, v_2, \ldots, v_n)$ is a set of $n$ network nodes where each node $v \in V$ represents a wireless mesh router with a circular transmission range/radius $r_i$. The physical location of a node $v_i \in V$ is static after the deployment phase,and illustrated by $(x_i, y_i)$. Moreover,there is no power limitation as in typical mobile ad hoc networks,since each node $v_i \in V$ has a rich power supply being a wireless mesh router.The neighborhood of $v_i \in V$ is denote by $N(v)$, which is a set of nodes that reside with in $v_i$ transmission range.Thus,there is a bidirectional wireless link between $v_i \in V$ and every neighbor node $v_j \in N(v)$, which is represented by an edge $(v_i, v_j) \in E$. $(v_i, v_j) \in E$ if and only if

$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \leq r_i \ .$$

**B.Performance Metrics**
The following metrics were used in various scenarios to evaluate the performance of LBM and our proposed routing metric:

•  Percentage of packet delivery :
The ratio between the number of data packets successfully received by the destination node and the total number of data packets sent by the source node. This metric reflects the degree of reliability of the routing protocol.

•  Total throughput :
This performance metric measure the rate of information transfer. They are all measured in bytes/ bits per second. It is the rate of successful message delivery over a communication channel.

•  Link and switch utilizations :
In [11] , defined the average and variance of link utilization for a given network as:

$$\bar{l} = \frac{1}{L}\sum_{k=1}^{L}\left(\frac{l_k}{b_k}\right) \tag{16}$$

$$\sigma_l^2 = \frac{1}{L}\sum_{k=1}^{L}\left(\frac{l_k}{b_k} - \bar{l}\right)^2 \tag{17}$$

Where $L$ is the number of links in the network, $l_k$ is the total traffic load on the $K$ th link and $b_k$ denotes the bandwidth of the $k$ th link. $\partial_l^2$ is a useful parameter that indicates the degree of link load balancing in the

network. Note that $\frac{l_k}{b_k}$ indicates the utilization of the $k$th link. In a similar way, in [11] defined the average and variance of switch utilization as:

$$\bar{s} = \frac{1}{n}\sum_{k=1}^{n}\left(\frac{s_k}{c_k}\right) \tag{18}$$

$$\sigma_s^2 = \frac{1}{n}\sum_{k=1}^{n}\left(\frac{s_k}{c_k} - \bar{s}\right)^2 \tag{19}$$

Where $n$ is the number of nodes $s_k$ is the total traffic load on the $k$th node and $c_k$ denotes the node capacity of $k$th node. For each topology, $\sigma_s^2$ is a useful parameter that indicates the degree of node load balancing. Note that $\frac{s_k}{c_k}$ indicates the utilization of the $k$th switch.

**7. RESULT AND DISCUSSION**
The results generated from the different performance metrics after implementing ICA clustering method in the WMN scenario are compared with the simple WMN scenario. The results are represented in the Fig. 3 to 5 and table1. The convergence behavior of the fitness function versus the iterations is given in Fig 3 . The comparison has been made with respect to the above mentioned four performance metrics and it is clearly visible that while ICA clustering method is applied to WMN, it gives better result in comparison to that of a simple WMN scenario . Table 1 indicates that the average values of link loads and switch loads are much less in WMN with the ICA clustering method. A good criterion to compare algorithms is their ability to provide load balance on links and switches. For this purpose, we showed the variances of the link and switch utilizations in Table 1.
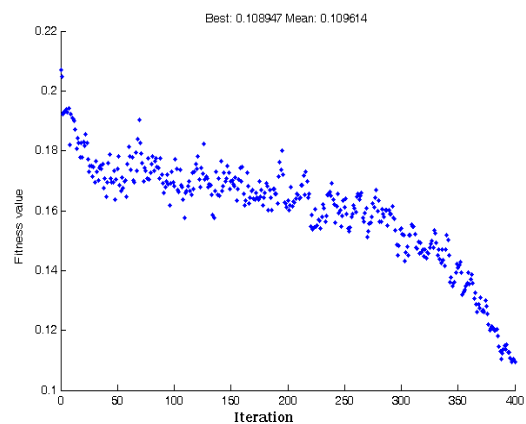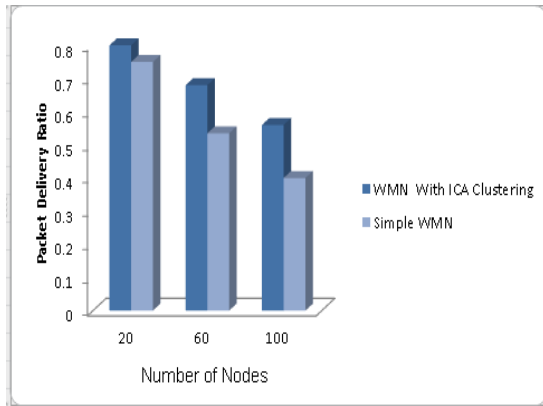


**Fig. 3.** Convergence behavior of the fitness function
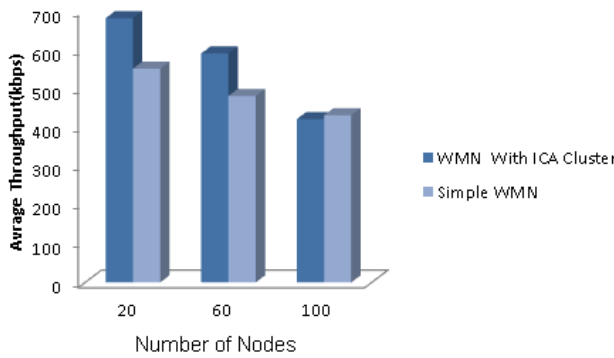
**Fig. 4.** Packet Delivery Ratio



**Fig. 5.** Average Throughputs

**Table 1.** Comparison of the performance metrics

|  | simple wmn | wmn with ica clustering |
| --- | --- | --- |
| Average link load(Mbps) | .8 | 1.4 |
| Average switch load(Mbps) | 3.2 | 5.3 |
| Variance utilization link | .07 | .05 |
| Variance utilization switch | .005 | .0067 |

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