Int. j. inf. tecnol. (August 2022) 14(5):2595–2602
https://doi.org/10.1007/s41870-022-01013-9

ORIGINAL RESEARCH

A soft computing based novel hybrid optimization algorithm H3PGAB3C and its application to routing in WMNs

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Received: 17 December 2021 / Accepted: 30 May 2022 / Published online: 22 June 2022

Abstract This paper proposes a novel hybridized optimization algorithm namely H3PGAB3C. This algorithm is a combination of the three-parent genetic algorithm (3PGA) and big-bang big-crunch (B3C) algorithm. 3PGA is used for global search whereas B3C performs local search for optimal solution. This hybrid algorithm is applied to find the optimal route in wireless mesh networks (WMNs). Performance of H3PGAB3C is compared with other 10 algorithms for different architectural scenarios of large-sized WMNs varying from 5000 to 10,000 node client WMNs. integrated link cost (ILC) measure is taken into consideration for performance comparison. ILC is evaluated by a fuzzy system consisting of three parameters; end-to-end delay, jitter and throughput. It has been observed that the proposed algorithm H3PGAB3C proved its superiority over all other 10 algorithms.

Keywords Soft computing · WMN routing · Hybrid optimization algorithm · H3PGAB3C · 3PGA · B3C

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1 Introduction

Soft Computing became very popular amongst researchers to find the solutions to complex problems like nondeterministic polynomial (NP)-complete and NP-hard problems [1, 2] in recent past decade. Soft computing is used to find solutions quickly where an optimal solution may be interchanged by good enough solution. The performance of soft computing based approaches is pretty good individually but they perform even better when they are hybridized [3–12]. Different combinations of soft computing approaches are proposed by many authors and found that the performance of the hybrid solution is enhanced. Search and optimization algorithms are widely being used for addressing complex problems and giving the way out to find a better solution in a definite time [13].

3PGA is one of the most efficient algorithm used for global optimization [9]. This algorithm is based on the biological process of three parents' child that has been applied in the domain of genetic reproduction. This algorithm was used to address the issue of mitochondrial-related diseases. This approach replaces the defective mitochondria of the mother with healthy mitochondria taken from a third parent (a donor mother) and results in the reproduction of better offspring. B3C algorithm is evolution theory based algorithm that has been used by many researchers to find optimized solutions [3, 14, 15]. B3C can be used in combination with other algorithms for increasing the performance of the algorithm resulting in hybrid approaches.

The WMNs [16] are dynamic self-balancing, self-organizing network used for communication between wireless radio nodes. WMNs are widely being used for the past few years. This is a network of interconnected radio nodes that can be connected using an Infrastructure based architecture or it can just be an interconnection of Infrastructure less radio nodes those create a client WMN [17]. Hybrid mesh networks are combination of mesh client and Infrastructure based WMNs. One of major attributes to find the efficiency of WMNs is routing. Literature is rich with routing protocols such as dynamic source routing (DSR), ad hoc on-demand distance vector with directional flooding (AODV-DF), anonymous on-demand routing (ANODR), ad hoc on-demand distance vector (AODV), fuzzy system based ad hoc on-demand distance vector (FW-AODV), associativity based routing (ABR), link-quality source routing (LQSR) [4, 18], etc. but in the category of reactive protocols, AODV and FW-AODV [4] are performing well. Even more efficiency can be provided by proactive routing protocols while comparing to reactive routing protocols [16].

Performance can be evaluated by any one of the performance measures available like minimum hop count, round trip time per hop, packet pair delay per hop, integrated link cost, expected transmission count, etc. for routing algorithms. Among these ILC [19] is a fuzzy-based performance measure having three parameters (throughput, jitter and delay) that is used in this paper for performance evaluation.

This paper is divided into five sections. Section 1 covers the introduction. literature review is presented in Sect. 2. Section 3 presents the proposed algorithm. Section 4 contains simulations, results and discussion. Section 5 presents the conclusion and future scope.

2 Literature review

Soft computing based optimization approaches are very much popular among the researchers working in the domain of WMNs for finding optimal paths. A lot of work has been contributed by many authors considering the efficiency of most popular algorithms like genetic algorithms (GA), artificial neural networks (ANNs), B3C etc. Better results are found by applying soft computing approaches while comparing with hard computing approaches.

Genetic algorithms were used for the optimization of complex mathematical non-linear problems [20]. For solving multi-objective as well as single-objective optimization problems, genetic algorithms based technique was used and compared with other problem solving techniques. Soundness of GA based technique was proved on standard benchmark problems.

Modified whale optimization algorithm (MWOA) [21] was proposed and compared the performance with simulated annealing (SA) and BBO. It was concluded that performance of MWOA was better than SA and BBO in terms of convergence of finding optimal solution for the design of cognitive radio system.

A hybrid soft computing based routing protocol was proposed by considering Hopfield neural network in combination of artificial intelligence based on multi-criteria optimization [1]. Results of the proposed approach were compared with two other routing protocols AODV and open shortest path first (OSPF). Result of intensive simulations confirm that proposed approach giving better results as compared to other two routing protocols AODV and OSPF.

Challenges of vehicular ad hoc network routing protocols are discussed and issues related to high mobility and unstable network has been highlighted. An improved routing protocol that uses the weighted clustering and methods for identifying cluster head on the basis of weight of vehicle has been used to improve the quality of service performance [22]. High mobility and finding an effective routing protocol are the major challenges in WMNs as well.

Taguchi method (TM) is applied on soft computing algorithm non-dominated sorting genetic algorithm (NSGA-II) for optimization of competitive congested location-pricing problem [2]. The proposed model was considered to be working on large scale complex problems. Its performance was compared with multi-objective particle swarm optimization (MOPSO) on multi-criteria and found that NSGA-II performs well as compared to MOPSO.

Hybridization of two or more methods/techniques provide better performance for the system while comparing it with results provided by individual method/technique. Support vector machine technique has been hybridized with Honeypot technique [23] for denial of service attack and proved to provide better security as compared to competing techniques. Utilizing the best of two or more techniques to find optimal solutions is the key feature of hybrid systems.

Performance of hybrid ant supervised by gravitational particle swarm optimization with a local search (PSOGSA-ACO-LS) [24] was compared with individual approaches and found that hybrid approach performed better. Another hybrid algorithm parallel cooperative (PACO-3Opt) [25] based on ant colony optimization was found more efficient than existing algorithms.

LEACH-PWO [26] is a hybrid algorithm that applied a combination of particle swarm optimization (PSO) and Wolf search optimization method over LEACH to optimize the usage of energy. The hybrid algorithm was compared with original LEACH method, genetic algorithms (GA) and ant cuckoo optimization method and found that the proposed hybrid algorithm LEACH-PWO is more energy efficient.

Source node compute routing (SNCR) protocol [27] addresses the issues of low efficiency and large overhead is extension of hybrid wireless mesh protocol. Results of SNCR are better than other comparable protocols. Adaptive neuro-fuzzy inference system (ANFIS) was combined with PSO to propose ANFIS-PSO and GA to propose ANFIS-GA [28] for optimizing the performance and it worked well. Results of ANFIS-PSO were outstanding as compared to other algorithms.

Markov-chain model [29] was proposed for optimized routing in wireless networks. The proposed model Markov-chain used the method to choose energy-efficient adjacent nodes for routing. Performance of the proposed model was compared with other methods and shown the superiority of Markov-chain model in finding the optimized routes in terms of residual energy, delay and energy consumption.

TM was combined with ANFIS and teaching–learning-based optimization (TLBO) [30] to improve the performance of TM. Performance of hybrid algorithm was better than other algorithms. A combination of grey wolf optimizer (GWO) and sine cosine algorithm (SCA) [31] were considered for hybrid approach and results of proposed hybrid approach proved better than comparable approaches. Another hybrid approach was applied to the combination of gray wolf optimization (GWO) with PSO [32] to form GWOPSO and effectiveness of proposed hybrid approach was found better.

B3C approach was used for searching optimal route in WMNs and results were compared with AODV algorithm and ant colony optimization (ACO) algorithm [33]. B3C was finding the optimal paths in short span. Performance was compared for WMNs of client nodes 10, 20, 30, 50 and 100. Evaluation of route cost was done by ILC measure. Results show that B3C was performing better and faster as compared to ACO and AODV. WMNs beyond 100 Client nodes were not considered in this paper.

AODV and soft computing based extension of AODV named FW-AODV were compared with BAT algorithm and ACO algorithm based routing approaches for finding routes in WMNs [4] for WMNs of Client nodes 100, 500 and 1000. ILC based route cost was evaluated and results showed the superiority of FW-AODV over all other three approaches namely AODV, ACO and BAT. Authors limited themselves to a maximum of 1000 client nodes WMNs.

Wireless mesh networks of 25, 64, 100 and 2500 nodes were considered for finding the shortest paths between source and destination nodes using biogeography based optimization (BBO) and B3C based routing approaches [19]. Performance of BBO and B3C were compared and found that B3C gives more optimal paths as compare to BBO. However, authors limited themselves to a maximum of 2500 node networks.

Parallel B3C (PB3C) based routing approach was proposed and results for WMNs of client nodes 100, 500, 1000, 1500, 2000 and 2500 were compared with Firefly algorithm (FA), ACO, BBO, BAT, DSR, AODV and B3C based routing approaches using ILC measure [6]. PB3C was found to be performing better than other seven routing approaches considered in the paper.

3PGA based routing approach was proposed and optimal path route cost was compared with eight other routing algorithms BAT, DSR, B3C, BBO, FA, GA, ACO and AODV [9]. Performance was compared for WMNs of maximum 2500 client nodes using ILC measure. Conclusion drawn was that performance of 3PGA was better out of nine algorithms for the given architectural scenario with given timing constraints.

Observations lead to the decision that individual approaches perform good but hybrid approaches give better results. Routing approaches which are based on soft computing give even better results in less time. Another common observation was that lot many authors limited themselves to a max of 2500 nodes client WMNs. Considering all the observations, we propose a novel hybrid approach that is a combination of 3PGA and B3C namely H3PGAB3C. This newly proposed approach is applied to find the minimal cost route in WMNs. We have considered WMNs of larger sizes from 5000 client nodes WMNs to 10,000 client nodes WMNs. ILC measure is used for route cost evaluation and performance was compared to nine other routing approaches.

3 Proposed approach

It is a fact that mitochondrial diseases are caused by genetic faults in mitochondria and results in affecting the body parts of children that may lead to multiple diseases like neurological problems, liver related diseases or heart diseases etc. Various techniques are proposed by scientists that includes 3-parent child to avoid such problems [7, 8]. Dr. Zang John Zhang removed nucleus from one of mother's egg cell having unhealthy mitochondria and replaced it with nucleus of donor's egg cell having healthy mitochondria [8]. The egg cell resulting from the mitochondrial deoxyribonucleic acid (DNA) of donor mother and nuclear DNA of original mother was fertilized with the father's sperm. This concept of 3-parent process with little changes was implemented for optimal route finding in WMNs [9].

In this paper, we proposed the new algorithm by hybridization of 3PGA and B3C named as H3PGAB3C. Firstly, 3PGA is applied for the global optimization and then B3C is applied for local optimization.

nodes that are placed randomly in 500×500 square meters of area is shown in Fig. 1.

```
H3PGAB3C Algorithm
begin
        Generate Initial (2-Parent) Population of N individuals.
         do while (not end of max_loop)
        /* 3PGA Phase starts [9]*/
                Effect Mitochondrial Change in the current population (Generation of
                3-Parent population takes place)
                Combine 3-Parent population with 2-Parent population.
                Evaluate the fitness of individuals and choose best 'N' individuals.
                Find elite solution.
                Generate new 2-Parent population using GA
                 1. Select best individuals for recombining
                 2. Apply cross-over on best individuals
                 3. Mutate the population.
                 4. Evaluate the fitness. Assign best fit individual as the elite.
                 5. Replace weak individuals with the best ones keeping best 'N'
                 individuals.
                 Repeat the steps until time permits or find the optimal results.
        /*3PGA Phase ends*/
        Pass the best 'N' individuals and the elite to B3C.
        /*B3C algorithm[10]*/
        do while (not end of local search)   //Termination Criteria
        /*Big Bang phase starts*/
                Generate a new population of 'N' individuals around the elite by
                adding/subtracting a randomly generated small number in the genes of
                elite.
                Check and correct bound violations if any
        /*Big Bang phase ends*/
        /*Big Crunch phase starts*/
                 Evaluate center of mass of the population as given in [10].
                 Alternatively best fit individual may be chosen in place of center of
                 mass [13].
                 Compare the best fit/center of mass of the current population with the
                 elite.
                 Replace the elite with the current best/center of mass of the current
                 population if its fitness is better than elite
        /*Big Crunch phase ends*/
        end do while
        /*B3C algorithm ends*/
        Merge the two populations of 3PGA and B3C. Select the 'N' best individuals
        as the next population.
        Current population=next population.
        end do while
        Return elite as the best solution.
end
```

We applied the proposed algorithm for finding optimal route in WMNs between source node and destination node. An architecture of wireless mesh network containing 25

The results of proposed algorithm are compared with 10 other algorithms. The results and discussions are shown in the next section.

4 Simulation, results and discussion

In order to validate the proposed algorithm H3PGAB3C and evaluate its performance, we applied the algorithm to find the optimal routes in WMNs of different architecture and sizes. We compared the results with 10 other routing algorithms. Implementation of routing approaches is done in MATLAB R2019a (64 bit) version on a computer system with a processor Ryzen 7-3700x, RTX 3070 8 GB Graphics and 32 GB RAM for client WMNs of 5000, 6000, 7000, 8000, 9000 and 10,000 nodes. Nodes of client WMNs were deployed randomly in the defined area and optimal cost route was enumerated between source to destination node using different routing approaches taken into consideration. We have considered a fixed radio range of 250 m for client nodes along with different timing constraints and evaluated the cost using ILC measure. Architectural scenario of Client WMNs is shown in the Table 1.

Simulated performance of a client WMN of 6000 nodes for an area of 2000 × 2000 square meters with a timing constraint of 0.5 s and radio range of 250 m is shown in the Table 2.

We have observed the route costs in the similar fashion for all the architectural scenarios presented in the Table 1. To keep the paper brief, only one simulation table is presented here however a total of 18 such tables (30 trials each) containing the observations of route costs for 5000 node client WMNs to 10,000 node client WMNs for different timing constraints has been prepared.

Table 1 Architectural scenario of client WMNs

No. of client nodes	Area (square meters)	Radio range of nodes	Given timing constraints (s)
5000	2000 × 2000	250	0.3, 0.4, 0.5
6000	2000 × 2000	250	0.3, 0.5, 0.7
7000	2500 × 2500	250	0.1, 0.3, 0.5
8000	3000 × 3000	250	0.1, 0.3, 0.5
9000	3000 × 3000	250	0.1, 0.3, 0.4
10,000	3500 × 3500	250	0.5, 0.7, 0.9

5 Overall performance

Performance for all Client WMNs has been compared and presented in Table 3. This performance is evaluated for WMNs with architectural details given in Table 1. It was observed that H3PGAB3C has searched minimal cost route 253 times that is maximum among all the minimal cost routes found by different approaches. 3PGA stands at 2nd position by finding minimal cost route 226 times. Thereafter, PB3C searched 82 times followed by GA searched 73 times and B3C searched 64 times. FA searched minimal cost path

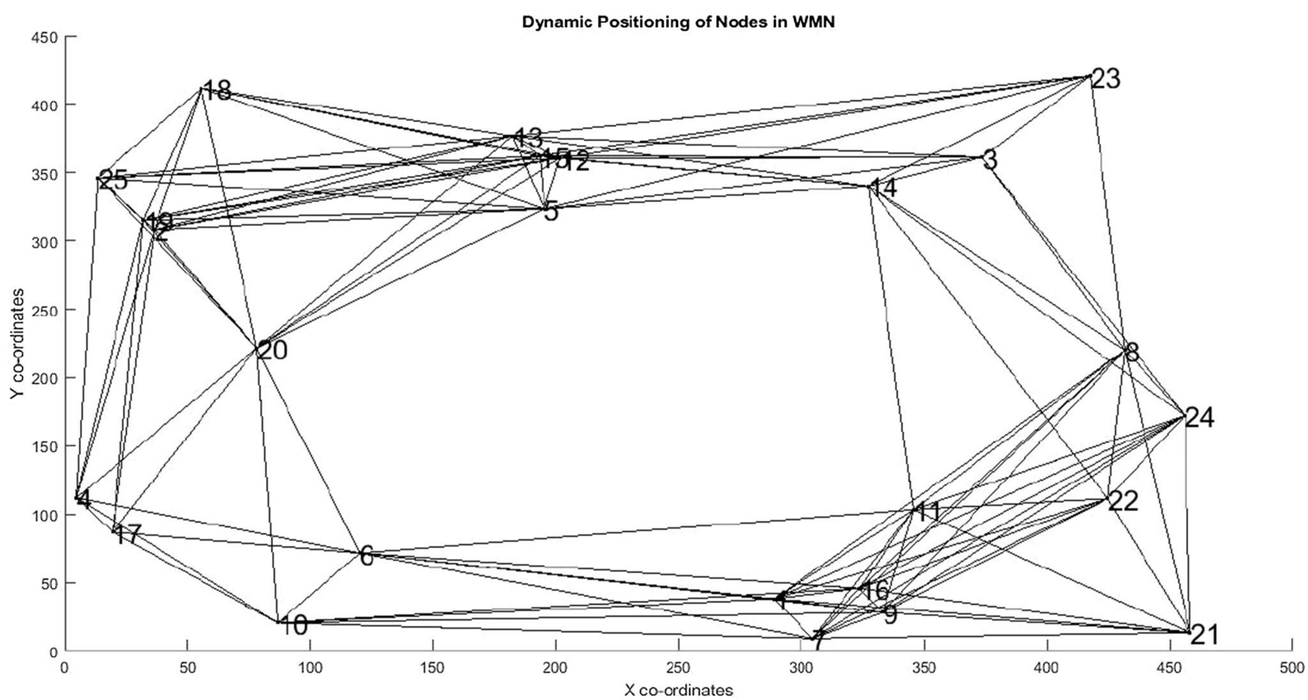

Fig. 1 Wireless mesh network of 25 nodes

Table 2 Simulation results of 6000 node client WMN, 2000 square meters area, 0.5 s timing constraint

Iteration/algorithm	AODV	ACO	BAT	BBO	DSR	FA	B3C	GA	PB3C	3PGA	H3PGAB3C	Min Route Cost
1	N/A	N/A	5.4193	5.4193	N/A	2.4251	**1.9373**	3.2538	2.2238	2.2113	3.9335	**1.9373**
2	N/A	N/A	6.5176	6.5176	N/A	4.1361	2.2403	2.0937	**2.0563**	2.7403	4.5356	**2.0563**
3	N/A	N/A	11.6697	11.6697	N/A	3.7643	2.3837	**2.3586**	3.528	3.45	2.7862	**2.3586**
4	N/A	N/A	19.4135	19.4135	N/A	5.7764	4.8351	3.9991	4.7172	**3.1845**	3.8999	**3.1845**
5	N/A	N/A	10.6757	10.6757	N/A	6.914	5.0729	7.6603	16.2622	4.111	**2.0733**	**2.0733**
6	N/A	N/A	14.5889	14.5889	N/A	6.5945	10.0369	7.9927	11.4119	5.7421	**5.416**	**5.416**
7	N/A	N/A	9.58	9.58	N/A	9.58	9.58	5.5862	**4.7033**	5.2831	5.2831	**4.7033**
8	N/A	N/A	10.3401	10.3401	N/A	10.34	**1.9534**	5.096	9.3314	3.8034	10.3401	**1.9534**
9	N/A	N/A	10.5183	10.5183	N/A	10.518	8.2382	5.2804	7.4836	4.55	**2.8525**	**2.8525**
10	N/A	N/A	11.345	11.345	N/A	4.6885	**3.115**	6.7824	3.8738	3.7577	3.7577	**3.115**
11	N/A	N/A	8.5929	8.5929	N/A	8.5929	7.0982	**5.6467**	9.8747	6.054	6.5651	**5.6467**
12	N/A	N/A	10.505	10.505	N/A	10.074	**3.3101**	7.0059	14.1739	4.1812	3.7059	**3.3101**
13	N/A	N/A	13.9344	13.9344	N/A	7.5358	4.9452	**3.4051**	3.5705	4.7682	4.4747	**3.4051**
14	N/A	N/A	3.657	3.657	N/A	3.657	3.657	3.657	5.863	3.657	**3.5964**	**3.5964**
15	N/A	N/A	10.891	10.891	N/A	6.8076	3.0105	6.387	5.1602	2.1493	**1.928**	**1.928**
16	N/A	N/A	11.0472	11.0472	N/A	4.3801	3.5166	3.6052	7.9982	**3.4463**	4.7528	**3.4463**
17	N/A	N/A	7.4446	7.4446	N/A	7.4446	4.9165	7.4446	**4.3323**	6.16	6.5181	**4.3323**
18	N/A	N/A	8.978	8.978	N/A	8.2447	4.6691	3.435	7.8851	4.1904	**3.3594**	**3.3594**
19	N/A	N/A	6.6166	6.6166	N/A	3.1412	4.0633	**2.6969**	4.2408	5.4368	5.2835	**2.6969**
20	N/A	N/A	4.3923	4.3923	N/A	4.3923	4.3923	3.6683	8.9559	4.3188	**3.0427**	**3.0427**
21	N/A	N/A	4.8725	4.8725	N/A	4.8725	4.8725	4.2461	**3.9886**	4.4247	4.4247	**3.9886**
22	N/A	N/A	7.2919	7.2919	N/A	7.2919	**5.4675**	7.2919	10.9781	7.2919	6.3866	**5.4675**
23	N/A	N/A	4.9279	4.9279	N/A	4.9279	4.9279	4.6938	9.5066	4.7913	**3.8396**	**3.8396**
24	N/A	N/A	8.7384	8.7384	N/A	8.7384	4.7705	5.6049	10.0256	**3.5327**	**3.5327**	**3.5327**
25	N/A	N/A	23.2939	23.2939	N/A	9.4797	11.0643	5.9754	13.5408	**3.6202**	4.1479	**3.6202**
26	N/A	N/A	15.007	15.007	N/A	9.841	**5.9551**	11.7601	17.273	7.3141	8.9468	**5.9551**
27	N/A	N/A	22.8546	22.8546	N/A	13.864	22.8546	12.4286	8.5936	**5.0388**	6.63	**5.0388**
28	N/A	N/A	31.5063	31.5063	N/A	31.506	13.3521	23.0673	16.8874	**4.1796**	**4.1796**	**4.1796**
29	N/A	N/A	16.2106	16.2106	N/A	16.211	16.2106	16.2106	10.9702	**7.1637**	7.3547	**7.1637**
30	N/A	N/A	14.1518	14.1518	N/A	14.152	14.1518	12.327	5.9034	**5.8711**	**5.8711**	**5.8711**
No. of times optimal path found	**0**	**0**	**0**	**0**	**0**	**0**	**6**	**4**	**4**	**8**	**11**	

Bold values are specifying the minimum cost of route from source to destination node in WMNs

Table 3 Performance comparison of overall client WMNs

Sr. no.	Nodes	Trials	AODV	ACO	BAT	BBO	DSR	FIREFLY	B3C	GA	PB3C	3PGA	H3PGAB3C
1	5000	90	0	0	1	1	0	5	20	16	6	28	30
2	6000	90	0	0	1	1	0	1	15	14	11	33	40
3	7000	90	0	0	1	1	0	8	6	12	21	32	38
4	8000	90	0	0	2	2	0	3	10	15	16	37	41
5	9000	90	0	0	1	1	0	2	6	10	18	47	51
6	10,000	90	0	0	0	0	0	1	7	6	10	49	53
Total no. of times optimal path found		540	0	0	6	6	0	20	64	73	82	226	253

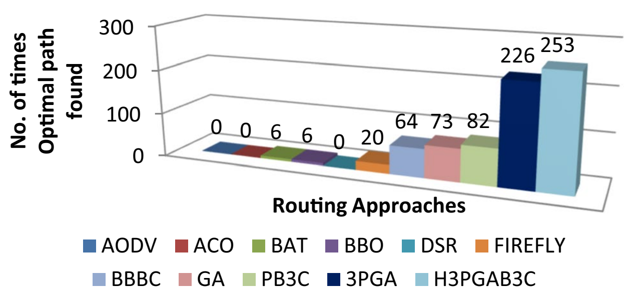

Fig. 2 Performance analysis of overall client WMNs

just 20 times. BAT and BBO can perform best only 6 times each for finding minimal cot route. This is to note that DSR, ACO and AODV failed to search any path for given architectural scenarios. Overall performance analysis is given in Fig. 2.

6 Conclusion and future scope

This paper proposes a soft computing based novel hybridized algorithm namely H3PGAB3C. H3PGAB3C is an amalgamation of three parent genetic algorithm and big-bang big-crunch approach; designed to search and optimize the solution of any NP-Hard or NP-complete problem. In order to validate the proposed algorithm, we applied it to evaluate the minimal cost route in client WMNs. Integrated link cost was used to evaluate the route costs. ILC is based on fuzzy system designed to measure the performance. We have considered client WMNs of 5000, 6000, 7000, 8000, 9000 and 10,000 nodes. Performance of H3PGAB3C was compared with 10 algorithms namely DSR, BBO, ACO, FA, BAT, AODV, PB3C, GA, B3C and 3PGA. It was observed that DSR, ACO and AODV failed to search route for any of the WMN within specified timing constraints. We carried out total of 540 trials. It was observed that H3PGAB3C searched optimal path 253 times, 3PGA 226 times, PB3C 82 times, GA 73 times, B3C 64 times, FA 20 times, BAT and BBO 6 times each. From the observations we conclude that AODV, ACO and DSR are not suitable for WMNs of large size. Further, we conclude that H3PGAB3C gave the best performance out of the 11 competing algorithms followed by 3PGA. In future, the work can be extended by taking large scale WMNs consisting of more than 10,000 client nodes. The proposed approach can be implemented for establishing the faster communication within Organization/University. The proposed approach can also be utilized for other complex problems for finding the optimized solutions.

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