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WSNs and PDNs: Similarities, Challenges and Application of Computational Intelligence

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ABSTRACT

In the world of interdisciplinary courses solution techniques has played significant role. Nowadays computational intelligence (CI) is common platform where several engineers land together. In this paper, power distribution networks (PDNs) and wireless sensor networks (WSNs) are analyzed in terms of similarity in network structure, challenges and the implementation of CI for the solution of discrete problems for energy efficient network design and operation. The PDNs structure is usually planned as radial in which several loads are connected at the load centre and the power flow is bidirectional. On the other hand, in WSNs the several sensor nodes are assigned with the single gateway or cluster head (CH). During operation distribution network are usually performed reconfigurations likewise WSNs adopted the efficient clustering. In practice, reconfiguration and clustering are discrete problem and computational intelligence found to be more effective for formulation of such problems in the optimization function.

Keywords: Power distribution networks, Wireless sensor networks, Reconfiguration, Clustering and Computational Intelligence.

1. INTRODUCTION

In the age of digital era, the advancement in technology has pivoted the world about a single point. This is christened as artificial intelligence (AI). AI is the study of making computers to do the work which humans presently do. AI involves two parts, namely 'soft' and 'hard' where later consists of logics and expert system. However, in soft AI several computational intelligent methods are developed in the recent research works. This has happened because of the fact that some problems have no fixed solution and therefore, best acceptable solution is taken from the set of solution or under the given circumstances. Optimization techniques can be divided into two categories namely: heuristics and meta-heuristic techniques. A heuristic approach follows the set objective in steps and always gives a single solution of the problem. The solution of the heuristic approach may or may not be the optimal but it is considered as the near optimal solution under the given constraints.

On the other hand, meta-heuristic approaches can be divided in two ways: neighbor based techniques and population based techniques. Meta-heuristic approaches always give a set of solution from where the best solution is taken. However, the best solution from the set of solution may not be the optimal for the problem but it can be considered as the near optimum.

In recent years, for engineering and technological development the use of CI techniques has increased many folds in the field of WSNs and PDNs. WSNs composed of large number of wireless sensor nodes with limited bandwidth [1]. Sensor nodes have limited power and they are incorrigible in the WSN field.

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WSNs have many constraints on it. The preeminent constraint is power consumption. Battery charge aggravates when sensor nodes communicate with base station (BS) and the network dies. Therefore, in order to increase the lifetime of network the operator face the challenge of reduction in energy consumption during communication. The energy depletion depends on different aspects of WSNs. Singh and Sharma [1], has presented different challenging issues in WSN along with the major optimization techniques developed for that. Moreover, authors in [2] and [3] have conferred localization system optimization techniques and coverage issues respectively. The operation of WSNs has been optimized by using the CI based techniques in [4]. Here, the system operation is optimized by efficient load balanced clustering, since clustering allows restructuring of the WSNs during operation. Bari et. al. [5] has presented different heuristic and approximation based techniques.

Similar to WSNs, in PDNs, there are several load point and the loads keep on varying with time of the day or season of the year. There exist several implementations of the CI techniques for optimization in the PDN's operation and planning. Optimization is performed for integration of distributed energy resources and the network reconfiguration [6]. In optimization function, these are the discrete problems. Reconfiguration allows the restructuring of the PDNs during operation under different constraints. Since, electrical load varies with the state of economy and the system voltage profile, it has no single solution [7]-[11]. In this scenario, the application of CI techniques plays a pivotal role in order to find the optimal solution of PDNs. Several nature exhilarated meta-heuristic techniques appeared in [12]-[14] for reconfiguration and the integration of the distributed energy resources in PDNs.

Kumar and Singh [11] presented the harmony search based reconfiguration of the PDNs under different practical load components. Since the variation in system loading is voltage dependent and therefore, it is not certain that how much load varies at which node. As a result, it is laborious to find a single solution of the problem using deterministic or analytical approach. Involving CI, several approaches like effect of load models [12], ant colony optimization in [13], and particle swarm optimization in [14] has been proposed by the researcher for PDNs. Thomas and Ali [15] developed the substation communication architecture for automation which in demands the application of above computational intelligent techniques for optimal operation.

From the literature, it has been observed that the optimization problems of WSNs and PDNs are quite similar. During operation, clustering allows the re-assignment of the sensor nodes with the gateways like reconfiguration in PDNs. Clustering and reconfiguration are the discrete problems and has no fixed solution. In practice, for accurate solution of these problems, the intelligence of the operator and the quality of solution depends upon the operator's experience of handling the operating constraints concurrently is required.

2. SIMILARITIES IN PDNs AND WSNs

PDNs and WSNs are similar in many aspects. In technical aspect the similarities can be defined in terms of network structure, operating constraints, problem formulation in optimization function and customer demands. The similarities between PDNs and WSNs are discussed as under,

2.1. Network Structure: Reconfiguration vs Clustering

Fig. 1 and Fig. 2 show the network structure of the PDN and the reconfigured PDN.

In the PDNs load is always connected after distribution transformer. Generally, voltage level before distribution transformer is 11kV or more whereas, this has reduced to 440V for secondary distribution. Since load in the secondary distribution side is voltage dependent and hence, load profile keep on varying in a day. In this scenario, some feeders may operate at over load whereas other may be operating at under loading. To maintain load balancing power utilities usually shift the load from one feeder to another. This

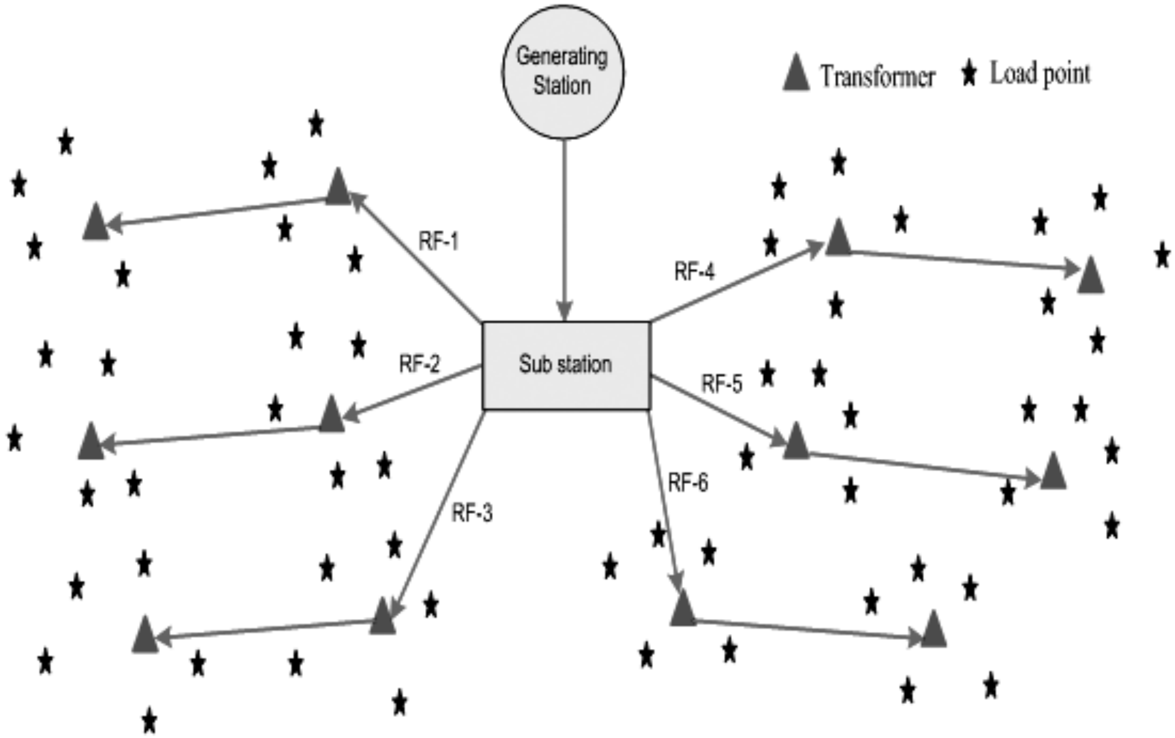

Figure 1: Base structure of PDNs with load points and transformers.

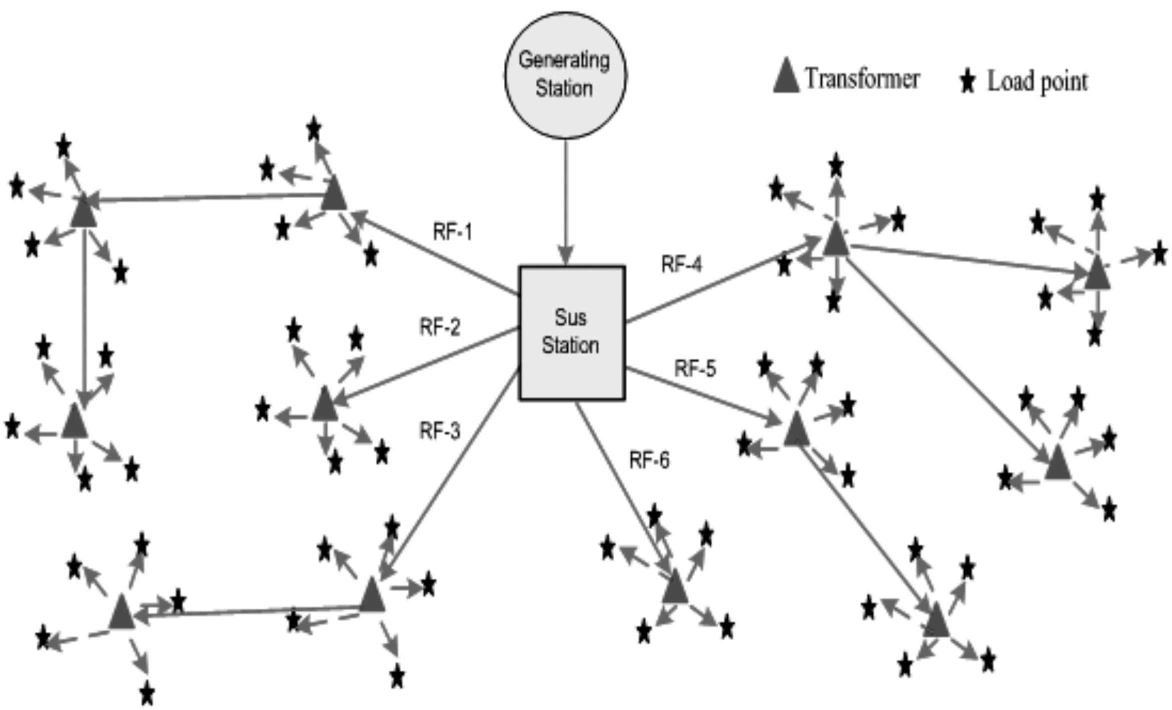

Figure 2: Re-structured PDNs with load points and transformers.

requires online network management and it is usually referred to as reconfiguration. Fig. 1 and 2 demonstrate the concept of the network reconfiguration where either load is shifted to other feeder or it is shared from other transformer, which allows the load balancing.

On the other hand, in WSNs the sensors are assigned to gateways. Gateways are also dubbed as cluster heads (CHs). Sensor nodes send the sensed information packet to the CH. CH aggregate that information and then send it to the BS directly or via another CH.

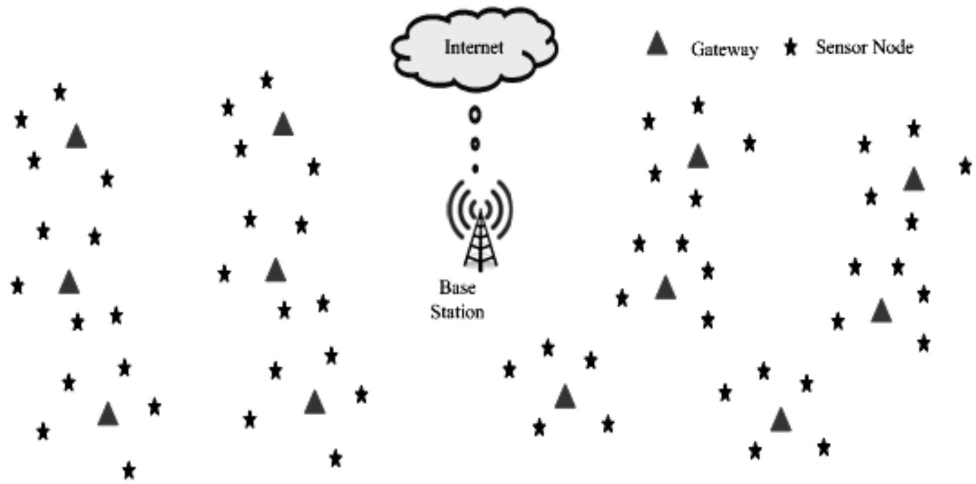

Figure 3: A sample WSN cluster architecture before clustering with sensor nodes and gateways.

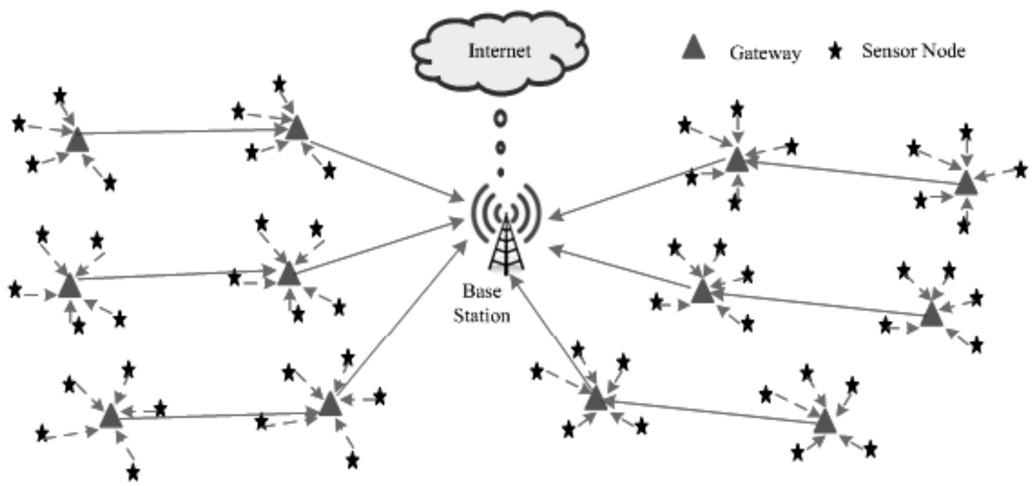

Figure 4: A WSNs architecture after clustering with multi-hop Routing

Here, it can be perceived that the power flow in PDNs is from source to load centre whereas, in WSNs the signal information flow is from sensor node to the base station. In practice, for both cases, flow of the processing quantity, i.e. power in PDNs and data information in WSNs, is bidirectional.

2.2. Operating Constraints

The various operating constraints in PDNs are loadability limit, voltage limits and thermal limit and in WSNs the constraints are energy consumption, coverage area and dead sensor nodes. Constraints restrict the system operation since violation of any one constraint may cause loss to operator, may be in terms of money, number of customer, power loss.

2.3. Formulation of optimization problem using computational intelligence

In optimization functions, the problem formulations for maximization and/or minimization need to be defined. Generally, in PDNs problem is formulated for loss minimization since it is believed that reduction in line loss improves energy efficiency. Similarly in WSNs, optimization is performed for load balancing and reduction in energy consumption.

2.4. Customer Demand

PDNs and WSNs are the demand supply networks and their operating structure and the optimization function varies significantly with the customer requirements. In PDNs, the system is usually restructured to meet the customer demand as per the priority and state of economy. As a result, sometimes system operation may not be allows to operate at its optimum.

On the other hand, in WSNs the network is restructured for the maximum coverage of the area with minimum energy consumption. Therefore, to meet this requirement efficient clustering with load balancing is performed in WSNs.

3. CHALLENGES IN PDNs AND WSNs

Section II described the similarities between PDNs and WSNs. Keeping them in mind there are certain challenges in PDNs and WSNs which are matched with each other, since in both the cases the operation depends upon the customer's requirement and the reliability of supplying the required demand. Different Challenges in WSN are [1]: Deployment, localization, clustering, routing, relay node placement, cross layer design. In PDNs the major challenges is thermal limit, voltage limit, loadability limit, integration of distributed energy resources, load profile, and reconfiguration.

The one to one metrics for performance evaluation in WSNs and PDNs are summarized below,

3.1. Possible sensor nodes connected with gateways vs Connected load

In WSNs the possible sensor nodes assigned with the gateways limit the system operation whereas, in PDNs the system performance need to be evaluated based upon the loadability limits i.e. the maximum possible load that can be supplied at a time.

3.2. Coverage area vs Voltage limit

In WSNs, coverage is the quality of service and service provider has to cover the area with better connectivity. On the other hand, In PDNs, voltage limit is the quality of the service and for customer satisfaction power utilities have to maintain the minimum level of voltage.

3.3. Dead sensor nodes vs thermal limit

The power lines have its capacity to bear load current and if it exceeds the limit the line conductor may break and disarray the supply. On the other hand, in WSNs, over load or impairment of the sensor node due to limited energy capacity may disrupt the signal in a particular area.

3.4. Energy consumtion per packet vs line power loss

In PDNs, line loss in a particular feeder can affect the system performance and in WSNs, the energy consumption per packet during communication needs to be determined.

3.5. Integration of DG vs Relay Node Placement (Fault Tolerance)

Due to excess of the load the feeder capacity for additional load decreases and, in this situation it needs to integrate the source of local generation with existing system. On the contrary, in WSNs, any node in the network may fail during communication and it is required that some specialized nodes to be placed in the network area. These nodes start working when some failure occurs.

4. COMPUTATIONAL INTELLIGENCE TECHNIQUES IN PDNs AND WSNs

As discussed above, the optimization problem in PDNs and WSNs has no fixed solution and therefore, for such problems CI techniques based on meta-heuristic approaches are found to be suitable. In the literature, it has been exemplified that in recent years, several nature inspired techniques such as genetic algorithm, harmony search algorithm, ACO and PSO are developed. The authors in [1] discussed the recently developed CI techniques in WSNs. The procedural steps of CI techniques are described as under,

4.1. Genetic Algorithm (GA)

It is a population based nature inspired computational intelligence technique used to solve the complex optimization problem. It follows three steps namely: selection, crossover and mutation. Initialization of the GA involves the selection of intial population and then crossover is performed. However, mutation is optimal which when handled carefully can ameliorate the performance of the algorithm.

4.2. Simulated Annealing (SA)

SA is inspired by the physical process of annealing in metallurgy. SA is a randomized approach which starts with a given solution. The objective function of the randomly generated solution vector is determined, and compared with recently generated new solution. If it is found better than the existing solution it is replaced with the new solution. In SA, the search is performed based on a probability distribution with a scale proportional to the temperature.

4.3. Particle Swarm Optimization (PSO)

This approach is inspired by social behavior of bird flocking. In PSO, the swarms or particles denote an individual solution and can explore 'N' number of parameters. Initially, the particles best position *Pbest* is determined and then best position in its local (*Lbest*) space and global (*Gbest*) space is explored. In every iteration particle moves towards *Pbest, Lbest or Gbest and* the best possible solution is determined.

4.4. Harmony Search Algorithm (HSA)

It is also a nature inspired approach developed for the solution of complex problems. In this technique, an initial harmony is generated and the improvisation of harmony is decided based upon the three rules namely: random search, harmony consideration and the pitch adjustment. However, band width is another factor which can affect the quality of result if handled carefully.

4.5. Ant Colony Optimization (ACO)

This algorithm is based upon the food search by the ants. Ants have the special chemical which they spread over the path they followed, in the search of the food. The chemical is known as the pheromone. The maximum pheromone will be deposited over the path followed by maximum time or by the maximum number of bees. Since, shortest path will be covered most and hence the solution is optimized.

4.6. Artificial Bee Colony Algorithm (ABC)

In this computational intelligent technique, the concept of sharing the knowledge of food source by the honey bee is developed. This knowledge contains position and nectar amount of food source. Based upon the purpose three types of honey bees are identified namely: Employ, Onlookers and Scout. In optimization, the solitary purpose of the bees is to find the food sources of higher nectar amount in less effort.

4.7. Gravitational Search Algorithm (GSA)

GSA is nature-inspired computational intelligent technique. This is derived from the law of gravitational forces between the agents. The agents in GSA have four parameters namely: position, inertial mass, active gravitational mass and passive gravitational masses. In GSA, heavier masses attract the other masses in surrounding and it represents the optimal solution in the search space.

5. PERFORMANCE EVALUATION OF PDNs AND WSNs

In this section sample results of the reconfiguration and the clustering of PDNs and WSNs, respectively, are discussed. Fig. 5 and 6 shows the 8-node radial distribution system in two different configurations. From the load flow solution the power consumed is found to be 22.66kW and 24.04kW in configuration-1 and 2, respectively. The load profile in these configurations is calculated as under,

Power in configuration-1,

$$P_{L(1)} = P_{L,nom} * [V_{i(1)}]^{\alpha} \quad (1)$$

Similarly, power in configuration-2,

$$P_{L(2)} = P_{L,nom} * [V_{i(2)}]^{\alpha} \quad (2)$$

Where, $P_{L(1)}$ and $P_{L(2)}$ are the load power at voltage $V_{i(1)}$ and $V_{i(2)}$. The voltage exponent (α) is taken as same as derived in [6] for load combination III.

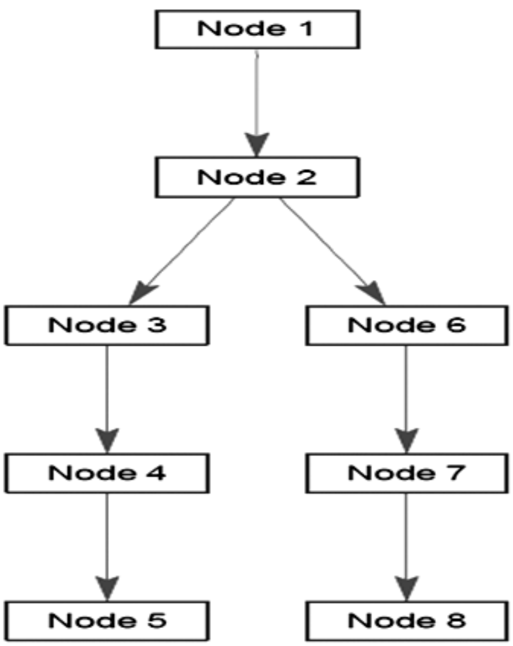

Figure 5: An 8-node PDN configuration-1.

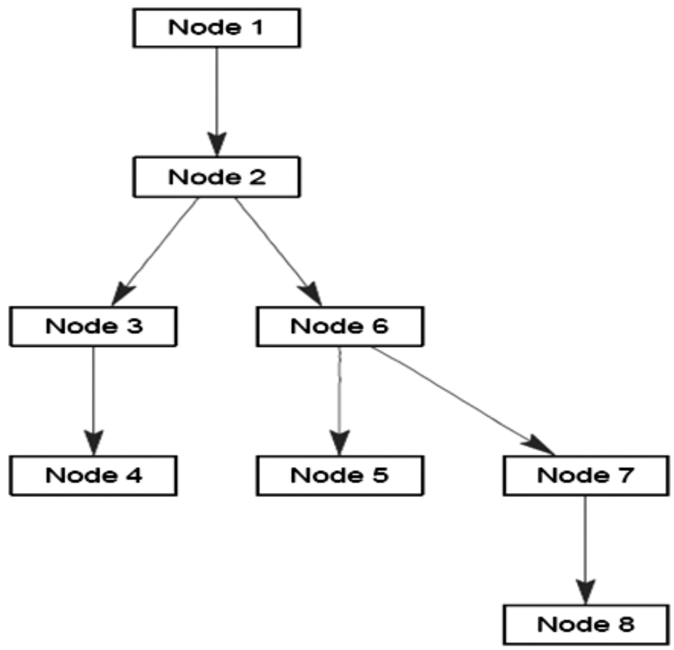

Figure 6: An 8-node PDN configuration-2.

5.1. Results of PDNs for sample network

Table-1 shows the performance of a distribution system in two different configurations. Here, $P_{L,nom}$ is the load power at rated or nominal voltage. From the test results it can be noticed that the system loading varies

Table 1
Load Profile in different Configurations

		Configuration-1		*Configuration-2*		
Load bus	$P_{L,nom}$ *kW*	$V_{i(1)}$*pu*	$P_{L(1)}$ *kW*	$V_{i(2)}$*pu*	$P_{L(2)}$ *kW*	$\|\Delta P_{L(1,2)}\|$ (kW)
2	44.1	0.9841	42.71	0.9841	42.71	0.0022
3	70.0	0.9804	67.27	0.9815	67.43	0.16
4	70.0	0.9786	67.04	0.9805	67.30	0.26
5	58.1	0.9774	55.50	0.9673	54.35	1.15
6	140.0	0.9708	131.94	0.9693	131.52	0.42
7	201.0	0.9657	195.83	0.9642	195.21	0.62
8	140.0	0.9633	129.91	0.9618	129.50	0.41

at load point and the variation in loading ($\Delta P_{L(1,2)}$) in two configurations is also calculated as shown in the last column of Table-1.

5.2. Results of WSNs for sample networks

Table-2 and 3 show the simulation results of least distance clustering (LDC) [5], particle swarm optimization (PSO) [16], and harmony search algorithm (HSA) [17] for two different networks. Here, 'mean' typifies the mean value of the fitness function and 'SD' exemplifies the standard deviation, as described in [5]. However, coverage aware heuristic has been presented by Singh and Sharma in [18]. Here, below results concern only about load balancing of gateways in comparison with computational intelligence techniques i.e. simple HSA and simple PSO.

Table 2
WSN Configuration#1 (30 Gateways)

CI Algorithms		*Sensor Nodes* 100	200	300
LDC	Mean	280.68	268.39	205.47
	SD	14.30	13.68	11.22
PSO	Mean	420.39	378.60	298.33
	SD	13.27	12.36	11.18
HSA	Mean	440.56	394.22	325.10
	SD	12.16	11.98	11.06

Table 3
WSN Configuration#1 (60 Gateways)

CI Algorithms		*Sensor Nodes* 400	500	600
LDC	Mean	467.30	359.20	298.30
	SD	16.80	15.55	16.20
PSO	Mean	785.40	544.69	431.83
	SD	19.23	15.41	18.16
HSA	Mean	802.46	648.20	488.39
	SD	20.36	16.07	19.01

6. CONCLUSIONS

This paper has presented the similarities, challenges and the application of CI techniques in PDNs and the WSNs. Reconfiguration and clustering of PDNs and WSNs, respectively, seems to be the cost effective means to improve system performance. These are the discrete problems and for such problem CI is most suitable technique since they give unique result under different operation conditions. From the analysis of performance of both networks it can be discerned that the CI techniques are applicable to the similar networks which have similar challenges in a same fashion. Therefore, it needs to explore these techniques in futuristic optimal operation of PDNs and WSNs.

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