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Coverage and Lifetime Optimization of WSN using Evolutionary Algorithms and Collision Free Nearest Neighbour Assertion

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ABSTRACT

Multipath transmission of raw sensor signals is the customary technique used in the wireless sensor network to improve end-to-end delivery. However, this technique suffers significantly because of the occurrence of multiple copies of data at the destination and their collision. The Collision-Free Nearest Neighbour Assertion (CNNA) method with n-d tree structure improves the collision removal which, in turn, avoids duplicate packets, but load balancing among neighbouring nodes is an essential issue. Optimising network performance by considering various network parameters and load balancing the network demands a good evolutionary-based optimisation technique other than traditional algorithms. Optimisation techniques based on Particle Swarm Optimisation (PSO) and Genetic Algorithm (GA) are applied and compared against various network parameters in this work.

Keywords: Collision-Free Nearest Neighbour Assertion (CNNA), genetic algorithm (GA), multipath transmission, Particle Swarm Optimisation (PSO).

INTRODUCTION

Coverage, network-life time and end-to-end delivery are the three important parameters that decide the performance of a wireless sensor network (WSN). In WSN, network lifetime and coverage are dependent parameters, meaning there is a trade-off between these two parameters. Coverage can be simply improved by making more sensors active for a unit amount of time but this affects the life time of the sensor network. Similarly, in order to improve the average life time of the sensor network more sensors are needed to be in sleep mode for the maximum possible duration but this approach affects coverage of the network critically (Vijayan et al., 2015). The balancing of sensor coverage and network lifetime is a fundamental issue because of the dynamic nature of mission requirement. End-to-end delivery is also an important parameter because it ensures all fruitful messages reach the base station; this

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demands multiple sensors to be active and a multipath transmission that ultimately affects network life time. So it is important to use good optimisation techniques to decide the optimal sensor scheduling that yields superior load balancing. The demand of the scheduling algorithm is purely on improving the pre-defined coverage and lifetime requirement. The dynamic nature of the application demands different coverage requirement but at the same time, lifetime parameters are always expected to be maximum. The proposed scheduling algorithm optimises coverage and life time based on the requirement by considering other network parameters like end-to-end delivery, throughput and load balancing etc. The type of sensor like static sensor or dynamic sensor requires different levels of attention in sensor scheduling because the requirement of coverage enhancement with a fixed number of static sensors cannot be solved using traditional techniques. Similarly, there are multiple mission requirements where the traditional algorithm fails, so an optimisation algorithm is needed that considers these multi-objective parameters for the best possible solution. Measurement coverage and life time are considered based on a spatial-temporal metric where the product of area and duration is calculated. In this work, we applied the collision-free Nearest Neighbour Assertion method in the inter-domain to improve the elimination of duplicate packets and energy, end-to-end delay, data loss etc. in WSN. The global measure of spatial-temporal coverage is taken from the average value of the individual local sites and such use of a network-wide metric guarantees global optimum solutions.

As the initial formulation of the problem confirms it is an NP hard optimisation problem, our objective was to optimise spatial temporal coverage by scheduling robotic sensors that use a centralised heuristic optimisation approach with the Nearest Neighbour Assertion method. As this is a classic problem of optimisation, coverage and lifetime measurement can be improved with the application of Genetic Algorithm (GA) (Vijayan et al., 2014) or Particle Swarm Optimisation (PSO). A comparison of the GA and PSO in this application context shows that each technique had its own strength according to context and configuration. However, challenges like creating initial populations, chromosome representation, selection of genetic operators etc. need to be solved in the implementation phase.

LITERATURE REVIEW

Robotic sensor coverage and lifetime optimising problems in a WSN has been discussed in detail. Convergent diversity like area coverage, point coverage and barrier coverage has been analysed precisely (Cardei & Wu, 2005). In coverage optimisation, most of the research focussed on minimising the number of wireless sensors without affecting coverage degree (e.g. 1-degree or k-degree) (Tian & Georganas, 2002; Wang et al., 2003) but these works did not consider network lifetime. A centralised scheduling algorithm can be used to activate sensors sequentially to ensure coverage and guarantee the O (logn) (Liu & Cao, 2010) factor of the improved network lifetime, where n is the total number of nodes. Further, application of a distributed scheduling algorithm improved the performance factor by O (logn*lognB), where B is the upper bound (Meguerdichian et al., 2001) of the initial battery. Connectivity is the other factor that needs research attention in WSN. For example, when coverage requirement could be satisfied, the conditions to achieve communication connectivity were derived (Kumar et al., 2005). If coverage is not up to the expected level it needs to be improved e.g. partial coverage can be slightly improved by proper application of routing protocols (Kasbekar et al., 2011) that ensure delivery of data at the destination.

Major research works treat lifetime as an important objective and coverage and end-to-end delivery etc. as constraints that need the scheduling of robotic sensors for a unit amount of time to optimise total spatial-temporal coverage redundancy. Differences in problem formulation approaches are applicable based on the mission requirement for coverage or network life time.

THE OPTIMISATION OF NETWORK PARAMETERS AND LOAD-BALANCING PROCEDURE

In order to yield the optimum result, the robotic sensors need to cover a maximum area without compromising on life time of the network and other parameters like end-to-end delivery etc. In the implementation of the total network time 'T' is divided into 'L' number of cycles and the various sensors within each cycle are turned on based on the present coverage and battery life. The same procedure is repeated in each cycle and the sleep mode of the sensor is used in the same way the power-saving mode of 802.11 is used. The purpose of optimum scheduling is to identify the 'L' local schedule, which ensures maximum overall spatial-temporal coverage.

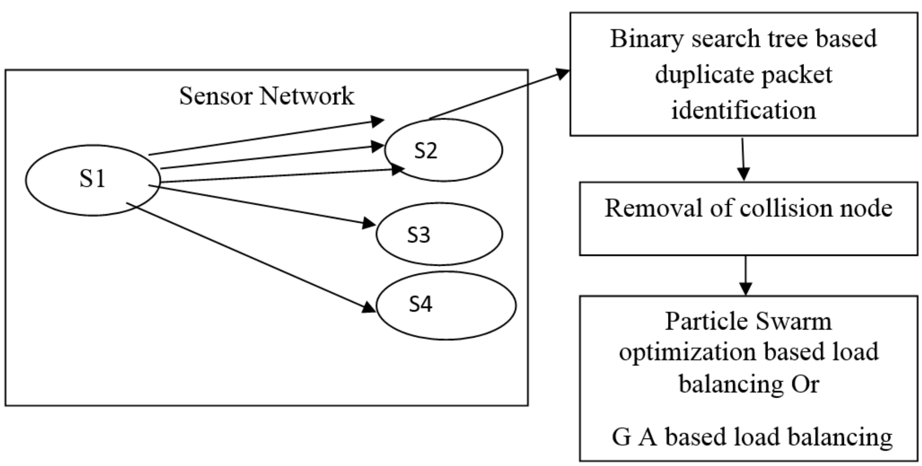

Figure 1. System architecture.

Here the initial step (Kumar et al., 2004) was to locate 'k' nearest neighbour sensor based on the distance or round-trip time in the wireless robotic sensor networks. Once the nearest neighbour list was identified a query would be sent to the nearest nodes and perimeter nodes around the query. A circle was formed around the query point and this space was further divided into subspaces of similar nature, with each subspace containing a perimeter node. Information from each subspace was collected through the perimeter node through a tree structure. Once the query was resolved the tree might be removed from the memory due to cost of maintenance.

The neighbour list created is used for Collision-Free Nearest Neighbour Assertion (CNNA) (Vijayan et al., 2016) and an n-d tree is created as shown in Figure 1. The focus is on locating the nearest robotic sensor nodes; we assume the locations of robotic sensor nodes usually do not change during this time. Many researchers concentrate on the static environment (Zou & Chakrabarty, 2005; Kumar et al., 2004), but here the focus was on the dynamic environment tracked by the robotic sensor network. The object near a query point was located and the number of indexing schemes were proposed as dynamic object databases (Bai et al., 2006; Cardei et al., 2005).

Figure 1 clearly describes the segregation procedure with the aid of a flow chart. The nearest neighbour assertion method creates a neighbour list using the binary search technique and duplicate packets are removed based on the variance (Vijayan et al., 2016) value computed on each node, which is higher than a pre-defined threshold value (Liu et al., 2005). The evolutionary algorithms are now applied to the network to optimise network performance and parameters with the focus of load balancing.

The genetic optimisation procedure on the n-d data structure in the CNNA method undergoes genetic operations like initial population, selection, cross-over and mutation operation. Genetic operations with a weighted variance are used to optimise the load factor in a robotic sensor network with other network parameters. Challenges identified during the implementation are representation of chromosomes and selection of different genetic operators.

The GA-based optimisation technique is replaced by PSO and the performance measure is done. PSO is a robust stochastic optimisation technique based on the movement and intelligence of swarms, which literally try to improve the candidate solution. The inherent behaviour of PSO like separation, alignment, cohesion etc. are most appropriate for a WSN environment.

Procedures of the Global Version

The algorithm for PSO is as follows:

1. Initialise an array of the population of particles with random positions and velocities in D dimensions in the problem space.
2. Evaluate the fitness function in the D variables for each particle.
3. Compare each particle's fitness evaluation with its 'pbest'. If the current value is better than the 'pbest', save the current value as 'pbest' and let its location correspond with the current location in the 'D' dimensional space.
4. Compare the fitness evaluation with the population's overall previous best. If the current value is better than the 'gbest', save the current value as the 'gbest' to the current particle's array index and value.
5. Modify the velocity and position of the particle according to the following equations:

$$V_{id} = V_{id} + C_1 r_1 (P_{id} - X_{id}) + C_2 r_2 (P_{gd} - X_{id}) \quad [1]$$

$$X_{id} = X_{id} + V_{id} \quad [2]$$

The difference is that the basic principles applied to GA and PSO yield slightly different performance especially in different contexts.

METHOD AND RESULTS

The robotic sensor network is a distributed ad-hoc network comprising a large number of robotic sensor nodes equipped with capabilities of computing, storing and communicating. In this research simulation was done on Network Simulator 2 to evaluate the performance of the proposed collision-free Nearest Neighbour method with GA and PSO in the inter-domain. In the simulation, n robotic sensors were deployed in an area of 20 X 20 square metres with random motion enabled; the value of n varied from 100 to 800. The sensing range was 1 unit unless, otherwise specified. The scenarios were identified such that the application requirement made it difficult to achieve coverage and lifetime. Both homogeneous and heterogeneous cases of battery states were considered. In the homogeneous scenario, every node had the same battery/network lifetime ratio, but in the heterogeneous scenario the battery life factor of each sensor node was considered different with value.

Result Analysis of CCNA with Optimisation Technique Applied

In order to analyse and infer the characteristics and functionality of the CNNA method with GA or PSO, we quantitatively simulated performance by considering a network size of 1000 * 1000 with simulation time varying from 100 to 800 (m/s). The routing protocol used was Dynamic Source Routing (DSR) Protocol and we compared the outcomes of the results achieved with the Genetic Optimisation (GO) algorithm and Particle Swarm Optimisation (PSO). The simulation results using NS2 simulator were compared and analysed using tabulated values and graphical form as given below. Table 1 shows the measured values that are evident for effectiveness of Genetic Optimisation algorithm and Particle Swarm Optimisation to support transient performance. The results were measured to obtain the collision-removal rate and comparison was made between the two techniques.

Table 1
Measure of Collision-Removal Rate & Measure of Load-Balancing Efficiency

Node Density	Collision Removal Rate (bps)		Load Balancing Efficiency in Terms of Load Balancing Factor (%)	
	CNNA with GA	CNNA with PSO	CNNA with GA	CNNA with PSO
100	2.105	2.055	48.15	43.10
200	3.472	3.172	51.25	46.20
300	3.750	3.650	57.35	52.30
400	4.025	4.045	61.15	56.10
500	5.275	5.125	64.24	41.59
600	4.135	4.225	53.45	62.60
700	9.105	9.035	70.05	65.00
800	11.255	11.150	71.08	66.03

Figure 2 shows that the Collision-Free Nearest Neighbour Assertion (CNNA) method provided a higher collision removal rate but it was comparable to both GA and PSO. The improved result was due to the application of collision-free nearest neighbour assertion methods that efficiently identified duplicate packets created for a time period using n-d data structure with binary tree search. The n-d data structure identified the collision node using the binary tree, which ultimately reduced duplicate packets in the network and the node overhead in processing duplicate packets.

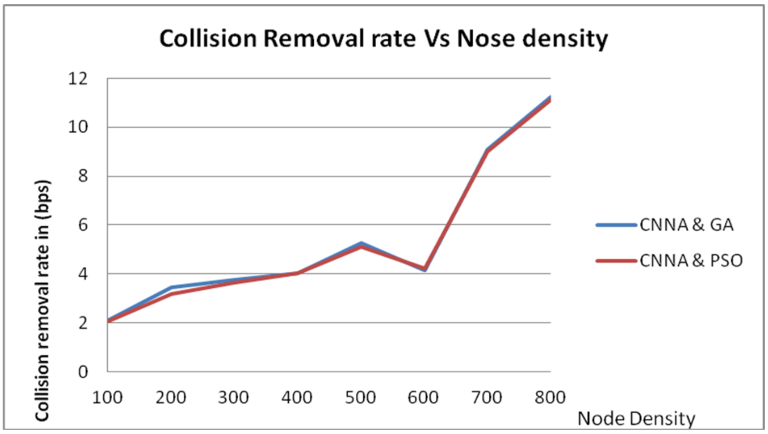

Figure 2. Impact of collision-removal rate on CNNA.

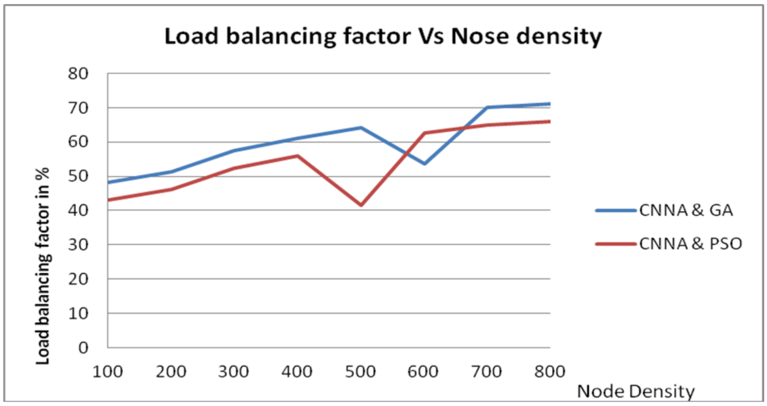

Figure 3. Impact of load-balancing efficiency with GA and PSO.

Figure 3 shows the load-balancing efficiency of both optimisation techniques. This result also proves that the effectiveness of both algorithms was comparable and that they performed equally well.

The comparison of the packet delivery ratio against the varying number of nodes for both GA and PSO was measured and tabulated as shown in Table 2. Figure 4 plots the packet delivery ratio of the two different optimisation techniques applied. It can be inferred from the graph that both GA and PSO provide a good packet delivery ratio with CNNA.

Table 2
Measure of Packet Delivery Ratio & Measure of Throughput.

Packet Delivery Ratio (%)			Throughput in %		
Node density	CNNA with GA	CNNA with PSO	Time	CNNA with GA	CNNA with PSO
100	30.25	36.35	100	66.3	32.35
200	32.45	42.44	200	59.1	37.48
300	38.56	48.52	300	58.2	42.55
400	42.35	52.35	400	52.0	58.42
500	45.55	55.45	500	66.33	62.59
600	55.45	60.45	600	70.53	70.25
700	34.45	45.25	700	65.23	70.38
800	72.35	72.45	800	66.70	70.45

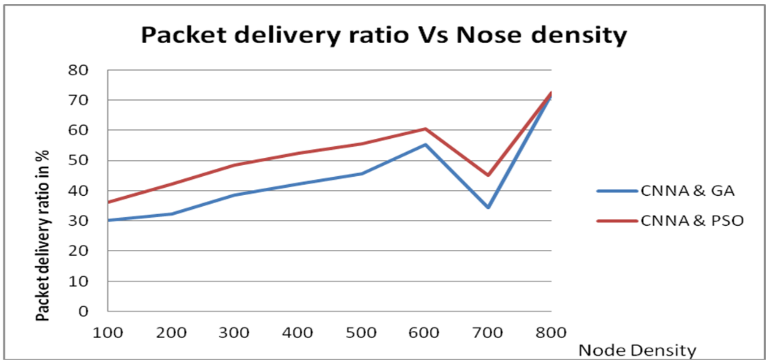

Figure 4. Impact of packet delivery ratio on varied node density.

The second part of Table 2 shows the measured value of the throughput against time and the corresponding graph plotted in Figure 5. It is evident from Figure 5 that the GA with CNNA is a good technique in the early stages of simulation while the PSO with CNNA performs well in the later stages of simulation.

From the various results obtained it can be inferred that the difference in performance between GA and PSO in different contexts is due to the operational principle difference of these techniques. Due to the strength of genetic operators like cross-over and mutation GA could bring an effective solution in the early period of network time. However, PSO operates with a previous value and memory and it can perform well once the solution is closer or in the later stage of the network.

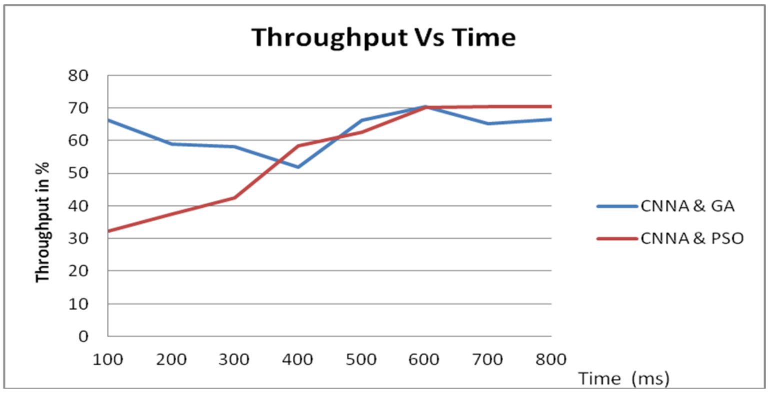

Figure 5. Impact of throughput on varying network time.

CONCLUSION

The application of Genetic Algorithm and Particle Swarm Optimisation in a wireless sensor network with Collision-Free Nearest Neighbour Assertion (CNNA) method is an effective technique for finding optimal sensor scheduling. The CNNA method eliminates duplicate packets in a network, which is generated due to multipath transmission. In this work, the optimisation technique solved the problem of load balancing in the network. The results proved that both GA and PSO performed equally well in collision removal, load balancing and packet delivery ratio for a dynamic network with a varying number of nodes. The results also proved that the throughput of the GA applied network was higher in the early stages of the scheduling and the throughput of the PSO applied network was higher in the later stages of scheduling. The performance difference was due to the operational difference of the optimisation techniques, where the GA produced higher fitness value initial populations quickly due to cross-over and mutation operations and due to the inherent nature of PSO i.e. it could operate on the existing values with large memory, performing well with later populations.

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