IJCTA, 10(07), 2017, pp. 217-223

Extending Connectivity And Coverage Using Robot Initiated K Nearest Dynamic Search For WSN Communication

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Abstract : Sensor networks driven by mission-specific applications usually have specific lifetime requirements. Moreover, sensor node density may not be large enough to persuade coverage requirement while satisfying lifetime restriction. Hence, coverage required to be traded for network lifetime. Wireless sensor networks comprising of wireless sensor nodes and robotic sensors have the prospective for monitoring large environments. To do so, in this work, a method called, Probabilistic Force-based *k*-Nearest Dynamic programming (PF-KND) is designed to assign tasks to robotic sensor nodes that result in minimization of communication time between sensor nodes and therefore extending the network lifetime. A neighbourhood probability model is designed that explicitly accounts for the probabilistic nature of wireless communication links and therefore depicts the coverage property. PF-KND method achieves communication links, which is measured by the minimum packet delivery between nodes in the network. Next, Force-based Sensor node deployment is constructed to provide probabilistic coverage reducing the computational time for packet delivery between nodes. Finally, *k*-Nearest Bellman-Held-Karp Dynamic-programming using robotic sensors are presented to assist sensor deployment and packet delivery to extend the network lifetime. Theoretical and simulation results show that PF-KND method outperforms other methods in terms of network lifetime, coverage, computational time and packet delivery rate.

Keywords : Wireless Sensor Network, Probabilistic, *k*-Nearest, Dynamic-programming, robotic sensor nodes.

1. INTRODUCTION

Network coverage and network lifetime are the two most important paradigms addressed by several researchers when wireless sensor network is considered. At the same time, with limited battery power of the sensor nodes, research works on robotic sensors are receiving greater interest. A neighbor coverage-based probabilistic rebroadcast protocol was designed in [1] with the objective of reducing the routing overhead. To improve coverage optimization, a distributed Parallel Optimization Protocol (POP) [2] was designed. On the other hand, both lifetime and coverage optimization was provided in [3] through distributed coordinated free sensor activation. This optimization model was based on polynomial time distributed algorithm.

In recent years researchers have done a lot of studies in non-uniform node distribution. Energy-aware and cluster-based routing algorithm was presented in [4] to choose with high energy and lower member nodes with the objective of balancing the energy consumption and improving the network lifetime. Another link stability and energy aware routing protocol was designed in [5] to improve network lifetime. On the other hand, a multi objective routing protocol was designed in [6] that used heuristic neighbor selection and geographic routing mechanism. In this paper, we propose a Probabilistic Force-

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based k-Nearest[7] Dynamic programming using robotic sensors for wireless sensor networks aiming at improving the coverage and network [9] lifetime. PF-KND[10] constructs Neighborhood Probabilistic model using competition range in order to improve[8] the coverage. To reduce computational/deployment time of communication between sensor nodes, a Force-based Sensor Node is deployed. Finally, with the probabilistic and force-based node deployment, a network assisted with robotic sensor is introduced that uses *k*-Nearest Bellman-Held-Karp Dynamic-programming algorithm to improve the network lifetime. Therefore, PF-KND achieves the network coverage and prolong the network lifetime through the assistance of robotic sensor nodes.

2. RELATED WORKS

Extensive research works have been dedicated to the study of clustering and transition models for improving coverage and lifetime in WSN. With the rapid transformation to nanoscale, the design and introduction of Integrated Circuits has resulted in the integration of high-performance processors and high-speed digital wireless communication circuits.

Coverage optimization for power balancing using clustered wireless sensor network was designed in [11] using Rayleigh Fading model. A variant of Maximum network Lifetime Problem (MLP) based on Column Generation scheme was presented in [12], ensuring coverage and network lifetime. Another method to improve communication range through Connected Dominated Set (CDS) was presented in using greedy approximation algorithm.

3. PROBABILISTIC FORCE-BASED K-NEAREST DYNAMIC PROGRAMMING

In this section, the network model is presented and then formulates the problem of extending coverage and network lifetime of sensor nodes using robotic sensors in the PF-KND.

A. Network model

Let us assume that the target area of consideration be a two-dimensional rectangular region, where ‘*n*’ sensors are randomly deployed. Then, the binary sensor model that expresses the coverage ‘*prob*(*a*, *b*)’ of a grid point ‘*b*’ by sensor ‘*a*’ is expressed as given below.

$$\mathrm{C}(a, b) = \begin{cases} 1, \text{if } \mathrm{Dis}\,(a, b) < \mathrm{R_D} \\ 0, \text{Otherwise} \end{cases} \tag{1}$$

Sensor ‘*a*’ is deployed at point ‘(x_a, y_b)’. For any point ‘*b*’ at ‘(x_a, y_b)’, the Euclidean distance between ‘*a*’ and ‘*b*’ is represented as ‘Dis(*a*, *b*)’, with the range of detection denoted as ‘$\mathrm{R_D}$’ respectively. The Euclidean distance is denoted as given below.

$$\mathrm{Dis}(a, b) = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2} \tag{2}$$

From (2), a point ‘(x_a, y_b)’ is covered by a sensor ‘*a*’ if its distance to the center ‘(x_a, y_b)’ of the circle is less than the range of detection ‘$\mathrm{R_D}$’. It is assumed that the point ‘*p*(*a*, *b*)’ is covered by the node set and as a result, the probability that the point ‘*t*(*a*, *b*)’ covered by the node set is then denoted as the union of ‘Prob_t’ and is expressed as given below.

$$\mathrm{Prob}_t = 1 - \sum_{a=1}^{\mathrm{N}} (1 - \mathrm{C}(a, t)) \tag{3}$$

B. Neighborhood Probabilistic model

A Neighborhood Probabilistic model based on the neighbourhood distance from monitoring sensor nodes that efficiently depicts the coverage property of sensor network is presented in the PF-KND method. The probabilistic model in the PF-KND follows a minimum node-to-node data packet delivery rate between any pair of sensor nodes in wireless sensor network.

Let us consider a sensor network in the form of a graph ‘G(V, E)’, where ‘V’ represents the set of all sensor nodes ‘S = s_1, s_2, ... s_n’, with ‘E’ representing the set of edges between any neighbouring nodes. Every pair of nodes ‘*a*, *b*’, have an edge ‘$a \rightarrow b$’ with packet delivery rate ‘Prob (*a*, *b*). Prob (*a*, *b*)’ denoting the probability of delivering data packets from ‘*a* to *b*’ in WSN. Then, the total probability of packet delivery rate from sensor node ‘*a*’, to senor node ‘*b*’ is represented as ‘PDR (*a*, *b*)’.

With the above graph model, link creation between distant nodes is made highly possible by estimating the lower bounds through probabilistic factor. Hence, the PF-KND only considers the delivery rates between neighbour nodes. Figure 1 shows the Neighborhood Probabilistic model followed for Packet Delivery between sensor nodes in PF-KND.

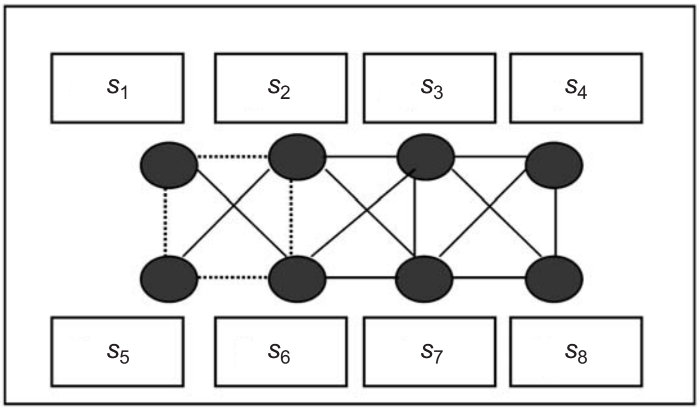

Figure 1: Neighborhood Probabilistic Packet Delivery between Sensor Nodes

As shown in the figure 1, direct packet delivery between ‘s_1’ and ‘s_4’ is not possible and therefore assumed to be zero. To start with let us consider a ‘2 * 2’ mesh and increase the network until all sensor nodes are included, where lower bound is considered in the proposed method. Let us assume a sensor node ‘s_1’ to be the source node and measure the packet delivery rate at ‘s_2, s_5, s_6’ respectively. Two paths exist between ‘s_1’ and ‘s_2’ with distance ‘11’ and ‘33’ respectively and are as given below.

$$(s_1 : s_2) \rightarrow s_1 \rightarrow s_2 \rightarrow (1) \rightarrow \text{Prob} \rightarrow \text{P} \tag{4}$$

$$(s_1 : s_2) \rightarrow s_1 \rightarrow s_5 ; s_5 \rightarrow s_6 ; s_6 \rightarrow s_2 (3) \rightarrow \text{Prob}^2 \rightarrow \text{P}^3 \tag{5}$$

From above (4) and (5), the accrued probability of packet delivery at ‘s_2’, ‘PDR (s_1 : s_2)’, is as given below

$$\text{PDR } (s_1 : s_2) = 1 - (1 - \text{P})(1 - \text{P}^3) \tag{6}$$

$$= 1 - (1^2 + \text{P}^2 - 2\text{P}) \tag{7}$$

$$= 1 - 1^2 - \text{P}^2 + 2\text{P} \tag{8}$$

$$= \text{P}^2 - 2\text{P} \tag{9}$$

Therefore, from the above assumptions made, when sensor nodes are initialized on a square mesh network with packet delivery rate between any two neighbouring sensor nodes is ‘P’, then the network delivery rate is as given below.

$$\text{NDR} \rightarrow \text{P2} - 2\text{P} \tag{10}$$

C. *k*-Nearest Bellman-Held-Karp Dynamic-programming

Despite improved network coverage, the sensor nodes in WSN run on limited battery power, so, with the objective of extending the network lifetime, the data packets sent has to be minimized. Moreover, the communication between the sensor nodes is designed in such a way they form a balanced structure, by introducing a robotic sensor. The PF-KND method allows the robotic sensors efficiently deploy and maintain sensor networks which enable data collection, extending network lifetime.

With this regard, robotic sensors are used that not only assist the sensor deployment but also perform the task of data collection. With further assumption that the robotic sensors in the PF-KND deploy sensor nodes and collect the data from these sensor nodes, the objective lies in the design of *k*-Nearest Bellman-Held-Karp Dynamic-programming Algorithm. The *k*-Nearest Bellman-Held-Karp Dynamic-programming algorithm persistently reports *k* nearest moving sensor nodes, where the robotic sensor nodes select the minimum path, therefore extending the network lifetime.The objective of k-Nearest Bellman-Held-Karp Dynamic-programming algorithm is to minimize the total length of the path which the robotic sensor travels. In this way, the total travel distance is minimized, maximizing the coverage.Let us consider a sensor network with sensor nodes '$S = s_1, s_2, \ldots s_n$', with set of robotic sensors '$RS(t) = rs_1, rs_2, \ldots, rs_n$' at time '$t$' assigned with an event '$E(t)$' with robotic sensors differentiated with sensor nodes by way of transmission range. In PF-KND, with the assumption that the transmission range of robotic sensors 'TR(RS)' is greater than that of the transmission range of sensor nodes 'TR(S)' in WSN is as given below.

$$TR(RS) \geq TR(S)\ TR(RS) \geq TR(S) \tag{11}$$

4. EXPERIMENTS AND PERFORMANCE EVALUATION

In this section, the performance of the PF-KND is evaluated by related simulations. In the environment of PF-KND, a region comprising of 600 m * 600 m and 400 sensor nodes are randomly distributed in the region for experimental purpose is designed. To conduct experimental work, Destination Sequence Based Distance Vector (DSDV) is used as routing protocol for PF-KND method. The PK-KND method's moving speed of the user or the communication between the nodes in WSN is about 15 m/s. For each sensor nodes, the simulation rate is set to 60 milliseconds to perform data packet delivery between sensor nodes through robotic sensors. Experiment is conducted on the factors such as sensor node density, network lifetime, coverage, computational time, data packet delivery rate. The performance of PF-KND is assessed and compared with other traditional coverage and lifetime extending methods, that is, Neighbor Coverage-based Probabilistic Rebroadcast (NCPR) [1] protocol and Parallel Optimization Protocol (POP) [2].

5. DISCUSSION

In this section the result analysis of PF-KND method are compared with two existing methods, Neighbor Coverage-based Probabilistic Rebroadcast (NCPR) [1] protocol and Parallel Optimization Protocol (POP) [2] in WSN. The nodes in PF-KND method are positioned in uniform topology. To evaluate the efficiency of PF-KND method, the following metrics like network lifetime, coverage, computational time, packet delivery rate with respect to sensor node density and network size is analyzed.

A. Impact of computational time

In this section, the impact of computational time is studied. Computational time is the time taken to establish communication between sensor nodes. To evaluate the computational time the sensor node density is the main factor to be considered. Next, the total force, that not only considers distance between sensor nodes but also the network density is taken into consideration. Therefore, computational time is the time taken to obtain the force and the sensor node density. Its mathematical formulation is expressed as shown below.

$$CT = \sum_{i=1}^{n} S_i * \text{Time}(\text{Force}_T) \tag{12}$$

From (12), the computational time 'CT' is obtained on the basis of the sensor node density 'S_i' and time to derive force 'Time (Force_T)' respectively. It is measured in terms of milliseconds (ms). In order to conduct experimentation, a network size of 600 m* 600 m was selected and was found that the time to obtain force using PK-KND method to be 0.35 ms, 0.42 ms when applied with NCPR and 0.52 ms when POP was applied out of 50 sensor nodes. Therefore the computational time is evaluated and tabulated

Figure 2 shows the computational time during data packet communication in wireless sensor networks with respect to varying sensor node density.

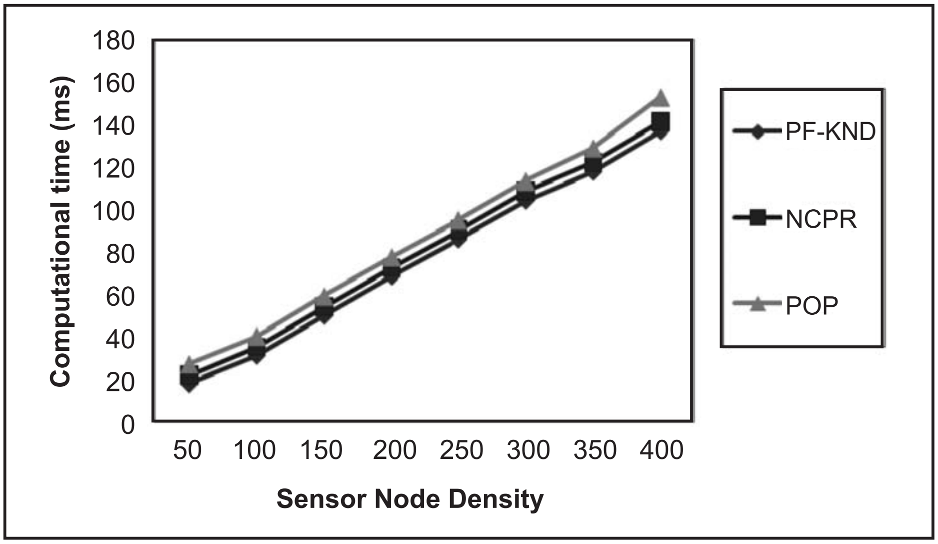

Figure 2: Comparison of computational time using PF-KND, NCPR and POP

It has been clearly shown that PF-KND minimizes computational time by 8% compared to NCPR and 19% compared to POP, therefore better in prolonging network lifetime compared to NCPR and POP.

B. Impact of network lifetime

In order to measure the network lifetime, two factors are considered. They are, simulation time and actual time. Network lifetime is the time at which the experiment gets started until the moment when the data packet delivery between any pair of sensor nodes in wireless sensor network is communicated.

$$NL = (Time_{sim} - Time_{DPD}) * \text{Number of sensor nodes} \qquad (13)$$

From (13) 'NL' measures network lifetime which is the difference between simulation time, '$Time_{sim}$', and data packet delivery,'$Time_{DPD}$' and is measured in terms of milliseconds (ms). In the experimental setup, the number of packets transmitted ranges from 9 to 72.

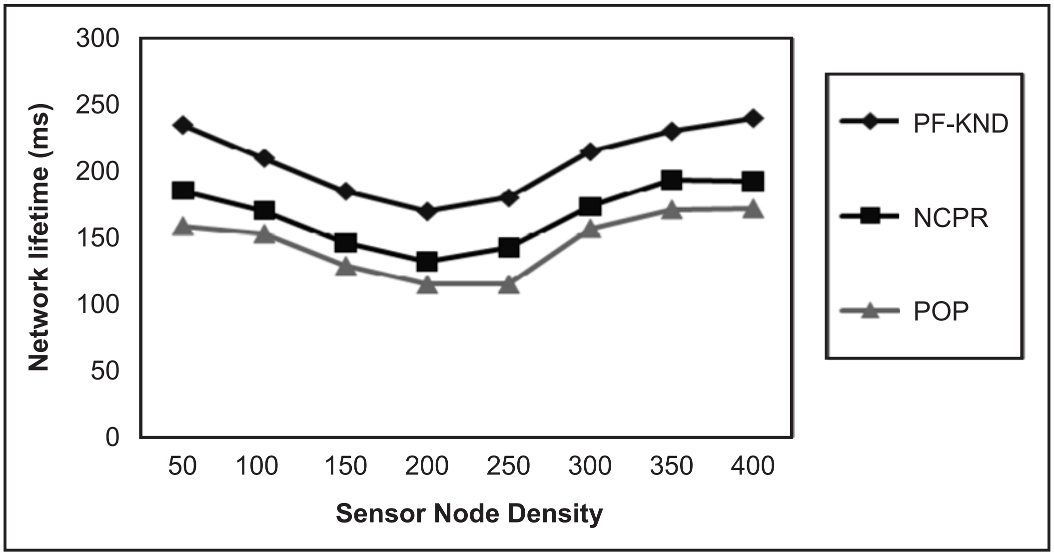

Figure 3: The average network lifetime in PF-KND, NCPR and POP

Figure 3 shows the average network lifetime fluctuation as the sensor node density increases. The targeting results of network lifetime using PF-KND method is compared with two state-of-the-art methods NCPR and POP in figure is presented for visual comparison based on the relevant information. An improvement of 20% is observed in PF-KNC method when compared to NCPR and 30% when compared to POP.

C. Impact of coverage

Coverage is defined as the ratio of the union of areas (in square meters) covered by each node and the area (in square meters) of the entire Region of Interest (ROI). Therefore, network coverage rate that is desirable to be maximized with the probability that the point of target region to be sensed to that of the network region is defined as

$$C = \sum_{i=1}^{n} \frac{A_i}{A} \tag{14}$$

From (14), the coverage 'C' is obtained as the ratio of the area covered by the '*i*' node to the area of region of interest 'A' with '*n*' representing the total number of nodes.

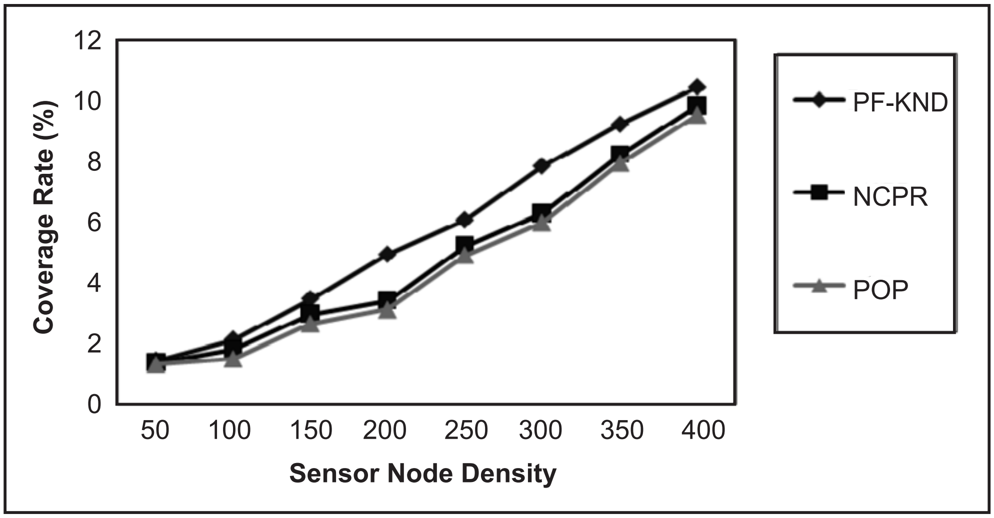

Figure 4 : Coverage rate in PF-KND, NCPR and POP

From the simulation results shown in figure 4, sensor node deployment to the uniform distribution is presented with overlapped coverage area by each other being relatively small. In order to further verify the validity of the method PF-KND, under the experimental environment, we, respectively, do the experimental simulation for NCPR and POP. The simulation results are as shown in Figure 8.And the coverage is said to be increased using PF-KND by 14% compared to NCPR and 20% compared to POP.

6. CONCLUSION

In order to extend the coverage and network lifetime, this paper proposes a Probabilistic Force-based k-Nearest Dynamic programming (PF-KND) based on robotic sensor nodes in Wireless Sensor Networks. Based on the Neighborhood Probabilistic model, coverage property of sensor node is addressed by considering delivery rate between neighbor nodes. With the neighboring nodes, a Force-based Sensor Node deployment is made, with the objective of minimizing the deployment time during communication between sensor nodes. Finally, *k*-Nearest Bellman-Held-Karp Dynamic-programming Algorithm is applied to the Force-based Node deployed network ensuring network lifetime. The simulation results show that the coverage rates of PF-KND method and network lifetime have increased evidently. And based on the same network coverage rate, compared with the traditional method of extending coverage and network lifetime, the PF-KND method performs better, especially under a large scale of nodes.

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