Permanent Relocation and Self-Route Recovery in Wireless Sensor and Actor Networks

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***Abstract*—Wireless sensor and actor network's connectivity and coverage plays a significant role in mission-critical applications, whereas sensors and actors respond immediately to the detected events in an organized and coordinated way for an optimum restoration. When one or multiple actors fail, the network becomes disjoint by losing connectivity and coverage; therefore, self-healing algorithm is required to sustain the connectivity and coverage. In this paper two algorithms; *Permanent Relocation Algorithm for Centralized Actor Recovery (PRACAR)* and *Self-Route Recovery Algorithm (SRRA)* for sensors have been proposed for connectivity and coverage. The effectiveness of proposed technique has been proved by realistic simulation results which ensure that our proposed technique better handles the connectivity and coverage.**

Keywords—Wireless sensor and actor networks; connectivity restoration; node mobility; route recovery node relocation

I. Introduction

Wireless sensor and actor networks (WSANs) consist of stationary sensor nodes and some moveable actor nodes [1]. Actor nodes are efficient than the sensor nodes in terms of their resources, including processing capabilities, energy and transmission ranges, etc. These actor nodes collaborate with each other and gather the data from the sensor nodes. For example, sensor nodes can detect the rising temperatures in specific areas in forest and forward this information to actor nodes in the form of packets [2]. The actor nodes correlate sensor nodes information and conclude the explosion of fire, and then actor nodes would stop the unwanted activity by coordinating.

Given the coordinative nature of WSAN activity, the inter-actor nodes connectivity is very important [3]. The failure of the actor nodes may disrupt the network which may block the collaboration among the actor nodes. For example, in environment like battlefield, an actor node may be destroyed by the bomb blast, or in the security applications, an enemy attack may cause some actor nodes out of order instantaneously. Relocation of the survival actor nodes is the best solution to establish the sensor network. The attractive solution depends on the cut-vertex only if, it restores the connectivity of the disjoint network due to the failure of cut-vertex. Additionally, the actor nodes relocation distance must be minimized because more energy consumes during the mobility and this recovery must be self-healing.

In this paper we present two algorithms, namely, Permanent Relocation Algorithm for Centralized Actor Recovery (PRACAR) and Self-Route Recovery Algorithm (SRRA) for the sensor nodes. The Permanent Relocation Algorithm for Centralized Actor Recovery replaces the failed centralized actor permanently by one of its neighbors and Self-route Recovery Algorithm recovers the optimum route for those sensors whose actor node is permanently relocated to a new position.

The proposed algorithms efficiently overcome the problems faced in existing techniques that are discussed in literature review section. Unlike, existing works that move a large number of nodes to the failed node's position, our proposed technique permanently replaces the failed node's position with its redundant nodes and provides an alternate route to the neighbors of failed node.

The main contribution of our proposed technique summarizes as follows:

- Firstly, Permanent Relocation Algorithm for Centralized Actor Recovery (PRACAR) is proposed to maintain the WSAN connectivity.
- Secondly, Self-Route Recovery Algorithm (SRRA) for the sensor nodes to find an optimal route for the transmission of data.

In the organization of rest of the paper, the next section explains the literature review, Section 3 describes the proposed research methodology, Section 4 explains the realistically simulated results, and Section 5 finally concludes this article.

II. Literature Review

In recent years, many approaches have focused on the restoration of disjoint WSANs network which is caused by the single actor failure. A Distributed Actor Recovery Algorithm (DARA) for WSANs which is based on cascaded movement and two-hop information of neighbors. This algorithm restores the broken WSANs [4]. Unlike DARA, an algorithm is proposed which is based on inward motion, called Recovery through Inward Motion (RIM) [5]. In RIM all the neighbors of the failed node move toward the location of failed node until they all are connected to each other. The individual overhead of the RIM is better than the DARA but the average overhead of the DARA is considered more optimal. A fault-tolerant algorithm is presented in [6], which is based on the multiple sensors to individual actor and multiple actors to individual sensor. This technique is applicable for the event notification in any case of the failure. To minimize latency and increase the lifetime of the sensors, the base-station movement based algorithm is proposed in [7].

In [8], [9], the authors proposed purely reactive algorithms for the restoration of the actor network connectivity. Once the failure of the actor node is detected, the centralized idea is to replace the failed actor with one of its neighbors or move neighbors inward in the area of failed actor. Normally, this type of recovery processes may causes the breakage/loss of more links, and the process of recovery repeats cascaded movement. Meanwhile, these reactive algorithms require collaboration among the healthy actor nodes. This type of recovery processes normally cause high overhead of messaging. Additionally, these algorithms only consider the single actor node failure considering the efficiency of resources, and do not focus on the recovery time.

The recovery of the WSANs is categorized into two categories; cascaded and block movement recovery. The higher connectivity of the pre-failure for the response coordination is required in the block movement [10]. An algorithm is proposed to maintain the two level connectivity of WSANs even under the node or link failure [11]. A similar idea is proposed by the authors of [12], which also aim to maintain the two level connectivity of the WSANs.

Block movement is often impossible in the absence of the higher connectivity level. Though, a fewer number of researchers focused on the shifted relocation and cascaded movement of the actor nodes [13], [14]. This type of algorithms are based on the shortest path movement. Simply, the cascaded movement idea is similar to RIM and Distributed Connectivity Restoration (DCR). The main objective of these techniques is to reduce the coverage holes which appeared due to the failure of the nodes. Some techniques like Partition Detection and Recovery Algorithm (PADRA) and DARA assume each actor node to maintain the two level connectivity information [10]. Volunteer-instigated Connectivity Restoration (VCR), RIM, and Coverage Conscious Connectivity Restoration (C^3R) avoid the two level connectivity information to decrease the overhead and maintain the single level connectivity information [15], [16]. The DARA and the DCR have been proposed to restore the connectivity which occurs due to the failure of the cut-vertex. The PADRA assume dominating set of connection (CDS) for the identification of the cut-vertex while DARA assume to ensure the convergence by considering all multiple network states.

For the critical detection of the node, CDS is not the accurate option; they apply Depth-First Search (DFS) to each node for the detection of the cut-vertex. Simply, a distributed algorithm is used by them, which requires the two level of connectivity information that directly increases the message overhead. Another technique that has been proposed also bases on the two level connectivity information for the detection of cut-vertex. The RCR (Resource Constrained Recovery) algorithm is proposed for the connectivity of restoration for disjoint WSANs which is based on the relay actor nodes [17]. In CBMAR (Connected and Balanced Mobile Actor Relocation) authors proposed to solve the load balance and connectivity problem which is based on the virtual Voronoi architecture of the actors [18]. NSCRA (Node Stability aware Connectivity Restoration Algorithm) technique has been proposed to handle the network partition issue by using efficient energy mechanism in which the selection of the actor for relocation is based on the backup power of the actor nodes [19]. A realistic technique is proposed in [20] to handle the connectivity restoration in WSANs. This technique is purely based on the path planning algorithm. A novel technique is proposed for the performance improvement in WSANs which is based on the coordination of the actor nodes [21].

The limitations of aforementioned techniques are cascaded and block movement of large number of nodes that result in more power and energy consumption. The proposed technique efficiently overcomes these limitations and provides permanent relocation of nodes to the failed node's position. Moreover, the proposed technique also provides an alternate route for the neighboring nodes of the failed node in order to transmit the important data to the concerned actor node.

III. Research Method

We have the prior information that WSAN concludes two types of entities, i.e. sensors and actors. Sensors have relatively low price, extremely restrained in energy consumption and limited computational abilities. On the other hand actors are highly capable of having more onboard energy, good data processing and communication capabilities. Sensor detects the observed phenomena, acquire the information from that phenomena and forwards it to the cluster head actor (which will be referred as CHA here after) for proceedings. Whereas, upon reception of the data from sensors, the actors react to the observed phenomena accordingly as well as at the same time forwards the data to the sink for remote monitoring in mission critical applications.

We take the following set of assumptions in our proposed techniques:

- It has been assumed that sensors and actors have three types of links, i.e. sensor-to-sensor, sensor-to-actor/actor-to-sensor and actor-to-actor. Sensor-to-sensor link can be classified further, i.e. as a routing path, for data transmission from a down-stream node towards the up-stream node by the remote sensors and as a link, used when needed in critical times.
- Sensors are assumed to be stationary and intelligent enough to discover the route for data forwarding in times when needed, whereas actors can move on demand when required.
- The assumed deployment of WSAN is shown in the figure A. Generally number of sensors nodes deployed are in abundance as compared to number of actors, where fewer number of actors are deployed. After random deployment of actors and sensors, both of them are assumed to discover each other and form the network as explained in [22].
- Range of communication (r_c) of an actor is the maximum Euclidean distance where its radio coverage can reach.
- Area that an actor can cover and serve is the action range of that actor and is assumed to be same for all actors as addressed in [23].
- It has also been assumed that actors can also find their location comparative to its neighbor utilizing the

onboard GPS by using existing techniques of localizations as explored in [24].

- Each of the actors maintains the list of its neighbors connected to and updates it through the heart beat messages [25].
- Application examples are recon mission in remote deserts and bordering coast areas, surveillance through unattended air-born-vehicles, under water monitoring where unattended water vehicles gather the information from static sensor nodes, which are connected through high speed optical communications to each other.

The problem that we are dealing with in this paper is that of coverage and connectivity in WSAN. We assume the failure of an actor which can cause the network into disjoint segments and can cause two issues that need to be overlooked which are coverage and connectivity.

In this article two algorithms are proposed for WSANs connectivity and coverage. We assume that a scenario as shown in Fig. 1 that there are seven CHA's (A,B,C,D,E,F, and G) and each having its own sensing area. The whole area of interest is covered through these CHA's and their associated sensor nodes. In this scenario the CHA "G" and its surrounding area is considered very important. The failure of "G" can result a huge coverage-hole. To fill this coverage-gap and maintain the inter-actor node connectivity two algorithms are proposed in this section: Virtual-Voronoi based Permanent Relocation Algorithm for Centralized Actor Recovery in WSAN and Self-route Recovery Algorithm to find the optimal path for the sensor node transmission.

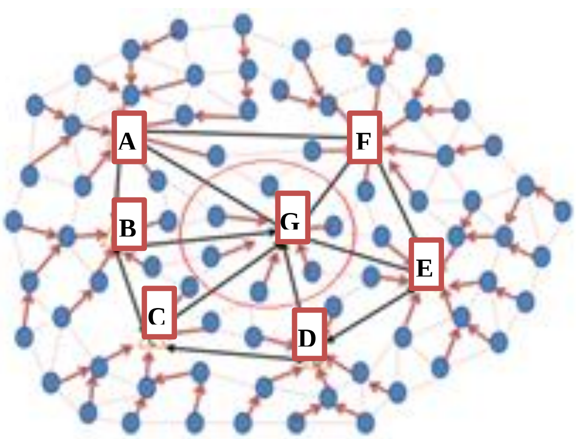

Fig. 1. WSAN Scenario.

A. *Permanent Relocation Algorithm for Centralized Actor Recovery (PRACAR) in WSAN*

The hybrid technique better suits the time-sensitive applications which are required fast recovery. The proposed model is hybrid because it consists of two algorithms. It is assumed that CHA "G" failure occurs as shown in Fig. 2. Fast relocation is necessary to maintain the network, therefore, Permanent Relocation Algorithm for Centralized Actor Recovery (PRACAR) starts working and inform all the actor nodes that the failed node is a critical node and fast recovery is needed for the network maintenance. PRACAR then select the best actor node for the recovery process on the basis of shortest-distance, lowest cluster sensors, and lowest coverage area. Every neighbor first calculates the distance from the failed CHA which is based on theorem 1, and then calculates the coverage area which is based on theorem 2, and share these information with neighbor actor along with the number of cluster sensor nodes. Now the WSAN having all the required information for PRACAR and considers that CHA "F" is efficient/optimal for the recovery process, so the "F" relocates failed actor permanently and continue the activity. In this way the WSAN restoration is completed as shown in Fig. 3.

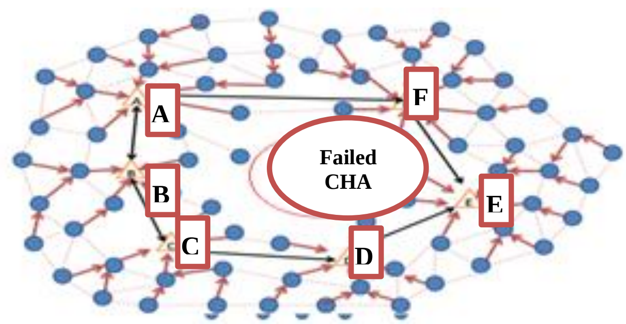

Fig. 2. Shows the Failed CHA "G" Scenario.

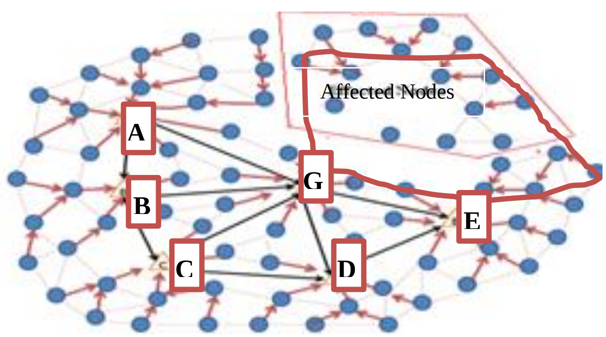

Fig. 3. Shows the Recovered WSAN.

B. *Self-Route Recovery Algorithm (SRRA)*

After the permanent relocation of CHA "F", its cluster nodes are lack of CHA and these affected nodes need the optimal route. Now SRRA starts working and finds an optimal route for the transmission of data. Firstly, each and every node broadcasts the recovery-packet (RP) and upon receiving of this RP in neighborhood cluster, the nodes acknowledge the message to the effected nodes. So, the affected cluster-nodes now evaluate the relative route distance as explained in theorem 3. Upon the discovery of multiple routes, nodes can select either single optimal route for transmission or multiple routes as shown in Fig. 4.

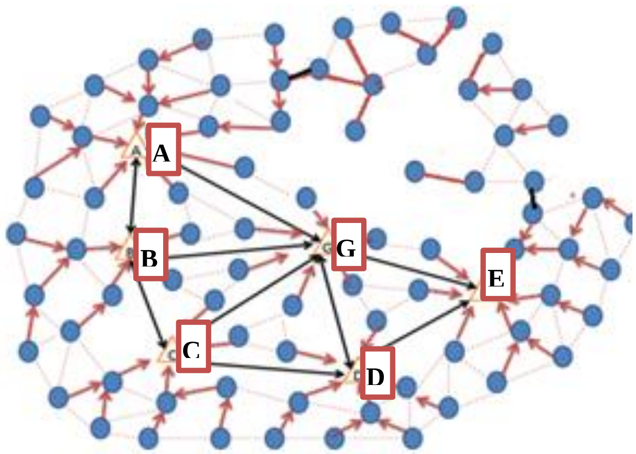

Fig. 4. Self-route established.

C. Theorem 1: Proof/Explanation for Shortest Distance

The recovery CHA synchronizes the concerned CHAs. As the CHA having maximum overlapped area and less number of the cluster-sensors is selected as a recovery CHA. The overlapped area of a CHA is the ratio of area lies within the range of failed CHA and the total area of the survival CHA. Whereas CHAs know their position with respect to its neighbors, estimation the overlapped area based on the communication range of the CHA. Considering the relation between r_c and the proximity of nodes to its neighbors, the intersection between the circles of radii r_c is higher if the distance between the two CHAs is smaller and vice versa. The two CHAs having overlapped area if the distance among CHAs satisfies the following relation:

$$d \leq 2 * r_c \tag{1}$$

As shown in Fig. 5, the overlapped area of two CHAs can be assessed if we calculate the $chord(B)$. If the two CHAs are neighbors, then they can evaluate the "d" between them by using the cosine law.

$$< A = 2\sin^{-1}(d / 2r_c) \tag{2}$$

Then, $chord(B)$ can be found by the sum of angles of the triangle.

$$chord(B) = \frac{B}{\pi} r_c^2 - \frac{d}{2} r_c \sin(\frac{B}{2}) \tag{3}$$

By using the below formula overlapped ratio can be calculated:

$$Overlapped_{Area} = \frac{2chord(B)}{\pi r_c^2} \tag{4}$$

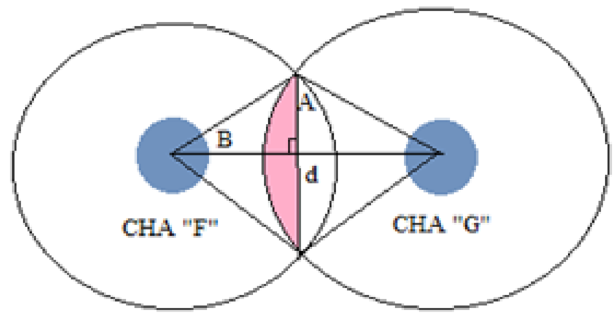

Fig. 5. Calculation of distance between CHAs.

D. Theorem 2: Proof/Explanation for Virtual-Voronoi

Virtual-Voronoi is the major portion which evaluates the optimal CHA in the WSAN. After the initial deployment, the critical CHA calculates this information by forming a virtual-Voronoi polygon based on the CHA smaller distance and with smaller coverage area. This calculation is very near to [15].

As every CHA repel each other with a force and the effect of this force is reduced and becomes inverse by the variation of the cluster-sensors. The CHA "F" is considered the optimal according to this theorem because it has smaller distance from critical CHA. So it indicates that "F" having less number of cluster-sensors and smaller area of coverage, that's why attracted little bit towards critical CHA "G" and considers the optimal CHA.

If $CHA(G) \geq CHA(F)$ then $distance(d_G) \leq distance(d_F)$; where d_G and d_F are the cluster-sensor separation from the CHA.

The CHA is assumed at the center of the cluster, having the CHA "F" with the smaller separation among the cluster-sensor and less number of the cluster-sensors. The smaller number of cluster-sensors is also proved by the smallest distance between the corresponding CHAs. Fig. 6 illustrates the scenario of the Virtual-Voronoi.

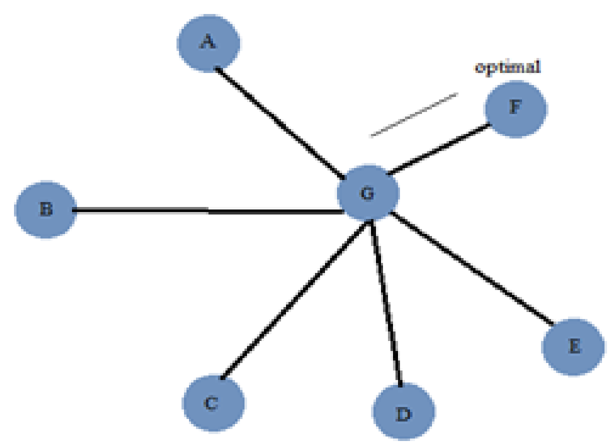

Fig. 6. Virtual-Voronoi polygon.

E. Theorem 3: Self-Route Recovery

Route recovery reduces latency and messaging, and improves the efficiency of energy, connectivity and coverage of the network. For WSANs, recovery of route is normally done using extension of the transmission power or multi-path routing. The estimation of the route process approximates the available path probability and the process of route selection, selects the set of paths that may be used for the routing. Simply, if a sensor detects that there is absence of next hop, then the sensor node increases the power of transmission to extend its range of communication to reach the further nodes. Another technique is recovery of the route by one-hop broadcast. This technique is a normal scheme of recovery that bypasses the faulty sensors or the compromised nodes and uses the information neighbor sensors to develop a new route. Our work assumes that the end cluster-sensor of each CHA lies in the range of the end cluster-sensor of another CHA. But before the relocation of CHA cluster-sensor repels another cluster-sensor as explained in theorem 2.

IV. Results and Analysis

We have compared our technique with two baseline algorithms DCR and RCR. As without the information of the partition, a centralized technique cannot be the best solution. Hence, we assume that the information of partition with the location of all CHAs is available at critical/centralized CHA. In this section we have discussed the results of our proposed technique PRACAR and the results of baseline techniques (i.e., DCR and RCR). In the experimental simulation, we have generated wireless sensor and actor topologies which consist of varying CHAs. CHAs are randomly deployed in the area of 600 m × 600 m. We have changed the communication ranges of the CHAs between 50-200 m hence the network becomes very strongly connected. Simulation parameters are shown in Table I.

TABLE I. Simulation Parameters

Parameters	Values
Number of nodes	100 – 200
Area	600 × 600 m^2
Communication range	25 - 200 m

The performance is evaluated by using the following metrics:

- Number of CHAs moved during the process of recovery: this parameter shows the efficiency of the recovery process.
- The number of exchange messages among the CHAs: this parameter tells about the recovery overhead and dissipation of energy.
- Total distance moved by CHAs during the process of recovery: this parameter scales the efficiency of proposed technique in terms of overhead and efficiency of energy.

A. Total Distance Travelled

Fig. 7 and 8 show the total distance moved by CHA until the connectivity restored. The proposed technique PRACAR outperforms significantly because it competes to move only those CHA which having the smaller distance from failed CHA. The performance efficiency of proposed technique remains consistently same even with higher communication ranges and higher densities of CHAs. However, this technique applies self-route only when the CHA permanently relocated. This technique evaluate to minimize the scope by moving the smaller distance CHA because they are even non-critical CHAs having smaller coverage area and less number of cluster-sensors. So, the results show the effectiveness of the proposed technique because by changing communication ranges and number of CHAs, the performance is not affected.

B. Number of CHA Moved

Fig. 9 shows the total number of CHAs that were moved during the process of recovery where proposed and baseline techniques were applied. The graph shows the effectiveness of the proposed technique which moves very less number of CHAs than the baseline approaches. The scope of relocation is limited because the proposed technique avoids the cascaded movements by choosing non-critical CHA that often has smaller coverage area and less number of cluster-sensors.

C. Number of Exchanged Messages

Fig. 10 and 11 show that message overhead is the function of communication range and network size. As the figures show, the proposed technique having very less messaging overhead than the baseline techniques. This is because only optimal CHAs are involved in recovery process, while in baseline algorithms, the messaging overhead is much higher. When the communication range increased then the messaging overhead remains same for proposed technique.

D. Coverage Reduction

Fig. 12 shows the effect of connectivity restoration on the field coverage, and the percentage field coverage reduction measurement. Overall proposed technique having very less coverage loss. In the sparse network coverage overlapped area is very little. The field coverage reduction in case of proposed technique with respect to baseline techniques is very less.

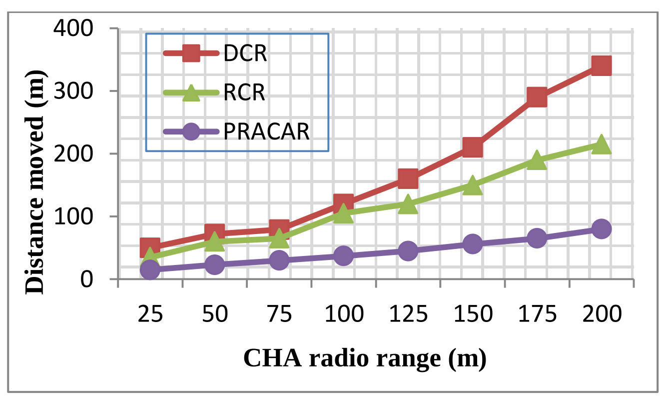

Fig. 7. Total distance moved in recovery against CHA radio range.

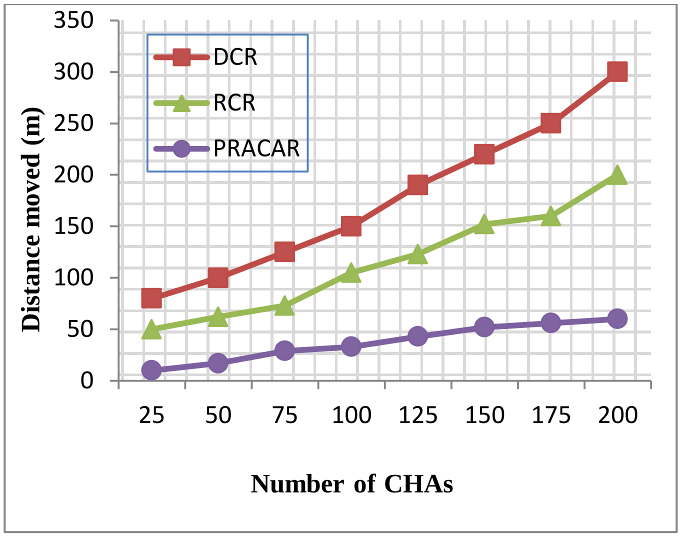

Fig. 8. Total distance moved in recovery against number of CHAs.

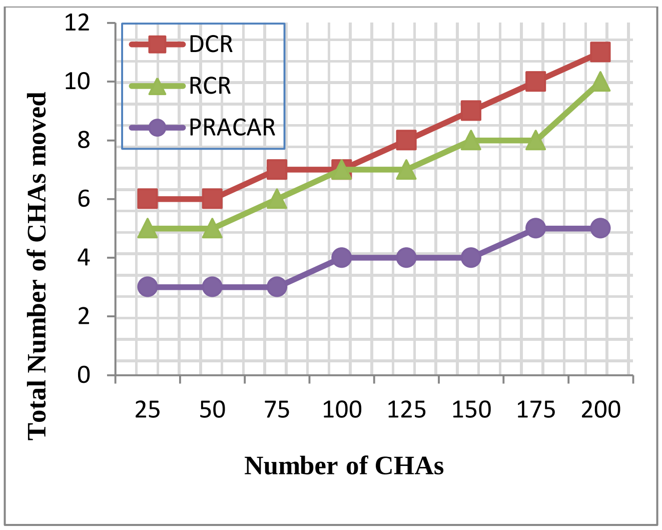

Fig. 9. Total number of CHAs moved.

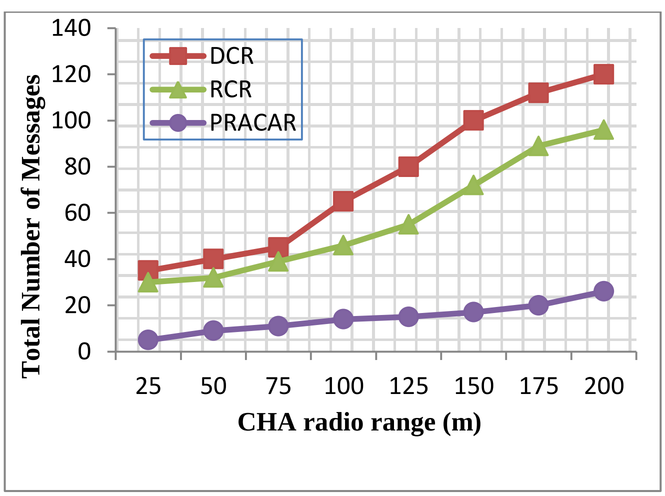

Fig. 10. Message overhead against communication range.

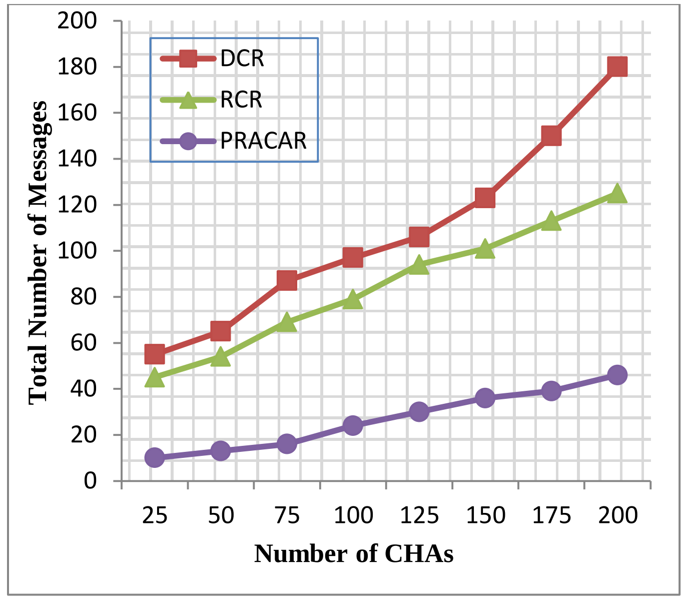

Fig. 11. Messaging overhead against CHAs.

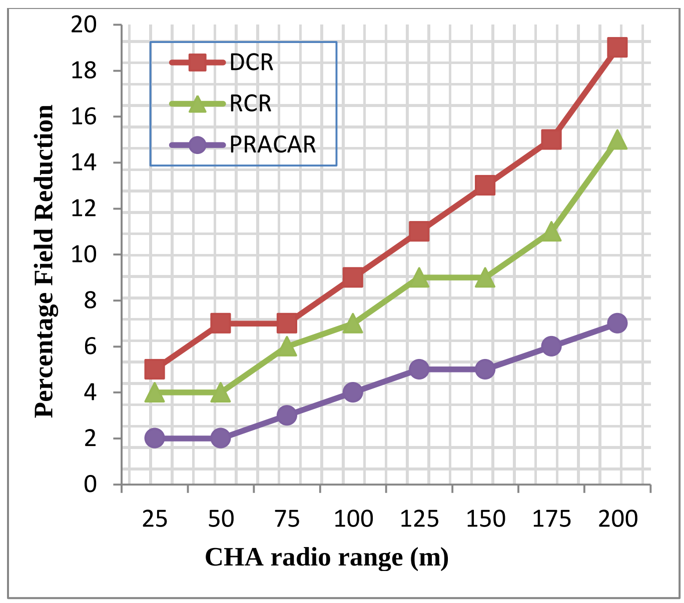

Fig. 12. Percentage reduction in field coverage.

V. Conclusion

WSANs started to use mobile sensors (Actors) which improved the flexibility of data collection and maintenance. In this article, we have proposed centralized permanent relocation algorithm for actors and self-route recovery algorithm for sensors. PRACAR attempts permanent relocation in such a way that it reorganizes the WSAN topology and retrieves the strong pre-failure connectivity. In order to recover self-route for sensors after the relocation of actor node, we proposed SRRA. The PRACAR and SRRA have been termed as hybrid-technique that relocates actor for the maintenance of WSANs connectivity and recovers self-route for sensors to maintain the coverage of the WSANs. The experimented simulation results have shown the effectiveness of this proposed technique.

Although, the proposed technique is an efficient technique, but it is designed only for the scenarios where the deployment area contains stationary sensor nodes surrounded by mobile actor nodes. In future, we will consider the scenarios where area of interest will have more mobile sensor and actor nodes. Moreover, we will also provide a routing technique to find an optimal path for routing in wireless sensor network using evolutionary technique i-e genetic algorithm.

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