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Obstacle Avoidance and Restoration with Energy Efficiency in Mobile Robotic Sensors

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ABSTRACT

In most of applications of mobile robotic sensor networks (MRSNs), the inter-sensor collaboration requires reliable application-level coordination however, the disturbing obstacles and harsh environment interferences the connectivity of the MRSN which can be easily compromised. The Obstacle-avoiding connectivity restoration strategy (OCRS) proposed method addresses this problem with fully exploring the mobility by avoiding any incoming convex obstacle conditions. The research is to efficiently dispatch mobile sensors to find an obstacle-avoiding shortest path. The sensing region is considered to be covered by static sensors and no holes at all. Static sensors sense along with their newly generated data are assumed to be delay-tolerant to applications.

***Keywords* :—** MRSN, OCRS, Mobile Sensors, Static Sensors, Obstacles, Energy Efficiency.

I. INTRODUCTION

Wireless Sensor Actor Networks (WSANs) are gaining interest due to suitability for mission critical applications which need autonomous and intelligent interaction to the environment. Examples of these applications may contain forest fire monitoring, disaster management, search as well as rescue, security surveillance, battlefield reconnaissance, space exploration, coast protection and border protection, etc. WSANs consist of stationary sensors and few mobile actors. The sensor nodes will report an event to one or multiple actors for processing and then makes decisions and performs appropriate actions. The role of an actor is crucial and depends on the environment and capabilities of actors which may differ from one another. For example an actor can extinguish a fire, rescue trapped survivors, deactivate a landmine and carry weapons. In these critical applications, actors need to collaborate and also coordinate with each other on planning an optimal response and then synchronize their operations. For example, in a forest monitoring applications, sensors report of detection of a fire, to the actors in the vicinity. Actors such as fire extinguishing robots or flying aircrafts need to be engaged as fast as possible in order to control fire and prevent spreading. Therefore, actors should identify the most appropriate set of actors or nodes that will participate in operations. This requires actors that are able to communicate with each other and also a strongly connected inter-actor topology which should be maintained always. Failure of one or multiple nodes can partition the inter-actor network. The network becomes incapable of delivering a timely response to a serious event. Therefore, recovery from a failure is of utmost importance. Since, WSANs operate autonomously by replacing the failed actor, this may be infeasible or take significant time, and the recovery is self-healing and agile [1]. The criticality of the applications and resource constrained nature of networks necessitate for low restoration time and reduced overhead as well.

II. LITERATURE SURVEY

Real-time connectivity restoration is to implements a recovery procedure whenever a node failure is being detected. Such reactive methodology is better suited to dynamic WSNs, because they are asynchronous in nature and also the network topology may change by time. Therefore, the adaptive schemes are best to scope the recovery process which depend on effect of the failure to the network connectivity. The idea to utilize the existing alive nodes that can move and then reposition them to appropriate locations as well. The network topology is restructured for regaining strong connectivity. Various approaches that are addressed to these questions have paved a way for variety of schemes as detailed further.

A. Distributed Actor Recovery Algorithm

The Distributed Actor Recovery Algorithm (DARA) is among connectivity restoration approaches which requires 2-hop information that need to assess criticality of node and then orchestrate recovery in distributed manner. Two variants of algorithm are namely DARA-1C and DARA-2C, and developed to address 1 hop and 2-hop connectivity requirements, respectively [2]. The idea is identify least number of nodes that should reposition in any order to re-establish particular level of connectivity. DARA strives to localize scope of recovery process and minimize movement overhead that imposed on involved nodes. In other words, DARA pursues any coordinated multi-node relocation in order for re-establishing communication links among impacted nodes. The main idea of DARA-1C is replace dead node by suitable neighbor. The selection of best candidate (neighbor) is based on node degree and physical proximity to dead nodes. The relocation procedures are recursively applied to handle nodes that gets disconnected due to movement of one of their neighbors (e.g., best candidate that has replaced faulty node) [2] – [3].

DARA-1C further extended to restore 2-hop connectivity. In 2-hop connected network, there are two node independent paths among each pair of nodes. Similar to DARA-1C, DARA-2C also identifies nodes affected, i.e., lost their 2-hop connectivity property, due to failed node. Detecting nodes and then restoring their bi-connectivity is very challenging problem. Such analysis made DARA-2C a very efficient approach to re-store bi-connectivity. Only a subset of neighbors of failed node is relocated to restore 2- connectivity.

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A variant of PADRA approach, has applied to Wireless Sensor Actor Networks (WSANs). However, approach is restricted to re-linking two partitions and does not handle multi-segments scenarios. The idea is pick closest node in two partitions and then move them towards each other until communication link can be established. Actors are assumed to initially disconnected and there is no node selection or any network state maintenance [4]. The closest nodes from partition identified sending messages from sensors and actors move to each other. However, such movement may disconnect repositioned nodes from partitions, additional nodes are picked from each partition to perform cascaded movements in order to maintain intra-partition connectivity. The collective effect is stretching topology of participating sub-networks towards others. Similar to, selection of appropriate nodes for cascaded motion is made by considering a CDS of individual partitions. The approach opts reposition non-CDS nodes in order to limit effect of relocating node on connectivity of other nodes in partition.

B. Least Disruptive Topology Repair

There are variations of above approaches which consider some constraints or additional objectives. For instance, LeDiR, denoting Least-Disruptive topology Repair[5], [6], [7] considers the connectivity restoration problem subject to the path length constraints. In some applications such as the combat robotic networks and the search operation and rescue operation, the timely coordination among nodes required and then extending shortest path between two nodes as side effect of recovery process would not be acceptable. LeDiR relies on local view of node about network to relocate least number of nodes and then ensures that shortest path between any pair of node is not extended to relative to pre-failure status. When node Af fails, its neighbors will then individually consult their possibly-incomplete routing of table to decide on appropriate course of action and define their role in recovery if any. If failed node is critical node, i.e., cut-vertex, neighbor Ai that belongs to smallest partition reacts. LeDiR limits relocation to nodes in smallest disjoint partition in order to reduce recovery overhead. The smallest block is one with least number of nodes and would be identified by the finding of reachable set of nodes for all 1- hop neighbor of Af and picking set with fewest nodes. Again, routing table will be used for. Intra-partition connectivity sustained through cascaded relocation as DARA and RIM, where node Aj loses contact with neighbor Ai travels toward new position of Ai [5].

C. OCRS

In lots of mission critical applications of MRSNs, inter-sensor collaboration that requires the reliable application-level coordination which is based on strong network connectivity with suggested solution. In practice, disturbing obstacles and harsh interferences connectivity of MRSN can be easily well compromised, especially when failure of critical sensors that results in disintegration of network into two or more disjoint segment. Existing connectivity restoration schemes which will fail to perform under harsh working conditions as they overlook on important fact where sensors may encounter the obstacles during relocation. The Obstacle-avoiding connectivity restoration strategy, that is, the proposed method addresses this problem by fully exploring mobility technique and avoiding incoming convex obstacle conditions. Backup selection algorithm (BSA) proactively determines cut-vertex sensors within network and assigns backup sensor to each cut-vertex node. Selected backup sensor which avoids obstacles, uses gyroscopic force controller where displaced restoring disturbed connectivity. Extensive simulation experiments and verify the OCRS capability to restore the connectivity with those guaranteed collision in avoidance, and also outperform any contemporary schemes in terms of message complexity and the traveling distance [10].

Motivated by observation, online Obstacle-avoiding Connectivity Restoration Strategy (OCRS) is used to fully explore mobility of sensors and to restore network connectivity while avoiding any unforeseen convex obstacles and the neighboring sensors. First, OCRS use local information of 2-hop neighbors only to determine all possible cut-vertices in that network. The determination is based on novel graph, Laplacian method with generated sub graph, which is fast and has low overhead and also, does not require any additional information. Secondly, an effective backup selection algorithm is proposed to select best available backup sensors to handle connectivity restoration problems with some minimized message overhead. Finally, gyroscopic force based motion controller are proposed to address obstacle-avoiding problem while avoiding any local minima phenomena caused by potential forces [10]. The proposed OCRS enables to restore network connectivity which will be subjected to failure of single cut-vertex sensor, while the inter-sensor and the sensor-to-obstacle collisions are avoided, and the existing communication links are maintained. Theoretical analysis and the simulation experiments are provided to evaluate performance of proposed strategy. The main contributions of the work are as follows: 1) proposed methods guarantees that no further partitions of network can occur during restoration. 2) A novel graph Laplacian method along with a generated sub graph which is designed to determine possible cut-vertices based on local information of 2-hop neighbors only; and 3) Obstacle-avoiding problem during restoration is effectively handled with an online solution.

III. PROPOSED SYSTEM

Considering the system model of a mobile robotic sensor, it have M mobile robotic sensor. Encode the inter sensor network, in terms of undirected graph, G. Graph consist of sets of edges and vertices. It also uses the concept of Euclidean distance. These all are allocated in a region, R. so this network model deals with the following definitions and are Connectivity, 1-Hop and 2-Hop neighbours, Collisions. In case of connectivity, an undirected graph is connected, provided there must be at least one path in between any two distinctive vertices. In case of 1-hop and 2-hop neighbours, j is the 1-hop neighbour of I and Ni is the 1-hop neighbour set of j. Similarly, k is the 2-hop neighbour of i and square of Ni is the 2-hop neighbour set of i. there is a sensing shell with a circle of radius Rs, and is centred at each sensors. As a result, the sensor can respond to any obstacles within it. In case of collision, a collision shell with radius Rc is centred at each robotic sensors, such that the collision occurs when a sensors collision shell intersect with the collision shell of the another sensor. The main objective of is that a good backup selection algorithm i.e., backup selection for cut-vertex and also restore connectivity with collision avoidance. For this restoration process, design a controller to drive the backup sensor towards the locations of the failed sensor node and also to avoid any collision between any sensors and obstacles [15] – [16].

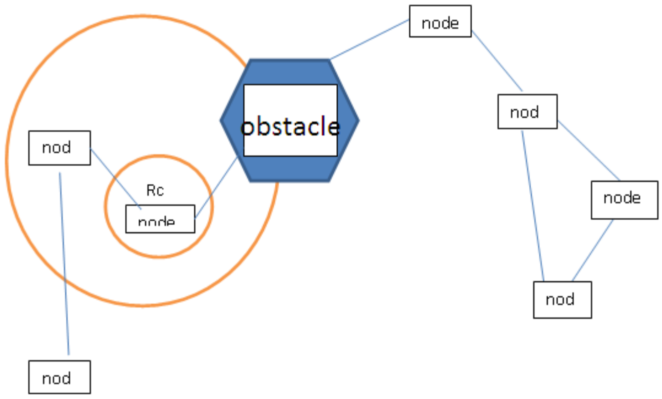

Fig. 1 System Model

A. *Backup Selection Algorithm*

Deals with three steps and are: Initialization, Determination, Backup Selection. In case of initialization, by periodically sending heartbeat messages to the 1-hop neighbour, as a result the sensor node will collect the neighbours information. Here the heartbeat message consist of three parameters and are sensors ID, geographic position and the one hop neighbour set, Ni. After successfully collecting the information, each sensor can build a complete set of 1-hop neighbours and a complete set of 2-hop neighbours. In case of determination, based on the complete set of 1-hop and 2-hop neighbour set, a sensor node, suppose sensor I, can determine whether there exists a cut vertex or not in the graph. For this purpose, consider a spanning sub graph which consist of set of 1-hop neighbours and sets of 2-hop neighbours. A Laplacian matrix is [14] used, in which, it is the difference between a diagonal matrix and an adjacent matrix. The resultant will be matrix, i.e., it's a symmetric positive semi-definite matrix, and all its eigen values will be non-negative. The eigen vector corresponding to the first eigen value is always one, 1. The second eigen value is the algebraic connectivity of the system and should be greater than zero. So if it is greater than zero then it is a non-cut-vertex, otherwise it's a cut-vertex. Now consider the next step, i.e., the backup selection, whenever a cut-vertex is identified, then a possible backup node should be used or positioned on the failed node position. The backup node is selected from the set of 1-hoop neighbours and then follows three steps. First, and the total degree of each node of possible cut-vertex. The total degree is identified in a way such that, it takes the union of set of 1-hop and 2-hop neighbours. Among this, we get an output set in which, for each element in the set will be the total degree of each node. Now the possible cut vertex is determined as sensor i. So secondly, the union of total degree will be send as a request message to the sensor node i. Finally from this set the least total degree will be selected and is considered as the backup sensor. The advantages of using total degree is that, a smaller group of sensors is required to move during the restoration. This will effectively reduces the travel distance as well as energy consumption. BSA allows sensors to backup a node for multiple cut-vertices. So it guarantees that every cut vertex sensors can locate a backup among its 1-hop neighbours regardless of the network topology density.

B. Implementation

The research is to efficiently dispatch mobile sensors to find an obstacle-avoiding shortest path. The sensing region is assumed to get covered by static sensors and no holes. Static sensors sense newly generated data, and are assumed to delay-tolerant. To achieve the goal, propose a technique that includes the three steps.

Region Division to Grid Cells, The sensing region is divided to grid cells and are same in size but may contain different number of static sensors. The size of each grid cell is in proportion to communication radius of sensors. Grid cells are basic unit of mobile sensors which is used to collect data sensed by static sensors. In order to move with minimal energy consumption, there is a sink position in each grid cell so that a mobile sensor moves to that position for collecting data sensed by the static sensors. Each grid cell is square in shape, the sink position is at the geometric center of grid cell. Static sensors are for reporting any suspicious events in grid cells. Mobile sensors then moves to these grid cells for in-depth analysis. Except for location of obstacles, mobile sensors can move to the sink position in each grid cells.

Obstacles Shape Regularization, the sensing field contain obstacles of different shape and size. How to efficiently dispatch mobile sensors and to find an obstacle-avoiding shortest path is really a big challenge. When the sensing region is divided to grid cells, obstacles may contain in some grid cells. The edges of obstacles may intersects grid cells and may occupy any part of some grid cells. Once obstacles may occupy part of one grid cell, then the grid cell is considered as an obstacles. Therefore, we obtain regularization shape of obstacles, so scheduling for mobile sensors turns to be easier. Mobile sensors have a huge data communication radius. Hence, static sensors are located in grid cells and are regarded as obstacles and their sensing data are collected by mobile sensors. Taking into account, complexity of system, one-to-one shortest path problem, that is, a single mobile sensor will be dispatched to a single event location.

Connection Graphs Application, considering existence of any obstacles, our goal is to find obstacle-avoiding shortest path from mobile sensors current position or called source grid cell to event location or called target grid cell by efficient method. It is obvious that shape of obstacles becomes to a polygon after regularization. We define set Lp for all maximal line segments which cross boundaries of polygon in grid cell. On the other hand, let Ls be set of all maximal line segments which includes source grid cell and Lt set of all maximal line segments that contain target grid cell. Note that all these line segments are horizontal or vertical. The connection graph, Gc, is the intersections of line segments in set L = Lp ∪ Ls ∪ Lt, which contains a shortest path from source to target grid cell, based on Manhattan distance. With the search space of mobile sensor from all grid cells to connection graph Gc, scheduling for mobile sensor will become more efficient.

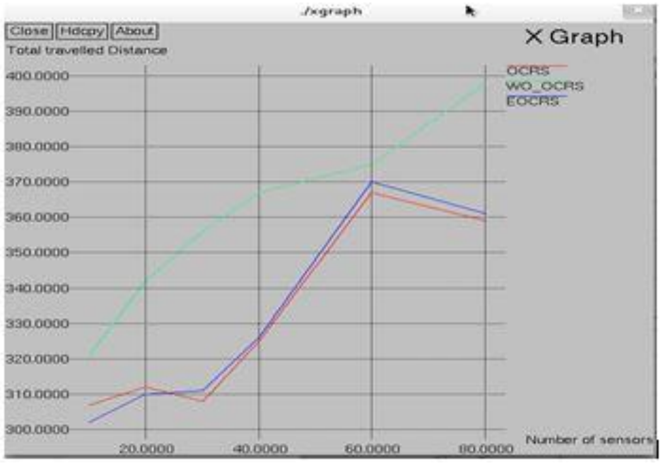

Fig. 2 Total Travel Distance

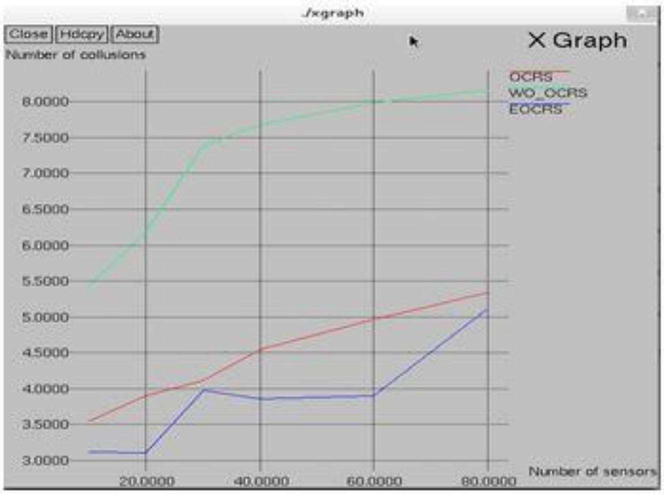

Fig. 3 Number of Collision

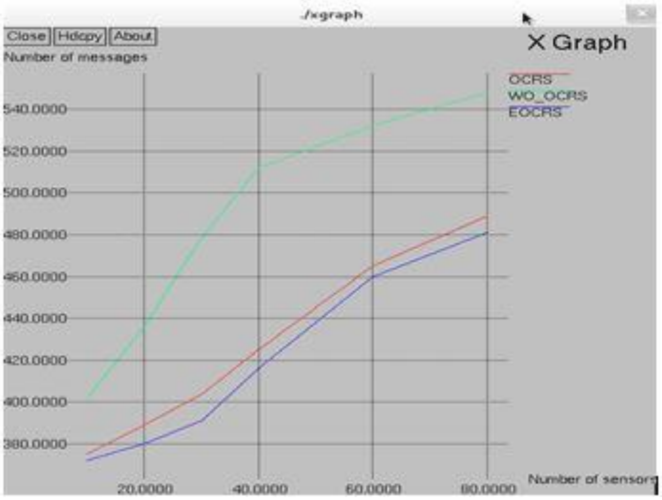

Fig. 4 Number of Messages

IV. CONCLUSION

This paper investigates on the importance of connectivity and restoration on mobile robotic sensors that works under harsh environments. The existing systems avoid the problem of obstacle avoidance. The paper suggests an effective methodology named, online connectivity restoration strategy, which withstands under real world working conditions. A theoretical study is undergone to compare the efficiency of OCRS and is proved based on the successful implementation and the results obtained. OCRS is more efficient, provide less time complexity and also avoid or reduce collision of nodes.

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