Advances in Computer Science Research, volume 44
3rd International Conference on Wireless Communication and Sensor Network (WCSN 2016)

Movement-Assisted Connectivity Restoration Algorithm for Wireless Sensor Networks

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***Abstract*-This Wireless sensor networks often suffer from fails or get damages. This may lead to network partitioning and thus hinder the fulfillment of the network applications. Therefore, it is critical to maintain the connectivity in applications of such networks. In this paper, we propose a movement-assisted connectivity restoration algorithm (MACRA) to achieve network connectivity restoration by using mobile nodes. Firstly, we design a rough connection recovery mechanism to obtain rough areas of sources and destinations for mobile nodes. The advantage of this scheme is to decrease computation complexity and achieve small connection distance and transmission delay. Secondly, we present an accurate connection recovery mechanism to achieve precise locations of sources and destinations for mobile nodes. The advantage of this scheme is to increase network invulnerability and reduce the probability of suffering from network partitioning again. The performance of MACRA is validated through simulation experiments.**

Keywords-wireless sensor networks; connectivity restoration; rough connection recovery; accurate connection recovery

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of a large number of sensor nodes which are typically powered by batteries with limited energy. WSNs, as key components of the Internet of Things [1-3], have wide range of military and civilian applications [4], [5] and enable us to achieve the dream of Smart City [6]. Sensor nodes are generally deployed in unattended and hostile environments where failures may usually occur due to various reasons, such as battery exhaustion, radio interference, or dislocation [7]. The failure of nodes may cause the coverage and connectivity losses. Therefore, it is necessary to provide adequate connectivity restoration strategies in presence of such frequent failures.

One solution for connectivity recovery of the network is re-deployment of nodes in place of failed nodes, but manual redeployment is not appropriate due to bad natural environment [7]. Therefore, WSN should have self-healing capability to handle such failures. On the other hand, sensor nodes are resource constrained devices, so the recovery procedure should be energy efficient. Furthermore, if possible, the recovery work should increase the ability of resisting the second failure or damage.

In recent years, many connectivity restoration techniques have been proposed to deal with node failure or damage in WSNs. These techniques are classified into two types: proactive methods or reactive approaches [8-10]. Mobile nodes are generally used to realize connectivity restoration. Mobile nodes are not only utilized to build network connectivity but are also used to improve network performance, such as coverage, network lifetime, throughput, etc. [10].

Akkaya et al. [11] present two distributed partition detection and recovery algorithms, named PADRA and MPADRA, to detect partitions and restore the network connectivity through relocation of movable nodes. The idea is to identify whether or not the node failure will cause network partitioning in advance. The goal is to localize the recovery scope and minimize the overhead. Younis et al. [12] present a distributed connectivity recovery algorithm, called Restoring Connectivity through Inward Motion (RIM). Instead of networkwide analysis and impact assess of node failure, RIM triggers a local recovery process through relocation of lost nodes. Abbasi et al. [13] propose a topology repair approach, called Least-Disruptive topology Repair (LeDiR), which moves a complete block of nodes towards failed node rather moving a single node. During movement, the block can cover the complete black hole and can maintain desired coverage requirement. A segment restoration approach is proposed in [14]. The approach first finds the partitioned segments and then pursues a coordinated actor movement in order to connect the sub-networks. Tamboli et al. [15] propose a connectivity restoration algorithm which considers both connectivity and coverage issues. Neighbors of failed node are placed one by one at the position of failed node according to a defined schedule. A distributed connectivity restoration (DCR) scheme is proposed in [16]. This method is based on partial network information including topological overhead associated with each node.

In this paper, we propose a movement-assisted connectivity restoration algorithm (MACRA) to achieve network connectivity by using moveable sensor nodes. This algorithm consists of two steps, the rough connection recovery mechanism and the accurate connection method. The advantage of the former is to decrease computation complexity and achieve small connection distance and transmission delay. Furthermore, by using the latter, the network invulnerability is enhanced and the probability of suffering from network partitioning again is reduced.

II. SYSTEM MODEL

Our algorithm applies to a network on a square area with N=n×n grid points, as shown in Fig. 1. A set of sensors with limited communication and processing capabilities spread on these grid points. A single sink is located randomly on the network. Similar to that in [17] and [18], the network is divided into M square sub-areas, denoted as A1, A2, …, AM. The area size is determined by the accuracy requirements of users. Thus, any point belongs to a specific area. The network suffers from a failure or damage, and there exist several isolated groups, any of which consists of one or more specific areas. This is equivalent to hierarchical model, which can increase the scalability of the network [19-21]. For instance, in Fig. 1, there are totally five isolated groups, i.e. G1, G2, G3, G4, G5, and isolated group G1 includes two areas, area A1 and area A2.

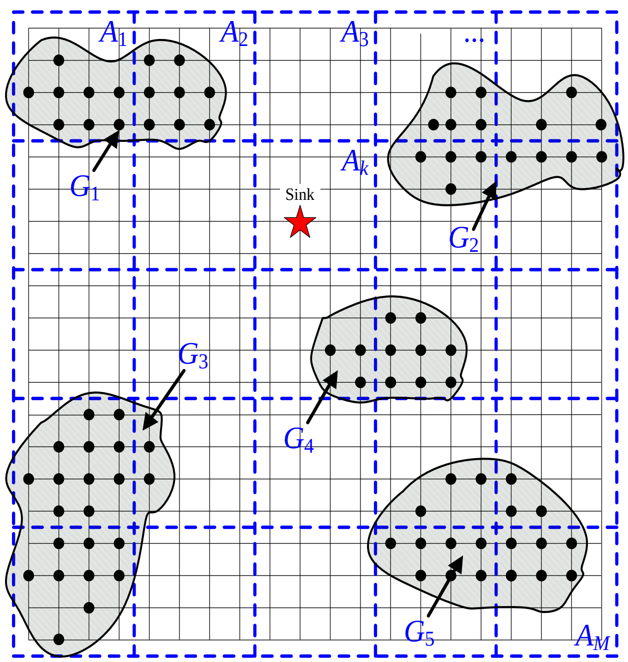


Figure 1. Network model.

III. MOVEMENT-ASSISTED CONNECTIVITY RESTORATION ALGORITHM

This paper investigates means for restoring connectivity from multiple isolated groups of WSNs. In the proposed MACRA, a set of moveable nodes move between different isolated groups and achieve network connectivity. The goal of MACRA is to find appropriate locations of sources and destinations between two isolated groups for moveable nodes. MACRA includes two steps, i.e. 1) rough connectivity recovery mechanism and 2) accurate connectivity recovery mechanism. In this section, the two steps are described in detail.

A. Rough Connectivity Recovery Mechanism

When multiple isolated groups are formed, they need to fulfill connection recovery by mobile nodes. As mentioned above, any isolated group located on specific areas. For any isolated group Gx, a relay group Gy is selected to realize connection recovery. Particularly, the sink can act as the relay of the isolated group. Specifically, the following formula is designed to complete the connection task.

$$\min f_1(G_x) = \alpha d(A_i, A_j) + \beta d(A_j, A_k)$$
$$\text{s.t.} \begin{cases} A_i \in G_x \\ A_j \in G_y \\ \text{sink} \in A_k \\ x \neq y \end{cases} \tag{1}$$

where $d(A_i, A_j)$ is the distance between area A1 and A2. Here the centre of the area represents the position of the area. In this way, the specific area Ai and Aj are selected, and the mobile nodes can be used to move between these two areas and realize connection recovery for the isolated group Gx. It's reflected from formula (1) that a short distance path is selected to achieve connectivity restoration due to the goal of energy saving of sensor nodes, although energy transfer is a new method emerged in recent years [22-26].

Take Fig. 2(a) for example, for the isolated group G3, the relay group G2 is selected and the related area Ai and Aj are selected to realize connection recovery by mobile nodes.

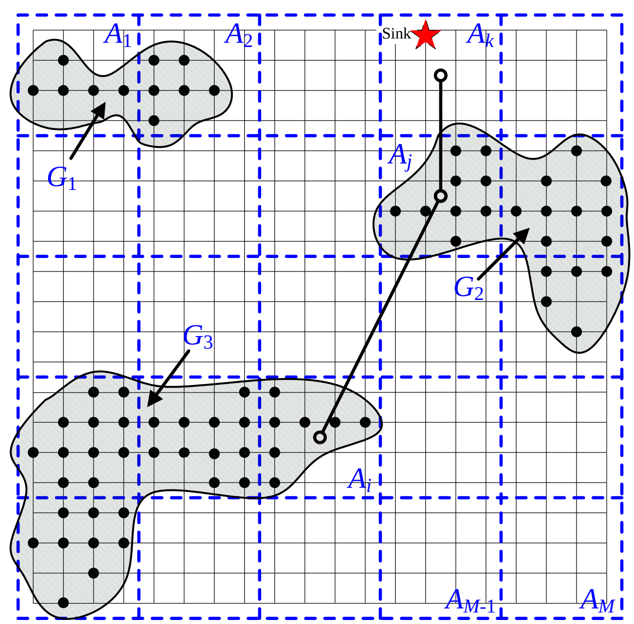


Figure 2. Rough connectivity recovery mechanism.

B. Accurate Connectivity Recovery Mechanism

The above rough connection recovery mechanism only selects two areas which represent the rough source and destination of the mobile nodes. However, the mobile nodes need accurate locations of the source and the destination.

This is achieved by the accurate connection recovery mechanism. The goal of such a mechanism is to select accurate locations of the selected areas rather than the centre of them.

Definition 1 (Local Node Density) [18]: For any point i, the total number of deployed nodes within a specific disk centered at this point is defined as the local node density of point i, denoted as σi.

After rough connectivity recovery, the source area A_i and the destination area A_j for mobile nodes are determined. By calculating the distance and the local node density, the source location P_i and the destination location P_j are designed respectively as follows:

$$\min f_2(G_x) = \mu d(P_i, P_j) + \varphi / \rho(P_i) \quad \text{s.t.} \begin{cases} P_i \in A_i \\ P_j \in A_j \end{cases} \tag{2}$$

$$\min f_2(G_y) = \mu d(P_i, P_j) + \varphi / \rho(P_j) \quad \text{s.t.} \begin{cases} P_i \in A_i \\ P_j \in A_j \end{cases} \tag{3}$$

This means that the location with short distance and large local node density will be selected as source location and destination location for mobile nodes.

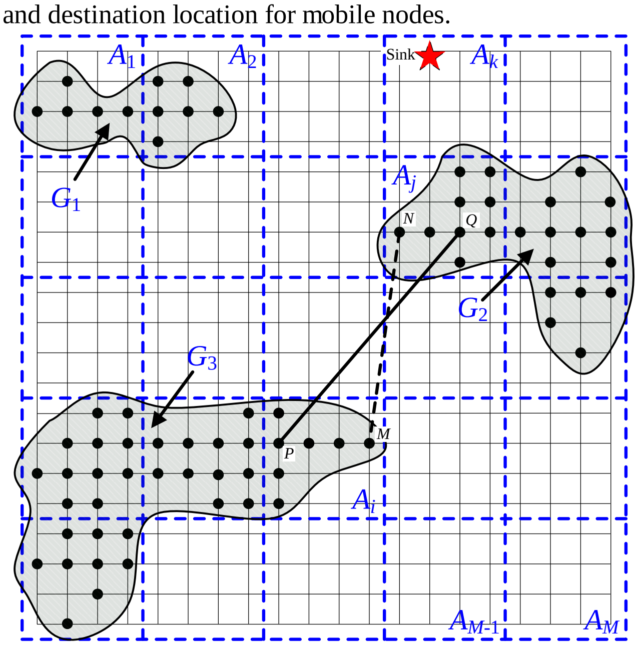


Figure 3. Accurate connectivity recovery mechanism.

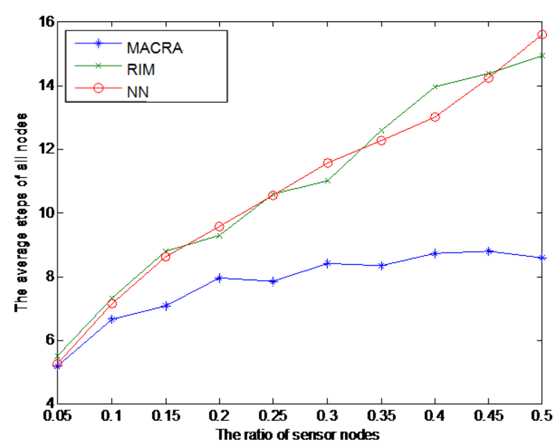
The advantage of the choice of locations with the maximum local node density is to increase network invulnerability and reduce the probability of suffering from network partitioning again. For example, in Fig. 3, a short path of node pair between isolated groups G3 and G4 is from M to N, however, such a path is not selected to achieve connectivity recovery by mobile nodes. This is due to the fact that the network will suffer from a second connectivity lost if the node next to M or N fails or damages. On the contrary, mobile nodes move from P to Q because these locations are with the maximum local node density and the network won't suffer from a second connectivity lost, even if the next node of P or Q fails or damages.

IV. SIMULATION RESULTS

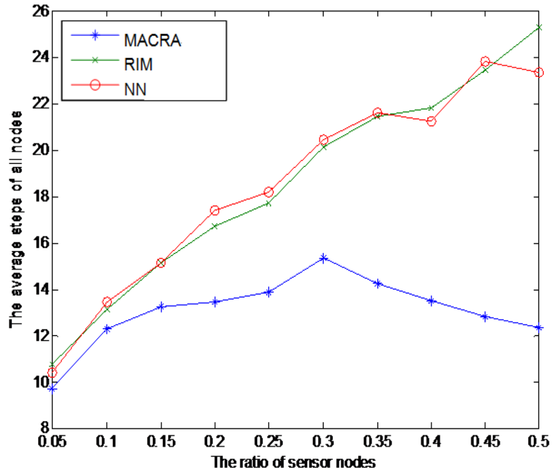
The effectiveness of MACRA is validated through simulation. This section discusses the simulation performance metrics and results. The experiments are conducted in a 16×16 grids and 24×24 grids square area where random topologies are generated and several isolated groups are formed. Other related connectivity restoration algorithms RIM [12] and the Nearest Neighbor (NN) [12] are compared together.

Fig. 4 shows the performance of delay of mobile nodes from source locations to destination locations. Here the average steps of all mobile nodes represent the delay. It can be seen from Fig. 4(a) and Fig. 4(b) that the values of RIM and NN increase rapidly with the increasing of the ratio of sensor nodes. However the values of MACRA increase slowly. Moreover, the value of MACRA is far less than that of RIM and NN all the time. This indicates the effectiveness of delay of MACRA.

Fig. 5 shows the energy consumption level of mobile nodes from source locations to destination locations. According to the power model in [17] and [18], the energy consumed is related to the transmission distance. So the travel distance of mobile nodes represents the energy consumption of mobile nodes here. It can be seen from Fig. 5(a) and Fig. 5(b) that the values of RIM and NN increase a little with the increasing of the ratio of sensor nodes, and the values of MACRA hardly increase. Furthermore, the value of MACRA is far less than that of RIM and NN, especially when the ratio of sensor nodes is large. This reflects the good performance of energy saving of MACRA.

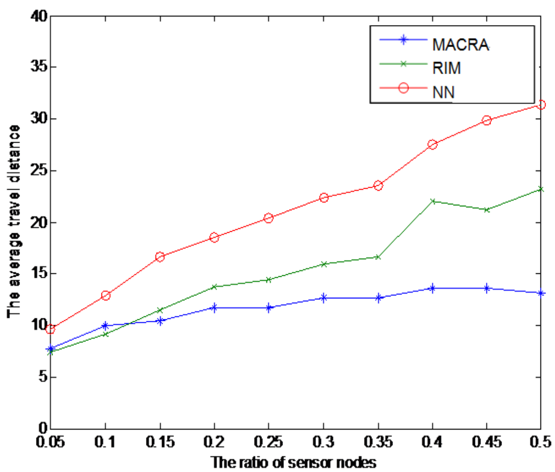


(a) 16×16 grids

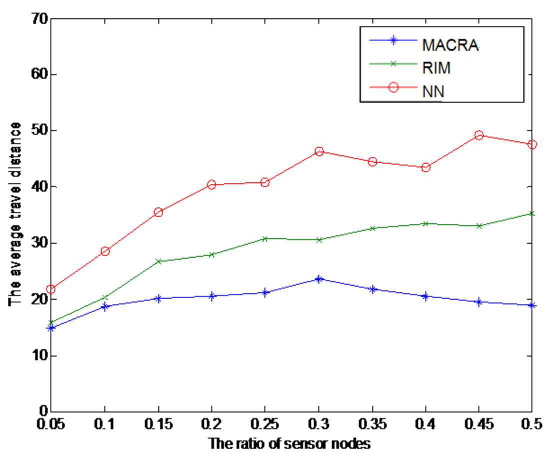


(b) 24×24 grids

Figure 4. Comparison of delay.



(a) 16×16 grids



(b) 24×24 grids

Figure 5. Comparison of energy consumption.

V. CONCLUSION

This paper proposes a movement-assisted connectivity restoration algorithm called MACRA to achieve network connectivity by using moveable sensor nodes. This algorithm consists of two steps, i.e. rough connection recovery mechanism and accurate connection recovery mechanism. This algorithm has low computation complexity and good network invulnerability. The performance of MACRA is validated through simulation experiments.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of China (Grant No. 61001112, 61372082, 61671209, 61271314), the Guangdong Natural Science Foundation, China (Grant No. S2013010012141), the Cultivation Program for Major Projects and Important Achievements of Guangdong Province, China (Grant No. 2014KTSCX012), and the Fundamental Research Funds for the Central Universities, China (Grant No. 2011ZM0030, 2013ZZ0042, 2015ZZ090).

REFERENCES

[1] Y. Liu, A. Liu, Y. Hu, Z. Li, Y. Choi, H. Sekiya, J. Li. FFSC: an energy efficiency communications approach for delay minimizing in Internet of Things, IEEE Access, 6: 3775-3793, 2016.

[2] S. He, J. Chen, X. Li, X. Shen, Y. Sun. Mobility and intruder prior information improving the barrier coverage of sparse sensor networks. IEEE Transactions on Mobile Computing, 13(6): 1268-1282 (2014).

[3] X. Liu, T. Wei, A. Liu. Fast program codes dissemination for smart wireless software defined networks. Scientific Programming, 2016: 1-21, 2016.

[4] X. Kui, Y. Sheng, H. Du, J. Liang. Constructing a CDS-based network backbone for data collection in wireless sensor networks. 2013: 1-12, 2013.

[5] Q. Zhang, A. Liu. An unequal redundancy level based mechanism for reliable data collection in wireless sensor networks, EURASIP Journal on Wireless Communications and Networking. 2016(258): 1-22, 2016.

[6] Z. Tang, A. Liu, C. Huang. Social-aware data collection scheme through opportunistic communication in vehicular mobile networks. IEEE Access, DOI: 10.1109/ACCESS.2016.2611863, 2016.

[7] A. Mahapatro, P. Khilar. Fault diagnosis in wireless sensor networks: a survey. IEEE Communications on Surveys & Tutorials, 15(4): 2000–2026, 2013.

[8] M. Younis, I. Senturk, K. Akkaya, S. Lee, F. Senel. Topology management techniques for tolerating node failures in wireless sensor networks: a survey. Computer Networks, 58: 254–83, 2014.

[9] V. Ranga, M. Dave, AK. Verma. Network partitioning recovery mechanisms in WSANs: a survey. Wireless Personal Communications, 72(2):857–917, 2013.

[10] M. Younis, K. Akkaya. Strategies and techniques for node placement in wireless sensor networks: a survey. Ad Hoc Networks, 6(4):621–55, 2008.

[11] K. Akkaya, F. Senel, A. Thimmapuram, S. Uludag. Distributed recovery from network partitioning in movable sensor/actor networks via controlled mobility. Computer IEEE Transactions, 59(2):258–71, 2010.

[12] M. Younis, S. Lee, A. Abbasi. A localized algorithm for restoring internode connectivity in networks of moveable sensors. Computer IEEE Transactions, 59(12):1669–82, 2010.

[13] A. Abbasi, M. Younis, U. Baroudi. Recovering from a node failure in

wireless sensor actor networks with minimal topology changes. IEEE Transactions Vehicular Technology, 62(1): 256–71, 2013.

[14] K. Akkaya, F. Senel. Detecting and connecting disjoint sub-networks in wireless sensor and actor networks. Ad Hoc Networks, 7(7): 1330–46, 2009.

[15] N. Tamboli, M. Younis. Coverage-aware connectivity restoration in mobile sensor networks. Journal of Network and Computer Applications, 33(4): 363–74, 2010.

[16] K. Sharma, T. Sharma. Distributed connectivity restoration in networks of movable sensor nodes, Computers and Electrical Engineering, available online, 2016.

[17] G. Huang, D. Chen, X. Liu. A node deployment strategy for blindness avoiding in wireless sensor networks. IEEE Communications Letters, 19(6), 1005-1008, 2015.

[18] X. Liu. A deployment strategy for multiple types of requirements in wireless sensor networks, IEEE Transactions on Cybernetics, 45(10): 2364-2376, 2015.

[19] X. Liu. A survey on clustering routing protocols in wireless sensor networks, Sensors, 12(8): 11113–11153, 2012.

[20] X. Liu, J. Shi. Clustering routing algorithms in wireless sensor networks: An overview, KSII Transactions on Internet Information Systems, 6(7): 1735–1755, 2012.

[21] X. Liu. Atypical hierarchical routing protocols for wireless sensor networks: a review. IEEE Sensors Journal, 15(10), 5372-5383, 2015.

[22] H. Dai, X. Wu, G. Chen, L. Xu, S. Lin. Minimizing the number of mobile chargers for large-scale wireless rechargeable sensor networks. Computer Communications, 46: 54-65, 2014.

[23] H. Dai, X. Wu, L. Xu, F. Wu, S. He, G. Chen. Practical scheduling for stochastic event capture in energy harvesting sensor networks. International Journal of Sensor Networks; 18(2): 85-100, 2015.

[24] Shibo He, Jiming Chen, Fachang Jiang, David K. Y. Yau, Guoliang Xing, and Youxian Sun. Energy provisioning in wireless rechargeable sensor networks, IEEE Transactions on Mobile Computing, 12(10):1931-1942, 2013.

[25] R. Deng, Y. Zhang, S. He, J. Chen, S. Shen. Maximizing network utility of rechargeable sensor networks with spatiotemporally-coupled constraints, IEEE Journal on Selected Areas in Communications; 34(6): 1-13, 2016.

[26] Y. Zhang, S. He, J. Chen. Data gathering optimization by dynamic sensing and routing in rechargeable sensor networks. IEEE/ACM Transactions on Networking, 24(3): 1632-1646, 2016.