Connectivity Restoration Techniques for Wireless Sensor and Actor Network (WSAN), A Review

Muhammad Kashif Saeed[*, #, 1], Mahmood ul Hassan[*, 2], Ansar Munir Shah[*, 3], Khalid Mahmood[*, #, 4]
[*]Department of Computer Science, IIC University of Technology, Phnom Penh, The Kingdom of Cambodia
[#]Department of Information Systems, King Khalid University, The Kingdom of Saudi Arabia

***Abstract*—Wireless Sensor and actor networks (WSANs) are the most promising research area in the field of wireless communication. It consists of large number of small independent sensor and powerful actor nodes equipped with communication and computation capabilities. Actors gather sensor's data and react collaboratively to attain application particular assignments. A powerful connected inter-actor network is required to coordinate its operations. Actor node may fail due to the battery depletion or any hardware failure and this failure may divide the network into disjoint segments. This problem can degrade the network performance but also reduce the efficiency and effectiveness of the network. To restore the network into its original state, the researchers have proposed many connectivity restoration techniques during last few years. This paper provides a brief review of the existing connectivity restoration techniques for WSANs with their advantages and limitations.**

***Keywords*—Wireless sensor networks; wireless sensor and actor networks; node failure; network partitioning; connectivity restoration; node movements**

I. Introduction

Wireless Sensor networks (WSNs) have gained a substantial attention in recent years. The wide spectrum of WSNs applications has open many research areas and it is being considered the most substantial modern technologies of recent times. As a result, huge research work has been done in different areas of WSNs. Wireless Sensor and Actor Network (WSAN) is a new paradigm that has reflected a significant impact on recent wireless sensor technologies. WSAN consists of sensor and actor nodes. Sensor and actor nodes in WSAN can be static or mobile. Sensors have limited power and energy resources and are responsible for sensing the important data from an area of interest and transmit it to the actor / base station. Actors are more powerful and high performance nodes furnished with more energy and computation resources, and work in close collaboration with the sensors to perform the fruitful tasks. Figure 1 shows the communication design of WSAN, in which sensors sense data from the environment and send to actors. Processing of data can be performed by actors or may send to base station for further processing.

Sensor and actor nodes can be failed due to battery depletion, hardware failure, or any external attack. As a result, network gets partitioned into disjoint segments, resulting in performance degradation [1]. Therefore, connectivity restoration process is needed to be performed. Human intervention is very less in such applications and there is no observer, who observe the network and takes timely decision. Moreover, it is not an easy task to replace the faulty nodes with the new nodes, especially in a harsh environment like the battlefield or dense forest. So a comprehensive mechanism is required which replaces the failed node with any of its neighboring. Collaboration among the healthy actor nodes is required to restore the connectivity at the pre-failure level. Node's mobility can improve the overall performance of the network like connectivity, coverage and network lifetime [2]. These recovery processes cause messaging overhead as well. Normally, these algorithms deal with single actor node failure, and do not consider the efficiency of the resources and also lack of emphasis on recovery time.

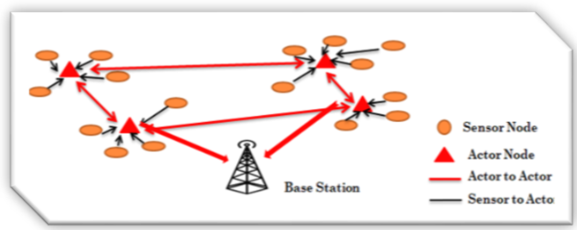

Fig. 1. WSAN Design

The main objective of the review paper is to provide a brief review of the connectivity restoration techniques for wireless sensor and actor network. Moreover, this review paper also provides a comparison of different connectivity restoration techniques for WSAN with their objectives, advantages and limitations.

Rest of the paper is organized as follows. Section II provides the overview on need of study. Section III contains the background of the study, whereas Section IV consists of the review of the existing techniques and finally Section V concludes the review paper.

II. Need of Study

Wireless Sensor and Actor Network (WSAN) is implemented in different civilian and industrial applications. It has an exceptional architecture which differentiates it from the ordinary Wireless Sensor Network (WSN). Sensor Nodes have limited battery and power resources and are responsible for sensing and transmitting the sensed data to the actor nodes. Whereas, actors are more powerful and high performance nodes having high power and computational resources. Actor nodes have the ability to gather process and, send the collective and aggregated data to the base station. Actor nodes play a key role in WSAN. Therefore, special attention should be given to the actor nodes in order to increase the performance of the network. Although, WSAN has a lot of benefits, but it is not free from obstacles and challenges. Communication of sensor to sensor, sensor to an actor, and actor to actor is very important. An efficient use and management of actor nodes can improve the overall performance of the network. The failure of an actor node causes disjoint segments in the network and sensed data could not reach to the base station. Therefore, connectivity restoration is the key problem to be addresses and solved.

III. BACKGROUND

In Wireless Sensor and Actor Networks (WSANs), sensor and actor nodes work together to perform certain tasks. Actor network is incorporated with the sensor network to make the wireless sensor and actor networks [3]. WSANs can be affected due to the change of environment, any change in event detection, an actor mobility or failure of the actor due to the depletion of energy, attacks or any communication link issues. Failure of actors can divide the network into disjoint segments, and affect the whole network. Inter-actor nodes connectivity is significant [4]. Due to the powerful characteristics of actor nodes, it can be managed through the relocation of mobile nodes but the actor failure can damage the network more than the ordinary sensor nodes. It can also affect the loss of coordination and connectivity between the nodes and restrict the event handling. For example, an actor node may be destroyed due to the catastrophic damage or enemy attack which disconnects the network and needs to be addressed instantaneously. Deployment of some relay nodes in the area can be a solution to replace the faulty nodes but it is not feasible in risky areas like war zones. Therefore, the early recovery process can be initiated through involving existing actor and sensor nodes by self-restoration techniques. Nodes repositioning methods have been introduced by number of researchers for restoring partitioned networks.

A typical WSAN architecture can be categorized into semi-automated and an automated architecture. These architectures are based on data passing and decision making. In an automated wireless sensor actor network, sensor nodes sense events and then send facts to their associated actor nodes which act as the base station. In semi-automated WSANs, sensor nodes sense facts from the field, and transfer to the sink node where sink node process the data, and communicate with actors to perform the necessary tasks, if needed. So coordination is very important in WSANs.

Fault tolerance techniques work in distributed manners. Fault tolerant techniques enable a system to perform its operations properly after single or multiple node failure. Figure 2 shows the node types in fault management techniques. Fault tolerant techniques are divided into critical and non-critical which solve the problem using 1-hop, 2-hop or multi-hop nodes information. Fault tolerance detection mechanism can be classified as proactive and reactive or hybrid. In proactive method, fault and restoration processes are addressed in the network setup in which redundant and backup nodes are deployed to ensure fault tolerance [5]. In reactive techniques, it utilizes the in house resources of the network and performs the recovery process dynamically through repositioning of the nodes. It requires monitoring system to check the nodes status and recovery scope. Reactive techniques are divided into distributed or centralized and are discussed comprehensively in [6-8]. Moreover, some techniques require a single node whereas some require a block of nodes to be moved to restore the connectivity of the network. Detailed taxonomy of such techniques is shown in the Figure 3. Some of these techniques will be discussed later in the paper.

The impact of a sensor/ an actor node failure can be different, according to the node type and its importance in the network. Fault management detection algorithms and restoration procedures can be categorized into critical and non-critical nodes [9-11]. The failure of a critical node divides the network into disjoint segments. Most of the techniques describe the critical nodes by using 2-hop messages whereas some have the 1-hop message interchange to check the critical sensor/ actor nodes. A study was conducted using 1-hop to identify the critical actor nodes [12]. To identify the critical node, the proposed technique calculates the distance of actor nodes from their adjacent nodes. If the distance is lesser than the neighbor's communication range, an actor will be considered as a non-critical node, otherwise critical.

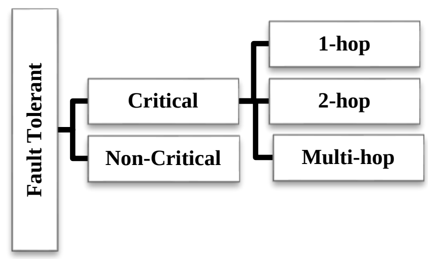

Fig. 2. Fault Management

Coordination is the important factor in communication like sensor to sensor, sensor to actor and actor to actor. Network efficiency can be improved by communication between actors to actor. In WSAN, a sensor and actor node can be static or mobile. During the network lifetime, nodes move, so topology management is equally important. Nodes failure can divide the network into small segments and create the coverage hole in the sensing area as well. Topology management techniques can be performed automatically for fault management.

IV. REVIEW OF EXISTING TECHNIQUES

Actor node failure can divide the network of WSAN into segments. An actor may fail due to the fault in hardware, energy depletion, physical attacks or any communication link issues. Although, there are less chances of actor failure than sensor failure, but it can be controlled through relocation of some mobile nodes. Connectivity between the nodes and coordination will be lost in case of an actor failure, and leads to disjoint of the wireless sensor actor network. Fault tolerance is an ability of the network to do its work smoothly in response to node failure [13].

WSAN are mostly deployed in tough areas like the battlefield, dense forest or massive destruction areas and suppose to do work for the maximum period of time. Such networks are normally deployed in far areas from the main control Centre, so connectivity restoration in an efficient way is a quite difficult process. Connectivity restoration process should be a distributed, self-healing and localized. Moreover, this process should be so fast that it reduces the impact of node failures, reduce overhead such that distance travelled, a number of messages while using limited energy supply. If a node travels too much to restore connectivity, then it will consume more energy and may also affect another network disconnection, especially if it is a cut-vertex. Moreover, it is difficult to find cut-vertex in large scale WSAN in a centralized and timely manner. So, connectivity restoration is a very challenging task in a distributed, localized, and an efficient manner. Reactive restoration techniques act passively and are initiated when a node failure occurs. No redundant resources are required in this case. Cooperative communication was introduced [14] which allowed a node to send a message away from its communication radius via its neighbor's. Two nodes can communicate with each other only if the received average Signal to Noise Ratio (SNR) is not less than the threshold. Strength of the signal reduces when we increase the transmission. Collaborative Single Node Failure Restoration algorithm (CSFR) [15] uses the cooperative communication approach to restore connectivity. It has low overhead but still has a long term process which consumes more energy and time. Therefore, it is not a suitable technique. In most of the reactive techniques, it reconnects a network by replacing a failure node with an appropriate backup node. It will be a recursive process that may relocate other nodes as well. It is mentioned earlier that only a cut-vertex node may break the network connectivity. A lot of techniques are available to detect whether the node is a cut vertex or not and then treat with its failure as well like NNN, DARA, PDARA, and PCR. In the improved version of PADRA, it forms a connecting dominating set (CDS). PADRA notifies in advance to a particular node about the partition occurrence in case of failure occurred.

Distributed Actor Recovery Algorithm (DARA) [16] finds a cut vertex by using two-hop neighborhood information. When a failure occurs, neighbors of the faulty node will select the most proper backup node. It will consider node's degree, distance and inform of its sibling nodes. Detailed process of identifying a cut vertex is not given in DARA technique in details. It is improved in PDARA in which it forms a connected dominating set (CDS). PDARA informs a particular node in advance whether a partition has occurred in case of failure. Nearest Non-Critical Neighbor (NNN) [17] decides whether it is cut-vertex or not and whether it preserves 2-hop neighbor's information of nodes. Distributed Partitioning Detection and Connectivity Restoration (DCR) algorithm [18] finds critical and non-critical actors in advance on the basis of information available locally and designates non-critical neighbor actors as backup actors. Once the failure of node occurs, the backup actor starts a recovery process which may include a coordinated method for relocation of multi actors. Recovery Algorithm for Multiple Nodes Failure (RAM) [18] handles two adjacent nodes failure simultaneously. It is a distributed hybrid technique which finds critical actors and assigns its backup nodes as well. Year-wise detailed comparison of different techniques is shown in Table 1. It covers techniques presented during the year 2007-2018 along with their objectives, node type, movement type, and node failure type. It shows that techniques are centralized or distributed and which technique has a capacity to restore connectivity of normal or cut-vertex node. This table also covers node movements like direct, cascade or block and also tells about the information that which technique has a capacity to restore connectivity of single, double or multi-node failure.

Recovery through inward Motion (RIM) [19] is a distributed technique which restores connectivity of critical and ordinary node. It maintains 1-hop information of each node; identifies nodes failure and starts recovery process by moving neighboring in cascade movement. All the one-hop neighboring nodes move towards the failed node till the distance is '' $R_C/2$''. It ignores the impact of coverage after restoring connectivity and does not differentiate between the positions of nodes. RIM is very simple and an efficient technique, but its performance reduces in the dense networks and messages overhead is be very high.

Node Recovery through Active Spare designation (NORAS) [20] is a recovery algorithm which can identify critical nodes and finds the backup nodes for such critical nodes before the failure occurs. After that, these backup nodes participate to restore connectivity. It also takes care of coverage and connectivity in an integrated manner. NORAS stores 2-hop information which causes the large communication overhead in the network. Moreover, the movement of nodes is increased as compared to other algorithms.

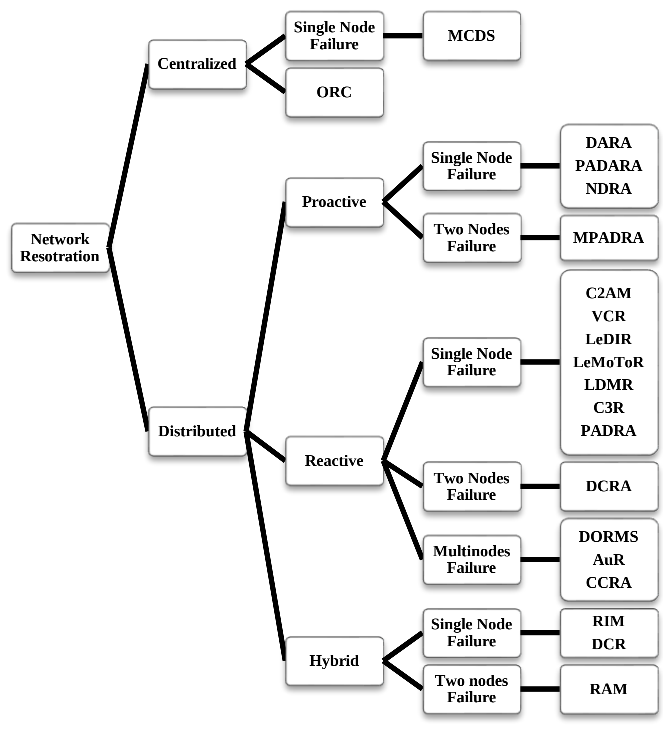

Fig. 3. Detailed taxonomy of techniques

C^3R-Coverage Conscious Connectivity Restoration [21] algorithm deals with the restoration of connectivity and coverage simultaneously. In this technique, failed node is replaced with the nearest node temporarily, and then it returns to its position. A neighboring node comes forward to replace it. It deals only with a single node failure, and does not support simultaneous nodes failure. Unnecessary movements of the nodes are reduced by introducing Energy Centric Optimized Algorithm (ECR) which consumes a lot of energy. It performs better than RIM and NN because it localizes the failure recovery and introduces few changes in the network topology. Frequent back and forth movements of the nodes are happening to restore connectivity and coverage which is not energy efficient. It has adverse effects on the network. Moreover, some extra nodes are required in the network, which increases the cost also.

Least Movement Topology Repair Algorithm (LeMoToR) [23] is a localized and distributed technique which solves the network partitioning problem with less number of nodes movements and messaging overhead. It utilizes the path discovery activities at the time of connectivity restoration to identify the topology structure and takes suitable action accordingly. Faulty node is replaced with the neighboring node from the smallest disconnected block. This algorithm uses the recursive process to find the best route of recovery in which a lot of computation is required.

TABLE I. COMPARISON OF CONNECTIVITY RESTORATION TECHNIQUES

Sr	Name of Technique	Year	Objective	Centralized/ Distributed	Movement Type	Node Type	Node Mobility	Node Failure Type
1	C^2AP	2007	Connectivity	Distributed	Cascade	Any node	Mobile Sensor/ Actor	Single node
2	DARA	2007	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor	Single node
3	NN	2008	Connectivity	Distributed	Direct move	Any node	Mobile Sensor	Single node
4	C^2AM	2009	Connectivity	Distributed	Cascade	Any node	Mobile Sensor	Single node
5	RIM	2010	Connectivity	Distributed	Cascade	Anyone	Mobile Sensor	Single node
6	C^3R	2010	Connectivity and Coverage	Distributed	To and fro movement	Any node	Mobile Sensor	Single node
7	NORAS	2010	Connectivity and Coverage	Distributed	Cascade	Cut-Vertex	Mobile Sensor	Single node
8	DORMS	2010	Connectivity with partial coverage	Distributed	Cascade	Any node	Mobile Sensor	Multi nodes
9	PADRA	2010	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Node/ Robot	Single node
10	MPADRA	2010	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Node/ Robot	Multi nodes
11	LeMoToR	2011	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single node
12	DCRA	2011	Connectivity	Distributed	Block movement	Cut-Vertex	Mobile Sensor	Two nodes
13	DCR	2012	Connectivity	Distributed	Cascade	Cut Vertex	Mobile Sensor/ Actor	Single node
14	PCR	2012	Connectivity	Distributed	Cascaded or shifted	Cut Vertex	Mobile Sensor/ Actor	Single node
15	RAM	2012	Connectivity	Distributed	Cascaded or shifted	Cut Vertex	Mobile Sensor/ Actor	Two nodes
16	AuR	2012	Connectivity with partial coverage	Distributed	Cascade	Any node	Mobile Sensor	Multi nodes
17	LeDIR	2013	Connectivity	Distributed	Block movement	Cut-Vertex	Mobile Sensor/ Actor	Single Node
18	NNN	2013	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single Node
19	DPCRA	2014	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single Node
20	CC-IC	2016	Connectivity and Coverage	Distributed	Cascade	Any node	Mobile Sensor	-
21	CSFR-M	2016	Connectivity	Distributed	Cascade	Any node	Mobile Sensor	Single node
22	CCRA	2016	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor	Multiple nodes
23	SFR-RNR	2017	Connectivity with partial coverage	Distributed	-	-	Mobile Sensor	-
24	HCR	2017	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single node
25	EAR	2017	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single node
26	DEENR[22]	2018	Connectivity with partial coverage	Distributed	Cascade	Any node	-	Single node
27	DCRMF	2018	Connectivity	Distributed	Cascade	Cut-Vertex	Mobile Sensor/ Actor	Single/ multi nodes
28	PRACAR	2018	Connectivity and Coverage	Distributed	Cascade	Any node	Mobile Sensor/ Actor	Single node

There is no clear approach used to find the smallest block, either through depth first or greedy approach among the disconnected blocks. Moreover, communication overheads will be high while finding the smallest block.

Least Disruptive Topology Repair (LeDiR) [24] is another localized and distributed algorithm which can detect cut-vertex and execute recovery from node failure using path discovery and routing information. Neighboring nodes of the faulty node will recomputed their routing tables and develop enrolment decisions for the recovery process. Each node calculates the shortest path to other node and updates its information in the routing table. After the node failure, its one-hop neighbor's will check if the failed node is critical or not. Neighbor from the smallest block will move to replace the critical node. If more than one neighboring nodes are a part of the smallest block, then the nearest node from the faulty actor node will be selected to cope block movement. It consumes more energy because all the nodes of the block will participate in the recovery process. Moreover, smallest block calculation performed at the time of recovery which is another drawback of this algorithm.

Distributed Prioritized Connectivity Restoration Algorithm (DPCRA) [25] is used to restore connectivity and partitions by using a few numbers of nodes only. It identifies the negative effects of actors on partitions. The recovery process did locally while storing limited information in every node. Numerous backup nodes are used for the partition recovery in the network. This algorithm failed to address proper backup node selection criteria and as a result, there are more chances of failure of nodes. It can also affect the overall network performance and energy consumption as well.

Advanced-self-healing Connectivity Recovery Algorithm (ACRA) [26] defines the nature of the actor node that whether the failed node is cut-vertex or the connectivity of the nodes by depth first search technique. It will restore the connectivity of cut vertex node in which an actor node with more transmission power and high coverage area is selected to take part in the recovery process. Sensors and actor nodes are deployed randomly and form clusters. Every node has a system to detect failure of a normal node and also cut vertex actor nodes. When a cut vertex node fails, a neighboring cluster head (CHs) sends a recovery message to all the nearest nodes, towards the sink node, till it finds the next actor node or CH. A stable sensor CHs is selected as per GA based criteria among the neighboring nodes as a joining router for connecting partitioned network. This algorithm uses more energy because of the cluster heads. Senor nodes are involved in the recovery process on the basis of sensor resources, and there are more chances of nodes failure. Details of some important connectivity restoration techniques for wireless sensor and actor networks are presented in Table 2. Main objectives of some of vital techniques and their limitations summary are shown in Table 2. Limitations found in earlier algorithms have been addressed in the later techniques, whereas most of the techniques need researcher's attention to resolve these issues.

Hybrid Connectivity Restoration (HCR) algorithm [27] works proactively during selection process and reactively in motion phase. An actor selects the backup node through its 1-hop neighboring table and notifies the backup node to oversee this process. When a node fails, its backup node try to move to that position in order to restore connectivity. It is a localized process which is repeated until connectivity is restored. HCR select the backup node which has to travel short. Moreover, HCR tries to reduce the number of messages by forwarding node failure information to its backup node only. It is an effective scheme with low complexity. It deals single node failure at a time, handles sequential nodes failure only and doesn't handle the coverage issues.

Efficient actor recovery paradigm (EAR) [28] is a recovery technique which can differentiate between critical and non-critical nodes. It allocates an appropriate backup node from its neighbor which is chosen on the basis of its signal strength, and control in its surroundings. It is supported by three algorithms. Node Monitoring and Critical Node Detection (NMCND) algorithm which monitors nodes and tells about the nodes type, and also handles the packet forwarding process if the primary node fails. Network integration and Message Forwarding (NIMF) is introduced to send packet. Process Based Routing for Node Failure Avoiding Algorithm (PRNFA) was developed to handle the routing process in which redundant messages was reduced to avoided network congestion. The main goal of this algorithm is to improve the node recovery process while maintaining the Quality of Services (QoS).

Distributed autonomous connectivity restoration method based on the finite state machine (DCRMF) [29] is a technique which looks for critical nodes in the region and defines how to reposition the related nodes. It performs restoration autonomously. Critical nodes updating process is launched after every restoration process. It relocates the non-dominating nodes from the neighboring nodes, so the total moving distance is reduced. It can effectively reduce the movement overheads of the nodes in connectivity restoration process. A distributed localized connectivity restoration algorithm is introduced to handle the multiple nodes failure problem. A few nodes will be relocated with less moving distances.

Permanent Relocation Algorithm for Centralized Actor Recovery (PRACAR) [30] replaces the failed actor by one of its neighbor permanently. It is a self-route recovery algorithm which finds the optimum path to the sensors. Actor nodes are relocated permanently to a new location. This permanent placement of the redundant node at the position of the faulty node will stop the extra movements. This is an energy efficient technique which saves energy to do other key tasks of the network.

TABLE II. ACTOR FAILURE TECHNIQUES OBJECTIVES AND LIMITATIONS

Sr	Name of Technique	Objectives	Limitations
1	DARA	Single node recovery with short total travel distance	• Do not handle actor failure. • Do not provide a mechanism to detect cut-vertices nodes.
2	C^2AM	Reduce total distance and minimize the message overhead	• Do not care coverage • Not suitable for mission critical
3	PADRA/ ACR	• Localize the scope of recovery • Reduce the message overhead and the total distance	• Nearest distance to the failed node which affect the overall network
4	RIM	• Minimize the total distance with fewer messages overhead.	• Don't considered coverage • A lot of nodes moving • Not suitable for multimode failure
5	DCR	• Minimize the scope of recovery, and total distance	• It manages the single failure at a time and doesn't consider energy.
6	PCR	• It uses a localized algorithm to recognize critical actors and designate backup nodes.	• It's focused on the sensor nodes and does not address the node failure.
7	NNN	• Total distance and cascade relocation overhead reduced	• It may involve the path increments among the nodes. • Algorithm executes recursively which increase overhead.
8	LeDIR	• It minimizes the scope using path length validation	• It does not handle multiple nodes failure.
9	DPCRA	• Restore connectivity by using small number of nodes.	• Fails to manage backup node selection criteria, so there are more chances of nodes failure.
10	ACRA	• It is a clustered based algorithm. Actor node having high transmission power and coverage area is selected to participate in connectivity restoration.	• Actor uses higher transmission power, and not energy efficient.
11	DCRMF	• Decrease the movement over heads of the sensor-actor nodes. • Nearest non-critical node replaced with the abnormal node	• Do not take care of coverage
12	LeDIR/ RNF	• It does not impose pre-failure overhead. • It can recover from a single node failure at a time only.	• It doesn't deal with multiple nodes failure.

V. CONCLUSION

Maintaining internode connectivity in an efficient manner is very important in applications of wireless sensor and actor networks. Failure of actor nodes may disjoint the network and QoS of the network may degrade. There are many algorithms so far presented to restore connectivity of actor nodes, which were briefly discussed above. Some techniques use large number of nodes movement, more distance travel to restore connectivity, which consume more energy during the restoration process. A comprehensive review on state of the art connectivity restoration techniques is provided, in which different limitations and drawbacks in the schemes are discussed which may be addressed and may be helpful for the researches to develop new connectivity restoration techniques in the light of these guidelines.

REFERENCES

[1] Mahmood, K., Khan, M. A., Shah, A. M., Ali, S., & Saeed, M. K. (2018). Intelligent On-Demand Connectivity Restoration for Wireless Sensor Networks. Wireless Communications and Mobile Computing, 2018.

[2] Younis, Mohamed, and Kemal Akkaya. "Strategies and techniques for node placement in wireless sensor networks: A survey." Ad Hoc Networks 6.4 (2008): 621-655.

[3] Akyildiz, Ian F., and Ismail H. Kasimoglu. "Wireless sensor and actor networks: research challenges." Ad hoc networks 2.4 (2004): 351-367.

[4] Kashi, Saeed Sedighian, and Mohsen Sharifi. "Connectivity weakness impacts on coordination in wireless sensor and actor networks." IEEE communications surveys & tutorials15.1 (2013): 145-166.

[5] Imran, Muhammad, et al. "Volunteer-instigated connectivity restoration algorithm for wireless sensor and actor networks." Wireless Communications, Networking and Information Security (WCNIS), 2010 IEEE International Conference on. IEEE, 2010.

[6] Younis, Mohamed, et al. "Topology management techniques for tolerating node failures in wireless sensor networks: A survey." Computer Networks 58 (2014): 254-283.

[7] Younis, Mohamed, and Kemal Akkaya. "Strategies and techniques for node placement in wireless sensor networks: A survey." Ad Hoc Networks 6.4 (2008): 621-655.

[8] Imran, Muhammad, et al. "Application-centric connectivity restoration algorithm for wireless sensor and actor networks." International Conference on Grid and Pervasive Computing. Springer, Berlin, Heidelberg, 2011.

[9] Abbasi, Ameer Ahmed, Mohamed F. Younis, and Uthman A. Baroudi. "Recovering from a node failure in wireless sensor-actor networks with minimal topology changes." IEEE Transactions on vehicular technology 62.1 (2013): 256-271.

[10] Morita, Kiyohiro, et al. "Sensor-actuator communication protocols in wireless networks." International Conference on Network-Based Information Systems. Springer, Berlin, Heidelberg, 2007.

[11] Abbasi, Ameer, Mohamed Younis, and Uthman Baroudi. "Restoring connectivity in wireless sensor-actor networks with minimal topology changes." Communications (ICC), 2010 IEEE International Conference on. IEEE, 2010.

[12] Imran, Muhammad, et al. "Localized motion-based connectivity restoration algorithms for wireless sensor and actor networks." Journal of Network and Computer Applications 35.2 (2012): 844-856.

[13] Sabri, Naseer, et al. "Towards smart wireless sensor actor networks: design factors and applications." Industrial Electronics and Applications (ISIEA), 2011 IEEE Symposium on. IEEE, 2011.

[14] Topology control in ad hoc wireless networks using cooperative communication. . *IEEE Transactions on Mobile Computing*, 5(6), 711-724.

[15] Wang, Huaiyuan, et al. "Adaptive connectivity restoration from node failure (s) in wireless sensor networks." Sensors 16.10 (2016): 1487.

[16] Abbasi, Ameer Ahmed, Kemal Akkaya, and Mohamed Younis. "A distributed connectivity restoration algorithm in wireless sensor and actor networks." Local computer networks, 2007. LCN 2007. 32nd IEEE conference on. IEEE, 2007.

[17] Haider, Noman, et al. "Performance analysis of reactive connectivity restoration algorithms for wireless sensor and actor networks." Communications (MICC), 2013 IEEE Malaysia International Conference on. IEEE, 2013.

[18] Imran, Muhammad, et al. "Localized motion-based connectivity restoration algorithms for wireless sensor and actor networks." Journal of Network and Computer Applications 35.2 (2012): 844-856.

[19] Younis, Mohamed, Sookyoung Lee, and Ameer A. Abbasi. "A localized algorithm for restoring internode connectivity in networks of moveable sensors." IEEE Transactions on Computers 59.12 (2010): 1669-1682.

[20] Vaidya, Ketaki, and Mohamed Younis. "Efficient failure recovery in Wireless Sensor Networks through active, spare designation." Distributed Computing in Sensor Systems Workshops (DCOSSW), 2010 6th IEEE International Conference on. IEEE, 2010.

[21] Tamboli, Neelofer, and Mohamed Younis. "Coverage-aware connectivity restoration in mobile sensor networks." Journal of network and computer applications 33.4 (2010): 363-374.

[22] ul Hassan, Mahmood, Khan, M. A., Ali, S., Mahmood, K., & Shah, A. M. (2018). Distributed Energy Efficient Node Relocation Algorithm (DEENR). International Journal of Advanced Computer and Applications, 9(3), 95-100.

[23] Abbasi, Ameer, Mohamed Younis, and Uthman Baroudi. "Restoring connectivity in wireless sensor-actor networks with minimal topology changes." Communications (ICC), 2010 IEEE International Conference on. IEEE, 2010.

[24] Abbasi, Ameer Ahmed, Mohamed F. Younis, and Uthman A. Baroudi. "Recovering from a node failure in wireless sensor-actor networks with minimal topology changes." IEEE Transactions on vehicular technology 62.1 (2013): 256-271.

[25] Ranga, Virender, Mayank Dave, and Anil Kumar Verma. "A hybrid timer based single node failure recovery approach for WSANs." Wireless personal communications 77.3 (2014): 2155-2182.

[26] Ranga, Virender, Mayank Dave, and Anil Kumar Verma. "A hybrid timer based single node failure recovery approach for WSANs." Wireless personal communications 77.3 (2014): 2155-2182.

[27] Yan, Ke, et al. "Hybrid connectivity restoration in wireless sensor and actor networks." EURASIP Journal on Wireless Communications and Networking 2017.1 (2017): 138

[28] Mahjoub, Reem K., and Khaled Elleithy. "Efficient Actor Recovery Paradigm for Wireless Sensor and Actor Networks." Sensors 17.4 (2017): 858.

[29] Zhang, Ying, Jun Wang, and Guan Hao. "An Autonomous Connectivity Restoration Algorithm Based on Finite State Machine for Wireless Sensor-Actor Networks." Sensors 18.1 (2018): 153.

[30] Khalid Mahmood, M. A. ‘’Permanent Relocation and Self-Route Recovery in Wireless Sensor and Actor Networks’’. International Journal of Advanced Computer Science and Applications (IJACSA), (2018) Vol. 9, No. 3.