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Decentralized Fault-Resilient Topology Management Scheme for Mixed Wireless Sensor Networks

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Abstract: *The paper introduces ADPV, a distributed fault-tolerant topology control algorithm for heterogeneous wireless sensor networks. The network comprises sensor nodes with limited energy and computing capability, along with supernodes having unlimited energy resources. The ADPV algorithm addresses the k-degree Anycast Topology Control problem, aiming to assign each sensor's transmission range to have at least k-vertex-disjoint paths to supernodes while minimizing total power consumption. The resulting topologies can tolerate k * 1 node failures in the worst case. The correctness of ADPV is proven by demonstrating that the generated topologies guarantee k-vertex super-node connectivity. Simulations show that the ADPV algorithm achieves up to a 4-fold reduction in total transmission power and a 2-fold reduction in maximum transmission power per node compared to existing solutions. This makes ADPV an efficient and fault-tolerant solution for topology control in heterogeneous wireless sensor networks.*

IndexTerms - Wireless sensor network, energy-efficient, faculty-Tolerance, Clustering, heterogeneous wireless sensor networks.

I. Introduction

This paper proposes the Disjoint Path Vector (DPV) algorithm for proactive fault-tolerant topology control in heterogeneous Wireless Sensor Networks (WSNs). The WSN consists of two layers: a lower layer with ordinary sensor nodes having limited battery power and short transmission range, and an upper layer with supernodes that have more power reserves and better processing capabilities. The supernodes may also include actors with special abilities for certain actions. The DPV algorithm aims to construct a fault-tolerant topology to route data from sensor nodes to supernodes efficiently. It ensures the k-connectivity of the communication graph, providing fault tolerance up to k-1 node failures. The algorithm is distributed and achieves significant power efficiency by minimizing total transmission power, maximum transmission power per node, and the number of control message transmissions.

Simulation results demonstrate that the DPV algorithm achieves impressive improvements compared to existing solutions, achieving a 2.5 to 4-fold reduction in total transmission power required in the network (depending on the packet loss rate) and a 2-fold reduction in maximum transmission power per node. These results highlight the effectiveness of the novel approach used in discovering disjoint paths for fault tolerance in heterogeneous WSNs.The proposed approach in this paper involves storing complete path information instead of just the next node information. This strategy significantly expands the search scope for discovering the best paths across the entire network without requiring a global network topology.

I.1 Fault Tolerance

Fault tolerance is a critical characteristic of a system that enables it to continue functioning correctly and reliably even in the presence of faults or failures. In various computing and engineering domains, including computer systems, networks, and hardware components, fault tolerance is essential to ensure continuous operation and prevent system-wide failures or disruptions. Figure 1 shows the Fault Tolerance Occurring in the Network, The goal of fault tolerance is to design systems in such a way that they can detect, isolate, and recover from faults or errors. A fault can be any unexpected deviation or failure that affects the normal behaviour of a system, such as hardware malfunction, software bugs, communication errors, power outages, or environmental disturbances. Key components of fault tolerance include: Fault Detection: The ability of a system to recognize the occurrence of faults and identify the affected components or processes. Fault Isolation: The capability to isolate the faulty component or subsystem from the rest of the system to prevent the propagation of errors. Fault Recovery: The process of restoring the system to a functional state after a fault has been detected and isolated. This may involve automatic recovery mechanisms or human intervention. Redundancy: The use of duplicate or backup components, processes, or data to ensure that the system can continue functioning even if one of the primary elements fails. Fault tolerance techniques vary depending on the specific system and its requirements. Examples of fault tolerance mechanisms include redundant hardware components (e.g., RAID arrays), error-correcting codes in data transmission, checkpointing and rollback recovery in distributed systems and graceful degradation in software systems

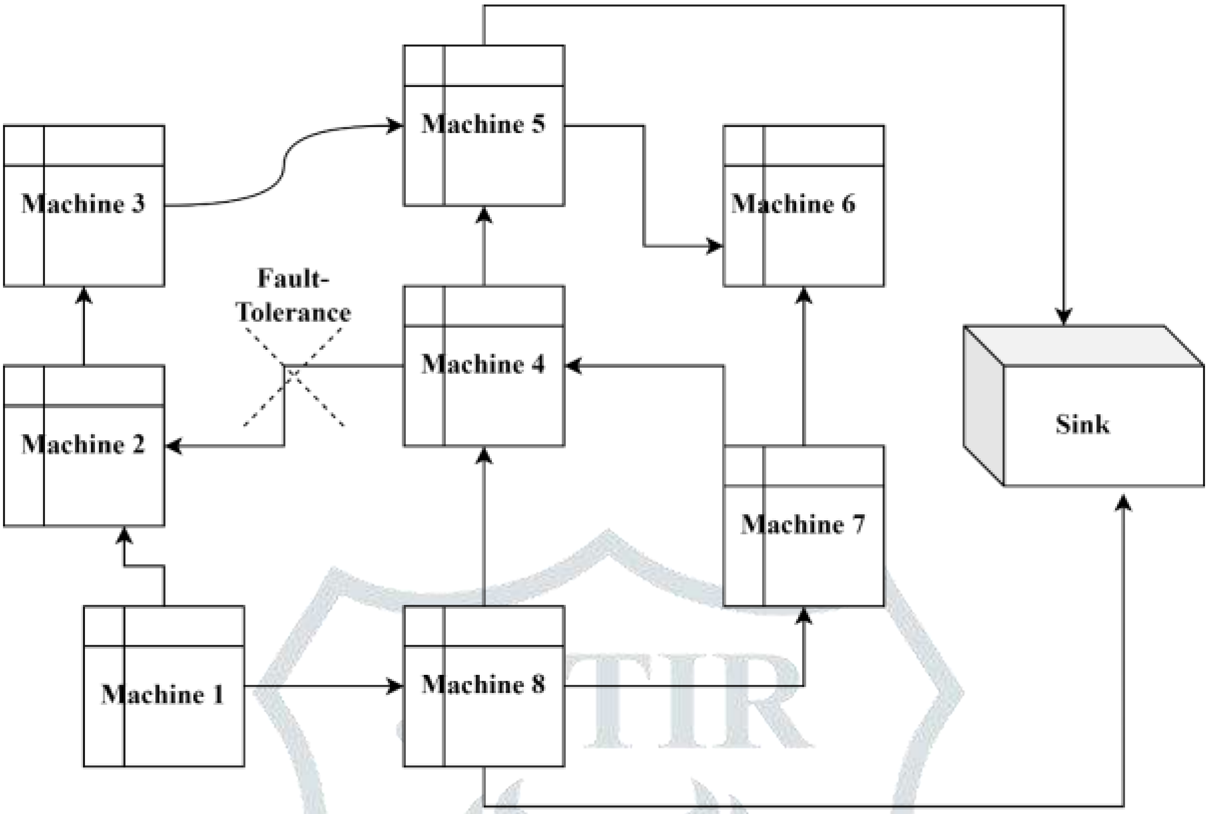


Figure 1 Fault Tolerance Occurring in the Network

By incorporating fault tolerance into a system's design, engineers can enhance its reliability, availability, and resilience, making it more capable of handling unforeseen challenges and ensuring smooth operation even in the face of failures.

I.2 Organization of the Paper

Section 2 provides an overview of related work on topology control algorithms for Wireless Sensor Networks (WSNs). This section discusses existing approaches and highlights the unique features and advantages of the proposed DPV algorithm. Section 3 elaborates on the approach and introduces the DPV algorithm in detail. This section outlines the methodology and explains how the algorithm efficiently discovers and stores complete path information for fault-tolerant topology control. Section 4 presents the simulation results of the DPV algorithm. The obtained results are analyzed and compared with existing solutions to showcase the efficiency and effectiveness of the proposed approach in terms of total transmission power, maximum transmission power per node, and control message transmissions. Finally, Section 5 concludes the paper, summarizing the key findings and contributions of the DPV algorithm. It also discusses potential future research directions and applications for the proposed approach. Additionally, the paper provides a supplementary file accessible on the Computer Society Digital Library, which offers further examples and detailed information about the DPV algorithm for interested readers. The supplementary file enhances the understanding and implementation of the proposed approach.

II. RELATED WORK

Topology control in Wireless Sensor Networks (WSNs) involves adjusting the neighbor set of nodes by modifying the transmission range or selecting specific nodes to forward messages [7]. These approaches can be categorized into two main types: homogeneous, where all sensors have the same transmission range, and nonhomogeneous, where nodes can have different transmission ranges. Various topology control methods have been proposed in the literature, categorized based on the techniques they use [34]. Transmit power adjustment techniques [8], [9], [10], [11], [12], [13] allow sensors to control their transmit power, while sleep scheduling algorithms [15], [14], [16], [17], [18] aim to reduce energy consumption during idle states. Other methods use geometrical structures, location, direction information, or combinations of these techniques [19], [20], [21], [22], [23], [24], [25], [36]. However, this work focuses on minimizing total transmission power in two-tiered heterogeneous topologies with supernodes, while previous studies mostly address flat homogeneous topologies. Additionally, the focus of this work is on the connectivity between a sensor node and supernodes, whereas others focus on connectivity between any two nodes in the network. Clustering is an alternative approach to topology control, aiming to organize the network into a connected hierarchy to balance the load and extend the network lifetime [26]. Hierarchical clustering techniques [27], [28], [29] select cluster heads based on specific criteria to create a layered architecture. However, these techniques start with a flat topology and then transition to a layered structure. In contrast, the proposed approach in this paper starts with a pre-defined layered architecture with supernodes. Instead of building clusters, the focus lies on maintaining fault-tolerant connectivity between sensor nodes and supernodes. This ensures reliable communication between the resource-limited sensor nodes and the powerful actor nodes in wireless sensor and actor networks (WSANs) [5]. In WSANs, there are two types of wireless communication links: actor-actor and sensor-actor links. The links between sensors and actors are assumed to be less reliable, prompting several methods to ensure reliable sensor-actor connectivity [30], [31], [32]. However, these methods do not guarantee k-connectivity between sensors and actors, leaving the network vulnerable to k-1 node failures. In contrast, the proposed approach in this paper addresses both k-connectivity and power efficiency simultaneously. By maintaining k-connectivity, the resulting topologies in heterogeneous architectures with supernodes offer fault tolerance, while optimizing power efficiency, ensuring the network's sustainability and resilience. This approach stands apart from existing works that focus solely on reliability or energy efficiency, providing a balanced and effective solution for WSNs.A significant contribution in the area of fault-tolerant topology control for heterogeneous WSNs with a two-layer architecture is presented by Cardei et al. [35]. Their work addresses both k-connectivity and energy efficiency, focusing on the k-degree Anycast Topology Control (k-ATC) problem. The goal is to adjust the transmission range of sensor nodes to achieve k-vertex supernode connectivity while minimizing the maximum transmission power of nodes. The authors propose two algorithms: the greedy centralized algorithm called global anycast topology control (GATC) and the distributed algorithm called distributed anycast topology control (DATC). While GATC is more theoretical in nature and impractical for large-scale WSNs due to the requirement of global topology knowledge, DATC provides a distributed and practical solution to the k-ATC problem. The DATC algorithm requires only 1-hop neighborhood topology information, which can be extended to h-hop. Its objective is to ensure that any neighbor node u, reachable within the neighborhood of any node v, is either directly reachable from v or there exist at least k-vertex disjoint paths from v to u. This ensures reliable connectivity between nodes and enhances the fault tolerance of the network. Overall, Cardei et al.'s work is significant in the domain of fault-tolerant topology control for heterogeneous WSNs, providing both theoretical and practical solutions to achieve k-vertex super-node connectivity and energy efficiency. Your algorithm stands apart from DATC due to the different approaches adopted for discovering vertex disjoint paths. In DATC, each node begins with a minimal set of neighbors and a minimal power level. The power level is then gradually increased, allowing the discovery of paths from reachable neighborhoods. However, nodes outside of the reachable neighborhood remain unknown to the node performing the discovery, limiting the search scope for finding k-vertex disjoint paths. Simulation results validate these differences and confirm that your ADPV algorithm performs favorably, offering improved chances of discovering more k-disjoint paths, ultimately enhancing fault tolerance and energy efficiency in heterogeneous WSNs.

III. Proposed Advanced Disjoint Path Vector (ADPV) algorithm

The Advance Disjoint Path Vector (ADPV) algorithm is a fault-tolerant topology control approach designed for heterogeneous Wireless Sensor Networks (WSNs) with a two-layered architecture. In this algorithm, the lower layer comprises low-cost ordinary sensor nodes with limited battery power and short transmission range, while the upper layer consists of supernodes with more power reserves and better processing capabilities. The main objective of the ADPV algorithm is to ensure k-vertex supernode connectivity while minimizing the total transmission power of the sensor nodes. To achieve this, ADPV employs a novel approach of storing full path information from supernodes to sensor nodes in local information tables. This strategy allows sensor nodes to discover paths that include nodes outside of their reachable neighborhood, significantly expanding the search scope for finding k-vertex disjoint paths. During the path discovery process, nodes in the ADPV algorithm operate with maximum power, increasing the likelihood of discovering more paths compared to other topology control methods like the distributed anycast topology control (DATC) algorithm. Figure 2 shows the Flow Diagram of Proposed

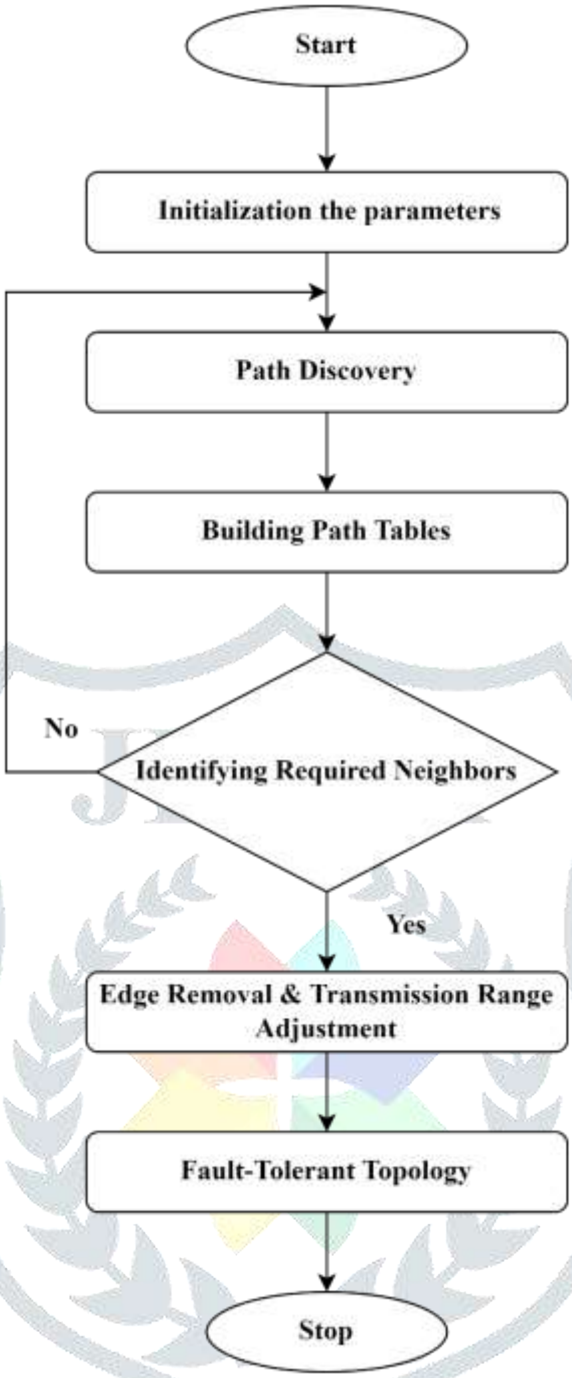


Figure 2 Flow Diagram of Proposed Advanced Disjoint Path Vector (ADPV) algorithm

Advanced Disjoint Path Vector (ADPV) algorithm,By maintaining k-vertex supernode connectivity, the resulting topologies in ADPV ensure fault tolerance, while optimizing power efficiency enhances the overall network lifetime. Simulation results demonstrate that the ADPV algorithm achieves substantial reductions in total transmission power required in the network and maximum transmission power required per node compared to existing solutions. This makes ADPV an efficient and practical choice for fault-tolerant topology control in heterogeneous WSNs, enhancing the network's reliability and energy efficiency.The Advance Disjoint Path Vector (ADPV) algorithm is a distributed and fault-tolerant topology control approach for heterogeneous Wireless Sensor Networks (WSNs). Here are the main steps of the ADPV algorithm: Initialization: Each sensor node in the network starts by setting its transmission range to the maximum value and maintaining its neighbors' information within its 1-hop neighborhood. Path Discovery: Nodes initiate the path discovery process by sending messages to their respective supernodes. These messages contain information about the path from the supernode to the sender node. The supernode uses a flood-fill strategy to disseminate these messages throughout the network. Building Path Tables: As messages propagate, each node stores the received path information from supernodes in local information tables. This process continues until all sensor nodes have updated path tables with information about multiple disjoint paths to the supernodes. Identifying Required Neighbors: Using the path tables, each node identifies a superset of required vertices to guarantee k-vertex supernode connectivity. These required neighbors are the ones that lie on one of the k-vertex disjoint paths from the node to a supernode. Edge Removal: Once required neighbors are identified, each node coordinates with its neighbors to remove edges that are not connected to any of the required nodes. This step ensures that each node is only connected to the required neighbors for fault-tolerant connectivity. Transmission Range Adjustment: After the edge removal, the sensor nodes decrease their transmission range while still maintaining communication with the farthest node among the required neighbors. This adjustment helps conserve energy and reduces transmission power. Fault-Tolerant Topology: By following these steps, the ADPV algorithm ensures that each sensor node is connected to at least one supernode through k-vertex disjoint paths. The resulting topology provides fault tolerance, as it can withstand k-1 node failures in the worst-case scenarios.

Distributed Execution: Importantly, the ADPV algorithm is distributed, and each sensor node independently performs the steps based on information within its 1-hop neighborhood. No global network topology information is required for the algorithm to function effectively. By executing these steps, the ADPV algorithm constructs a fault-tolerant topology in a distributed manner, improving network resilience and energy efficiency in heterogeneous WSNs.

The formula for Availability is defined as:

Availability (%) = (MTBF / (MTBF + MTTR)) * 100

Where:

MTBF (Mean Time Between Failures) is the average time between two consecutive failures of a system or component.

MTTR (Mean Time To Repair/Recovery) is the average time taken to repair or recover a failed system or component.

The availability is expressed as a percentage, representing the proportion of time the system is operational and available for use.

A higher availability percentage indicates a more fault-tolerant system, as it means the system is less prone to failures and can recover quickly in case of a failure.

For example, suppose a server has an average MTBF of 5000 hours and an MTTR of 1 hour. The availability would be calculated as follows:

Availability (%) = (5000 / (5000 + 1)) * 100 ≈ 99.98%

This means that the server is available and operational approximately 99.98% of the time.

It's important to note that fault tolerance involves various strategies, redundancy techniques, and system designs to achieve high availability. The formula above is a simple representation of availability and doesn't account for all possible factors that can affect system reliability and fault tolerance in real-world scenarios. For mission-critical systems, it is crucial to consider multiple factors and perform in-depth analysis and testing to ensure high fault tolerance and reliability.

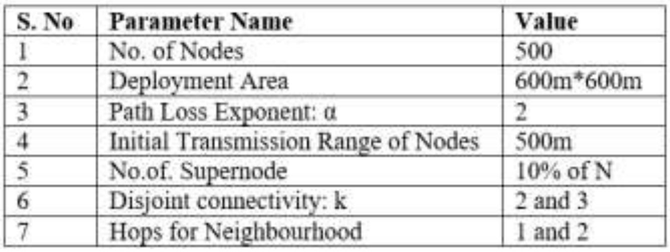
III.1. Advanced Disjoint Path Vector (ADPV) algorithm Code

```
# Step 1: Initialization
for each sensor node in the network:
    set transmission_range to maximum_value
    maintain neighbor information within the 1-hop neighborhood
# Step 2: Path Discovery
send path_discovery_message to respective supernode
path_discovery_message contains path from the supernode to the sender node
use flood-fill strategy to disseminate path_discovery_messages
# Step 3: Building Path Tables
for each node:
    receive path_discovery_messages from supernodes
    the store received path information in the local information table
# Step 4: Identifying Required Neighbors
for each node:
    identify required_neighbors using path tables
    required_neighbors are nodes on k-vertex disjoint paths to supernodes
# Step 5: Edge Removal
for each node:
    coordinate with neighbors to remove non-required edges
    ensure each node only connects to required_neighbors
# Step 6: Transmission Range Adjustment
for each node:
    decrease transmission_range while maintaining communication with the farthest required_neighbor
# Step 7: Fault-Tolerant Topology
for each node: ensure the node is connected to at least one supernode through k-vertex disjoint paths
```

IV. Result and Discussion

In this section, the authors present the results of their experimental evaluations to assess the performance of the proposed ADPV algorithm. They compare its performance with two existing algorithms, GATC and DATC. The authors implemented all three algorithms using a custom simulator that they developed for this purpose.

Table Simulation Parameters



S. No	Parameter Name	Value
1	No. of Nodes	500
2	Deployment Area	600m*600m
3	Path Loss Exponent: α	2
4	Initial Transmission Range of Nodes	500m
5	No.of. Supernode	10% of N
6	Disjoint connectivity: k	2 and 3
7	Hops for Neighbourhood	1 and 2

The simulator allows them to: Generate Random Network Topologies: The custom simulator can create random network topologies to simulate various scenarios that resemble real-world wireless sensor networks. Execute Algorithms: The simulator facilitates the execution of the ADPV, GATC, and DATC algorithms on the generated network topologies. Each algorithm's behavior is simulated based on the specific rules and procedures defined in its implementation. Calculate Metrics: During the simulation, the custom simulator calculates various metrics to evaluate the performance of each algorithm. Figure 3 shows the Transmission power vs the Number of nodes and Table 2 shows the related Numerical values of Transmission power vs the Number of nodes. These metrics may include total transmission power, maximum transmission power, network lifetime, fault tolerance, and other relevant measures. Visualize Results: After the algorithms complete their execution, the simulator allows the authors to visualize the outputs and results of the experiments. This visualization helps in understanding the algorithm's behavior and its impact on the network topologies. By utilizing their custom simulator, the authors gain the ability to conduct controlled experiments, explore different network configurations, and compare the algorithms' performance under various conditions. The simulator provides a comprehensive framework for assessing the DPV algorithm's efficiency and its superiority over the GATC and DATC algorithms in terms of energy efficiency, fault tolerance, and other relevant metrics. This empirical evaluation validates the effectiveness of the ADPV algorithm and provides valuable insights for researchers and practitioners working in the field of wireless sensor networks.

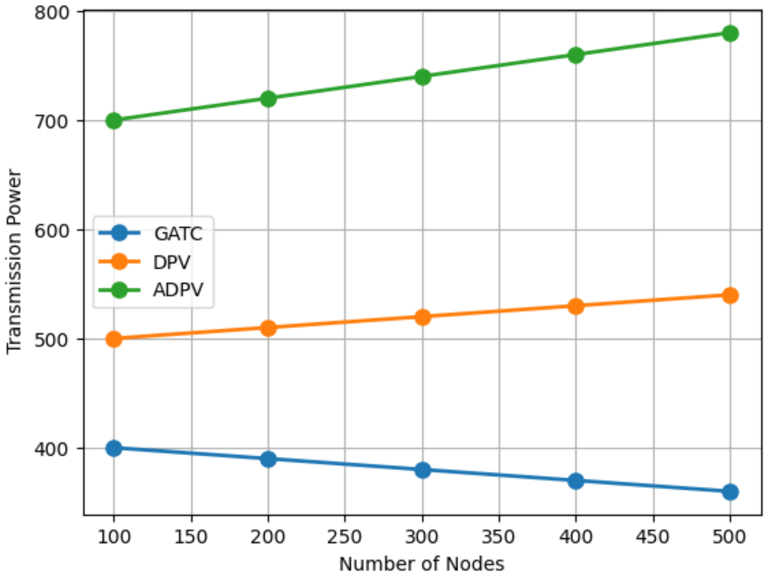


Figure 3 Transmission power vs Number of nodes

Table 2 Numerical values of Transmission power vs Number of nodes

Algorithm Name	**Transmission Power**				
	100-Nodes	**200-Nodes**	**300-Nodes**	**400-Nodes**	**500-Nodes**
GATC	400	390	380	370	360
DPV	500	510	520	530	540
ADPV	700	720	740	760	780

Figure 4 shows the Maximum Transmission power vs the Number of nodes and Table 3 shows the related Numerical values of Maximum Transmission power vs the Number of nodes

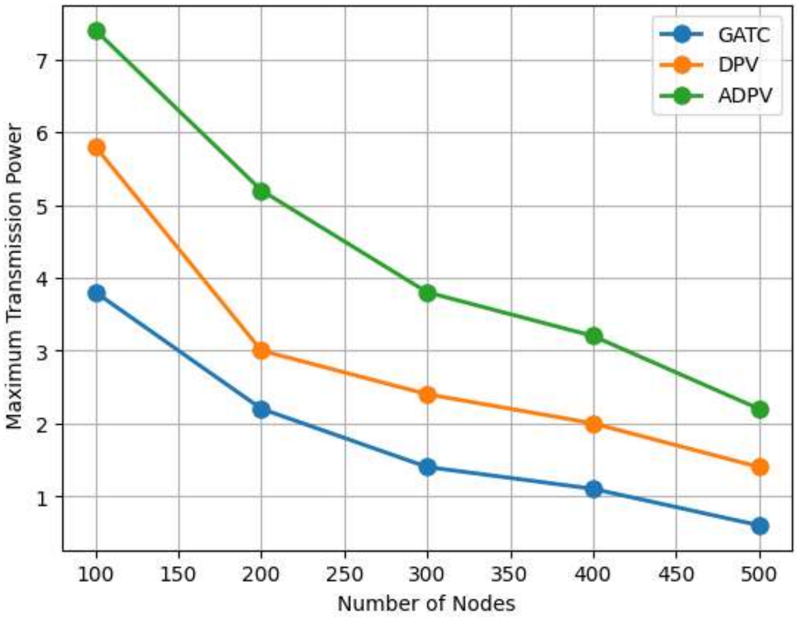


Figure 4 Maximum Transmission power vs Number of nodes

Table 4 Numerical values of Maximum Transmission power vs Number of nodes

Algorithm Name	Maximum Transmission Power				
	100-Nodes	200-Nodes	300-Nodes	400-Nodes	500-Nodes
GATC	3.8	2.2	1.4	1.1	0.6
DPV	5.8	3	2.4	2	1.4
ADPV	7.4	5.2	3.8	3.2	2.2

Figure 5 shows the Total Transmission power vs the Number of nodes and Table 4 shows the related Numerical values of Total Transmission power vs the Number of nodes. Table 6 Numerical values of fault tolerance in %. Figure 6 shows the Fault tolerance in % vs the Number of nodes.

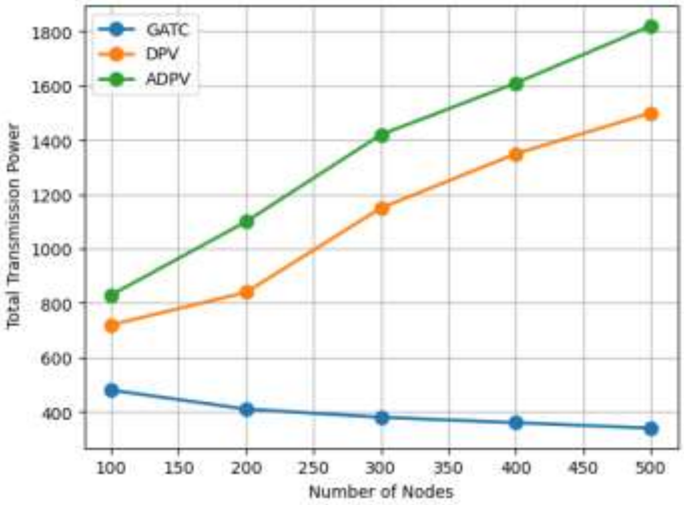


Figure 5 Total Transmission power vs Number of nodes

Table 5 Numerical values of Total Transmission power vs Number of nodes

Algorithm Name	Total Transmission Power				
	100-Nodes	200-Nodes	300-Nodes	400-Nodes	500-Nodes
GATC	480	410	380	360	340
DPV	720	840	1150	1350	1500
ADPV	830	1100	1420	1610	1820

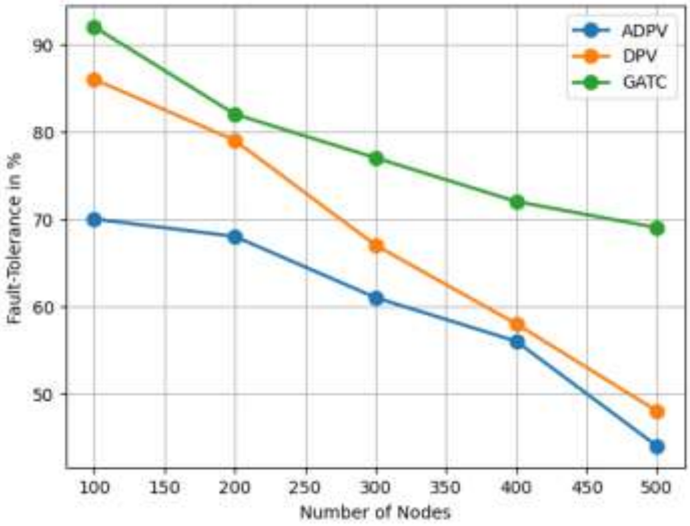


Figure 6 Fault Tolerance in %

Table 6 Numerical values of Fault Tolerance in %

Algorithm Name	Total Transmission Power				
	100-Nodes	200-Nodes	300-Nodes	400-Nodes	500-Nodes
GATC	92	90	87	82	79
DPV	86	79	67	57	42
ADPV	80	72	63	56	44

V. Conclusion

In this paper, the authors introduce the Advanced Disjoint Path Vector Algorithm (ADPV) as a novel distributed and fault-tolerant approach to constructing topologies for heterogeneous wireless sensor networks, which consist of supernodes and ordinary sensor nodes. The main goal of the ADPV algorithm is to minimize the total transmission power of the nodes while ensuring that each sensor node has at least k-vertex disjoint paths to the supernodes, achieving fault tolerance. The algorithm's performance is evaluated through extensive simulations, showcasing its superior energy efficiency compared to existing solutions. When compared to the DATC algorithm, the ADPV algorithm achieves a remarkable 4-fold reduction in total transmission power and a 2-fold reduction in maximum transmission power without considering packet losses. Even with a packet loss rate of 0.1, the ADPV algorithm achieves a 2.5-fold reduction in total power consumption. Additionally, the ADPV algorithm requires fewer message transmissions and receptions than DATC, making it more efficient in terms of communication overhead. The key contribution of this study is the ability of the ADPV algorithm to generate fault-tolerant topologies with total transmission powers like those of centralized algorithms, such as GATC. However, unlike GATC, ADPV is a distributed and localized algorithm, making it scalable and practical for large-scale wireless sensor networks, making it suitable for real-world applications. This makes ADPV a valuable and practical solution for improving the energy efficiency and fault tolerance of heterogeneous wireless sensor networks.

VI. REFERENCES

[1] J. Yick, B. Mukherjee, and D. Ghosal, “Wireless sensor network survey,” Comput. Netw., vol. 52, no. 12, pp. 2292–2330, 2008.

[2] G. Anastasi, M. Conti, M. Francesco, and A. Passarella, “Energy conservation in wireless sensor networks: A survey,” Ad Hoc Netw., vol. 7, no. 3, pp. 537–568, 2009.

[3] H. Liu, A. Nayak, and I. Stojmenovic, “Fault-tolerant algorithms/ protocols in wireless sensor networks,” Guide Wireless Sensor Netw., pp. 261–291, Chapter 10, 2009, DOI: 10.1007/978-1-84882-218-4_10.

[4] P. Santi, “Topology control in wireless ad hoc and sensor networks,” ACM Comput. Surveys, vol. 37, no. 2, pp. 164–194, 2005.

[5] I. F. Akyildiz and I. H. Kasimoglu, “Wireless sensor and actor networks: Research challenges,” Ad Hoc Netw., vol. 2, no. 4, pp. 351–367, 2004.

[6] M. Yarvis, N. Kushalnagara, H. Singh, A. Rangarajan, Y. Liu, and S. Singh, “Exploiting heterogeneity in sensor networks, in,” in Proc.IEEE Int. Conf. Comput. Commun., 2005, vol. 2, pp. 878–890.

[7] Y. Wang, “Topology control for wireless sensor networks,” in Wireless Sensor Netw. Appl., pp. 113-147, Chapter 5, 2008, DOI: 10.1007/978-0-387-49592-7_5.

[8] X. Wang, M. Sheng, M. Liu, D. Zhai, and Y. Zhang, “RESP: A connected residual energy-aware topology control algorithm for ad hoc networks,” in Proc. IEEE Wireless Commun. Netw. Conf.,2013, pp. 1009–1014.

[9] L. Li, J. Halpern, P. Bahl, Y. Wang, and R. Wattenhofer, “A cone based distributed topology control algorithm for wireless multihop networks,” IEEE/ACM Trans. Netw., vol. 13, no. 1, pp. 147–159, Feb. 2005.

[10] N. Li and J. C. Hou, “FLSS: A fault-tolerant topology control algorithm for wireless networks,” in Proc.10th ACM Annu. Int. Conf.Mobile Comput. Netw., 2004, pp. 275–286.

[11] N. Li and J. C. Hou, “Localized fault-tolerant topology control in wireless ad hoc networks,” IEEE Trans. Parallel Distrib. Syst., vol. 17, no. 4, pp. 307–320, Apr. 2006.

[12] L. Wang, H. Jin, J. Dang, and Y. Jin, “A fault-tolerant topology control algorithm for large-scale sensor networks,” in Proc. 8th Int.Conf. Parallel Distrib. Comput, Appl. Technol, 2007, pp. 407–412.
[13] D. M. Blough, M. Leoncini, G. Resta, and P. Santi, “The k-neigh protocol for symmetric topology control in ad hoc networks,” in Proc. 4th ACM Int. Symp. Mobile ad hoc Netw. Comput., 2003, p. 152.

[14] Y. Chen and S. H. Son, “A fault-tolerant topology control in wireless sensor networks,” in Proc. 3rd ACS/IEEE Int. Conf. Comput. Syst. Appl., 2005. p. 57.

[15] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, “Span: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks,” Wireless Netw., vol. 8, no. 5, pp. 481–494, 2002.

[16] S. Kumar, T. H. Lai, and J. Balogh, “On k-coverage in a mostly sleeping sensor network,” in Proc. ACM Annu. Int. Conf. Mobile Comput. Netw., 2004, pp. 144–158.

[17] C. Hua and T.-S. P. Yum, “Asynchronous random sleeping for sensor networks,” ACM Trans. Sensor Netw., vol. 3, no. 3, pp. 1–15,2007.

[18] Y. M. Baryshnikov, E. G. Coffman, and K. J. Kwak, “High-performance sleep-wake sensor systems based on cyclic cellular automata,” in Proc. Int. Conf. Inform. Process. Sensor Netw., 2008, pp. 517–526.

[19] O. Younis and S. Fahmy, “HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks,” IEEE Trans. Mobile Comput., vol. 3, no. 4, pp. 366–379, Oct. 2004.

[20] N. Li, J. C. Hou, and L. Sha, “Design and analysis of an MST-based topology control algorithm,” IEEE Trans. Wireless Commun., vol. 4,no. 3, pp. 1195–1206, May 2005.

[21] X. Li, Y. Wang, and. Song, “Applications of k-localMSTfor topology control and broadcasting in wireless ad hoc networks,” IEEE Trans. Parallel Distrib Syst, vol. 15, no. 12, pp. 1057–1069, Dec. 2004.

[22] W. Wu, H. Du, X. Jia, Y. Li, and S. C.-H. Huang, “Minimum connected dominating sets and maximal independent sets in unit disk graphs,” Theoretical Comput. Sci., vol. 352, no. 1, pp. 1–7, 2006.

[23] J. Wu, F. Dai, M. Gao, and I. Stojmenovic, “On calculating poweraware connected dominating sets for efficient routing in ad hoc wireless networks,” IEEE/KICS J. Commun. Netw., vol. 4, no. 1,pp. 59–70, Mar. 2002.

[24] W.-Z. Song, Y. Wang, X.-Y. Li, and O. Frieder, “Localized algorithms for energy efficient topology in wireless ad hoc networks,”in Proc. ACM Int. Symp. Mobile Ad-Hoc Netw. Comput., 2004,pp. 98–108.

[25] W.-Z. Song, X.-Y. Li, O. Frieder, and W. Wang, “Localized topology control for unicast and broadcast in wireless ad hoc networks,” IEEE Trans. Parallel Distrib. Syst., vol. 17, no. 4,pp. 321–334, Apr. 2006.

[26] O. Younis, M. Krunz, and S. Ramasubramanian, “Node clustering in wireless sensor networks: Recent developments and deployment challenges,” IEEE Netw., vol. 20, no. 3, pp. 20–25, May/Jun.2006.
[27] K. K. Mamidisetty, M. J. Ferrara, and S. Sastry, “Systematic selection of cluster heads for data collection,” J. Netw. Comput. Appl.,vol. 35, pp. 1548–1558, 2012.

[28] S. Bandyopadhyay and E. J. Coyle, “An energy efficient hierarchical clustering algorithm for wireless sensor networks,” in Proc.22nd Annu. Joint Conf. IEEE Comput. Commun., 2003, vol. 3,pp. 1713–1723.

[29] M. Azharuddin, P. Kuila, and P. K. Jana, “A distributed faulttolerant clustering algorithm for wireless sensor networks,” in Proc. IEEE Int. Conf. Adv. Comput., Commun. Inform., 2013,
pp. 997–1002.

[30] J. Wu, S. Yang, and M. Cardei, “On maintaining sensor-actor connectivity in wireless sensor and actor networks,” in Proc. IEEE Conf. Comput. Commun., 2008, pp. 888–896.

[31] K. Ozaki, K. Watanabe, S. Itaya, N. Hayashibara, T. Enokido, and M. Takizawa, “A fault-tolerant model for wireless sensor-actor system,” in Proc. 20th Int. Conf. Adv. Inform. Netw. Appl., vol. 2,Apr. 2006, p. 5.

[32] T. Melodia, D. Pompili, V. C. Gungor, and I. F. Akyildiz, “A distributed coordination framework for wireless sensor and actor networks,” in Proc. 6th ACM Int. Symp. Mobile ad hoc Netw. Comput.,2005, pp. 99–110.

[33] C. Cirstea, M. Cernaianu, and A. Gontean, “Packet loss analysis in wireless sensor networks routing protocols,” in Proc. 5th Int. Conf.Telecommun. Signal Process., Jul. 2012, pp. 37–41.

[34] Z. Gengzhong and L. Qiumei, “A survey on topology control in wireless sensor networks,” in Proc. 2nd Int. IEEE Conf. Future Netw., 2010, pp. 376–380.

[35] M. Cardei, S. Yang, and J. Wu, “Algorithms for fault-tolerant topology in heterogeneous wireless sensor networks,” IEEE Trans.Parallel Distrib. Syst., vol. 19, no. 4, pp. 545–558, Apr. 2008.

[36] M. Haghpanahi, M. Kalantari, and M. Shayman, “Topology control in large-scale wireless sensor networks: Between information source and sink,” Ad Hoc Netw., vol. 11, no. 3, pp. 975–990, 2012.

[37] M. Younis, I. F. Senturk, K. Akkaya, S. Lee, and F. Senel,“Topology management techniques for tolerating node failures in wireless sensor networks: A survey,” in Comput. Netw., vol. 58,pp. 254–283, 2014.

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