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AN EFFICIENT DISTRIBUTED FAULT TOLERANT TOPOLOGY CONTROL ALGORITHM FOR HETEROGENEOUS WSNS

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Abstract:
This article presents An Efficient Distributed Fault-Tolerant Topology govern Algorithm for Heterogeneous WSNs, which uses the Disjoint Path Vector (DPV) algorithm to govern heterogeneous wireless sensor networks. Sensor nodes in these networks have limited energy and computational resources, while super nodes have unlimited resources. The DPV algorithm solves the k-degree Anycast Topology Control problem by finding each sensor's optimal transmission range. The suggested method connects each sensor to a minimum of k-vertex-disjoint super node paths to conserve energy. Even in the worst case, network topologies can function with k-1 nodes. This method works because DPV topologies allow k-vertex super node communication. This study's simulations show that the DPV algorithm outperforms state-of-the-art methods.

Keywords: Topology control, fault tolerance, k-connectivity, disjoint paths, heterogeneous wireless sensor networks, energy efficiency.

1. INTRODUCTION

Regional WSNs have many wirelessly connected sensor modules. Small sensors are typical. New technologies have made sensor module production cheaper. Small but capable, they sense, process, and communicate. Wirelessly networked sensor nodes in collaborative settings offer several monitoring and tracking uses. Power efficiency and fault tolerance are needed to survive energy depletion, device failure, communication issues, and harsh environmental conditions in Wireless Sensor Networks (WSNs). These events will likely occur frequently in WSNs. Minimizing energy use and maintaining network connectivity requires topology control. This paper examines proactive fault-tolerant topology control in two-layered heterogeneous WSNs.The lowest tier of this design uses low-cost sensor nodes with limited battery capacity and transmission range. Top layer super nodes have higher power, processing, and storage. The super nodes have larger communication ranges and faster data delivery. Super nodes' limited availability drives their high pricing. Super nodes have special powers to actively prevent certain events. The unique Disjoint Path Vector (DPV) technique creates a fault-tolerant network structure to transmit data from sensor nodes to super nodes.WSNs need k-connectivity of the communication graph to be fault-tolerant. The architecture can handle k-1 nodes failing worst-case. The DPV algorithm, a distributed method, solves the problem efficiently. In our approach, we limit topology transmission power, optimize sensor node transmission power, and reduce control message transfers. To overcome Wireless Sensor Networks' resource limits, many routing solutions have been developed.

1.1 Overview Of Localization And Positioning Methods Based On Machine Learning:

Multiple learning methods have been used in sensor networks to improve localization precision. Machine learning in Wireless Sensor Network (WSN) localization has many benefits, making it an interesting issue. Using machine learning in algorithm implementation simplifies and improves localization. Using fewer anchor points allows learning algorithms to produce precise and robust results. Using range measurement devices is not necessary to estimate distances. A main goal of machine learning is to improve localization algorithms' accuracy with low resources and easy implementation. Using machine learning in localization algorithms reduces expenses and energy use.

The below words are commonly employed within the literature on Wireless Sensor Network (WSN) localization.

- An unknown node refers to a node that lacks the ability to ascertain its present position.

- Beacon node (or anchor node) is any node that has the capability to recognize its location by using positioning hardware or from its manual placement. In most systems, the beacon node is used as a reference point to provide an approximation of the coordinates of other unknown nodes.

- Received signal strength indication (RSSI) is an indicator of the received signal intensity, used to represent transmission performance or distance.

1.2 Channel Modeling:

Many adoption learning localization techniques use RSSI readings to approximate node positions.The path loss log normal shadowing model is often utilized in modern research due to its computational simplicity and low error rate.The equation represents training received power and expresses the model.

$$P_{rx} = P_{tx} + K_c - 10\eta log\left(\frac{d}{d_o}\right) + X_\sigma \quad \text{(1)}$$

Where P_{tx} is the transmitted power in [dBm] and K_c is given by

$$K_c = 20log\left(\frac{4\pi}{\lambda}\right) \quad \text{(2)}$$

η is the path loss coefficient, 0,d is the reference distance, d is the transmitter-receiver distance and σX is a Gaussian random variable with zero-mean and variance σ taking into account the noise contribution.

2. LITERATURE SURVEY

This study examines wireless network direction-finding. The research classifies routing systems into three construction types. QoS-based hierarchical, location-based, flat structures. Protocol processes include query-based, negotiation-based, multipath-based, and routing schemes [1].Wireless Sensor Networks (WSNs) connect central nodes and users via dispersed wireless nodes and connected infrastructure. Wireless Sensor Networks (WSN) efficiently deliver data to the sink during network operations. To finish the procedure, sensor nodes emit electrical or optical signals from atmospheric data [2].High-quality lavender Wireless Sensor Networks have several benefits. Benefits include remote communication and reduced performance. New data sources can boost WSN performance and accuracy. Time intervals and triggered events help Wireless Sensor Networks (WSNs) monitor progress unstructured

[3].Advanced businesses need jungle fire detection for emergency response and workflow [4].Wireless Sensor Networks (WSNs) are widely explored due to their many uses. Applications include environmental monitoring, military surveillance, health care, tracking, and smart home systems [5].Wireless Sensor Networks (WSNs) collect, analyze, and transmit data from numerous tiny sensors. Independent sensor nodes achieve an objective without infrastructure. WSNs must be power efficient and fault resistant to survive energy depletion, hardware failures, communication link issues, and adverse environmental conditions. WSNs likely experience these [6], [7].To improve fault tolerance, [8], [11] build k-connected networks with alternate paths. Wireless Sensor and Actor Networks (WSANs) have cheap sensor nodes at the bottom and strong actor nodes at the top. Nodes make informed decisions and act appropriately [9].We present a secure hierarchical energy-efficient routing protocol [10]. This protocol aims for safe, energy-efficient network communication. Topology control approaches that modify transmit power involve sensors [12, 13, 14, 15, 16, 17]. In some algorithms, sleep scheduling saves energy when nodes are idle. The current ADPV algorithm [15] modifies sensor node transmission powers, unlike static methods. This update keeps super nodes connected after node failures. An HWSN algorithm adapts network architecture to changing conditions. The multi-routing tree approach guarantees k-disjoint super node paths, unlike ADPV.Reference research [16] described HWSN benefits. By appropriately distributing nodes, heterogeneity can enhance network lifetime by five. Academy topology control approaches are classified [18]. We use geometrical structures, position, and direction [19].Contrary to flat homogenous topology studies, this study reduces transmission power in two-tiered heterogeneous topologies. This study concentrates on sensor-super node link, while theirs covers any two nodes. Hierarchical network clustering is another topology control approach. Clustering evens load and prolongs network life. Hierarchical clustering ranks cluster heads using many criteria. Surface topology precedes stratification. The architecture starts with layers and super nodes. Developing clusters comes after fault-tolerant sensor-super node communication. Fault-tolerant topology control in two-layer heterogeneous wireless sensor networks was studied by Cardei [20]. This paper discusses k-connectivity and energy efficiency in such networks. Any-cast Topology Control is problematic. This challenge connects n-vertex super nodes by increasing sensor node transmission range and reducing transmission power.

3. PROPOSED METHOD

A Hybrid Wireless Sensor Network (HWSN) with numerous super nodes with plentiful resources and many low-cost conventional sensor nodes is presented in this paper. Our HWSN model includes M resource-rich super nodes and N low-cost sensor nodes, with $M \geq N$. An undirected graph G = (V, S, E) depicts the network topology, with V = {v1, v2, v3 … vn} representing sensor nodes, S = {s1, s2, s3 … sm} representing super nodes, and $E = \{(vi,vj) \mid vi,vj \in V \cap d(vi,vj) < Min(Ri,Rj)\}$ representing edges.

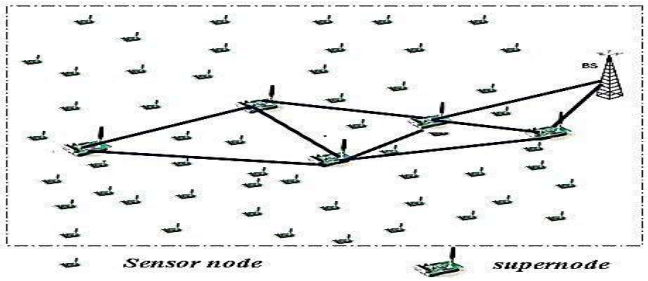


Figure 1: Heterogeneous WSN

A sample HWSNs environment is illustrated in Figure 1. Our algorithm aims to construct a fault tolerant network topology and minimize the energy consumption. It is assumed that each sensor possesses the capability to adapt its transmission range as necessary, with the maximum transmission range denoted as R_{max}. It is assumed that the super nodes possess unlimited energy resources and have the capability to establish direct communication with a base station or other super nodes [13, 15]. We also have the following definitions:

Definition 1 (1-hop neighbour): Let $N^1(x_i)$ denotes the 1-hopneighbors of x_i, where x_i can be a super node or a sensor node. For $\forall v_j \in N^1(x_i)$, dis $(x_i, xj) <= \min (R_i, R_j)$.

Definition 2 (power consumption): $\forall\ v_i, v_j \in V$, the minimum necessary transmission power, sending a message from v_i to v_j, can be computed through formula (3).

$$C_{ij} = \propto \times d^{\beta}(v_i, v_j) \quad \text{.....(3)}$$

Where α is a constant, n is pathloss factor and $d(v_i,v_j)$ is the Euclidean distance between v_i and v_j.

Definition 3 (multi-routing tree): An undirected graph is a multi-routing tree if it meets the following conditions:

- Each node holds a level value. Let Lev_{sup_i} and Lev_i denotes the level of super node s_i and sensor nodes v_i separately, and the initial value of which is 0. If $Lev_i = 0$, it can be redefined as formula (4).

$$Lev_i = \begin{cases} 1, v_i \in N^1(s_j) \\ M, v_i \in N^1(v_j) \cap Lev_j = M - 1 \end{cases} \quad \text{.....(4)}$$

- For ∀vi, if $Lev_i = 1$, then v_i has several super nodes as its father node and uncle nodes. If $Lev_i = M$ (M >= 2), v_i has one father $Father_i$ and k-1 uncle $Uncle_{ix}$, and $LevFather_i = M - 1 \cap LevUncle_{ix} = M - 1$.

- All the nodes in level 1 are the roots of a sub trees. The edges that link to node v_i and all its sons only belong to one sub tree.

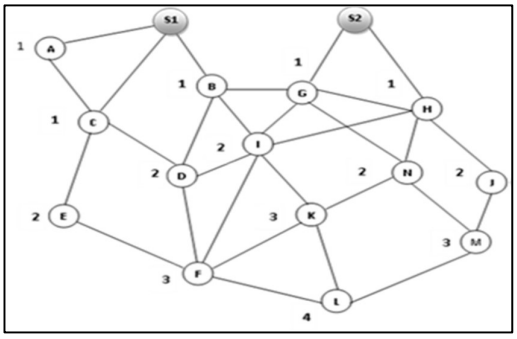
3.1. Topology Construction Using Multi-Routing Tree

The algorithm involves two phases: fault tolerant topology construction phase and topology reconstruction phase, and the latter phase is invoked each time the super node connectivity is broken.The construction process of fault tolerant network topology will be handled as follows:

- Step 1: Assign levels first. Sensor and super nodes start with 0 Levx. Super nodes assign levels. Every super node sends sensor neighbors DL its ID and level. Vi resets Levi = 1 after getting a message. Then it continues. Node vj verifies its Levj after receiving a DL from vk, where Levk = m. If Levj = 0, reset vj to m+1, otherwise drop message. The process continues until Levi > 0 for ∀vi ∈ V. Super nodes S1 and S2 hold sensor nodes A, B, C, and N in Figure 2(a). Nodes get levels following assignment.

- Step 2: Tree-building with several paths. Each sensor node's father and k-1 uncle are chosen from upstream neighbors. Upstream neighbors for ∀vi ∈ V, where Levi = m, are defined as: USi = {(vj)|Levj = (m - 1) ∩d(vi,vj) <= min (Ri,Rj) Vi chooses its father and uncle nodes from the nearby USi and others. Node vi must choose a new father node if vj was the father of another node with the same root node to avoid intersecting routes. Continue until all sensors have a parent and (k-1) uncle.

- Step 3: Change node transmission. To develop the fault-tolerant network topology, each node adjusts its transmission range to reach its k disjoint neighbors after building the multi-routing tree. Figure 2 (b) displays k=2 network structure. The path from L to the super node set is {L - K - I - G - S2}. I is K's father and F's nearest level 2 node, thus F chooses D to avoid a collision. See Figure 2(b) for fault-tolerant network topology.



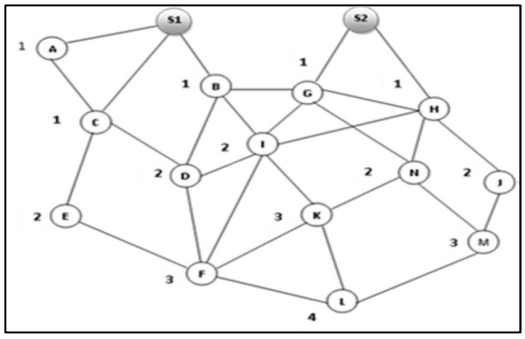


Figure 2 (a): Level value assignment **Figure 2(b): Fault tolerant network topology**

3.2. Topology Restriction

In topology maintenance, the method reconstructs the network after super node communication is disrupted. Node vi checks if vj is its father or uncle if it fails the neighbor test. Vi does not handle the fault if vj is not the father or uncle. Node vi will build discontinuous pathways to super node specified otherwise. Process will be as follows:

- Step 1: The father node of vi is vj. If fault node vj is vi's father, vi will reselect an uncle node as its father. Vi will also choose a new uncle node from USi. Vi will alter its transmission power to add one uncle

node if USi has no neighbors. Figure 2 (a) shows that K's father node, node I, fails to transfer data. K chooses a father node from its uncles. Figure 2 (b) shows K choosing N as its father. The updated path from L to the super nodes is (L - K - N -H - S2). Node K should also reselect an uncle node from its level 2 neighbors to ensure two distinct pathways to the super node set. K will choose its uncle from nearby nodes if they exist. Node K adjusts its transmitting power to the next node v if the following mathematical expression is met: (Levm = Levk - 1) ∩ (d(K, vm) > d(K, N)) ∩ (d(K, vm) > d(K, O)) ∩ (∄vn ∈ V ∩ d(K, vn) < d

- Step 2: vj is the uncle node of vi. Vj will choose another uncle to ensure k-disjoint pathways between vi and the super nodes if vj is vi's uncle. Same method as step 1 for uncle node selection.

4. SIMULATION AND RESULTS

The defect and event detection technique is evaluated using positive and negative detection rates.True positives are hits in the first condition when an issue or occurrence is true.Second, an issue or incident stays undiscovered, presumably a false negative.To determine the false detection rate, add the FPR and FNR rates (1−detp and 1−detn).Evaluate event border neighborhoods using hitting and false detection rates. S contains the true event boundary neighbourhood node and sensor nodes detected as it, omitting the malfunctioning node.Mistaking C's sensor nodes for event boundary neighbors.

$ef = \{S \cap S'\}\{S\}$……..…… (5)

$ed = \{C\}\{S\}$……..……..... (6)

Sensor nodes are randomly arranged in 32x32 WSN grids. All sensors must confirm detection. All devices fail equally. In an experimental environment with 30% sensor faults, all sensors have a 30% chance of delivering false results. To eliminate random fluctuation and achieve statistical significance, the detection method is performed 100 times every experiment. 1024 sensor nodes are randomly placed in the 32x32 WSN. This deployment tests our method with sensor network interval and failure. The detection effectiveness in this study is influenced by two factors: the sample size (denoted as k) and the failure rate of the sensor network. The experimental outcomes are presented in Figure 3. The event's TPR declines and FNR increases as the failure rate rises. Rising fault TPR and FNR. Zoned sensor networks increase node discovery and reduce false alarms. Keeping the failure rate constant, k improves the hit rate. Thus, the normal sample interval better matches the fluctuation interval. This study chose k=40 for the following experiment due to sensor node storage capacity limits.

Table 1: Experimental parameters

SL.NO.	Parameter	Value
1	Sensing area	32 x 32
2	Measurement value of the sensor in the event area	100,10
3	Measurement value of the sensor out of the event area	28,30
4	Faulty measurement value of the sensor	30,100

5	Communication radius	√2

This section has five experiments. Figure 3 shows how sensor network sample size and failure rate affect this methodology's experimental parameters. The method's detection impact under varying failure rates and sensor amounts is shown in Figures 4 and 5.Our approach works and is fault-tolerant, unlike [11]. Table 2 displays experimental fault identification results for our approach and reference [19] at varied failure rates. Figures 6, 7, 8, and 9 show how sensor network density and defect rates effect circular or square event border neighborhood detection.

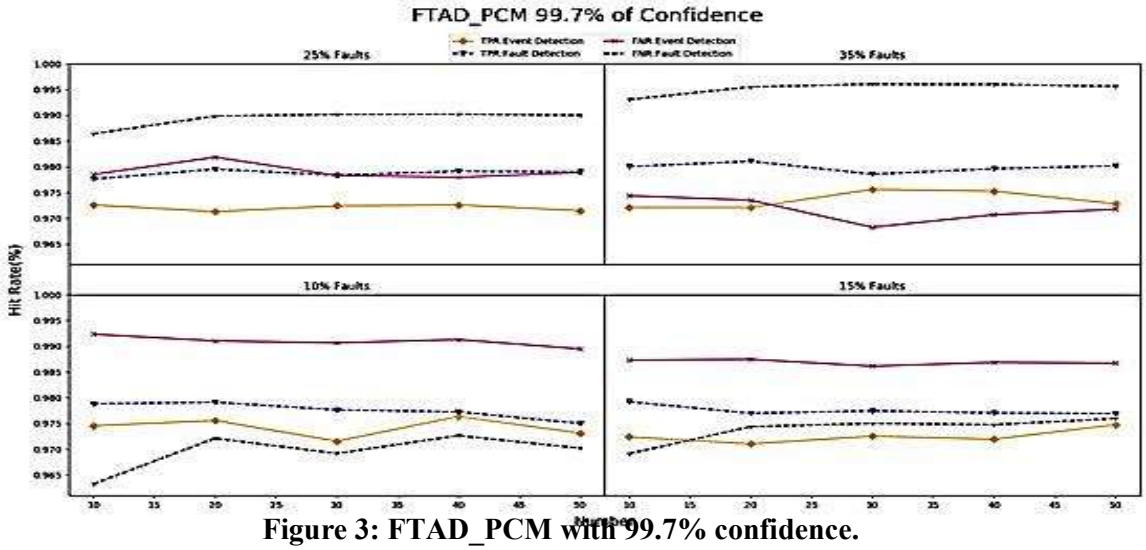


Figure 3: FTAD_PCM with 99.7% confidence.

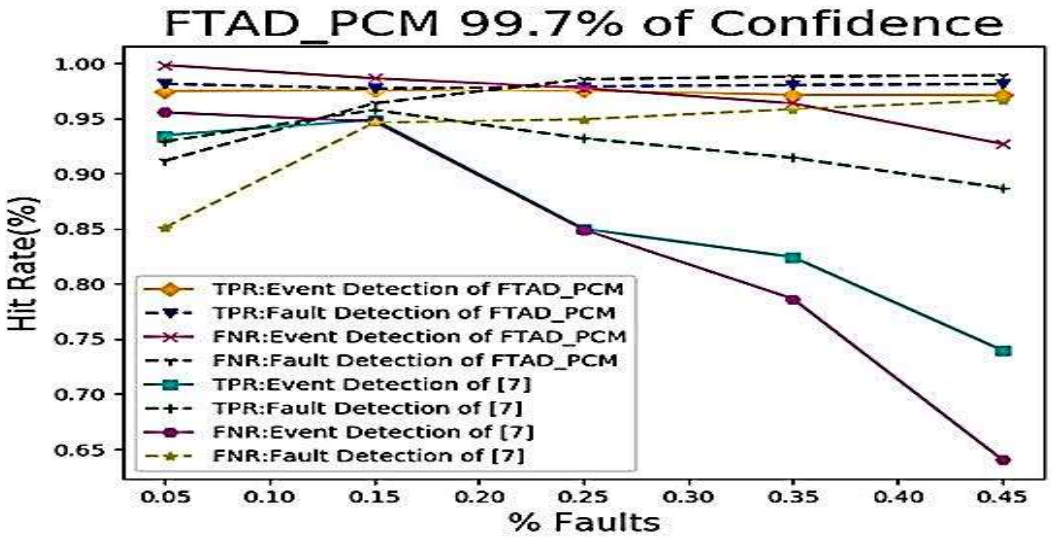


Figure 4: FTAD_PCM detection rate vs. the rate of sensor faults.

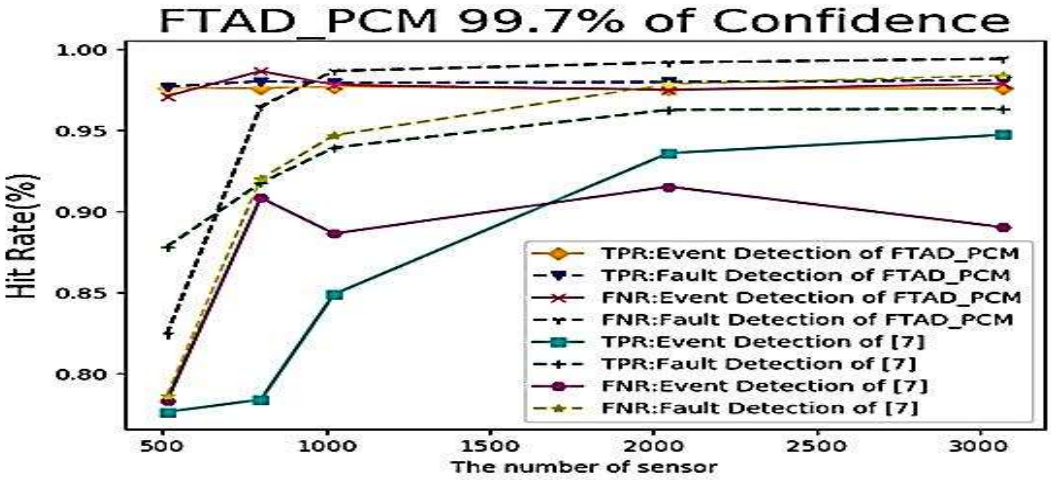


Figure 5: FTAD_PCM detection rate vs. the number of sensors.

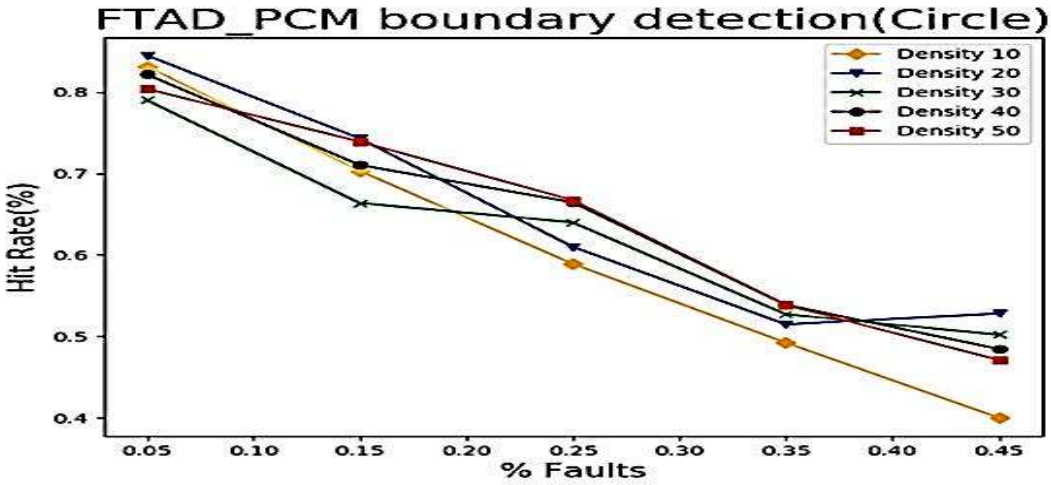


Figure 6: FTAD_PCM boundary detection (circle).

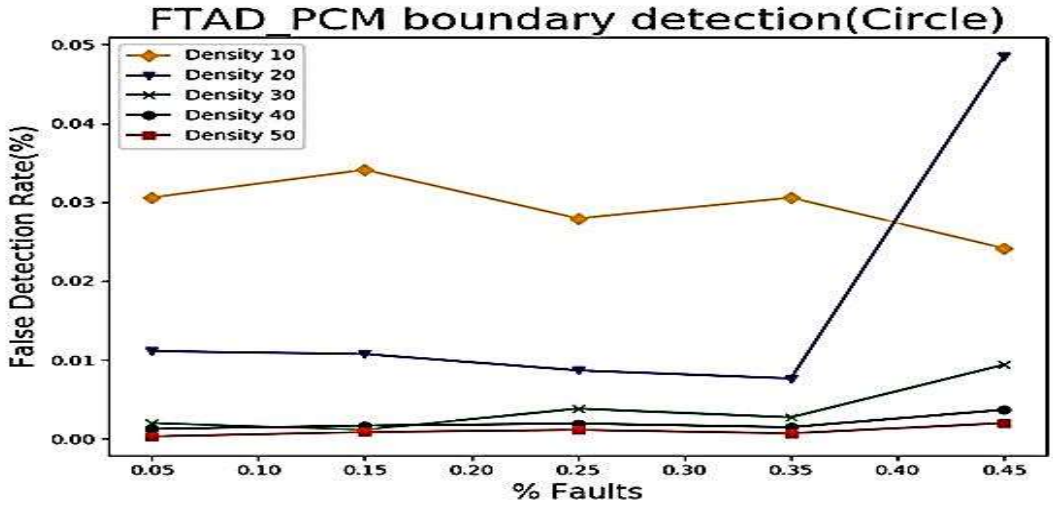


Figure 7: FTAD_PCM boundary false detection (circle).

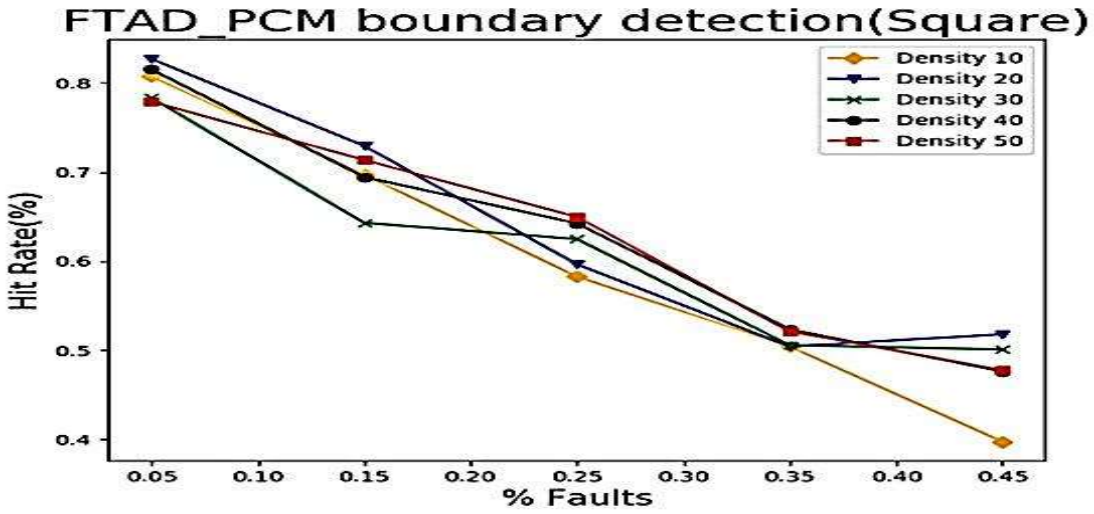


Figure 8: FTAD_PCM boundary detection (square).

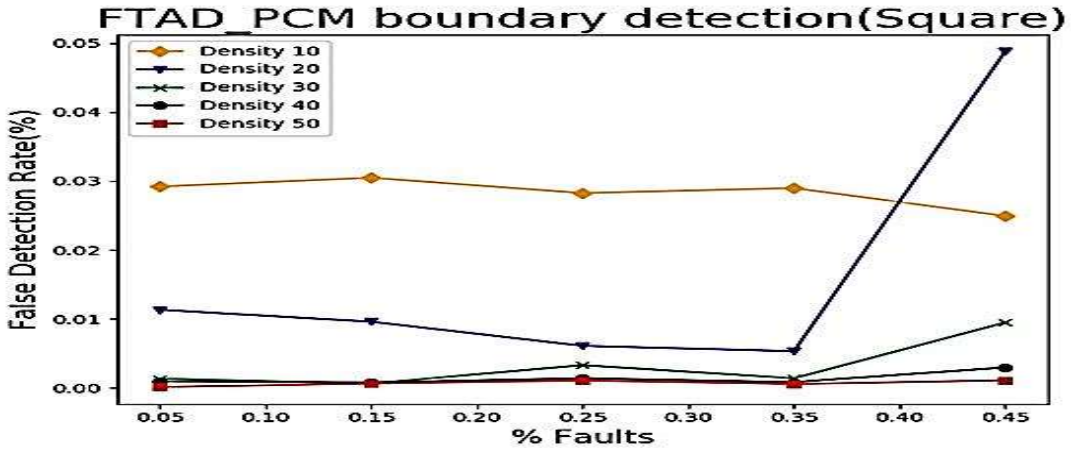


Figure 9: FTAD_PCM boundary false detection (square).

Table 2: FTAD vs. KPCA and FDS

Result	TPR				FNR			
Method	**5%**	**15%**	**25%**	**35%**	**5%**	**15%**	**25%**	**35%**
FTAD	98.8%	98.4%	98.4%	98.0%	91.6%	96.8%	98.7%	98.7%
KPCA	95.0%	92.5%	89.4%	85.0%	94.0%	93.8%	91.0%	90.0%
FDS	97.5%	95.3%	92.0%	88.9%	96.5%	94.5%	92.8%	91.1%

Event and fault detection analysis

Our technique was assessed using Table 2's simulated data and failure rates. Comparisons were made using Table 2's simulated data and [7] parameters. The network has 1024 sensors. In tests, malfunctioning node rate affects sensor network performance as shown in Figure 4. High sensor network failures lower event node TPR and FNR. Even with 45% sensor node loss, event detection hits 98%. Nearly 91% of instances are false positives. Detecting anomalies involves spatial and temporal correlation. The temporal correlation component uses spatial and beginning states to calculate the node's end state. True positive and false negative errors are

higher at the problematic node. Neighbor hooding allows the network model to discover sensor network irregularities. Neighborhoods detect irregularities differently. When failure rates reach 15%, event nodes' TPR and FNR plummet [7]. Although problematic nodes' FNR increases, it remains below the study's plan. We can neighborhoodize sensor networks using spatial-temporal correlation. Shifting sensor nodes with 25% failure yields Figure 5. Sensor network size significantly affects event and defective TPR and FNR compared to reference [7]. Table 2's simulated data and other factors from [7] are used in this observation. Sensor networks grow. Sensor network size influences many [7] notions. Sensor network size dramatically affects malfunctioning node false negatives. Add sensor nodes to reduce false alarms. Event and defective node TPR and FNR are well-preserved. In fault-prone communities, low-density sensor networks matter. This event detection approach works for low-density sensor networks. Table 2 compares the suggested technique to numerous algorithms [4, 17] with varying failure rates. The original study used Table 2's simulated data and other parameters. To reduce false alarms, set γmin to 0.5, c1 to 0.1, and c2 to 0.5 in the FDS approach. Fault level lowers TPR. FNR rises with fault node size. The suggested system has excellent detection accuracy and low false alarms at failed nodes. Table 2 shows our method trumps FDS and KPCA. PCM model effectiveness depends on its capacity to detect irregularities and segment the sensor network for fault detection.

Analysis of Event Boundary Neighborhood Detection

Figures 6 and 7 demonstrate circular event boundary investigations with different failure rates and sensor network density. Figures 8 and 9 illustrate square border neighborhood results. Each side utilizes Table 1 parameters. Figures 6 and 8 indicate reduced hit rates with higher sensor failure rates. When the failure rate approaches 45%, the average hit rate remains around 50% regardless of the event border neighborhood. The detection results are similar across sensor network densities. The results reveal that sensor network density does not impair event boundary proximity detection. This strategy works for circular or square event zones. IN Figures 7 and 9, boundary neighborhood false detection rates are shown. Erroneous detections rise with sensor failures. As the failure rate approaches 45%, the false detection rate drops to 0.05%, the worst case situation. This concludes that detection at the event border is effective.

5. CONCLUSION

Disjoint Path Vector (DPV) is a distributed method designed to ensure fault tolerance in wireless sensor network topology control. The proposed technique allocates sensor transmission ranges to super nodes to ensure at least k-vertex-disjoint paths for the k-degree Anycast Topology Control problem. Overall power usage is reduced by this method. The calculations show that Disjoint Path Vector (DPV) could reduce total and maximum transmission power by four or five compared to current methods. Compared to current methods.

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