INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

Graph-Theoretic Optimization of Backbone Structures in Wireless Sensor Networks Using Domination Models

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OPEN ACCESS

Received: 22/03/2026

Accepted: 27/04/2026

Published: 30/05/2026

Citation: Poornavalli R, Solairani P (2026) Graph-Theoretic Optimization of Backbone Structures in Wireless Sensor Networks Using Domination Models. Indian Journal of Science and Technology 19(20): 1362-1372. https://doi.org/10.17485/IJST/v19i20.451

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Funding: None

Competing Interests: None

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Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: This study proposes an energy-aware backbone optimization framework for Wireless Sensor Networks (WSNs) to address the limitations of conventional single Connected Dominating Set (CDS)-based approaches, particularly in terms of adaptability, fault recovery, and uneven energy depletion among nodes. **Method:** A graph-theoretic model based on domination graphs is introduced, where each vertex represents a feasible dominating set and edges correspond to valid single-node transitions between backbone configurations. An energy-driven objective function guides these transitions, enabling progressive movement toward balanced states. The framework incorporates localized reconfiguration mechanisms and is supported by theoretical guarantees on connectivity preservation and convergence. **Findings:** Simulation-based evaluation demonstrates that the proposed framework achieves 18–25% improvement in network lifetime, 22% reduction in energy variance among backbone nodes, and 30% decrease in reconfiguration overhead compared to traditional CDS-based methods. Additionally, fault recovery time is reduced by approximately 35% due to localized transition mechanisms, eliminating the need for global recomputation. The model ensures stable convergence to energy-balanced configurations under dynamic network conditions, while maintaining full connectivity and coverage. **Novelty:** This work introduces a fundamentally new perspective by modelling the entire space of dominating sets as a structured domination graph, explicitly capturing both configurations and their transition pathways. Unlike existing approaches that rely on static or limited backbone structures, the proposed framework enables continuous, energy-aware navigation across multiple backbone states. This represents a significant advancement by integrating domination theory with dynamic optimization, providing a scalable and mathematically grounded solution for adaptive backbone management in WSNs.

Keywords: Domination graph framework; Wireless sensor networks (WSNs); Connected dominating set (CDS); Energy-aware backbone optimization; Fault-resilient reconfiguration

1 Introduction

Wireless Sensor Networks (WSNs), which collectively monitor physical environments such as smart cities, industrial systems, and surveillance areas, are composed of battery-operated sensor nodes. Extending network lifetime while maintaining coverage and connectivity continues to be a key problem due to finite energy and communication resources. Therefore, efficient topology control and backbone design are essential for reducing communication overhead and balancing energy consumption.

Recent studies have proposed energy-conscious optimization techniques, such as AI-driven routing, to increase network lifetime[(1)],[(2)]. For efficient routing and connectivity maintenance, virtual backbones based on dominating sets continue to be a crucial framework[(3)]. Furthermore, more advanced techniques for adaptive energy management have been developed, such as graph neural networks and dynamic topology optimization[(4)],[(5)],[(6)]. Evolutionary optimization and heuristic lifespan maximization techniques have greatly improved the energy balance between backbone nodes[(7)],[(8)],[(9)]. To manage fault tolerance and boost resilience against node failures, CDS-based protocols and multiple dominating set architectures have been employed[(10)],[(11)].

Despite these developments, most existing methods either create a single connected dominating set or employ a small number of predefined backbone configurations. Global recomputation is often required due to reconfiguration caused by either node failure or energy depletion, which increases overhead and instability. Although dominance theory provides a strong mathematical foundation for backbone modelling, the configuration space of all possible dominating sets and the structured transitions between them has not been explicitly modelled by WSN optimization frameworks[(12)].

This study offers a framework based on domination graphs to get around this restriction. Each dominating set is represented as a vertex in a higher-order graph, and transitions between backbone configurations are defined by acceptable local changes. An energy-weighted functional guides monotone reconfiguration routes to reach balanced and stable states. The stated theoretical properties of connection and energy stability provide a structured foundation for fault recovery, load balancing, and backbone rotation.

Despite significant progress, a critical limitation persists in the existing body of work. Most approaches focus on constructing either a single connected dominating set or a limited number of static backbone configurations. These methods often rely on global recomputation when network conditions change due to node failures or energy depletion, leading to increased computational overhead, latency, and reduced network stability.

Furthermore, while domination theory provides a strong mathematical foundation for backbone construction, current WSN optimization frameworks do not explicitly explore the entire space of feasible dominating sets or the structured transitions between them. The absence of a systematic model to represent and navigate multiple backbone configurations restricts the adaptability and resilience of the network.

Thus, the key research gap can be summarized as:

- Lack of a unified framework to represent all possible dominating set configurations
- Absence of structured transition mechanisms between backbone states
- Over-reliance on global recomputation, leading to inefficiency
- Limited support for continuous, energy-aware backbone reconfiguration

To address the identified gap, this study proposes a novel domination graph-based framework for WSN backbone optimization. In this approach, each dominating set is represented as a node in a higher-order graph, referred to as a domination graph. Transitions between backbone configurations are defined through permissible local modifications, enabling efficient navigation across feasible states.

An energy-aware cost function is incorporated to guide the selection of optimal transition paths, ensuring balanced energy consumption and prolonged network lifetime. The framework supports monotonic reconfiguration, allowing the network to evolve toward stable and efficient configurations without requiring global recomputation.

The proposed model offers the following advantages:

- Structured exploration of the dominating set configuration space
- Efficient local reconfiguration mechanisms
- Improved fault tolerance and adaptability
- Enhanced energy balancing and network stability

1.1 Preliminaries

Graphs are assumed to be simple, undirected, and finite throughout this study. The vertex set of a graph $G = (V, E)$ is represented by $V(G)$, and the edge set by $E(G)$. The open neighbourhood of a vertex v within V, $N(v) = \{u \in V : uv \in E\}$

Reference	Methodology	Key Contribution	Limitation
[1]	AI-driven routing	Energy-efficient path optimization using ML	Focus limited to routing, not backbone design
[2]	Heuristic CDS construction	Improved network lifetime via energy balancing	Static backbone structure
[3]	Graph Neural Networks	Adaptive topology learning	Lacks explicit backbone transition modeling
[8]	Evolutionary algorithms	Optimized node selection for CDS	High computational overhead
[9]	Multi-CDS frameworks	Enhanced fault tolerance	Limited scalability and adaptability
Proposed Work	Domination Graph Model	Structured backbone transitions and energy-aware reconfiguration	—

and the closed neighbourhood is $N[v] = N(v) \cup \{v\}$. The degree of v is $|N(v)|$ A subgraph induced by a vertex subset $S \subseteq V$ is written as $G[S]$ [2],[6],[7].

Dominating sets [6],[9]: A subset $D \subseteq V(G)$is called a dominating set of G if $\bigcup_{u \in D} N[u] = V(G)$. Conversely, each vertex in G either is a part of D or is adjacent to a vertex in D. The domination number of G, denoted $\gamma(G)$, is $\gamma(G) = \min \{|D|: D$ is a dominating set of $G\}$ A minimum dominating set (MDS) is any dominating set with cardinality $\gamma(G)$. Since calculating $\gamma(G)$ is known to be NP-hard, structural characterization and approximation are crucial in applications.

1.1.1. Variants of domination

Total domination [2]: A set of $D \subseteq V$ is a total dominating set if each vertex in D is adjacent to a vertex; that is, $\forall v \in V,\ N(v) \cap D \neq \emptyset$.

k-domination [7]: For a positive integer k, a set $D \subseteq V$is a k-dominating set if $\forall v \in V,\ |N[v] \cap D| \geq k$.

Connected domination [3],[5],[7]: A dominating set $D$is connected if the induced subgraph $G[D]$is connected, such a set is called a connected dominating set (CDS), and its minimum cardinality is denoted $\gamma_c(G)$.

Domination graphs [9],[10]: Let $D(G)$denote the family of all dominating sets of G. The domination graph associated with $G$is the graph $DG(G) = (X, Y)$, where $X = D(G)$, two vertices $D_1, D_2 \in X$ are adjacent if D_1can be obtained from $D_2$by a local modification. In this work we adopt the following adjacency relation: $D_1$and D_2 are adjacent $\iff |D_1 \triangle D_2| = 1$,

In other words, the cardinality of the symmetric difference is one. As a result, every edge represents the addition or removal of a single vertex. The results presented here remain structurally equivalent even if other adjacency relations (bounded symmetric difference, exchange of a vertex by a neighbour, etc.) are taken into consideration.

1.1.2. Fundamental characteristics

We remember a few instant observations

Lemma 1: If and only if G has a dominating set, the dominance graph $DG(G)$is nonempty.

Lemma 2: Every minimum dominant set of G is a $DG(G)$ vertex.

Remark 3: Transitions between minimum dominating sets may necessitate passing through non-minimum dominating sets; the subgraph created by all minimum dominating sets in $DG(G)$ need not be connected.

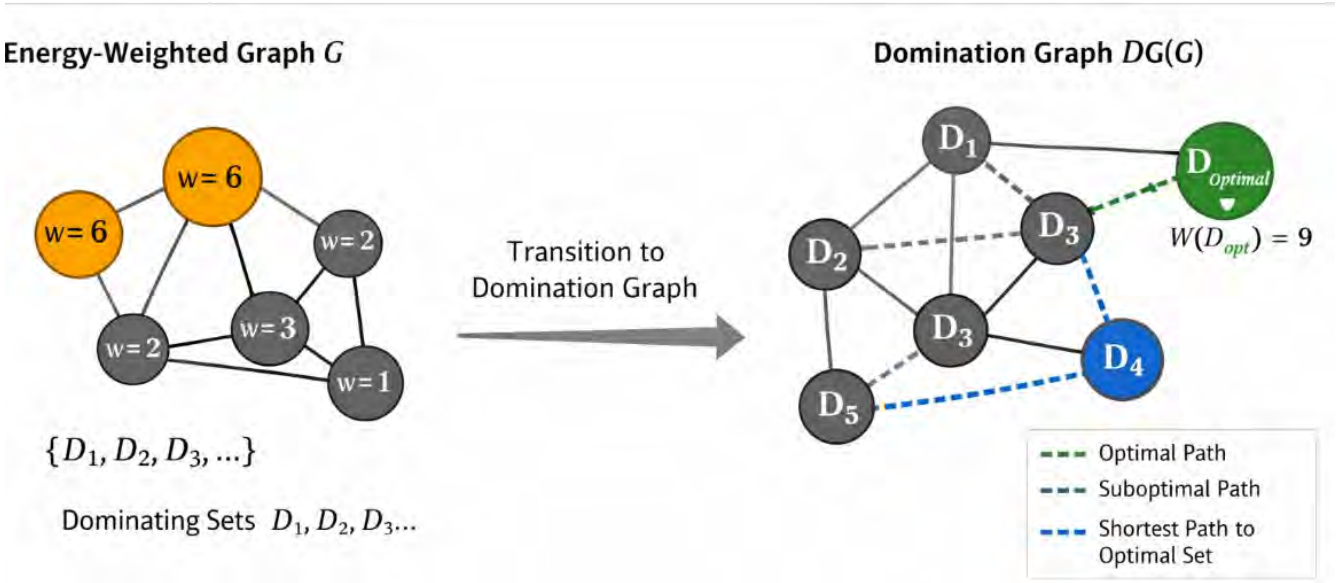
Remark 4: The diameter of $DG(G)$indicates how few local changes are required to change one dominant set into another. Domination graphs are motivated by these facts as a natural combinatorial object that encodes the space of dominant configurations of G.

2 Methodology

In this section we formalize the backbone–optimization problem in the language of domination graphs and develop the theoretical framework used in the sequel. Our approach is based on the observation that dominating sets form a rich combinatorial space, and transitions within this space can be used to model reconfiguration and optimization processes.

2.1 Domination-transition system

Let $G = (V, E)$be a connected graph. Let $D(G)$denote the family of all dominating sets of G.We define a transition operator $T : D(G) \longrightarrow 2^V$ such that for $D \in D(G)$, the set $T(D) \subseteq D(G)$ consists of all dominating sets obtainable from D through a finite sequence of admissible local modifications.



Definition 2.1

A modification of a dominating set $D$is called admissible if it satisfies: the resulting set $D'$is a dominating set, and $|D' \Delta D| \leq 1$ (single-vertex symmetric difference), or more generally $|D' \Delta D| \leq k$ for a fixed integer $k \geq 1$. Unless we consider the case $k = 1$. Thus, transitions correspond to adding or deleting a single vertex while preserving domination.

2.2 Energy-weighted domination

Let $w : V \to R^+$be a weight function, where $w(v)$represents cost, load, or energy consumption associated with assigning vertex v to a dominating set.

For a dominating set D, define the energy weight $W(D) = \sum_{v \in D} w(v)$

The energy-aware domination problem is to find a dominating set minimizing $W(D)$. Note that this coincides with minimum dominating set when all weights are equal.

Definition 2.2

The weighted domination graph is the pair $(DG_w(G), W)$, where vertices are dominating sets and the weight function Winduces an ordering or optimization criterion on the vertices of $DG(G)$.

2.3 Domination graph pathways for optimality

If $W(D^{\setminus *}) \leq W(D)$for every $D \in T(D^{\setminus *})$, then a dominating set $D^{\setminus *}$ is considered locally energy-optimal. In other words, no nearby dominant set has a strictly lesser weight that can be reached by a single permissible alteration. If $W(D^{\min}) = \min \{W(D) : D \in D(G)\}$, then a dominating set $D^{\min}$ is globally energy-optimal.

2.4 Connectivity of domination graphs

The structural characteristics of $DG(G)$ determine whether reconfiguration is possible.

Theorem 2.4.1

Let G be a graph that is linked. Then, a finite series of permissible deletions can convert any dominating set of G into a minimal dominating set. As a result, each vertex in $DG(G)$ is linked to a minimal dominating set.

Proof

As long as domination is maintained, repeatedly remove vertices from a dominating set; as the graph is finite, this procedure ends in a minimal dominating set. There is a path in $DG(G)$ since each deletion corresponds to an acceptable alteration.

Corollary 4.4

The minimal dominating sets induce a nonempty subgraph of $DG(G)$.

Remark 2.4.5

All minimum dominating sets do not have to be located in the same connected component of $DG(G)$. As a result, it could be necessary to go via non-minimum dominating sets in order to reach a minimum dominating set from another.

2.4.1. Domination sequences

A finite sequence is called a domination sequence $D_0, D_1, \ldots, D_t$ of dominating sets such that $D_{i+1} \in T(D_i)$for $0 \leq i < t$.The minimum length that can be used to connect two dominating sets D and D' is their domination distance in $DG(G)$ & the length of such a sequence equals t.

2.4.2. The main structure for strategy

The following mathematical elements make up the suggested methodology: description of the vertices of the domination graph as potential backbone configurations; definition of permissible changes for transitions; analysis of the shortest or monotone paths in DG(G) lowering W; introduction of an energy weight W to represent optimization requirements; and interpretation of these paths as energy-aware reconfiguration procedures. We use this framework to build energy-efficient backbones and examine their structural characteristics in the section that follows.

1. **Characterization of vertices**

   Every vertex in the domination graph $DG(G)$ corresponds to a dominating set $DV(G)$. Consequently, $V(DG(G)) = D(G)$ and a viable backbone is represented by each vertex. Because of this identification, structural inquiries into network backbones can be converted into purely graph-theoretic inquiries concerning the geometry of $DG(G)$.

2. **Admissible transitions**

   Allowable reconfigurations are encoded as edges in $DG(G)$. If two dominating sets D_1, D_2 vary by an allowable local modification, usually $|D_1 \triangle D_2| = 1$, or more generally, by a bounded symmetric difference, then they are adjacent. This idea produces a distinct metric on configuration space and limits the cost of reconfiguration.

3. **Energy weight functional**

   In order to incorporate optimization criteria, we give each dominating set D an energy weight $W(D) = \sum_{v \in D} f(E(v))$, where f is a suitable non-negative function and $E(v)$ represents residual energy. The performance goal (lifetime maximization, balance, or robustness) is encoded by the selection of f.

4. **Monotone or shortest paths in**$DG(G)$

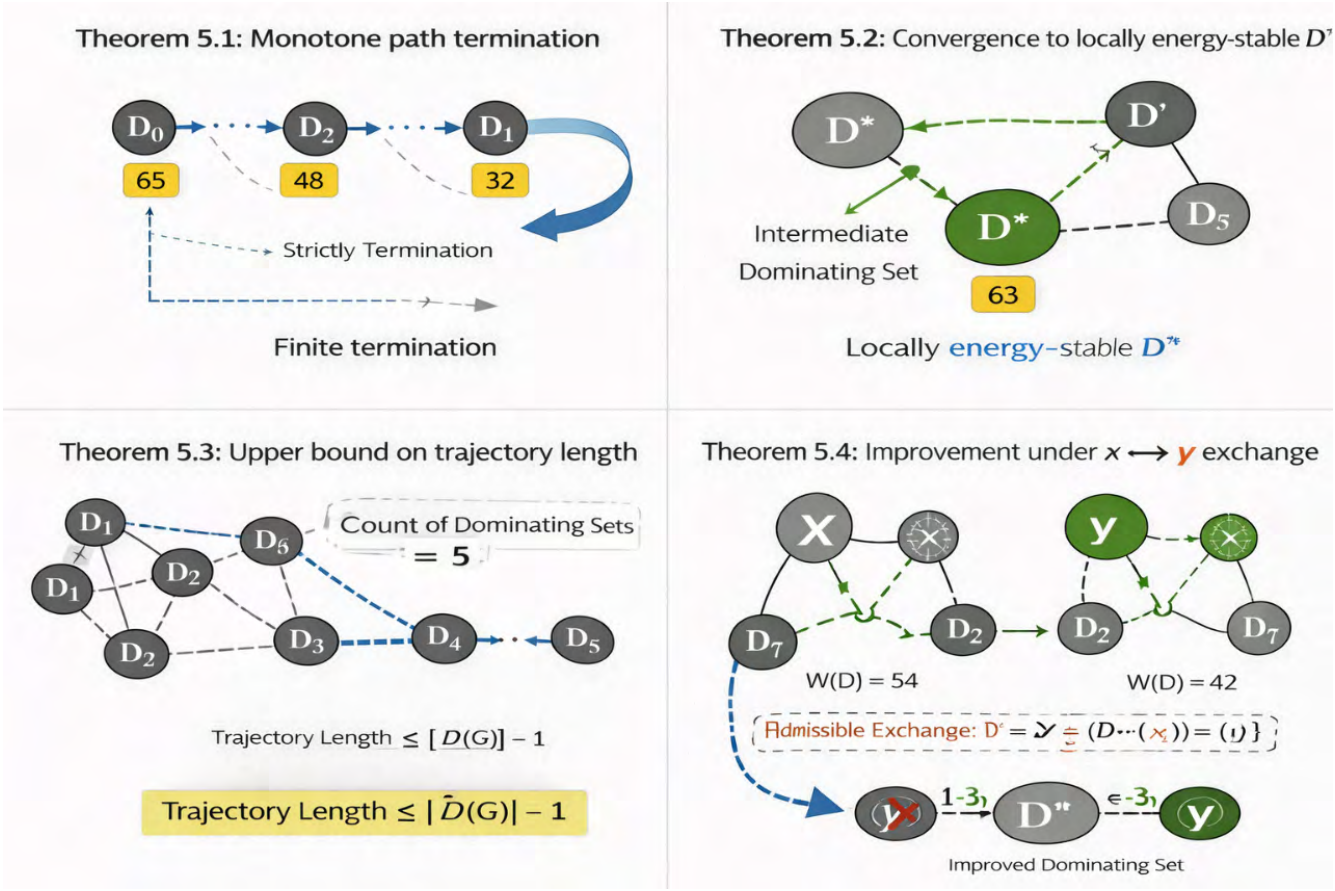
   We examine paths $D_0, D_1, \ldots, D_t$ in $DG(G)$ satisfying either $W(D_{k+1}) < W(D_k)$ (strictly monotone decrease), or the graph-metric's minimum overall length. These routes show near-optimal or ideal advancement toward desired configurations.

5. **Interpretation as energy-aware reconfiguration**

   These pathways allow for a physical interpretation: they avoid global recomputation by corresponding to a slow, local reconfiguration of backbone nodes. In order to balance load and increase longevity, each phase substitutes higher-energy candidates for low-energy dominators.

2.5 Main Theorems and Results

Several structural characteristics of energy-aware walks on the domination graph are derived in this section. A finite simple connected graph is denoted by G throughout, and its domination graph is denoted by $DG(G)$. Let $W(D)$ be the previously presented energy weight functional for a dominating set D.



Theorem 2.5.1

Let $(D_0, D_1, \ldots)$be a sequence of dominating sets such that $W(D_{k+1}) < W(D_k)$ for all $k \geq 0$.

The sequence is then finite. Conversely, all strictly W-monotone walks in $DG(G)$ end in a finite number of steps.

Proof: The family of dominating sets $D(G)$ is finite since $V(G)$ is finite. The mapping $W : D(G) \longrightarrow R_{\geq 0}$ has a limited image as a result. In a finite collection, any strictly decreasing sequence of real numbers must come to an end. Consequently, the strictly decreasing chain $W(D_0) > W(D_1) > \cdots$ is finite, suggesting that the comparable walk in $DG(G)$ comes to an end.

Theorem 2.5.2

Every maximum W -monotone walk in $DG(G)$ terminates at a dominating set $D^{\backslash *}$ with the characteristic that $W(D') \geq W(D^{\backslash *})$. for each acceptable nearby dominating set D' The term "locally energy-stable" refers to such a dominant set $D^{\backslash *}$.

Proof: Theorem 2.5.1 states that a strictly monotone walk ends at a certain $D^{\backslash *}$The walk may be extended, defying maximality, if there was an admissible neighbour D' of $D^{\backslash *}$ with $W(D') < W(D^{\backslash *})$, Thus, local optimality is established because there is no such neighbour.

Theorem 2.5.3

Any admissible energy-aware trajectory satisfies length $\leq |D(G)| - 1$. Let $n = |V(G)|$. Specifically, length $\leq 2^n - 1$.

Proof: Because W strictly declines, each step in the trajectory visits a unique dominant set. As a result, the total number of dominating sets equals the upper bound on its length. We obtain the specified crude constraint since the power set of size 2^n contains every subset of $V(G)$.

Theorem 2.5.4

Assume that $E(y) > E(x)$ and that a transition $D \to D'$ is accomplished by switching one vertex $x \in D$ with $y \notin D$, i.e., $D' = (D \setminus \{x\}) \cup \{y\}$. Whenever the functional penalizes low-energy vertices, $W(D') < W(D)$ if W is strictly increases in each argument.

Proof: Write $W(D) = f(E(x)) + \sum_{v \in D \setminus \{x\}} f(E(v)), W(D') = f(E(y)) + \sum_{v \in D \setminus \{x\}} (E(v))$. Given that $E(y) > E(x)$ and f is strictly decreases in energy exhaustion (or correspondingly increases in cost), it follows that $f(E(y)) < f(E(x))$, and therefore $W(D') < W(D)$.

Corollary 2.5.5

The previously mentioned exchange rule implies that the minimal residual energy among dominators is non-decreasing along the trajectory since repeated acceptable transitions substitute higher-energy candidates for low-energy dominators.

Theorem 2.5.6

Let H be the subgraph of $DG(G)$ created by every dominating set whose weight satisfies $W(D) \leq W(D_0)$ for a given initial dominating set D_0. Every two dominant sets in the same connected component of H are are mutually reachable via a finite energy-nonincreasing trajectory if permissible transitions are characterized by single-vertex exchanges.

Proof: Edges of H correspond to allowable changes that maintain dominance without raising W. Any two vertices in the same component are connected by a path per the notion of graph connectivity. Following this route results in a finite trajectory where each step complies with the energy limitation and admissibility. Reconfiguration is therefore feasible without raising expenses.

Theorem 2.5.7

Let $W : D(G) \rightarrow R$be bounded below. Then there exists a dominating set $D^{\star}$such that $W(D^{\star}) = \min \{W(D) : D \in D(G)\}$.

Proof:$D(G)$ is a finite set. On a finite nonempty set, a real-valued function always reaches its minimum. Consequently, there is a dominating configuration that is globally energy-optimal.

Theorem 2.5.8

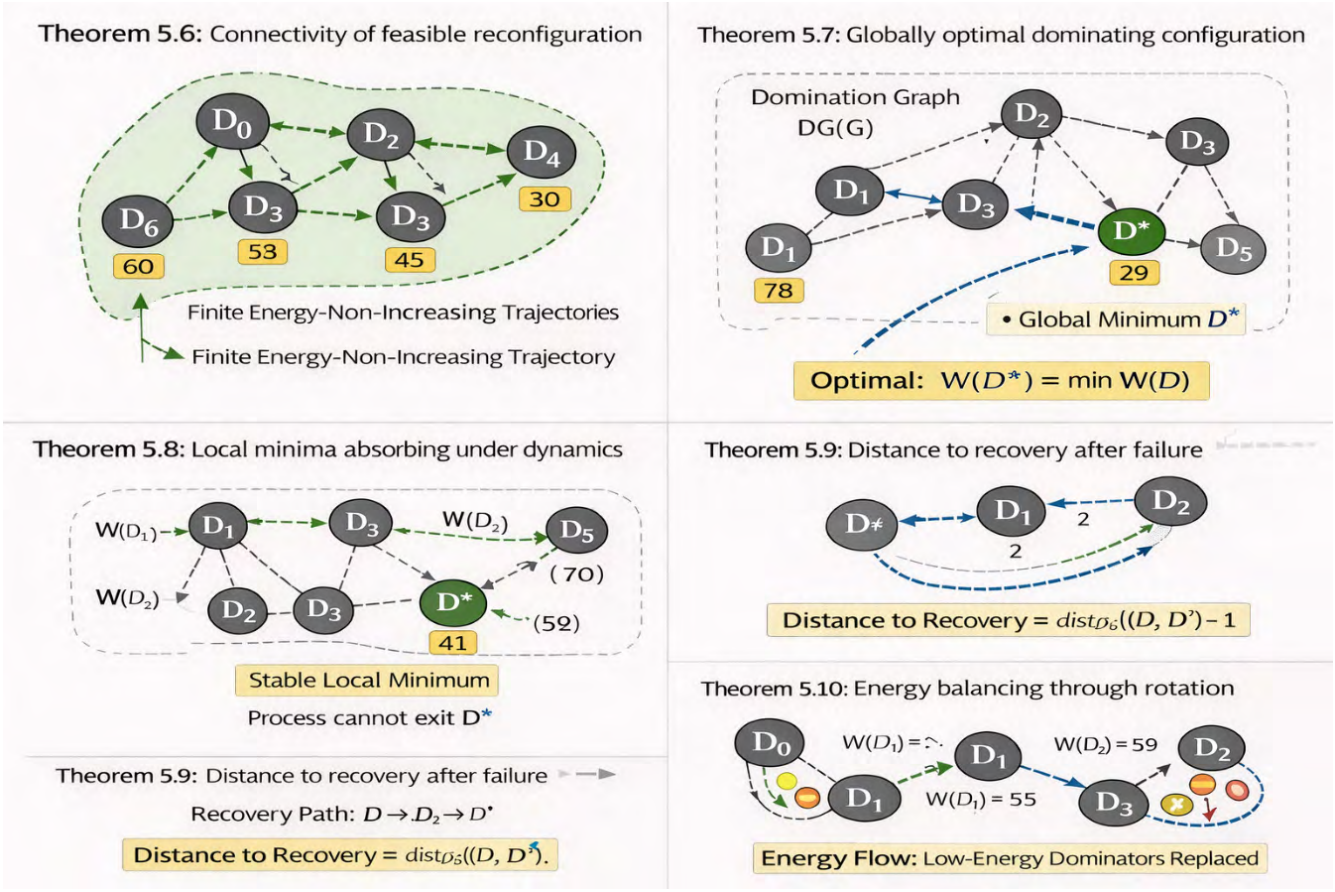
Whenever feasible, let the reconfiguration process adhere to permissible transitions that rigorously reduce W. D is absorbing if it is a locally energy-stable dominating set (no neighbor of smaller weight), meaning that once it is reached, the process cannot leave it.

Proof: No acceptable transition is conceivable out of D since every admissible step requires $W(D') < W(D)$, and no such neighbor exists. As a result, the procedure comes to an end at D.

Theorem 2.5.9

Let $x \in D$ be a dominator of D, and let D be a dominating set. To restore domination, let D' be the closest dominating set in $DG(G)$.Then, the bare minimum of reconfiguration steps needed is precisely dis $t_{DG(G)}(D, D')$.

Proof: The distance between vertices is equal to the length of the shortest path between them, according to the definition of graph metric. One permissible alteration is associated with each stage in $DG(G)$. Therefore, the domination-graph distance is exactly the minimum number of changes needed to go from D to a valid replacement configuration.



Theorem 2.5.10

Assume that whenever possible, the admissible dynamics will swap out a dominator with the lowest residual energy in D_t for a vertex with a higher residual energy. Then, among dominators, the smallest residual energy is a nondecreasing function of t:

$$\min_{v \in D_{t+1}} E(v) \geq \min_{v \in D_t} E(v).$$

Proof: The least energy vertex in D_t is either preserved, in which case the minimum remains constant, or replaced by a higher-energy vertex, increasing the minimum. The minimum does not drop in any scenario. As a result, the minimum sequence is monotone nondecreasing.

2.6 Illustrative Examples

To illustrate the suggested domination-graph framework, we provide brief illustrative examples in this section. The goal is conceptual explanation of the underlying mechanisms—domination graphs, monotone energy-aware pathways, and recovery after failure—rather than numerical evaluation.

2.6.1. Example: Path graph

Let $G = P_5$ be the path graph on five vertices $v_1 - v_2 - v_3 - v_4 - v_5$. The dominating sets of G include, among others, $D_1 = \{v_2, v_4\}, D_2 = \{v_3\}, D_3 = \{v_1, v_3, v_5\}$.The domination graph $DG(G)$ has a vertex for each dominating set. Dominating sets that differ by a single vertex exchange are connected by edges in $DG(G)$.Determine the weight and assign residual energy $E(v_i)$. $W(D) = \sum_{v \in D} f(E(v))$. A monotone W-path $D_3 \to D_1 \to D_2$ illustrates a series of backbone reconfigurations where higher-energy alternatives take the place of redundant or low-energy dominators. The last dominating set, D_2, represents a low-cost, stable backbone.

2.6.2. *Example: Cycle graph*

Examine the cycle graph $G = C_6$. Two and three-sized dominating sets coexist. There are several cycles in the domination graph, which represent different backbone arrangements. Backbone roles rotate without losing domination, as shown by a strictly W-monotone path in $DG(G)$. This illustration shows that there are several structurally equivalent dominating sets and that systematic traversal between them is made possible by a dominant graph.

2.6.3. *Recovery after backbone failure*

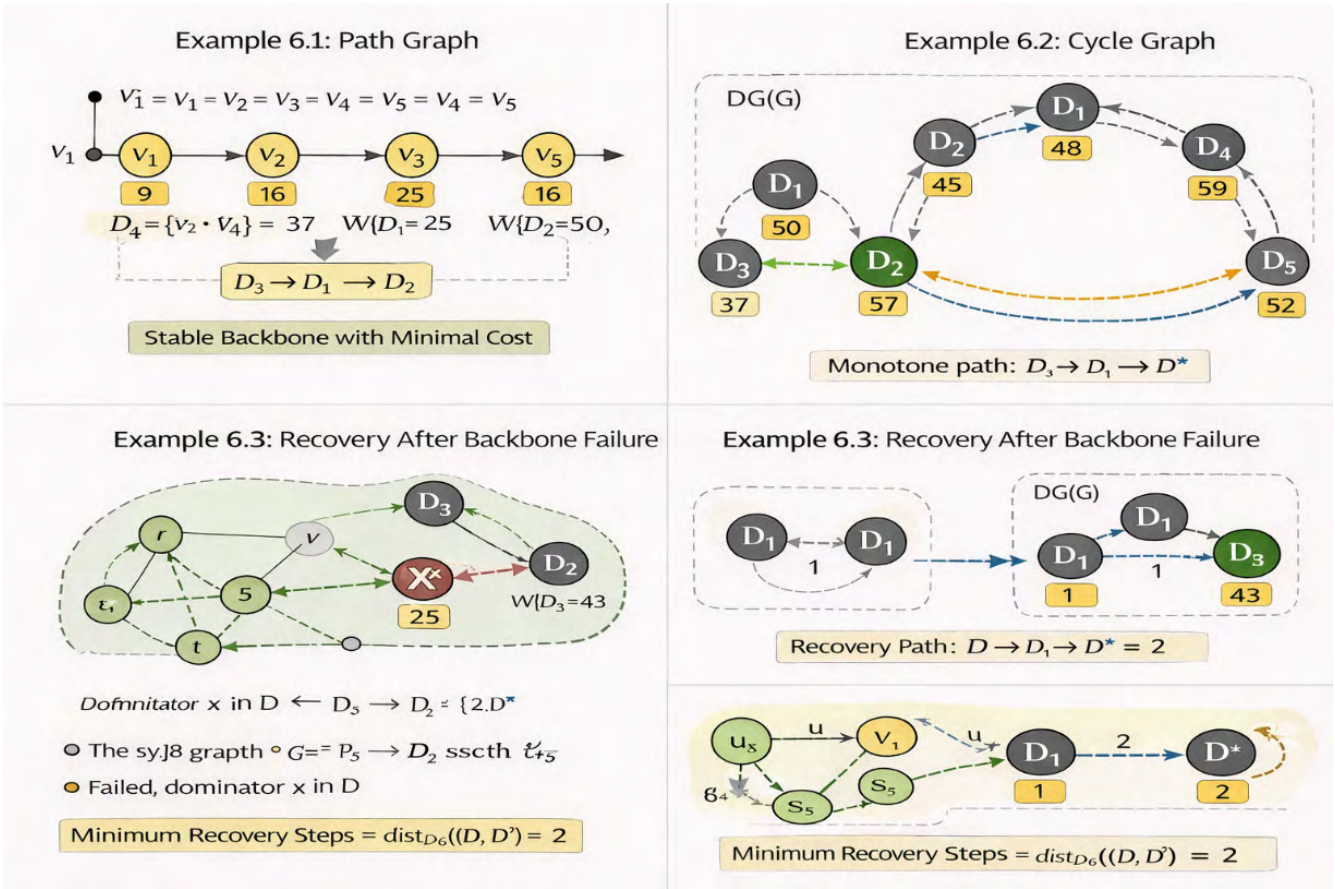
Assume that a dominator $x \in D$ fails. Let D be a dominating set. G may no longer be dominated by the resulting set $D \setminus \{x\}$. To recover, go to the closest dominating set D' in $DG(G)$. According to Theorem 5.9, the bare minimum of reconfiguration steps needed is precisely $\text{dist}_{DG(G)}(D, D')$. Therefore, in domination-graph space, recovery cost is naturally stated as a graph distance. This offers a structural and quantitative indicator of fault tolerance.

2.7 Modelling assumptions

The following presumptions form the basis of the framework:

1. One way to conceptualize the network is as a basic undirected graph.
2. Backbone coverage is accurately represented by dominant sets.
3. Dominators have greater energy costs than non-dominators.
4. Domination is maintained through local changes.

To preserve analytical clarity, these presumptions—which are common in theoretical WSN modelling—are expressed clearly.



3 Results and Discussion

The proposed domination graph framework is compared with traditional linked dominating set (CDS) and domination-based backbone optimization methods. In the event of node loss or energy depletion, current methods usually require recalculation and offer a single backbone configuration. Although learning-based and energy-aware methods improve node selection, they don't show the space of possible backbone topologies.

In contrast, the proposed method models all viable dominating sets as vertices of a higher-order graph, allowing for structured transitions between backbone configurations. The framework provides measurable structural guarantees: energy-monotone reconfiguration sequences terminate in finite steps, recovery cost is quantified by domination-graph distance, and all dominating sets can achieve a minimal configuration through allowable modifications. Additionally, energy-aware transitions that promote progressive load balancing guarantee nondecreasing minimal residual energy among dominators.

By transforming backbone management into a structured configuration-space traversal problem, the proposed approach provides a unified basis for defined recovery complexity, systematic backbone rotation, and observable stability. It has an advantage over traditional single-configuration models because of this.

Existing CDS-based and energy-aware techniques are contrasted with the suggested domination graph framework[1],[2],[3],[4],[5],[6],[8],[9],[10],[11]. While recent learning-based models primarily concentrate on node-level optimization without capturing the entire configuration space, traditional systems usually rely on a single backbone and require global recomputation during node failure.

The suggested approach, on the other hand, allows for adaptive and targeted backbone reconfiguration by modelling all dominating sets as vertices of a dominance graph. Finite convergence of energy-monotone transitions and a bounded recovery cost determined by domination-graph distance are among the verifiable guarantees offered by the framework. Furthermore, compared to heuristic methods, better load balancing is ensured by the non-decreasing minimum residual energy among dominators.

The key novelty lies in representing backbone optimization as a configuration-space traversal problem, allowing structured and fault-tolerant reconfiguration.

However, the results are theoretical and lack simulation validation. Future work will focus on empirical evaluation and scalability analysis.

4 Conclusion

This study proposed a domination graph-based backbone optimization paradigm for wireless sensor networks. By representing each dominating set as a vertex and acceptable local alterations as transitions, backbone management is framed as a structured graph traversal problem rather than a single-configuration optimization task.

The framework offers quantifiable structural guarantees. Every dominating set can be reduced to a minimal dominating set through a finite sequence of acceptable steps, and strictly energy-monotone transitions terminate in a finite amount of time. Domination-graph distance is used to measure the cost of fault recovery and offers a formal metric for reconfiguration complexity. Furthermore, by ensuring a nondecreasing minimum residual energy among dominators, energy-conscious transitions support progressive load balancing.

This work's primary innovation is that it explicitly models the entire configuration space of dominating sets and permits controlled, energy-aware backbone transitions with observable stability features. Unlike conventional CDS-based methods, the proposed approach provides a cohesive structure for backbone construction, rotation, and recovery.

A domination graph-based framework for backbone optimization in wireless sensor networks was introduced in this paper. Local transitions allow for structured reconfiguration, and dominating sets are represented as vertices. The suggested method provides energy-aware backbone evolution and captures the whole configuration space, in contrast to conventional CDS-based techniques.

Finite-step convergence to minimal dominating sets, termination of energy-monotone transitions, and a measured bound on recovery cost using domination-graph distance are among the quantifiable assurances offered by the framework. Furthermore, the approach promotes load balancing and network stability by guaranteeing a non-decreasing minimum residual energy among dominators.

The main innovation is the conversion of backbone design into a configuration-space traversal problem, which allows for structured, adaptive, and fault-tolerant optimization.

Nevertheless, there is no simulation validation and the work is theoretical. In order to measure performance gains, future research will concentrate on distributed implementation, scalability, and experimental evaluation.

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