A Novel Lucas-based Clustering Optimization for Enhancing Survivability in Smart Home Design

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ABSTRACT

This study presents a novel Lucas-based topology optimization framework to enhance network survivability in smart homes, particularly against random node failures. As the proliferation of interconnected devices in the Internet of Things (IoT) environments increases, so does the vulnerability of these networks to node failures, which can significantly disrupt connectivity and functionality. By integrating the mathematical properties of Lucas numbers with advanced graph theory concepts, specifically the Trimet Graph Optimization (TGO) model, this framework systematically addresses the challenges posed by random node failures. The proposed model optimizes network topologies to ensure robust connectivity and resilience, allowing smart home networks to maintain operational integrity even under adverse conditions. Simulations and theoretical analyses demonstrate the effectiveness of this approach, highlighting its potential to improve the reliability of smart home networks.

Keywords-topology optimization; survivability; random node failures; Lucas model; TGO model

I. INTRODUCTION

Graph theory has attracted interest because of the rapid growth of interconnected devices in IoT environments and the increase in node failures that affect the entire network. Graph theory can help overcome this problem by enhancing the survivability of random node failures, representing devices and connections as vertices and edges. Combining the Lucas topology optimization model and Trimet Graph Optimization (TGO) can help resolve these challenges [1]. The Lucas model complements graph theory by addressing the impact of random node failures. By considering failure probabilities and their consequences, researchers can devise strategies to enhance resilience. Integrating the Lucas model with graph theory-based approaches, such as TGO, enables the design of robust, scalable, and resource-efficient network topologies [2]. TGO is a method for designing resilient IoT network topologies. The network topology defines how interconnected devices communicate within a system. In today's dynamic world, ensuring network survivability is crucial, referring to the ability to maintain functionality and connectivity despite disruptive events such as hardware failures or cyberattacks. Integrating survivability strategies into network topology design is essential for reliability and resilience. This involves analyzing network layouts, identifying potential points of failure, and implementing redundancy mechanisms.

Different network topologies offer varying levels of survivability [3-4]. Advances such as Software-Defined Networking (SDN) and network function virtualization enhance survivability by allowing dynamic resource reconfiguration and rapid response to failures [5]. Network models are fundamental to modern communication systems that determine connectivity and resilience among interconnected devices. In today's dynamic digital landscape, addressing the impact of random node failures is crucial [6]. These failures, caused by hardware malfunctions, cyberattacks, or environmental factors, pose significant challenges to network reliability and performance. Considering random node failures in networks is vital to designing robust architectures capable of sustaining functionality under adverse conditions. This can be achieved by integrating probabilistic analyses and fault-tolerant mechanisms into network topology design. Various network models, including traditional topologies such as star, mesh, and ring, as well as emerging paradigms such as SDN and edge computing, offer diverse strategies to address random node failures [7]. These models leverage redundancy, load balancing, and dynamic routing algorithms to enhance resilience and minimize downtime when nodes fail.

Advances in machine learning and artificial intelligence enable predictive analytics and proactive maintenance strategies, allowing network operators to anticipate and address potential failure points before disrupting operations [8]. By harnessing these technologies, network models can dynamically adapt to changing conditions and optimize resource allocation to mitigate the impact of random node failures. This study investigates the intersection of network models with random node failures, exploring strategies to enhance resilience and ensure continuous operation despite unpredictable events. Through theoretical analyses and simulation studies, it aims to provide insights into effective approaches to designing and managing robust network architectures capable of withstanding the challenges posed by random node failures in today's interconnected world [9]. In Figure 1, IoT communication technologies are categorized into technology, topology, and devices [10].

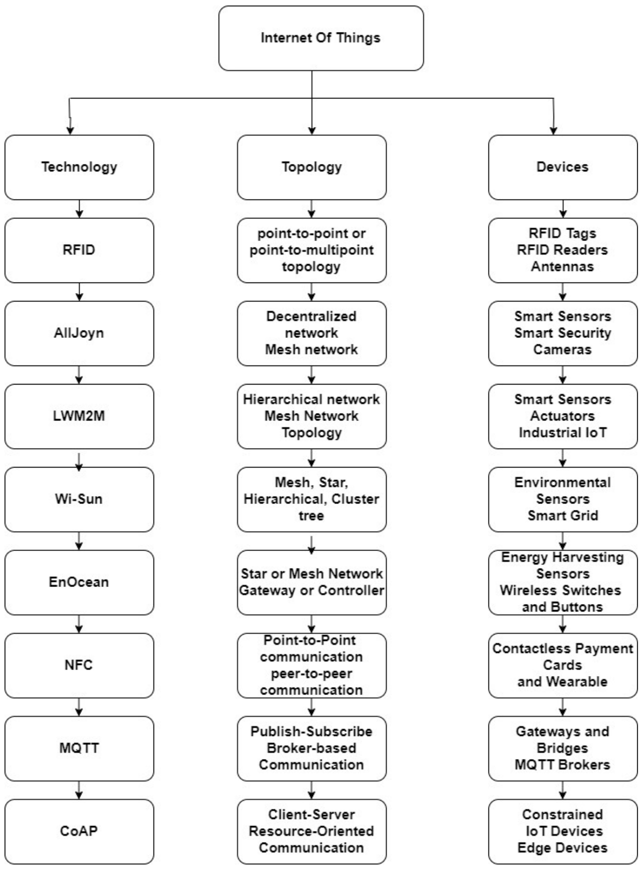

Fig. 1. IoT communication technologies.

II. LITERATURE SURVEY

The intriguing connection between Lucas numbers, a sequence with deep mathematical roots, and TGO has sparked growing interest in recent years. TGO offers a powerful method for deciphering and manipulating complex networks, while Lucas numbers exhibit fascinating properties with potential applications in network analysis [11-12]. Existing research highlights promising avenues for leveraging Lucas numbers as a novel source of invariants in TGO tasks, such as network embedding, symmetry detection, and graph matching. Initial investigations focused on specific applications, such as utilizing Lucas numbers to determine the chromatic number of certain trimetric graph classes. Other studies investigated the generation of new TGO invariants through spectral features derived from Lucas numbers. Perhaps the most challenging but potentially impactful direction involves examining the notoriously difficult task of distinguishing between isomorphic trimetric graphs using Lucas numbers. By critically evaluating these efforts and identifying open questions, the existing literature lays a strong foundation for further exploration. This growing field aims to unlock the untapped potential of Lucas numbers in TGO, paving the way for innovative network analysis and optimization methods to reveal the hidden relationships within complex systems. TGO has been used to reveal latent relationships in graph-structured data [13-15], uncovering hidden relationships within networks by optimizing a trimetric objective function defined at the graph's edges. Although not directly related to Lucas numbers, this concept suggests possibilities for utilizing Lucas sequences or related number-theoretic concepts within its framework. In the context of network topology optimization, the main objective is to restructure the network to meet specific performance criteria, particularly focusing on node survivability [16].

The proposed Lucas-based topology optimization model focuses on enhancing edge survivability in networks by utilizing the mathematical properties of Lucas numbers. These numbers, which share similarities with Fibonacci numbers but begin with 2 and 1, serve as a foundation for developing algorithms that tackle complex optimization challenges, particularly in network design. The primary goal of this model is to restructure network topologies to improve edge survivability, ensuring that the connections between nodes remain intact even when some nodes fail randomly [17]. Edge survivability is defined as the network's ability to maintain connectivity despite the failure of specific nodes, which is crucial for applications where uninterrupted service is essential. The model incorporates strategic design principles that aim to minimize the negative impacts of random node failures on network edges [18]. By considering the unpredictable nature of these failures, the approach enhances the overall robustness of the network, allowing it to withstand disruptions while preserving essential connections. Key components of this model include an optimization algorithm that systematically adjusts the network's topology using Lucas numbers to bolster edge survivability. This method not only improves computational efficiency but also allows for scalability, making it applicable to larger networks. Practical applications of this model extend to various fields, including communication networks, power grids, and transportation systems, where maintaining operational integrity during node failures is critical. In general, the Lucas-based topology optimization model represents a significant advance in designing resilient network structures that can withstand random disruptions [19].

Research on TGO topology has explored various aspects of network design and analysis. Several studies have evaluated the performance of the TGO topology in different scenarios, showing that it performs better than the star topology [20].

III. PROPOSED LUCAS-BASED CLUSTERING OPTIMIZATION

Lucas-based tiling and the Lucas spiral have gained significant attention in recent years for their unique properties and applications. Lucas-based tiling involves arranging shapes or tiles according to the Lucas sequence, which is closely related to the Fibonacci sequence. This method creates visually appealing patterns and structures with mathematical precision [21]. The Lucas spiral, akin to the Fibonacci spiral, is formed by connecting arcs based on the Lucas sequence. Starting from the center, each arc's radius is determined by the subsequent number in the Lucas sequence. This results in a spiral characterized by self-similarity and logarithmic growth. Both Lucas-based tiling and the Lucas spiral find diverse applications in art, design, architecture, and mathematics. They offer captivating visual aesthetics and can be used to optimize layouts and arrangements in various contexts. They serve as educational tools for exploring mathematical concepts such as sequences, symmetry, and geometry. The exploration and utilization of Lucas-based tiling and the Lucas Spiral provide valuable insights into mathematical principles while offering creative avenues for design and expression. In the context of graph theory, devices in an IoT network are represented as vertices, while connections between them are depicted as edges. The integration of Lucas numbers into graph theory facilitates a probabilistic approach to analyzing node failures [22]. Incorporating failure probabilities associated with each vertex can help in using Lucas numbers to model potential connectivity scenarios and optimize network resilience. For instance, when applying the TGO model, Lucas numbers assist in determining optimal clustering strategies that enhance survivability. By analyzing relationships between nodes using adjacency matrices, critical points of failure can be identified, and redundancy mechanisms can be implemented based on the properties of Lucas numbers. This integration leads to robust and scalable network topologies that can dynamically adapt to changing conditions and maintain functionality despite disruptions. Furthermore, future research directions can be explored, such as improving optimization algorithms for efficiency in diverse IoT environments, integrating machine learning for predictive maintenance, and examining the application of the Lucas model in various network topologies. Addressing practical deployment challenges emphasizes the ongoing relevance of this study in enhancing network resilience in an interconnected world.

TABLE I. NOTATIONS OF PROPOSED ALGORITHM

Symbol	Description
s1	List storing results for cluster tree topology.
T	List storing results for equal Cqustering of TGO topology.
Ft	List storing results for Lucas TGO unequal clustering.
Sm	List storing results for mesh clustering topology.
N	Number of nodes in the network.
Lx	List storing the maximum rounds for each iteration.
TOT	Topology of the network.
G3	Network graph.

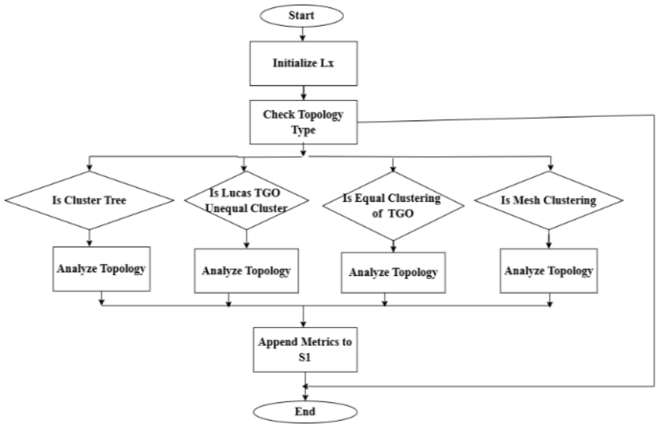

Fig. 2. Flowchart representation of Lucas-based clustering model.

```
Algorithm1: Lucas-based Clustering
            Optimization
Input: Nodes in the network.
Output: Visualization of survivability
1:  Start
2:  //Initialize Data Structures
    Initialize s1, t, ft, and sm as empty
    lists.
3:  // Define Topology Analysis Functions
    GenerateAndAnalyzeTopology(
    topologyType, G3):
      Generate TOT based on topologyType
      Analyze TOT metrics
      Return analyzed metrics
4:  //Iterate Over Different Numbers of
    //Nodes
    For each n in nodes:
      Initialize an empty list lx
      For i from 1 to 20:
      // Repeat for statistical
      // reliability
5:      If topologyType == "Cluster
        Tree":
          vx =
          GenerateAndAnalyzeTopology(
          "StarOfStars", G3)
          Append maximum rounds to lx
          Append analyzed metrics to s1
        End_if
6:      If topologyType == "Lucas TGO
        Unequal Clustering":
          vx =
          GenerateAndAnalyzeTopology(
          "TrimetOfTrimet", G3)
          Append maximum rounds to lx
          Append analyzed metrics to ft
        End_if.
7:      If topologyType == "Equal
          Clustering of TGO":
          vx = GenerateAndAnalyzeTopology(
          "TrimetOfTrimet", G3)
```

```
          Append maximum rounds to lx
          Append analyzed metrics to t
        End_if
8:      If topologyType == "Mesh
        Clustering":
          vx = GenerateAndAnalyzeTopology(
          "TrimetOfStars", G3)
          Append maximum rounds to lx
          Append analyzed metrics to sm
        End_if
      End_for
    End_for
9:  Visualization
    Plot the results against the number of
    nodes for each topology
    Label the x-axis as "Nodes" and y-axis
    as "Rounds"
    Title the plot as "Survivability"
    Add a legend for clarity
10: Stop
```

IV. IMPLEMENTATION OF LUCAS-BASED CLUSTERING OPTIMIZATION

The proposed algorithm outlines a systematic approach to visualize the survivability of different network topologies in the context of random node failures. The process begins by initializing the essential data structures that will store results for various topologies, including the cluster tree, Lucas TGO unequal clustering, equal clustering of TGO, and mesh clustering. This initialization is crucial to organize the data collected during the analysis phase. This step is vital, as it allows a comprehensive examination of how each topology behaves under node failure conditions. The algorithm then iterates over a range of node counts, performing multiple trials for each topology to ensure statistical reliability. This repetition enhances the robustness of the results, allowing for a more accurate assessment of each topology's survivability. Figure 2 shows the proposed Lucas-based clustering model. The proposed Lucas-based clustering model leverages the unique properties of Lucas numbers to create a graph structure that enhances survivability through a strategic blend of low, medium, and high-density clusters. By dividing a set of 100 nodes into clusters based on this sequence, the model not only optimizes communication and resource allocation but also ensures robustness against node failures and dynamic changes in network topology. This innovative approach has significant implications for various applications in network design, data management, and distributed systems.

Subsequent steps involve generating and analyzing each topology in detail. For each topology, the algorithm computes the network topology using designated methods such as StarOfStars for Cluster Tree and TrimetOfTrimet for the TGO-based structures. The performance metrics are analyzed, and results are stored for further evaluation.

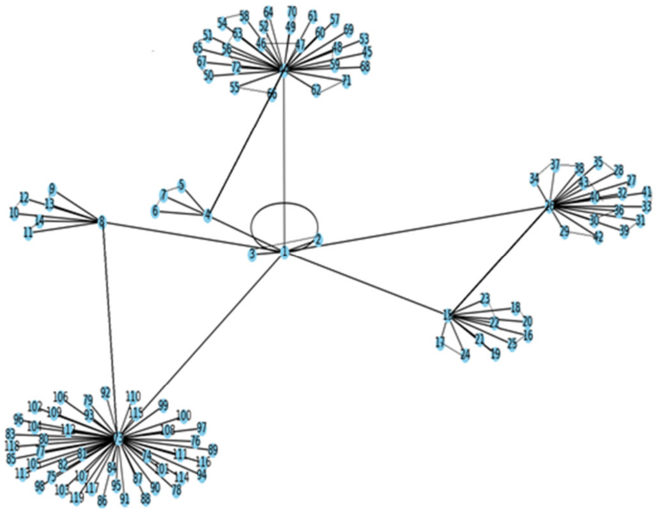

Fig. 3. Representation of Lucas-based clustering model.

Fig. 4. Cluster tree.

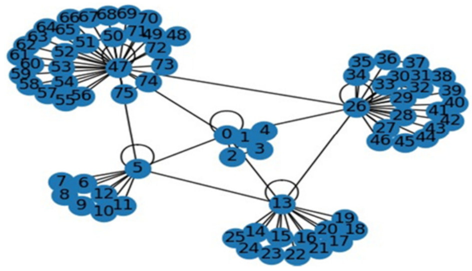

Fig. 5. Mesh network.

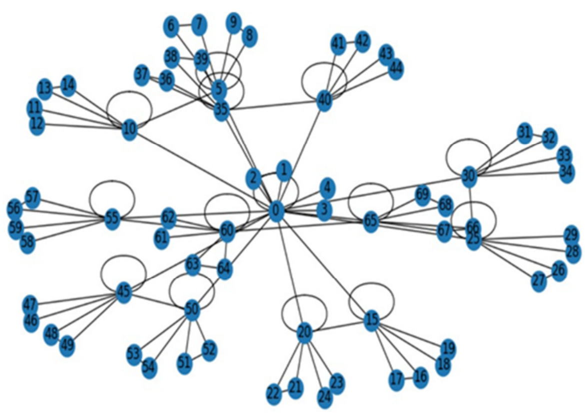

Fig. 6. TGO mesh network.

After completing the analysis for all topologies, the algorithm visualizes the data by plotting the survivability results against the number of nodes. Figures 3-6 show representations of different smart home models, including cluster tree, mesh, and TGO mesh networks. This study introduces a novel clustering approach based on Lucas numbers to optimize node distribution and enhance network survivability. By employing unequal cluster sizes derived from the Lucas sequence, the model offers an innovative strategy that improves robustness against node failures and disruptions, ensuring reliable network functionality. The arrangement of nodes into clusters facilitates more efficient communication pathways, which is crucial for applications requiring rapid data transmission. Furthermore, the varied cluster sizes promote effective load balancing and resource management, preventing bottlenecks and enhancing overall performance. Ultimately, this study lays the groundwork for future investigations of mathematical approaches in network design, demonstrating the practical applicability of Lucas numbers and paving the way for further exploration of other mathematical sequences in optimizing network structures.

V. RESULTS AND DISCUSSION

The implementation of the Lucas-based topology optimization framework to improve network survivability in smart homes was evaluated through a series of simulations to compare various topological configurations. This study focused on five distinct network structures: cluster tree, Lucas TGO unequal clustering, equal TFO clustering, and mesh clustering. Each topology was analyzed under conditions that simulated random node failures to assess its resilience and performance. The results showed that the Lucas TGO unequal clustering model exhibited superior edge survivability compared to traditional ZigBee models, particularly in scenarios involving dynamic random node failures. This topology effectively maintained connectivity by strategically redistributing network resources and optimizing paths based on the properties of Lucas numbers. Simulations demonstrated that the proposed approach significantly reduced the number of disrupted connections, thereby improving overall network reliability. Furthermore, the analysis revealed that the cluster tree topology provided a balanced performance in terms of survivability and resource allocation. However, the mesh clustering topology, although robust, showed a higher susceptibility to performance degradation under random failures due to its inherent design complexity.

The findings underscore the importance of selecting appropriate topological structures in smart home networks to ensure sustained operational integrity, especially in environments where node failures are unpredictable. This study contributes valuable insights into the application of advanced mathematical frameworks, such as the Lucas model, to optimize network designs for improved resilience against failures. The Lucas-based topology optimization model has significant practical applications across various sectors, highlighting its versatility and potential impact. In smart home networks, it can optimize device arrangements for enhanced connectivity and energy efficiency. In telecommunications, the model can improve network topologies to minimize latency and maximize bandwidth, resulting in better service quality. In transportation networks, it can optimize routes and connections to reduce congestion. In healthcare networks, it can enhance the layout of medical devices and information systems, improving patient care through better resource allocation. Lastly, in industrial IoT, the model supports the design of robust sensor networks for reliable data collection and transmission [22-25]. Overall, this innovative approach addresses specific challenges across diverse fields, contributing to smarter and more efficient systems.

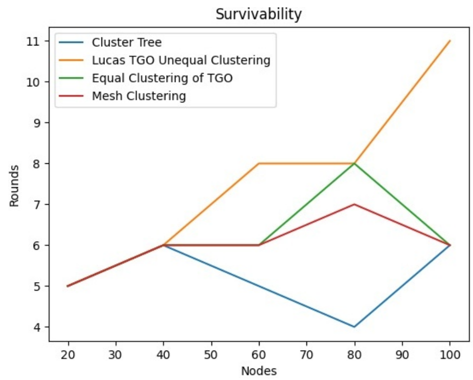

Fig. 7. Dynamic comparison-1 of different smart home topologies with Lucas-based clustering.

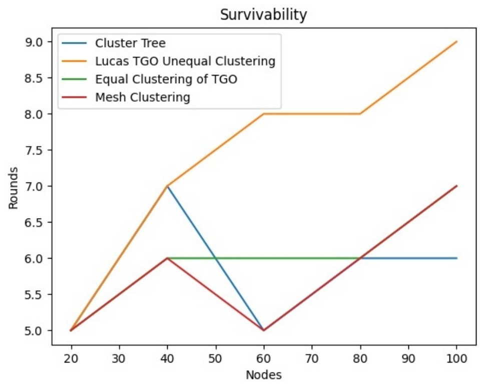

Fig. 8. Dynamic comparison-2 of different smart home topologies with Lucas-based clustering.

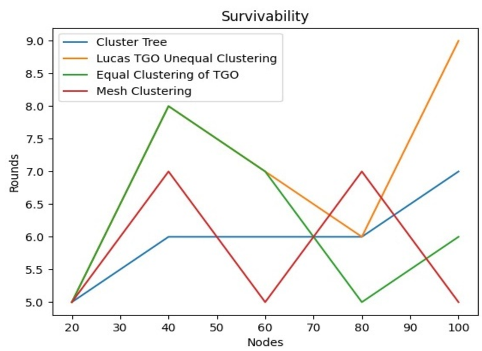

Fig. 9. Dynamic comparison-3 of different smart home topologies with Lucas-based clustering.

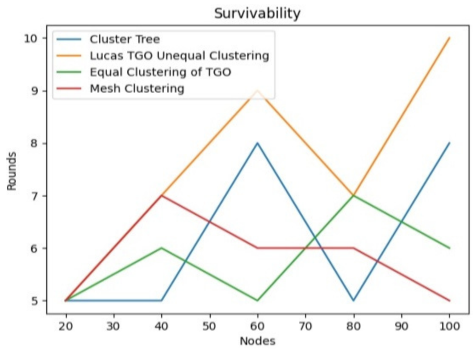

Fig. 10. Dynamic comparison-4 of different smart home topologies with Lucas-based clustering.

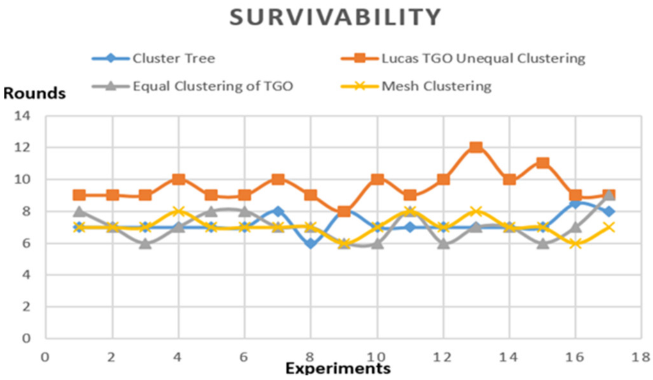

Fig. 11. Consolidated comparison of different smart home topologies with Lucas-based clustering.

Among the four clustering methods tested in 30 experiments, Lucas TGO unequal clustering consistently performed best, maintaining 9-12 rounds of survivability. The other three methods, cluster tree, equal TGO clustering, and mesh clustering, showed similar but lower performance, averaging 6-8 rounds. This suggests that Lucas TGO unequal clustering is the most effective method of survivability.

VI. CONCLUSION

The Lucas-based topology optimization framework significantly enhances the survivability of smart home networks amid random node failures by leveraging the unique properties of Lucas numbers along with the TGO model. This framework optimizes network topologies to maintain connectivity and operational resilience, emphasizing the integration of advanced mathematical models in network design, particularly for smart home environments where reliability is crucial. A dedicated simulator was developed to evaluate the models, iterating each configuration 20 times to assess the maximum rounds of sustainability at intervals of 20, 40, 60, 80, and 100. The results showed that as the number of nodes increased, the proposed Lucas-based clustering method demonstrated superior survivability due to its optimal mathematical model characterized by the sequences 3, 4, 7, 11, 18, and 29. In contrast to traditional approaches such as clustering trees and equal clustering methods within TGO, which often rely on established numerical techniques that may not effectively address random node failures, the proposed method directly confronts these challenges with a unique model that improves network resilience. Additionally, while mesh topologies aim to maximize connectivity through fixed structures, they can be vulnerable to single points of failure. The proposed dynamic clustering strategy based on Lucas numbers optimizes network layout and adapts to changing conditions in real-time. This differentiation underscores both the novelty and practical implications of the proposed approach for improving network reliability in smart home environments.

VII. FUTURE WORK

Future work for the Lucas-based topology optimization framework will focus on refining optimization algorithms with machine learning for real-time adaptability, expanding its application to various IoT environments, and developing advanced simulation tools to model network behavior under different failure scenarios. Comparative studies should benchmark the framework against traditional methods, while exploring hybrid models may yield optimal designs. Further investigation of the mathematical properties of Lucas numbers can enhance theoretical foundations, and practical implementations in real-world smart homes can validate effectiveness and incorporate user-centric design principles for improved usability.

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