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Efficient Geographic Routing for High-Speed Data in Wireless Multimedia Sensor Networks

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ABSTRACT

In recent eras, a large amount of data has been transferred through wireless networks in fifth-generation communication using a two-phase geography greedy forwarding (TPGF) routing algorithm with reconfigurable routing metrics represented by RrTPGF in random duty-cycled wireless multilevel multimedia sensor networks (WMSNs). The proposed method reduces the sleep delay in geographic routing networks. the systematically forwarded node in the geographic routing network to identify the significant neighboring nodes. The proposed algorithm is efficient in identifying the geographical distance of the neighboring node and identifying the sleeping delay of the nodes during the communication process. The proposed algorithm efficiently differentiates the worked node from the unworked node on the basis that it identifies the optimal single routing path with a low sleeping delay time at geographic routing. As per the simulation result, the performance of the proposed method shows better results as compared to the conventional methods when considering the scenario size of 750mm × 450mm and 250 nodes with respect to the average delay of the proposed method, which is reduced to 0.6%, and the average hop counts, which are reduced to 0.56% as compared to the conventional method.

1. INTRODUCTION

With the fast development of sensor technology and the availability of cheap equipment like cameras and microphones, wireless sensor networks (WSNs) have moved into a new field of use called wireless multimedia sensor networks (WMSNs). A basic block diagram of a wireless sensor network (WSN) is shown in Figure 1.

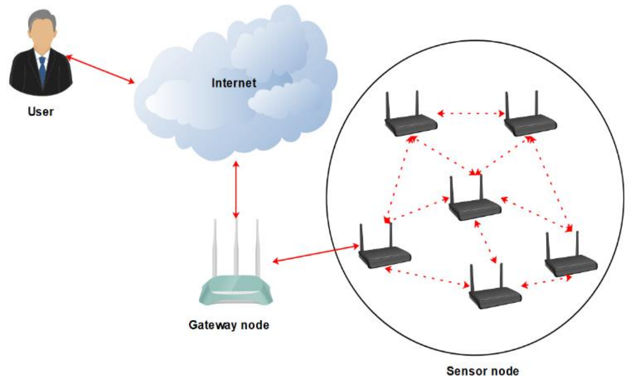


Figure 1. Fundamental block diagram of wireless sensor network (WSNs)

A WMSN is a network of sensor nodes that are wirelessly connected and have multimedia devices. It can be used for a wide range of applications that need to see and hear information, such as industrial process management, traffic control systems, and sensor networks for surveillance, as shown in the WMSN fundamental block, Figure 2. Transmitting data in WMSNs is hard for a number of reasons, most of which have to do with the following: (1) The features of real-time multimedia data, such as its need for a high bandwidth, real-time delivery, and the amount of end-to-end latency that can be tolerated. (2) The limits of WMSNs in terms of energy, bandwidth, data rate, memory, buffer size, and computing power. Several cross-layer optimised transmission methods, such as the studies [1-3], have been made to improve how well WMSNs send and receive data. A few ways have been made to help with packet routing as part of WMSN's network layer routing research. The people who came up with the ASAR [4-6] algorithm provided a QoS routing model for WMSNs. This model chooses a number of optimal paths based on the QoS needs of different types of services. It mostly looks into how data gets sent from a cluster head to a sink node and how routing works between cluster heads. For WMSNs, the TPGF (Two-Phase Greedy Forwarding) method [7] looks for the almost shortest routing paths between nodes that don't connect to each other and get around holes. TPGF offers multi-path transmission by frequently running the algorithm to find more on-demand routing paths that don't connect to the same node. As far as we know, none of the previous works on routing in WMSN took the network model with duty-cycled sensors into account. wireless multimedia sensor networks (WMSNs) are an advanced type of sensor network that is capable of gathering and transmitting multimedia data, such as video, audio, and images, over wireless channels. Unlike traditional sensor networks that primarily deal with scalar data like temperature, humidity, or light levels, WMSNs are equipped with multimedia sensors that capture richer, more complex data types.

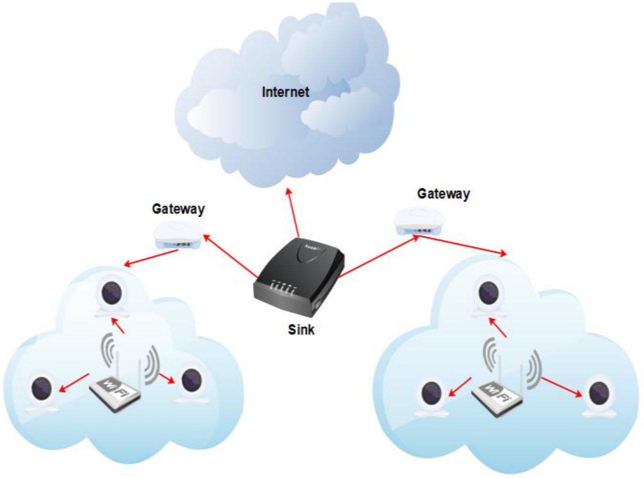


Figure 2. Fundamental block diagram of wireless multimedia sensor networks (WMSNs)

So, in our work, we look at a more complex network model with a duty cycle that changes all the time. Traditional WMSN routing methods may not work as well in this network model as they do in random duty-cycle WMSNs. Some changes must be made first to meet the QoS requirements [8-11]. We keep doing study based on the TPGF, and our goal is to change the TPGF routing measure so that end-to-end latency is better. RrTPGF is the changed version of TPGF, and models are being used to test how well our suggestions work.

1.1 WMSNs research gaps

Wireless multimedia sensor networks (WMSNs) are an evolving field combining wireless sensor network technology with multimedia data like audio, video, and images. Identifying research gaps in this domain involves understanding the current state of the art and where further advancements can be made. Here are some potential research gaps in WMSNs:

Energy Efficiency: Multimedia data transmission consumes significant power. Developing energy-efficient protocols and algorithms for data compression, transmission, and processing remains a crucial research area.

- **Quality of Service (QoS):** Ensuring high-quality multimedia transmission in terms of resolution, frame rate, and delay, especially in bandwidth-constrained and variable network conditions, is a challenge.
- **Scalability:** As the number of sensor nodes in a network increases, managing and processing the data efficiently while maintaining network performance is a significant issue.
- **Security and Privacy:** With the increase in multimedia data transmission, ensuring data security, privacy, and integrity is a critical concern. Research on robust encryption and authentication mechanisms is needed.
- **Data Fusion and Processing:** Advanced techniques for effective data fusion, including the integration of data from various types of sensors and processing it to extract meaningful information, are required.
- **Network Topology and Management:** Developing dynamic and adaptive network topologies that can handle node failures, changes in network size, and environmental conditions is a research gap.
- **Real-Time Processing:** Developing systems that can process and analyze multimedia data in real-time for applications like surveillance and environmental monitoring is challenging.
- **Machine Learning and AI Integration:** Integrating AI and machine learning for intelligent data analysis, pattern recognition, and decision-making in WMSNs is a growing field with many research opportunities.
- **Hardware Development:** Creating more efficient and powerful sensor hardware capable of capturing high-quality multimedia data while being energy-efficient is a significant area of research.
- **Cross-Layer Design:** Research on cross-layer design that optimizes the interaction between different network layers (physical, data link, network, transport) to improve overall network performance is needed.

Here's how the rest of this article is put together: In Section II, we talk about how useful our study is. We do this by drawing conclusions from related research in the fields of geographic routing, duty-cycled WSNs, and packet routing in WMSNs. In Section III, we talk about the network model for our research. In Section IV, we talk about the architecture of our method. In Section V, we run a number of large-scale simulations to see how much better our method is than TPGF. Section VI wraps up this paper.

2. RELATED WORK

Wireless multimedia sensor networks (WMSNs) are an extension of traditional sensor networks that focus on capturing, processing, and transmitting multimedia content like audio, video, and images. They find applications in various fields such as surveillance, environmental monitoring, healthcare, and traffic management. Here's an overview of related work in this field:

2.1 Key developments and research areas

Energy-Efficient Multimedia Transmission: Research is focused on optimizing the energy consumption of sensors during multimedia data transmission. Techniques like efficient encoding, data compression, and power-aware routing protocols are common.

- **Quality of Service (QoS) Improvement:** Ensuring high-quality multimedia content transmission under network constraints. Techniques like adaptive multimedia transmission, priority-based scheduling, and error resilience are explored.
- **Advanced Data Processing:** Implementation of complex algorithms for on-sensor data processing to reduce the amount of data to be transmitted. Edge computing and fog computing concepts are also being integrated.
- **Security and Privacy:** Developing encryption algorithms, secure data transmission protocols, and

privacy-preserving techniques specifically for multimedia content in WMSNs.

- **Machine Learning and AI Integration:** Using AI and machine learning for automatic data analysis, anomaly detection, and decision-making processes.

2.2 Notable projects and applications

- **Surveillance Systems:** WMSNs are widely used for security and surveillance, enabling real-time monitoring of public places, borders, and sensitive areas.
- **Environmental Monitoring:** They are used for monitoring wildlife, forest conditions, water quality, and atmospheric conditions. Multimedia content provides richer data compared to traditional sensor networks.
- **Healthcare Applications:** In telemedicine and patient monitoring, WMSNs facilitate remote monitoring of patients through multimedia data, improving healthcare delivery.
- **Smart Cities:** Used in traffic management, public safety, and urban planning. WMSNs allow for real-time monitoring and management of city resources.

2.3 Challenges and future directions

- **Scalability:** Addressing the challenges in scaling WMSNs for larger networks without compromising performance.
- **Real-Time Processing:** Enhancing the capability for real-time data processing and timely decision-making, especially in critical applications like healthcare and public safety.
- **Interoperability:** Ensuring WMSNs can efficiently interact with other types of networks and technologies.
- **Sustainable and Green WMSNs:** Developing eco-friendly and sustainable network models to reduce the environmental impact.

The field of wireless multimedia sensor networks is dynamic and rapidly evolving, driven by advancements in sensor technology, wireless communication, and data processing techniques. As these networks become more sophisticated and integrated into various domains, they promise to unlock new capabilities and applications, transforming how we interact with and understand our environment.

2.4 Geographic routing

For geographic routing, there are three main types of packet forwarding algorithms: greedy forwarding, limited directional flooding, and hierarchical approaches. When a relay node gets a packet in a greedy forwarding area, it sends the packet to a friend in the direction of the sink's forwarding. One way is to send the package to the neighbour who lives closest to the washbasin, as shown in Figure 3, which is a basic block map of geographic routing. It tries to cut down on the number of hops a packet has to make to get to the sink. When the forwarding node is closer to the sink than all of its peers, greedy routing may not find a path between the sender and the sink, even if there is one between each of the two nodes. Planar graph navigation has been suggested as a way to solve the local minimum problem by some methods. Face routing is shown by the methods used in face-2 [12], GPSR [13], and GoAFR [14]. A list of terms [15] One way to do hierarchical routing is to use 2-level hierarchical routing. A proactive distance vector method is used to send packets to the sink if it is close to the forwarding node in terms of hops. When moving over long distances, greedy geographic routing is used. When a long-distance packet gets close to its destination, it goes back to the local routing plan to be sent on its way. In short, the following network model is used by these standard geographic routing algorithms: Because every node in the network is always on and the link is reliable, these methods use distance as the only factor to figure out the routing for the next hop. On the other hand, geographic routing in WSNs with a random duty cycle has not been reported as far as we know.

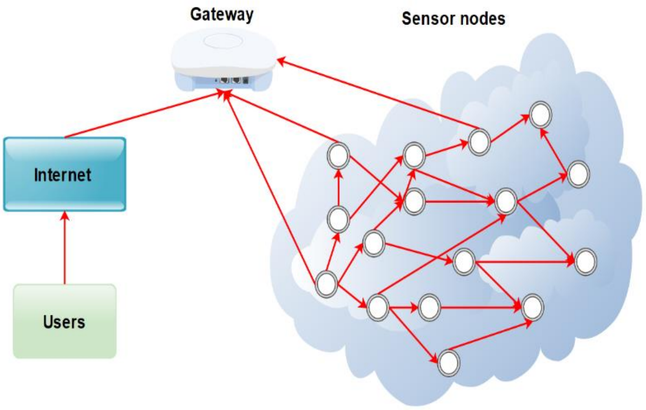


Figure 3. Fundamental block diagram of geographic routing

2.5 Duty-cycled WSNs

The duty-cycle scheduling method tries to make applications last longer by letting nodes sleep for as long as possible and waking them up when a packet is sent to them. In the study field of low duty-cycle networks [16-21], the researchers did a thorough analysis of how long it takes for data to travel from a node to a sink in networks where nodes work at different times. And some researchers say that the best choice is to use dynamic forwarding, which takes both the sleeping latency and the link quality into account and always sends the packet to the node with the desired metric [22]. CKN [23] is the first geographic routing algorithm for duty-cycled WSNs.

Suman Nath uses the CKN method to make sure that each node in the network has at least K awake neighbours at all times and that the whole network stays connected. Then it keeps going to the neighbour, who is now awake [24-28]. The major benefit of the CKN algorithm, which only works for scheduled duty-cycled WSNs, is that it makes sure that the network is always connected. In our work, we use a network model of randomly duty-cycled WSNs to run simulations, and we try to improve the measure for route choice by adding the time spent sleeping to it. This will improve the performance of geographic routing beyond what is possible with traditional geographic routing methods.

2.5.1 Duty-cycled WSN benefits and advantages

Duty-cycled Wireless Sensor Networks (WSNs) offer several benefits when compared to other techniques used in WSNs, particularly in terms of energy conservation, network longevity, and operational efficiency. Here's a comparison of duty-cycling with other common techniques in WSNs:

- **Energy Conservation**

Significantly reduces energy consumption by alternating between active and inactive states. This is especially beneficial for battery-powered or energy-harvesting nodes. Techniques like energy-efficient routing, data aggregation, and low-power communication protocols also save energy but may not be as effective as duty-cycling in minimizing idle power consumption.

- **Network Lifetime**

Extends network lifetime substantially by conserving energy, which is crucial for long-term deployments. Techniques like efficient battery management and renewable energy sources extend network life but may involve additional costs or infrastructure.

- **Scalability**

Facilitates larger networks due to lower energy consumption per node, allowing more nodes to be deployed without increasing overall power requirements. While methods like hierarchical clustering and multi-hop communication improve scalability, they don't inherently reduce the power consumption of individual nodes.

- **Reliability and Maintenance**

Reduces the frequency of battery replacements, lowering maintenance efforts and costs. Predictive maintenance and fault-tolerant designs improve reliability but may not significantly reduce maintenance requirements.

- **Data Quality and Processing**

Nodes can allocate more power to processing and transmitting higher-quality data when active, though at reduced intervals. Real-time processing and edge computing enhance data quality and speed but can increase power consumption.

- **Adaptability**

Duty-Cycling Can be programmed to adjust the active/inactive intervals based on environmental conditions or network demands. Adaptive routing and dynamic power management are also adaptable but focus more on network performance than on energy conservation.

- **Environmental Impact**

Lowers environmental impact due to reduced energy consumption and less frequent battery disposal. While methods like renewable energy integration are environmentally friendly, they may require more infrastructure.

- **Suitability for Harsh Environments**

Ideal for remote or harsh environments where power resources are limited or maintenance is challenging. Rugged sensor designs and robust network protocols are effective in harsh conditions but don't address power limitations as directly as duty-cycling.

In summary, while various techniques aim to optimize different aspects of WSNs, duty-cycling stands out for its effective balance between energy conservation, extended network lifespan, and reduced operational costs, making it a preferred choice in many scenarios.

2.6 The TPGF algorithm

The TPGF [29] method is one of the first geographic routing algorithms that focuses on multimedia streaming solutions in wireless multimedia sensing networks. Two steps are taken by TPGF to find paths between the source and sink nodes. In the first step, the packet is sent to the partner node that is closest to the sink node. TPGF is different from other geographic routing algorithms because it doesn't use the standard method of putting the chosen node closer to the sink node than the moving node itself to solve the local minimum problem. In the second step, the paths found in the first step are made better by getting rid of unnecessary nodes and dropping the number of hops. These nodes that have been turned off can be used to send packets. In other words, this method makes it possible for TPGF to find more multi-nodes. On CKN-based schedule duty-cycled WSNs, the TPGF algorithm has been successfully used [30]. Figure 4 shows an example of TPGF for duty-cycled WSN schedule based on CKN.

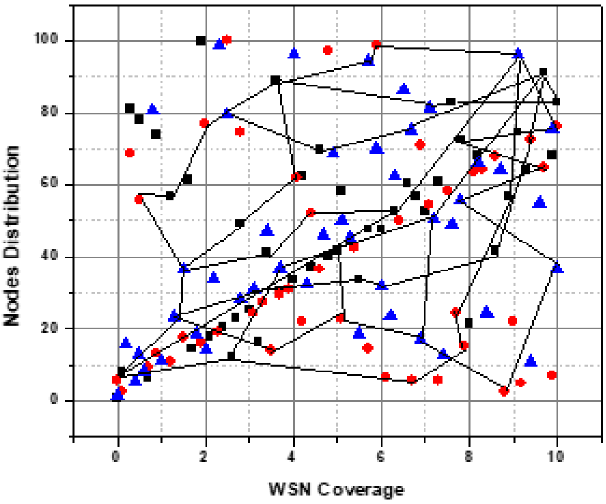


Figure 4. Simulations of TPGF on the schedule duty-cycled WSNs on the basis of CKN with K = 1

The major contributions of our work are as followings:

a. The RrTPGF routing algorithm models are done in completely random duty-cycled WMSNs. This means that the geographic routing algorithm doesn't have to make sure that every node is always active. As far as we know, this is one of the first works to look at how to model geographic routing in a network model of WMSNs with random duty cycles.
b. The forwarding node changes a number of measures, such as the geographic distance and the time it takes for the coordinate node to sleep, in order to find routes. Also, this multi-metric method (RrTPGF) shortens the time it takes for our simulation to run from start to finish.

3. NETWORK MODEL

A Geographic Wireless Sensor Network (GWSN) is a type of wireless sensor network where the locations of the sensor nodes are important and play a significant role in the network's operation. In a GWSN, sensor nodes are distributed across a geographical area, and their positions in physical space are known and utilized for various network operations and data processing tasks.

Here are some key characteristics and concepts related to Geographic Wireless Sensor Networks:

- **Location Awareness**

One of the defining features of GWSNs is that the sensor nodes have location awareness. Each node is equipped with some form of location-determining technology, such as GPS (Global Positioning System) receivers or localization algorithms, which allow them to determine their own positions within the geographical area.

- **Spatial Data Collection**

In GWSNs, sensor nodes collect data from the environment in a spatially distributed manner. This means that the data collected from different nodes corresponds to specific geographical locations. This spatial information can be valuable for various applications such as environmental monitoring, disaster response, precision agriculture, and habitat monitoring.

- **Geographic Routing**

Routing protocols in GWSNs take advantage of the geographical positions of nodes to make routing decisions. Geographic routing algorithms use location information to determine the next hop for data forwarding, often selecting nodes that are closer to the destination in terms of physical distance.

- **Energy Efficiency**

Geographic routing can lead to more energy-efficient communication because nodes can often communicate directly with their physically nearest neighbors, reducing the number of hops required to reach the destination. This can help conserve energy and extend the network's lifetime.

- **Localization**

Accurate localization of sensor nodes is a crucial component of GWSNs. Localization techniques may include GPS, triangulation, ranging, and collaborative algorithms that use inter-node communication to estimate positions.

- **Challenges**

GWSNs face challenges such as node mobility, varying signal propagation conditions, localization inaccuracies, and network scalability. Algorithms and protocols need to account for these challenges to ensure reliable communication and data delivery.

- **Applications**

Geographic Wireless Sensor Networks can be used to watch the environment (temperature, humidity, pollution levels), track animals, make cities smarter (parking, traffic monitoring), do precision farming, keep an eye on things, and handle disasters.

GWSNs make it possible to collect data in a way that makes more sense in the context than standard wireless sensor networks. The spatial knowledge of sensor nodes makes it easier to collect data, analyse it, and make decisions based on how information is spread out in space.

We think about a world-wide wireless sensor network with N sensor nodes and a low duty cycle. At any given time, a sensor node is either active or not active. In our network model, a node can wake up at any time to send a packet, but it can only receive packets when it is active. Also, the cycle time, slot time, and job cycle are all 50 seconds, 5 seconds, and 10 seconds, respectively [31-36].

We also assume that each node in the network knows the location of its own node, the sink nodes, and the nodes that are one hop away. Any two nodes can join to each other safely. In this type of network structure, once a node gets a packet, it has to wait until the next hop node wakes up before sending it on. And the question is how to estimate the next hop based on this information to reduce the time spent sleeping and keep hop counts from getting too high in duty-cycled WSNs [37-40].

3.1 Key characteristics of GWSNs

GWSNs are a specific type of wireless sensor networks where the geographic location of sensor nodes is a key aspect of their operation. These networks leverage the geographical information to improve efficiency in communication, data routing, and resource management. Here's a detailed look at the key characteristics and concepts related to GWSNs:

- **Geographic Routing**

Concept: In GWSNs, routing decisions are made based on the geographical positions of the nodes rather than network topology or node IDs. This approach is known as geographic or location-based routing.

Advantages: It simplifies the routing process, reduces overhead, and is more scalable and efficient in dynamic networks where node positions may change frequently.

- **Location Awareness**

Importance: Each node is typically aware of its own location, often through GPS modules or localization algorithms.

Application: This information is crucial for geographic routing, spatial data collection, and location-specific tasks.

- **Energy Efficiency**

Geographic Optimization: By knowing the exact location of nodes, GWSNs can optimize communication paths and reduce energy consumption.

Relevance: Energy efficiency is vital due to the limited power resources of sensor nodes.

- **Scalability**

Aspect: GWSNs are highly scalable, capable of handling large-scale deployments efficiently.

Reason: Geographic routing reduces the need for complex routing tables and network-wide information, making it easier to add new nodes.

- **Data Aggregation**

Process: GWSNs often employ data aggregation techniques, where data from multiple nodes is combined to reduce redundancy and save bandwidth.

Geographic Relevance: Aggregation can be location-based, with data being aggregated from nodes in a specific geographic area.

- **Network Topology Management**

Dynamic Nature: GWSNs can adapt their topology based on node mobility and changing environmental conditions.

Location-Based Decisions: Decisions about network formation, maintenance, and reconfiguration are often based on geographic information.

- **Fault Tolerance and Reliability**

Challenges: GWSNs face challenges like node failures, environmental obstacles, and variable signal strengths.

Solutions: Geographic information aids in dynamically rerouting data and managing network redundancy to maintain reliability.

- **Application-Specific Design**

Diverse Applications: GWSNs are used in various applications like environmental monitoring, military surveillance, and disaster management.

Customization: The network design often varies based on specific application requirements, such as the area of coverage, data type, and node mobility.

- **Security**

Concerns: Security in GWSNs involves safeguarding location information and data transmission.

Approaches: Encryption, secure routing protocols, and intrusion detection systems tailored to geographic aspects of the network.

- **Integration with Other Technologies**

Trend: GWSNs are increasingly being integrated with other technologies like IoT, cloud computing, and AI.

Purpose: This integration enhances data processing capabilities, decision-making processes, and overall network functionality.

4. THE RRTPGF ALGORITHM

The reconfigurable routing metrics Two-Phase Geography Greedy Forwarding (RrTPGF) is an algorithm used in wireless sensor networks and mobile ad hoc networks for data packet forwarding. It's an extension of the basic greedy forwarding algorithm designed to improve packet delivery rates and reduce energy consumption in these networks [41, 42]. In wireless networks, especially those with a large number of nodes and dynamic topologies, efficient data packet forwarding is crucial for maintaining network connectivity and delivering data to their intended destinations. Greedy forwarding involves forwarding packets to the neighbor that is closest to the destination, based on some metric (usually distance or hop count). However, this can lead to premature termination due to local minima in the network, where a packet cannot be forwarded further toward the destination [43-48].

Our algorithm's structure is derived from the TPGF algorithm. We combine the RrTPGF with the duty-cycled WSN characteristic and focus on lowering end-to-end latency. In the sections that follow, we address the issues. The RrTPGF addresses this issue by introducing a two-phase approach:

- **Initial Forwarding Phase**

In this phase, nodes try to forward the packet greedily based on proximity to the destination. However, if a node encounters a situation where it cannot make progress towards the destination, it does not immediately drop the packet. Instead, it enters the second phase.

- **Rendezvous Phase**

In this phase, nodes that could not make progress during the initial phase cooperate to find a suitable intermediate node that can help forward the packet closer to the destination. This intermediate node is often chosen based on some optimization criteria, such as reducing the distance to the destination or optimizing the energy consumption.

The RrTPGF attempts to combine the advantages of greedy forwarding with a more cooperative approach to overcome local minima and improve packet delivery rates. It's particularly useful in scenarios where the network topology is highly dynamic or the nodes are constrained in terms of energy.

4.1 The definition of sleeping-delay

Wireless Sensor Networks (WSNs) consist of a large number of tiny, resource-constrained sensor nodes that are deployed to monitor and gather data from the environment. These nodes are often powered by batteries, which have limited energy capacity. To extend the network's lifetime, it's crucial to minimize the energy consumption of individual sensor nodes.

One way to achieve energy efficiency in WSNs is by incorporating sleep modes into the operation of the nodes. When a sensor node is not actively transmitting or receiving data, it can go into a low-power sleep mode. This significantly reduces its energy consumption during periods of inactivity. However, there's a trade-off between how much time a node spends in sleep mode and how quickly it can respond to events or transmit data when needed.

Designing an optimal sleeping schedule and managing the sleeping delay are important tasks in WSNs to achieve the right balance between energy efficiency and responsiveness. Researchers and engineers often work on developing algorithms and protocols that help determine when nodes should sleep, when they should wake up, and how they can synchronize their sleep cycles to maximize network performance.

If the neighboring node is now inactive, the forwarding node should wait for a while before transmitting the packet when the node wakes up. In our paper, this delay induced by waiting for the neighbor to wake up is referred to as the "sleeping delay [49, 50].

4.2 The definition of multi-metric

Wireless Sensor Networks (WSNs) and the use of multiple metrics to evaluate and manage the network's performance. WSNs are composed of numerous sensor nodes that collaborate to monitor and collect data from their environment. These networks can be evaluated based on various metrics, which could include:

- **Energy Efficiency**

This metric focuses on how effectively the network utilizes energy resources. It might involve minimizing the energy consumption of sensor nodes, prolonging network lifetime, and optimizing sleep and active periods.

- **Latency**

Latency measures the delay between an event occurring in the environment and the moment the corresponding data is transmitted and received by the network. Lower latency is crucial for real-time applications.

- **Throughput**

Throughput refers to the amount of data that can be transmitted successfully within a given time frame. High throughput is important for applications that require frequent data exchange.

- **Reliability**

Reliability assesses the network's ability to deliver data without loss or corruption. It might involve strategies like redundancy and error correction.

- **Coverage**

Coverage measures the extent to which the sensor nodes can monitor the target area. Full coverage ensures that no part of the environment goes unmonitored.

- **Scalability**

Scalability refers to how well the network can handle the addition of more nodes without a significant drop in performance.

- **Security**

Security metrics evaluate the network's ability to protect data and communication from unauthorized access and malicious attacks.

- **Cost**

Cost-effectiveness considers factors like the deployment cost, maintenance cost, and overall return on investment of the network.

In our study, the route measure is made up of two parts: the distance between the Neighbour and the washbasin and the time it takes the neighbour to go to sleep. You can figure out the multi-metric weight with the following equation [51]:

$$W = a * disi + b * si \tag{1}$$

where, 'a' and 'b' are constant factors, 'disi' is the distance from the neighbour to the washbasin, and'si' is the sleeping delay of the neighbour at that time.

4.3 The basic design of RrTPGF

The RrTPGF is based on the TPGF algorithm, but with a few changes. The TPGF algorithm, which was explained in a part of related work, uses two phases to maximise the number of node-disjoint pathways while avoiding the gaps in the traditional geographic network model [52]. In random duty-cycled wireless sensor networks (WSNs), the end-to-end delay of any path changes when the state of the relay nodes along the path changes. This means that there is no need to look for all the node-disjoint paths in the network topology at a certain point in time. Also, since the delay of the same path might change after the second phase of optimisation, we cancel the TPGF optimisation process. At the same time, because the routing metric of distance to the sink is no longer enough to meet the QoS criteria of end-to-end delay, the sleeping delay of neighbour nodes must be lowered in random duty-cycled WSNs [53] in order to find paths.

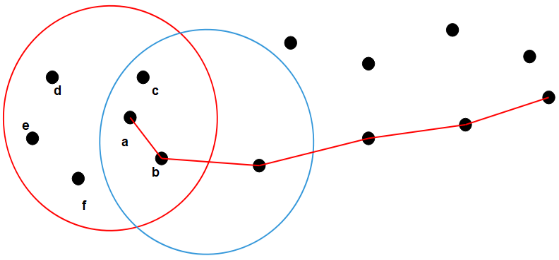


Figure 5. Node 'a' always sends packets to node 'b' because it is the closest to the sink node, node a sends the packet to node c

In short, standard TPGF with a random duty cycle sends packets to the neighbour who is closest to the sink, while RrTPGF sends packets to the neighbour whose routing weight is the lowest. Figure 5 shows the TPGF, and Figure 6 shows the RrTPGF. The second problem is how to keep our new routing measure from causing routing loops. RrTPGF ties the node ID and packet ID together after the author has sent the packet. Before making routing decisions, the forward node must also check to see if the neighbour node is already bound to the packet.

Using the node id and packet id. The packet is only forwarded to the neighbor whose id has not been bond to this packet [54-56]. The difference between RrTPGF and TPGF algorithm as shown in Table 1.

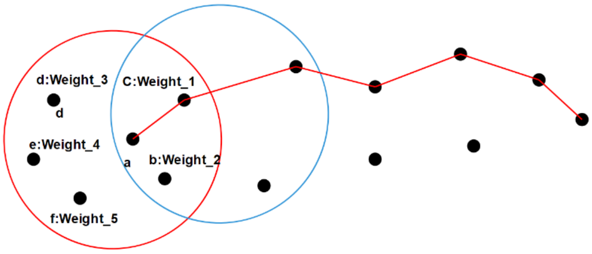


Figure 6. At this time, node C has the least weight for routing. Even though node b is closest to the si

4.4 Block node and step back

Block nodes are those in which no one could be identified as being a given node’s subsequent hop. When a node is designated as a block node, it simply moves back to the hop that forwarded the packet to it, designating itself as a block node.

Block Node and Step Back" could possibly refer to a strategy or mechanism used in a WSN to manage and optimize network operations. Here's a speculative interpretation:

- **Block Node**

This might refer to a specific sensor node that temporarily halts its regular data transmission or sensing activities. There could be several reasons to "block" a node, such as conserving energy, reducing interference, or avoiding congestion in the network.

Table 1. The difference between RrTPGF and TPGF algorithm

Aspect	Reconfigurable Routing Two-Phase Geography Greedy Forwarding	TPGF Algorithm
Reconfigurability	Specifically designed to adjust its routing strategy based on changing network conditions, such as node mobility or varying signal strength.	Does not inherently include mechanisms for dynamic reconfiguration based on real-time network conditions.
Operational Complexity	Potentially more complex due to the added functionality for adapting to network changes.	Relatively simpler as it follows a fixed two-phase process without additional reconfigurability.
Application Scenarios	Ideal for highly dynamic or mobile networks where the network topology changes frequently.	Suitable for more static networks where network topology does not change rapidly.
Flexibility	High flexibility in routing decisions to optimize performance under varying network scenarios.	Standard flexibility limited to the predetermined two-phase routing process (greedy forwarding and recovery phase).
Primary Focus	Focuses on adaptability and responsiveness to maintain efficient routing under diverse network conditions.	Focuses on efficiently finding a routing path using greedy forwarding and recovery strategies.
Technical Description	Includes the standard TPGF two-phase process but with additional algorithms or mechanisms for reconfiguring the routing strategy as needed.	Follows the standard two-phase process: a greedy forwarding phase and a recovery phase when the greedy approach is not feasible.
Intended Audience	Targeted towards researchers and professionals dealing with dynamic wireless sensor networks.	Applicable to a broader range of users, including those in education, research, and practical applications in sensor networks.
Performance in Dynamic Networks	Likely to perform better in environments where network topology or conditions are frequently changing.	May not perform as optimally in highly dynamic or rapidly changing network conditions without reconfiguration capabilities.

- **Step Back**

This could imply that after the node "blocks" its activities, it then waits for a certain period of time before resuming normal operations. "Stepping back" might involve entering a low-power sleep mode to save energy or to give the network time to adjust to changes.

In a WSN, energy efficiency is a critical concern due to the limited power resources of the sensor nodes. Therefore, strategies that involve nodes periodically entering sleep or low-power modes to conserve energy are common. These strategies might involve synchronized sleep schedules, dynamic adjustments based on network conditions, and methods to efficiently wake up nodes when they are needed. Table 2 show the technical concepts difference between step back and block node.

Table 2. Technical concepts differ between step-back and block nodes

Criteria	Step Back	Block Node
Functionality	Used for dynamically finding alternative paths when the intended path is not feasible or optimal.	Used to exclude certain nodes from the network's routing mechanism, either temporarily or permanently.
Operational Context	Activated during the routing process, particularly when a dead-end or unreachable node is encountered.	Implemented as a preventive measure, either for network optimization, maintenance, or security reasons.
Network Impact	Can lead to increased resilience and flexibility in routing, ensuring data packets are not dropped.	Can increase the overall robustness of the network but might lead to longer routing paths and increased latency.
Adaptability	Highly adaptable, as it responds to real-time conditions and reroutes dynamically.	Less adaptable, as it requires manual intervention to block or unblock nodes.
Usage Scenarios	Ideal for dynamic or unpredictable environments where network topology can change frequently.	Suitable for scenarios requiring enhanced security, network maintenance, or specific traffic management.
Resource Efficiency	May use more computational resources due to the need for continuous assessment and rerouting.	Can be more resource-efficient if blocking nodes helps streamline the network traffic and reduces congestion.
Reversibility	Decisions are reversible, and nodes can be reintegrated into the routing process.	Decisions can be irreversible in the short term, especially if nodes are blocked for security or damage.

4.5 The detailed process of the RrTPGF algorithm

Considering the characteristic of random duty-cycled WSNs, we give our design in Algorithm 1.

"Reconfigurable-Routing Metric TPGF" likely refers to a networking or routing concept involving the use of the Tree-Based Priority-Graph Forwarding (TPGF) protocol with multiple routing metrics in a network, potentially in the context of Wireless Sensor Networks (WSNs).

The Tree-Based Priority-Graph Forwarding (TPGF) protocol is a routing algorithm designed for WSNs to efficiently forward data packets from source nodes to a sink node or base station. TPGF constructs a tree-based structure that determines the forwarding paths for data packets. It's designed to be energy-efficient and adaptable to the dynamic nature of sensor networks.

When the term " Reconfigurable -routing metric" is added to TPGF, it likely means that the protocol takes multiple metrics into account when making routing decisions. In networking, metrics are quantitative measurements used to evaluate different paths or routes for data transmission. These metrics can include factors like hop count, link quality, energy levels, latency, and more. By considering multiple metrics, the routing protocol can make more informed decisions about the best path to use for data transmission based on a combination of factors.

Integrating multiple routing metrics with TPGF could enhance the protocol's ability to adapt to various network conditions, such as energy constraints, link quality variations, and congestion. It would allow the protocol to dynamically choose the most suitable path for data transmission based on a combination of factors that align with the network's goals and requirements.

4.6 The complexity of RrTPGF

The complexity of a routing protocol like Multi-Routing Metric Tree-Based Priority-Graph Forwarding Reconfigurable-Routing Metric TPGF) is typically assessed in terms of time complexity and space complexity. These complexities help us understand how the protocol's performance scales with the size of the network and the number of nodes.

- **Time Complexity**

Time complexity measures how the execution time of a protocol grows as the network size increases. In a routing protocol, this involves considering factors like the number of nodes, the frequency of updates, and the operations performed by the protocol. More complex operations and frequent updates can lead to higher time complexity. For example, constructing routing trees, computing metrics, and updating routes all contribute to the time complexity.

- **Space Complexity**

Space complexity refers to the amount of memory or storage needed by the protocol to operate. This includes the memory required to store routing tables, data structures, and other information. As the network grows, the amount of information that needs to be stored and managed can impact the space complexity of the protocol.

When dealing with multiple routing metrics, the complexity can be affected by how these metrics are collected, processed, and utilized. If each metric requires additional calculations or comparisons, it could increase the computational complexity.

To analyze the complexity of a specific protocol like Multi-Routing Metric TPGF, you would need to examine its algorithmic details and how it handles different routing metrics. Generally, if a protocol involves more complex computations, interactions, or decision-making processes based on multiple metrics, its complexity may increase.

As demonstrated in TPGF, the time complexity of RrTPGF should be O(n) all the same, where n is the number of nodes of the network.

5. EVALUATION

Simulations are carried out on the NetTopo platform [57-69]. In our simulations, we change the TPGF to RrTPGF and compare the results. The following is the simulation scenario: We place sensor nodes on a 750mm × 450mm flat, with each node having a transmission radius of 60m. The duty-cycle in our simulation case is 10 since the cycle-time is 50 seconds, each node has 10 slots, and each slot is 5 seconds. In terms of the effects of hop counts, we assume that each hop causes a one-slot-time delay. We run simulations on two different aspects to make our results more compelling. First, we run simulations on the topologies.

ALGORITHM 1: THE RRTPGF ALGORITHM

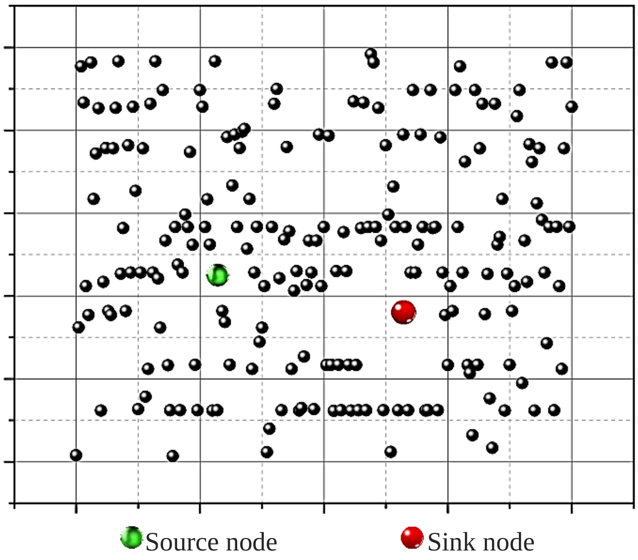
```
Step_1:
        Check to see if the sink node is one of the forwarding node's one-hop
         neighbours.
        IF (one-hop neighbour)
                Packets are forwarded to sink node,
                Executed
                Else
                Proceed to Step 2
Step_2:
        Determine the geographical distance between each unblocked neighbouring node;
Step_3:
        Get the sleeping-delay of each neighbouring node that isn't blocked.
Step_4:
        Figure out the route weight of each neighbouring node that isn't blocked.
Step_5:
        Pick out of the remaining nodes the one with the lowest weight value;
Step_6:
        Verify the packet-node id, which could lead to a route
        loop, to see if the next hop node is already on the path;
        If (already on the path)
        proceed to Step_5;
else
        Forward the packet to the designated node; bind the packet id to the id of the forwarding node.
Step_7:
        If a node has no neighbours other than the blocked
        node, it must return to the prior hop node and become
        a block node.
        step back to the prior hop node; transform into a block node;
proceed to Step_5
Step_8:
        The algorithm will terminate either when the packet
        has arrived at the sink node or when the source node
        has no remaining unblocked neighbours.
```

The dimensions of 750 mm × 450mm and 250 nodes. However, the way that each of these sensor nodes is deployed varies. Each of the 25 different deployments is simulated 20 times.

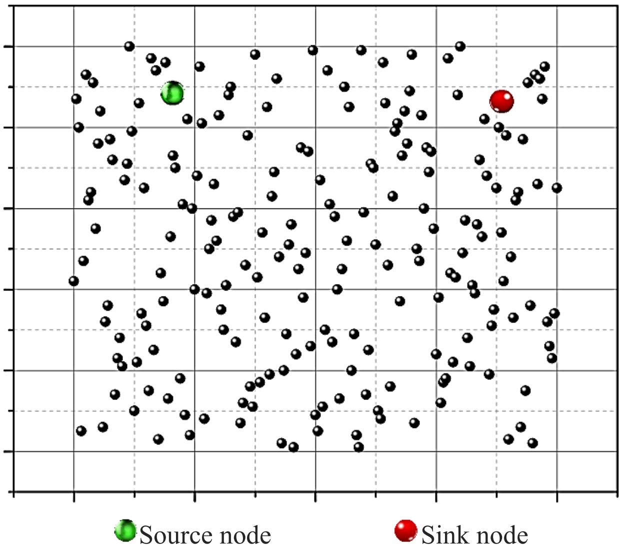
In order to modify the density of nodes in these topologies, we change the number of nodes in the flat with the same size. Nevertheless, we run 25 simulations on each of the 25 topologies with various node densities. The descriptions of the simulation parameters for the two aspects are shown in Table 3. Additionally, Figure 7 displays instances of our simulation scenarios for the two aforementioned elements.

Table 3. Simulation parameters on aspect 1 and aspect 2

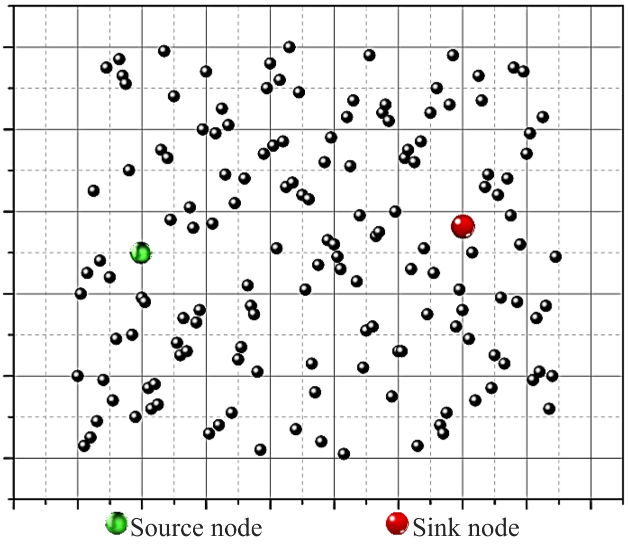
Parameters	Ranges
Topology size	750mm × 450mm
Number of nodes in network	250 (Aspect_1) 175-500 (Aspect_2)
Network duty-cycle	15
Duty cycle of network	8s
Each hop delay	1 slot
Cycle time length	15 slot
Number of deployments	25



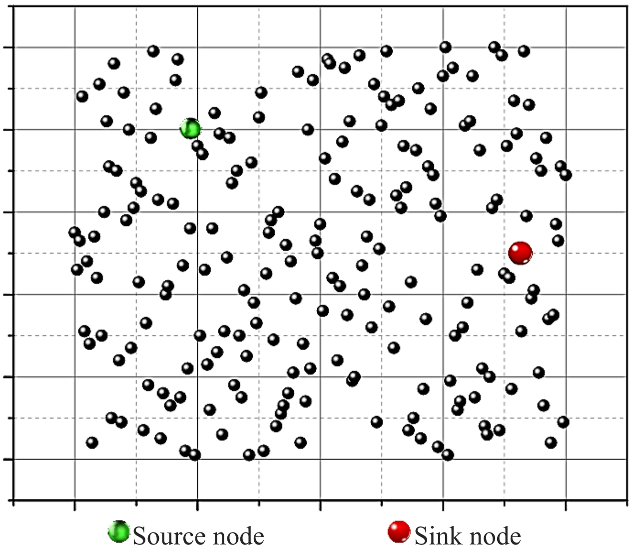
(a) The simulation result of scenario 250 nodes with a topology size of 750mm × 450mm



(b) The simulation result of scenario 275 nodes with a topology size of 750mm × 450mm



(c) The simulation result of scenario 175 nodes with a topology size of 750mm × 450mm



(d) The simulation result of scenario 350 nodes with a topology size of 750mm × 450mm

Figure 7. (a) and (b) show two scenarios with 275 nodes in our simulation. (c) and (d) show scenarios with 175 and 350 nodes, respectively. Both the source and sink nodes are in the same place

After running simulations 400 times on both delay and hop counts, we use the average number of delay and hop counts as our final results. Figure 8 and Figure 9 show the results of our simulations of the first part. Based on the number of nodes and the seed, NetTopo makes different network situations. Figure 8 shows that each seed is a different distribution of 275 nodes in a scenario. In our simulation, the geographic distance and sleeping-delay factors are both one, but in the standard TPGF method, the distance and sleeping-delay factors are both zero. The results of our simulations for the second part are shown in Figures 10 and 11. There are between 175 and 500 links. We use the average of the delay and hop counts for our final data. In our simulation, it is clear that RrTPGF has a shorter average delay than TPGF, and its average hop counts are almost the same as TPGF's in both groups.

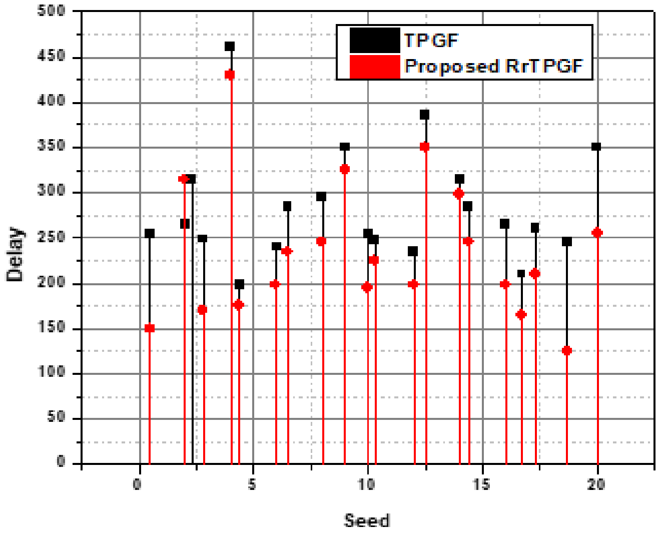


Figure 8. The average delay of our 400-time simulation tests with 275 sensor nodes and the scenario size 750mm × 450mm

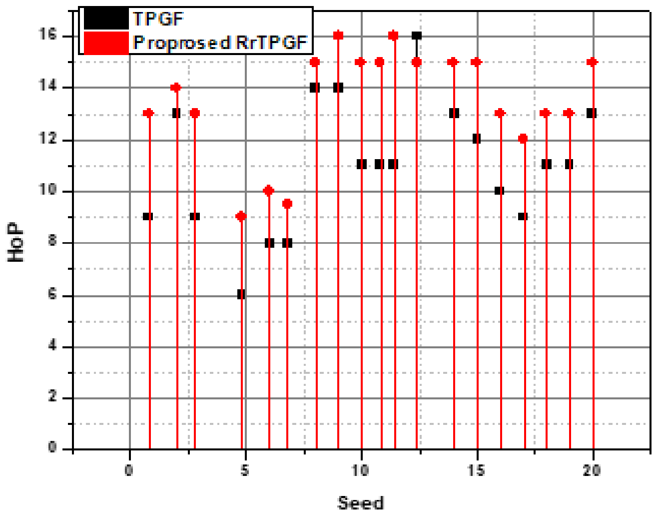


Figure 9. The average number of hops in our 400-time tests with 275 sensor nodes and a 750 mm 450 mm scenario size

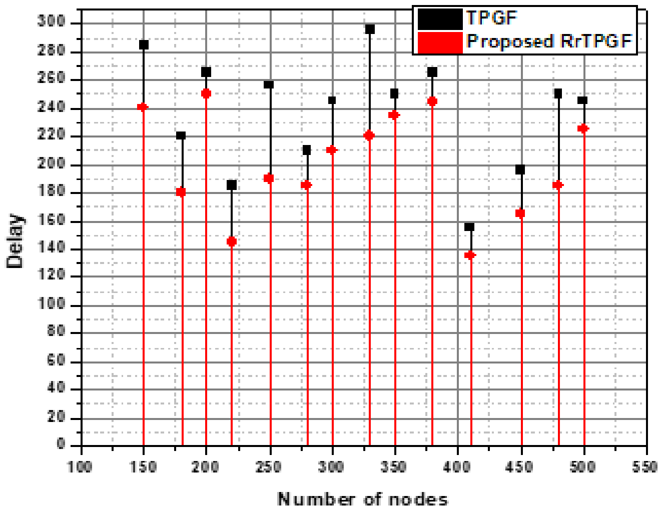


Figure 10. The average Hop count of our 400-time simulation test with 275 sensor nodes and the scenario size 750 mm × 450 mm

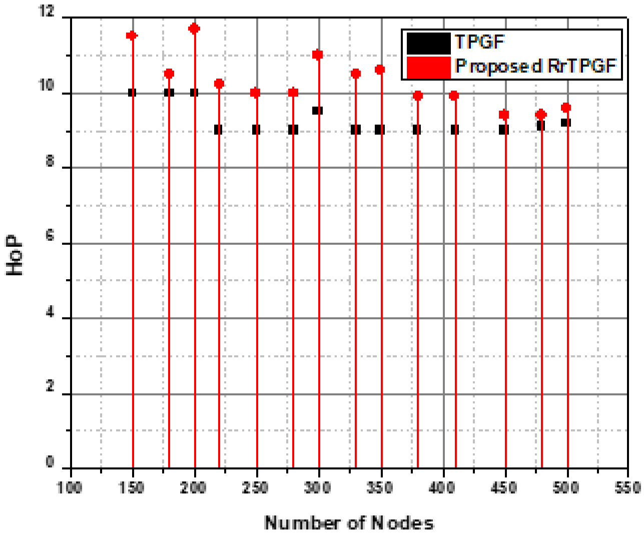


Figure 11. The average number of hops in our 400 tests with different conditions was 750mm × 450mm is the size of the scenario and the number of distributed nodes

6. CONCLUSION

In this paper, a proposed algorithm effectively contributes to data transmission in WSNs with random delay cycles. Using the proposed reconfigurable routing metrics for two-phase geographical greedy forwarding (RrTPGP), the proposed method performs better in fifth-generation communication. The proposed method significantly reduces sleep delay and also reduces the delay caused by differentiating between work and unwork nodes. Apart from this, the proposed method efficiently identifies the optimal single routing path to enhance the communication process in a geographic routing network. As per the simulation result, the proposed method shows better performance by reducing the average delay and hop count by 0.6% and 0.56%, respectively, by considering a scenario size of 750mm × 450mm with 250 nodes in a geographical routing network.

Future Scope:

Reconfigurable Routing with Two-Phase Geographic Greedy Forwarding (RrTPGF) in Wireless Sensor Networks (WSNs) future scope can be summarized in a few key areas as mentioned below:

- **Dynamic Adaptation:** Developing algorithms that allow for flexible adaptation to changes in network conditions, such as node mobility or failure.
- **Energy Efficiency:** Focusing on strategies to reduce energy consumption, which is crucial for extending the lifespan of sensor nodes.
- **Integration with IoT:** Exploring how RrTPGF can be effectively integrated into the Internet of Things (IoT) environments, particularly for applications in smart cities and agriculture.
- **Scalability:** Addressing challenges in scaling TPGF for densely populated networks and analyzing performance in such scenarios.
- **Security Enhancements:** Investigating security aspects of TPGF in WSNs, including data protection and node security measures.
- **Quality of Service (QoS):** Ensuring QoS in WSNs, especially for time-sensitive applications, and exploring data traffic prioritization techniques.
- **Fault Tolerance:** Enhancing the network's resilience to faults and rapid reconfiguration in response to node failures or environmental changes.
- **Cross-Layer Design:** Exploring cross-layer optimizations to improve overall network performance and efficiency.
- **Hardware Considerations:** Studying the impact of sensor hardware on RrTPGF performance and potential hardware improvements.
- **Real-World Testing:** Validating simulation models through real-world experiments to understand practical challenges and performance metrics.

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