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Improved Route Construction Protocol for Mobile Wireless Sensor Networks

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Abstract: Mobile wireless sensor networks (MWSNs) are a new development of static wireless sensor networks that allow the mobility of sensor nodes. Mobile sensor nodes are fundamental components of MWSNs. Because of this mobility of sensor nodes, the link between sensor nodes frequently changes, and packet loss occurs. Despite the packet loss of MWSNs, they also face challenges in energy consumption, communication overhead, and others. This research aims to analyze the performance of the hierarchical routing graph construction (HRGC) routing scheme. Its working mechanism and network structure suit all real-time applications with involved mobility. We discuss the limitations of the HRGC scheme theoretically and propose an improved routing scheme for data transmission in MWSNs based on HRGC. It should overcome the main limitations of HRGC, such as high data communication overhead, high energy consumption during network maintenance, data transmission process, and route failure issues due to mobility.

Keywords: mobile wireless sensor networks, routing protocols, data transmission, sink, sensors.

改進的行動無線感測器網路路由建置協定

摘要：行動無線感測器網路是靜態無線感測器網路的新發展，允許感測器節點的移動性。移動感測器節點是行動無線感測器網絡的基本組成部分。由於感測器節點的這種移動性，感測器節點之間的連結經常發生變化，從而出現丟包的情況。儘管行動無線感測器網絡存在丟包問題，但它們也面臨能耗、通訊開銷等方面的挑戰。本研究旨在分析分層路由圖建構路由方案的效能。其工作機制和網路結構適合所有涉及移動性的即時應用。我們從理論上討論了層次路由圖構建方案的局限性，並提出了一種基於層次路由圖構建的改進的行動無線感測器網絡資料傳輸路由方案。它應該克服層次路由圖構建的主要局限性，例如資料通訊開銷高、網路維護、資料傳輸過程中的高能耗以及由於移動性而導致的路由故障問題。

关键词：移动无线传感器网络、路由协议、数据传输、接收器、传感器。

1. Introduction

Wireless sensor networks (WSNs) are networks of low-power, small-sized devices called sensors with multiple capabilities, such as sensing, sending, receiving, and forwarding data [1]. These nodes can be deployed in various physical environments to monitor environmental or physical parameters such as air quality, humidity, and temperature [2]. Nodes transmit the collected data to the gateway or base station, which processes and communicates with other devices or networks [3]. To adopt environmental changes and monitor huge areas, we need mobile nodes that can move, monitor, and collect required data from various locations considered by MWSNs. Sensor nodes can move around freely with the help of agents such as vehicles or robots or themselves [4-7]. Various nodes move differently and have been assigned different jobs based on the type of real-time application. Some applications require partially mobile networks, and some require a fully mobile network. The following are some MWSN-based real-time applications that require a partially or fully mobile network.

Section 2 discusses the applications of MWSNs. Section 3 explains the challenges in MWSNs. Section 4 discusses the existing works on routing schemes for MWSNs. Section 5 presents results and explains the working of the HRGC scheme and its critical analysis, discusses the improved scheme, and gives a theoretical analysis of the proposed scheme. Section 6 concludes the research.

2. Applications of the MWSNs

In this section, we briefly describe some real-time applications using MWSNs.

2.1. Forest Fire Monitoring

Forest fire spread monitoring can use sensor nodes to monitor forest environmental parameters. Most of these nodes are attached to solar cells and optical systems to collect data and communicate it cooperatively with each other and the sink [8].

2.2. Smart Home Applications

An end user can remotely control and handle household appliances such as refrigerators, VCRs, cameras, doors, televisions, and vacuum cleaners by attaching sensor nodes [9].

2.3. Telemedicine Application

Sensor nodes can be attached to human bodies to monitor their body parameters continuously, delivering the recorded data to the doctor or sink for quick response in case of any emergency [8].

2.4. Animal Monitoring

Sensor nodes attached through collars or wrists to the animal bodies can monitor their body parameters, behavior, and environment. These sensor nodes collect the required data and forward information to the sink node [10].

2.5. Vehicle Monitoring Systems

MWSN plays a vital role in vehicle management systems to track vehicular speed during driving and is used for inter-car security and parking management systems [11].

When WSN involves mobility, connectivity becomes the most essential issue that causes route disconnections and route failure. It affects various parameters in the network and becomes a challenging task to manage data transfer between nodes.

3. Challenges in the MWSNs

In this section, we discuss the main challenges that exist in MWSNs.

3.1. Energy Consumption

Wireless sensor nodes are battery-dependent devices that quickly consume their batteries when performing multiple tasks such as sending, receiving, and forwarding data, especially in hazardous environments where battery recharge or replacement facilities are not available.

3.2. Localization

The deployment of nodes is the most critical issue during network management. In most networks, nodes are deployed randomly in the deployment area. Finding a location to obtain an efficient path for data transfer between nodes is essential because nodes are unaware of each other's locations.

3.3. Coverage

High network coverage depends upon the localization of sensor nodes and efficient coverage algorithm selection, so it can cover the entire network area when data transfer is performed between sources and sinks through intermediate nodes.

3.4. Clocks

Time synchronization is one of the most critical challenges in WSNs. All sensor nodes in the network must share a general time scale among nodes. Most real-time applications require clock synchronization when monitoring and tracking in the network.

3.5. Connectivity

When WSN involves mobility, it causes connectivity issues in the network. Nodes make unexpected or informed moves from one location to another during data transfer, which causes packet loss and deliver ratio and network lifetime.

3.6. Communication Overhead

A vast number of control and data packets sent throughout the network to maintain network connectivity and communication among nodes causes high energy consumption in the network nodes.

4. Literature Review

Routing protocols in wireless sensor networks are the most essential theme of many researchers in the literature. However, in the past few years, researchers have advanced various ideas and suggestions for advanced routing techniques to overcome the existing limitations of wireless sensor networks. Furthermore, further investigation is necessary to enhance the performance of routing schemes in terms of mobility, scalability, and energy efficiency.

[12] proposed an energy-efficient routing scheme to increase network lifetime by robustly aggregating data packets and managing traffic flow with less resource utilization in a more uniform manner.

[13] proposed energy-efficient schemes with multiple mobile base stations. They used an integer linear program to find new locations of base stations and flow-based routing to make the network energy efficient during each round.

[14] proposed an energy-efficient multipath routing scheme to address finding an efficient path between the source and destination that uses a multipath on-demand routing algorithm (MDR) to reduce communication overhead and perform reliable data transmission. The algorithm delivers the data successfully in high mobile networks owing to its robust feature toward mobility.

[15] proposed an energy-efficient unequal clustering (EEUC) mechanism to resolve the hotspot issue in wireless networks by periodically gathering data. It divides the network into unequal-sized clusters where clusters close to the sink are smaller than others, so cluster heads (CHs) near the base station (BS) can save their energies for data forwarding during the inter-cluster process.

[16] proposed a mobility-based communication technique to resolve the issue of network disconnections and lifetime enhancement in WSNs. The authors have summarized the existing work and introduced a new approach named trajectory-based mobile platform computation.

[17] proposed Dual Sink, a distributed and energy-efficient technique for data gathering in WSNs. This technique uses static and mobile sinks, where the mobile sink node broadcasts its location to its neighbor nodes when it stays at a particular location for some time.

[18] proposed a scheme to increase the network lifetime using controllable mobile cluster heads. Mobile CHs move toward nodes having high energy levels, and they collaborate with other CHs and BS to maintain their connectivity to obtain high PDR with less delay in data transfer. Their scheme provided a 40% improvement over existing routing protocols.

[19] proposed a novel energy-effective and reliable routing scheme by keeping source nodes and sink mobile in the network design that aims to combine features of cluster-based and hierarchical network structures. They introduced the concept of a CH panel to reduce re-clustering time by assigning one CH and two deputy CH nodes in each cluster.

[20] proposed a novel energy-efficient clustering-based routing scheme in a WSN with CH selection based on its RE, distance between a candidate node and BS, and nodes that have already become CHs. Each CH works according to its defined schedule using sleep- and TDMA-based transmission. Nodes transmit data toward CHs and BS in a multi-hop fashion. The transmission session terminates when the CH energy level falls to half of its energy amount.

[21] proposed connectivity restoration by clustering for mobile sensor networks to overcome the issue of link failure and energy exertion. They used the connectivity restoration using the clustering (CRC) technique, in which a simple recovery mechanism minimizes packet loss issues. They claimed that the CRC scheme restores connectivity efficiently compared to existing schemes.

[22] proposed delay-aware green routing for mobile sink-based WSNs to overcome the hotspot issue. They used the Green routing protocol to reduce energy overhead and delay data transfer at the sink when it broadcasts its location to its neighbors to inform them about its current position. Their scheme uses the concept of virtual infrastructure-based delay-aware routing that makes updating of mobile sink location limit and creates multiple rings in the sensing area. They claimed that DGRP outperforms existing schemes regarding throughput and energy consumption.

[23] proposed an energy-efficient cooperative routing scheme for heterogeneous WSNs. The authors have created various networks in a geographical environment where sensors initiate packet transmission for their network and other networks. They create dynamic routes based on the RE of the underlying nodes and their transmission direction. The node aggregates the packets when it receives the same ones from a similar node to save the delivering energy of the nodes.

[24] proposed an energy-efficient architecture for WSNs in healthcare applications using a quaternary transceiver as a sensor component to increase the

number of transmitted bits per symbol instead of a binary one. It reduces energy consumption due to multiple-bit transmissions at the same time. They claimed that it reduces 76.99% of energy consumption in neural network SRAM implementation in clustering-based systems.

[25] proposed an efficient tree-based power-saving scheme with a mobile sink to reduce the transmission distance between nodes. They created the network structure in a tree cluster manner. Distance between nodes and BS is calculated based on the location of BS, its RE, and the distance between other network nodes. Their proposed algorithm performs routing by efficient decision, extending the node lifetime by balancing the network load.

[26] proposed a network lifetime enhancement method for sink relocation and its analysis in wireless sensor networks. The authors used a moving strategy sink relocation idea and transmission range adjustment to save the energy of the sink.

5. Results and Discussion

5.1. Critical Analysis of HRGC

[27] proposed using HRGC to transfer data from source to destination in MWSNs considering a heterogeneous network with static sensor and mobile source nodes for evaluation. The denotation node is also static. The scheme works in two phases. In the first phase, the HRGC scheme constructs the route between static nodes using the skeleton graph construction protocol. It uses the well-known protocol WirelessHART [28]. In the second phase, mobile source nodes send data through a tree constructed with static nodes. However, this scheme has the following main limitations.

5.1.1. Data Communication Overhead

The authors of HRGC claimed that all mobile nodes send or receive packets every 4 seconds through all available routes to and from the gateway, which causes high communication overhead in the network, resulting in a low packet delivery ratio, high packet loss, and high energy consumption of nodes.

5.1.2. Grafting Mobile Nodes into the Skeleton Graph

As in the working process of HRGC, they construct the graph for mobile nodes on all static nodes in advance. It is impossible to define routes for mobile nodes in advance because nodes can move at any time at any location randomly, and the network will be in the grafting process all the time.

5.1.3. Route Failure Issue

The authors have not considered route or node failure issues after skeleton network construction or mobile node grafting in the network. If any node dies because of energy exhaustion after skeleton graph construction or mobile node grafting, no route reconstruction scheme is defined in HRGC.

5.1.4. Assumption of Mobile Nodes near Static Nodes

They have assumed that mobile nodes exist near static nodes, but this assumption is not valid for the mobility case because mobile nodes cannot remain in the range of all static nodes to remain connected with the latter.

5.2. Improved Routing Scheme

In this section, we propose an improved routing scheme (IRS) to overcome the limitations of the HRGC scheme. The IRS scheme works in two phases: static network construction and mobile node grafting in the IRS.

5.2.1. Static Network Construction

In the static network construction phase, each node broadcasts P-msg periodically at every T-time. On receiving P-msg, the sensor node will send R-msg based on information such as node ID, residual energy, and its location to the sender node. After completing the massage exchange process, each sensor node will generate its route information table (RIT). This RIT consists of information on nodes, such as node IDs, residual energy level, and location information, as shown in Fig. 1.

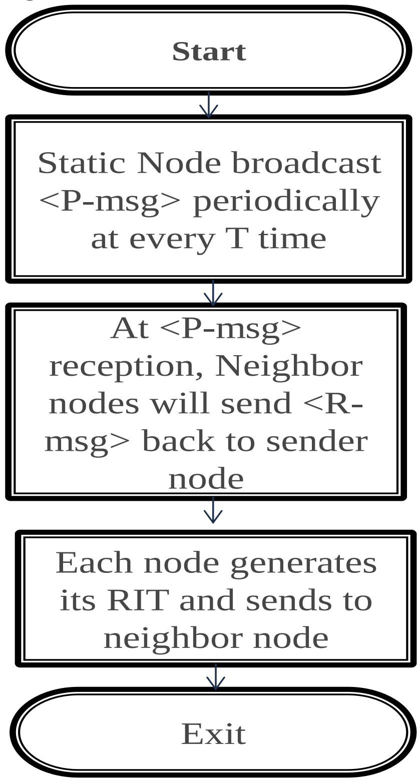

Fig. 1 Static network construction

5.2.2. Mobile Node Grafting in the IRS

In the mobile node grafting process, each node should update its routing table after a specified time t. All static nodes in the range of mobile nodes send P-msg after time T of each node. The mobile node selects the route for data packet transmission based on link weightage, as shown in Fig. 2. This link weightage is calculated based on residual energy and distance between source and destination nodes. Route with low weightage will be selected as an efficient route for data transmission, and if multiple nodes have equal link weightage, then the sender node will choose the route randomly.

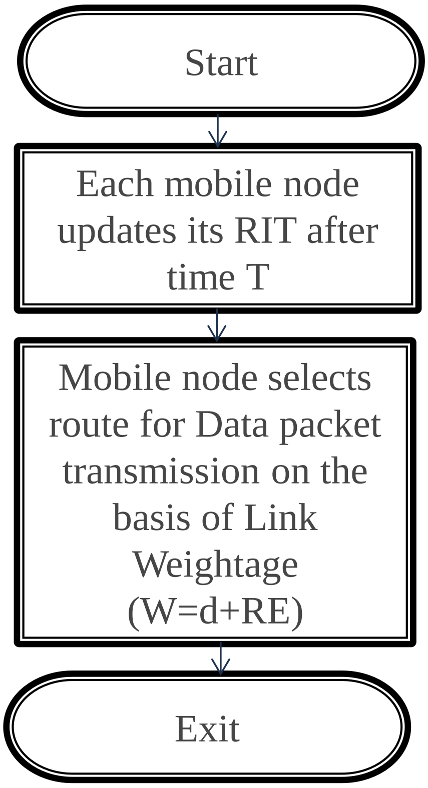

Fig. 2 Mobile node grafting

5.3. Theoretical Analysis of the IRS Scheme

Our proposed IRS scheme overcomes the limitations of HRGC as follows:

- Reduces communication overhead by sending data through the best route instead of all available routes.
- Makes it possible to calculate the best route based on the remaining energy of nodes. Thus, it increases the network lifetime.
- Provides less communication overhead, resulting in fewer packet collisions. Hence, it improves the packet delivery ratio and decreases packet loss.

6. Conclusion

Mobile sensor nodes are fundamental components of MWSNs. Due to the mobility of nodes, most MWSN-related research faces various issues, such as high communication overhead, connectivity, energy consumption, and data loss.

This research paper studied a recent work (HRGC scheme) proposed in MWSNs. We analyze the scheme and highlight the limitations of the scheme.

We have proposed an improved routing scheme to overcome the addressed limitations of HRGC. We analyzed our proposed IRS scheme theoretically and showed that our proposal overcomes the main limitations of HRGC by reducing communication overhead, packet loss ratio, enhanced PDR, and enhanced network lifetime.

Our proposed scheme can be implemented in any real-time application with involved mobility. This will provide the best path to send data between senders and sinks with less energy consumption, low communication overhead, and a high delivery ratio.

6.1. Recommendations and Future Work

Our ongoing work is on the implementation and experimental evaluation of our improved routing scheme by comparing it with HRGC and other schemes in practice. We also propose a route reconstruction scheme in case of node failure due to energy exhaustion, specifically after skeleton network construction and mobile node grafting. The proposed scheme's efficiency can be analyzed by finding the optimal ratio between static and mobile nodes while satisfying connectivity.

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