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Self-Healing Approach for Fault-Tolerant Data Aggregation in WSN

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ABSTRACT

Wireless Sensor Networks (WSNs) are prone to node failures and data loss, affecting their efficiency and reliability. This project proposes a self-healing approach for fault-tolerant data aggregation using SCR (Self-Clustering Routing) and SCR-DTRA (Self-Clustering Routing with Dynamic Trust and Recovery Aware) algorithms. SCR optimizes energy consumption through dynamic clustering, while SCR-DTRA enhances fault tolerance with trust-based node selection and adaptive recovery. These techniques improve data accuracy, fault recovery, and network lifetime, making WSNs more robust for real-time applications. The proposed method ensures seamless data transmission even in the presence of failures. Simulation results show significant improvements in network stability and energy efficiency compared to traditional approaches. This approach reduces data redundancy and enhances communication reliability. It is particularly useful for applications requiring continuous and accurate data monitoring. Additionally, it minimizes packet loss and optimizes resource utilization, ensuring a more efficient network.

Keywords : ANs, WSN,SCR and SCR-DTRA

I. Introduction

The ease of deployment of multiple wireless sensors and actuators networked together, makeswsnan attractive option for myriad application domains like environmental monitoring, surveillance, industrial automation, etc. wsns are increasingly being used as basic building blocks for iots. due to the multiplicity of sensor nodes deployed together, wsns possess inherent redundancy feature, making them an attractive low-cost option to develop a fault-tolerant and robust framework for a host of iot and smart cities applications .

However, in a bid to provide miniaturised hardware, the wireless sensors carry limited storage & processing capabilities, and battery-energy. while this limitation to a certain extent is offset through collective collaboration of sensor nodes, it involves exchange of large amounts data and control messages leading to high network traffic and data transmission energy costs. as result wsns encounter frequent disruptions due to node energy drain-out.

Clustering is a popular approach in wsns, where a set of closely located nodes are grouped together into a cluster. one of the nodes acts as ch to take care of all communication and data aggregation needs of the cluster nodes. the chs network together in a multihop topology to communicate the sensed signals to the root node or the base station (bs). however, in such multihop topology, the chs closer to the topology centre (root node) handle bulk of the communication and hence tend to deplete energy at a much faster rate than other Chs.

To ease the network traffic load, wsns resort to data aggregation, where an intermediary sensor node (also termed as aggregator node), instead of merely forwarding the data that it receives from its neighbouring nodes, aggregates the data, and forwards only an aggregate to its parent node.

this approach has led to the development of several data aggregation schemes that optimize energy consumption of sensor nodes through clustering and strategic selection of a cluster head (ch) to perform data aggregation in order to prolong the network life-time .

II. LITERATURE STUDY

System analysis is conducted to assess whether the system is adaptable to designing information based on organizational policies, strategic plans, and user requirements while addressing the limitations of the existing system. This chapter explores the current system, the proposed improvements, and key system requirements.

Several approaches have been introduced to tackle the issue by examining the maximum lifetime routing problem. This problem focuses on optimizing flow control and transmission **power** to extend the network's operational lifespan, which is defined as the time until the first sensor node depletes its energy. Various distributed algorithms, such as subgradient based and utility-driven techniques, have been proposed to address this challenge. However, a common assumption in these methods is that data flows remain constant throughout transmission from sensor nodes to the sink node. In reality, this assumption does not hold for WSNs since sensor nodes in close proximity often collect spatially correlated data.

A major drawback of these conventional approaches is that they tend to overburden nodes along the minimum-energy path, leading to rapid depletion of their energy. This is problematic in sensor networks, as all nodes work collaboratively for a shared objective, and failed nodes cannot always be replaced by others. Consequently, an efficient and fault-tolerant routing mechanism is required to ensure a balanced energy distribution and prolonged network functionality.

Drawbacks

- The existing approaches do not account for the temporary formation of WSNs, which can lead to increased transmission delays and higher energy consumption in relay nodes.
- When deployed in complex environments, these methods may experience reduced performance.
- Most of the proposed techniques modify traditional protocols, making future scalability difficult. Additionally, forcefully merging different architectures can result in inefficiencies and redundancy.

III. SELF-HEALING APPROACH FOR FAULT-TOLERANT DATA AGGREGATION IN WSN

While the failure of a cluster node may not drastically impact overall cluster performance, the failure of a **Cluster Head (CH) node** can have significant consequences. To mitigate this issue, new clusters and CHs are assigned after each round to handle faults. However, this method requires frequent network reconfiguration, which disrupts the data aggregation tree structure and alters precedence relations. To overcome this limitation, the **SCR** (Self-Clustering Routing) approach proposed in this study identifies alternative paths for affected nodes, allowing them to reconnect to the root component without requiring complete network reconfiguration. This ensures that the network tree structure remains stable while maintaining the necessary precedence relations.

A fundamental assumption in this approach is that the network graph remains connected, even when certain nodes become faulty. Based on this assumption, algorithms are designed to restore connectivity for disconnected dependents of failed nodes or clusters.

The primary goal of this study is to develop an efficient self-healing mechanism that can tolerate node failures without requiring additional resources. The proposed approach treats the network as a **root component tree**, which can fragment into subtrees when intermediate nodes fail. The developed algorithms establish **new** links between subtrees and the root component by reconfiguring neighboring nodes. This ensures that functional nodes continue to remain part of the root component, even if their parent nodes fail, while also preserving precedence relationships in the network.

Benefits:

- This mechanism can not only enable the relay to support the function of "store-carry-forward", but also switch to mode according to the change of network environment, thus reducing the transmission delay of the relay nodes.
- On the other hand, the energy consumption of nodes can also be saved. We add the relay mechanism to an active algorithm and make a simulation comparison.
- It is found that our mechanism can make the algorithm perform better in the case of restricted network.

SYSTEM FLOW DIAGRAM:

MODULE DESIGN

Convergence of the Distributed Algorithm :

The efficiency of the distributed SCR algorithm can be evaluated by examining the normalized aggregated data rate at the sink node across different network sizes. This data rate is adjusted relative to the optimal value obtained using the centralized SCR algorithm. Once again, it is evident that the distributed SCR algorithm effectively minimizes the data rate while maintaining approximation ratios below 105% of the optimal results produced by the centralized approach.

Routing Model :

The routing algorithm suitable for use belongs to the class of SCR-DTRA algorithm. Every sensor node is assumed to know its own position as well as that of its neighbors, which can be obtained with some localization schemes. Each node can forward packets to its neighbors within its transmission range that are closer to the sink node than itself.

Data Aggregation Model :

A salient feature of sensor networks is that data collected by the neighboring senor nodes may carry redundant information due to the spatio-temporal correlation characteristics of the physical medium being sensed such as the temperature and humidity sensors in a similar geographic region or magneto metric sensors tracking a moving vehicle. To remove the redundant information and reduce the traffic, it is necessary to aggregate the data at the intermediate nodes. To incorporate data aggregation with the geometric routing, we adopt the SCR-DTRA model.

IV. RESULT AND DISCUSSION

A high-quality output is one that aligns with the user's needs and presents information in a clear and understandable manner. In any system, the results of processing are communicated to users and other systems via outputs. The **output design** process determines how information should be displayed for immediate use, as well as in printed format. This is the most important and direct method of conveying information to the user. Effective and thoughtful output design enhances the system's ability to support **user decision-making**.

1. The design of computer outputs should be carried out in a systematic and thoughtful manner, ensuring that each output element is carefully developed. It's important that the output is designed in a way that makes the system easy and effective for users to interact with. During the analysis and design phase, it's essential to identify the specific outputs necessary to meet the user's requirements.
2. Choosing appropriate methods for presenting the information is key.
3. Creating documents, reports, or other formats to present information generated by the system.

Stage of Development of a System :

- Feasibility assessment
- Requirement analysis
- External assessment
- Architectural design
- Detailed design
- Coding
- Debugging
- Maintenance

Feasibility Assessment :

In Feasibility this stage problem was defined. Criteria for choosing solution were developed, proposed possible solution, estimated costs and benefits of the system and recommended the course of action to be taken.

Requirement Analysis :

During requirement analysis high-level requirement like the capabilities of the system must provide in order to solve a problem. Function requirements, performance requirements for the hardware specified during the initial planning were elaborated and made more specific in order to characterize features and the proposed system will incorporate.

External Design :

External design of any software development involves conceiving, planning out and specifying the externally observable characteristic of the software product. These characteristics include user displays, report formats, external data source and data links and the functional characteristics.

Internal Design Architectural and Detailed Design :

Internal design involved conceiving, planning out and specifying the internal structure and processing details in order to record the design decisions and to be able to indicate why certain alternations were chosen in preference to others. These phases also include elaboration of the test plans and provide blue prints of implementation, testing and maintenance activities. The product of internal design is architectural structure specification.

The work products of internal design are architectural structure specification, the details of the algorithm, data structure and test plan. In architectural design the conceptual view is refined.

Detailed Design :

Detailed design involved specifying the algorithmic details concerned with data representation, interconnections among data structures and packaging of the software product. This phase emphasizes more on semantic issues and less synthetic details.

Coding :

This phase involves actual programming, i.e, transacting detailed design into source code using appropriate programming language.

Debugging :

This stage was related with removing errors from programs and making them completely error free.

Maintenance :

During this stage the systems are loaded and put into use. They also get modified accordingly to the requirements of the user. These modifications included making enhancements to system and removing problems.

V. CONCLUSION AND FUTURE ENHANCEMENT

An optimized routing and data aggregation strategy has been developed to maximize the network lifespan of sensor networks. By leveraging the unique structure of the sensor network, an SCR smoothing approximation function is introduced to address the **non-**differentiability of the original optimization problem, enabling a distributed solution. The optimality conditions have been established, leading to the design of a corresponding distributed algorithm. The proposed approach effectively minimizes data traffic while significantly enhancing network longevity. Additionally, the distributed algorithm demonstrates efficient convergence to the optimal value.

SCOPE FOR FUTURE ENHANCEMENT

The results of physical experiments show that the scheme is achievable, which will encourage our future work, such as identifying different types of data packet applications, further refining the processing priority, and selectively discarding instant messaging (real-time communication) in order to collect more effective data, we will continue to expand the scale of the experiment by increasing the number of relays.