Hybrid Multi-hop Data Transfer Modelling in Wireless Sensor Network for Bridge Structural Health Monitoring System

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***Abstract*— Static itinerary planning is a commonly employed multi-hop itinerary planning method in wireless sensor networks (WSN) due to its commendable energy efficiency and ability to minimize overhead. However, this approach lacks reliability due to the possibility of inactive sensor nodes in the WSN throughout the multi-hop process. This research presents a hybrid multi-hop strategy that combines static itinerary planning with dynamic adjustment. In the event of a malfunctioning sensor during the multi-hop procedure, data transfer can persist until it reaches the sink node. Our model integrates the benefits of utilizing a genetic algorithm for static route planning and making dynamic adjustments to ensure network functionality, even in the case of node failures during data transmission. This hybrid strategy provides reliable and robust data collection by overcoming the constraints of conventional static methods, which are vulnerable to disruptions when nodes are not reachable. Furthermore, a peak detection technique is employed to specifically process the incoming vibration data produced by the bridge, thus ensuring the collection of accurate and unambiguous data for FFT analysis. The experimental results demonstrated that, despite the hybrid model's somewhat longer processing time compared to the static method, it significantly improves the network's ability to rapidly recover and maintain consistent performance. This effectively ensures uninterrupted data transmission and processing even in the event of node failures.**

Keywords*— *Static itinerary planning, in-network processing, wireless sensor network (WSN), hybrid itinerary planning, dynamic adjustment.

I. Introduction

Real-time structural monitoring is possible with the Structural Health Monitoring System (SHMS) [1]. The design of SHMS allows for continuous evaluation of structural integrity, which aids in identifying or predicting damage and simultaneously generates periodic reports on the structure's condition [2]. SHMS have been widely employed in bridges, towers, and other public infrastructure to reduce possible hazards and enhance structural efficiency [3]. Wireless sensor networks (WSN) can facilitate the monitoring process on SHMS by being more cost-effective than cable-based sensor networks [4]. For Bridge Structural Health Monitoring (BSHM), a series of accelerometer-based WSNs can be installed on the right and left sides of the bridge, which will measure the structural integrity of the bridge when a heavy vehicle crosses it [5].

WSNs are a type of network system that employs wireless sensor nodes to monitor many aspects of the surrounding environment [6]. Since WSN consists of sensor nodes, sink nodes, communication protocols, and power supplies that frequently run on batteries, energy savings have become crucial [7]. Smart cities, structural building, and environmental monitoring are among the fields that have implemented the WSN [8], [9], [10]. Network Data Flow (NDF) is the process by which data is transmitted from source nodes to a specific destination inside a WSN. The three variants of NDF are centralized [11], local processing [12], and cluster-based [13]. Centralized NDF entails the presence of a central node, also known as the sink node or base station, which is tasked with the collection, processing, and supervision of data from all sensor nodes in the network [11]. Local processing involves the examination and manipulation of data at the sensor node's level before it is transmitted [12]. The last one is derived from the process of clustering. During the clustering procedure, every zone designates a master node, known as the cluster head (CH), to gather data from all the nodes and transmit it to the base station or sink node [13].

Recently, there has been a significant amount of studies focused on utilizing WSN for SHM. In 2024, researchers concentrated on developing user-friendly, wireless, durable, and cost-effective systems for alerting and monitoring the structural health condition of IoT-based bridges [14]. In 2022, a scholarly publication released research that examined a real-time BSHM system capable of data collection and analysis in close proximity to data sources [15]. In the same year, a research study proposes a low-power multi-hop wireless sensor network that is well-suited for monitoring extensive civil infrastructure [16]. In 2020, an academic work presented a novel idea for an event-based sensing system. This system employs an ultra-low-power microcontroller equipped with a configurable event-detection mechanism [17]. In 2019, a research publication introduced a sustainable vibration system named ECOVIBE. When a train passes over a bridge, this system is automatically activated utilizing sensor technology that operates when needed, and it smartly stops functioning once all tasks are completed [18]. Prior research has identified several challenges associated with the use of WSN, such as energy consumption, delay, scalability, network reliability, and fault tolerance. WSN is commonly deployed in off-grid settings where battery replacement is not feasible [19]. Furthermore, the rapid transfer of data is essential for promptly resolving structural concerns [20]. Within the framework of SHMS, a considerable quantity of sensor nodes is required to cover a vast expanse [21], thereby increasing the