Pilot Agent-Driven Wireless Acoustic Sensor Network for Uninterrupted Data Transmission

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Abstract — Wireless acoustic sensor networks (WASN) usually demand uninterrupted and reliable data transmissions and an efficient path from the source nodes to the destination nodes, thus ensuring reliable delivery of sensitive or critical data with the use of multipath routing protocols. This paper presents a novel agent-driven WASN relying on a set of static and mobile agents. In the proposed technique, the location address is functioned into the operating node and the destination node. Calculations of the midpoint between the operating and the destination nodes are followed by identifying the shortest path based on a reference axis, using a mobile agent and a location address. Such an approach aims to ensure maximum utilization of the communicating paths. Based on the information concerning partial topology of the network, the destination node computes the weight factor and multiple paths using node distances, energy ratios and efficiencies of specific links. Then, the destination node selects the appropriate path from the multiple paths available, to transmit the data. This article also analyzes the performance of the proposed system with various parameters taken into consideration and shows its efficiency in comparison to other existing techniques.

Keywords — agent technology, audio signal, multipath routing, partial topology, WASN

1. Introduction

Sensor nodes used in wireless acoustic sensor networks (WASNs) have the ability to sense, compute, and communicate wirelessly. They can communicate with one another, or with the destination node, using multi-hop communication to acquire data on a regular basis and relay it to the destination node [1]–[5]. The use of traditional audio data collection and processing techniques in WASNs could potentially result in undesired issues, such as excessive energy consumption, high latency, redundant data transfers, and bandwidth overhead. The lifespan of WASNs is also crucial, as such networks rely primarily on the battery power of several nodes [6].

In WASNs, the multipath routing strategy has recently gained popularity as a means of increasing predictability of data transmissions, while also enhancing performance of the network. The routing protocols are categorized into 3 groups: flat, hierarchical, and location system-based. Depending on how what their operating principle is, these protocols are further divided into QoS-based, multipath-oriented, and negotiation-oriented routing strategies.

Data reporting, fault tolerance, node heterogeneity, scalability, network coverage, and connectivity are just a few examples of routing-related difficulties encountered in WASNs [7]–[9]. In WASNs, the transmission cost measure frequently exceeds the computation cost by several orders of magnitude. In the routing phase, the collected audio signal and control messages are transmitted from one node to another along their way to the final destination, and such an approach uses a lot of energy. Consequently, a variety of routing methods have been developed to save energy and boost the lifespan of sensor nodes. The high density of sensor nodes and the limited communication range necessitates the adoption of multi-hop data transmission strategies for packet forwarding. Paper [10] presents a multipath routing approach using Bezier curves to forward data between a specified pair of nodes (destination and source). Such a solution aids in balancing the load between the relay nodes in order to increase the lifespan of the entire wireless sensor network.

Agent technology is emerging as a new paradigm in artificial intelligence and machine learning, enabling the development of complex software characterized by such properties as flexibility, scalability, customization, and reduced network traffic, as presented in [11], [12]. Agents are autonomous programs that perceive their surroundings and use that information to take appropriate action [13]–[15].

This paper proposes a novel agent-driven WASN which uses a collection of static and mobile agents. In this system, the addresses of operating and destination nodes are assumed. The midpoint value is calculated considering the operating node and the destination node. Mobile agents are replicated from an operating agent taking into account various pieces of information, such as type of the operation, details of the path passing through intermediate nodes, location address, node address, bandwidth availability and connectivity of neighboring nodes, and deliver this information to the destination node.

The article is structured as follows. Section 2 contains a literature review aiming to identify the problem domain. Section 3 deals with the proposed methodology and architecture. Section 4 demonstrates the experimental simulation setup and compares various solutions based on different parameters. Finally, Section 5 concludes the paper.

2. Literature Review

Paper [16] presents a low interference energy-efficient multipath routing protocol to enhance QoS demands of event-driven applications. Network lifetime is maximized by ensuring balanced consumption of energy among nodes containing sensors, based on parameterized probability defined in [17]. Depending on a number of factors, including the distance from the intermediate node to the destination node, and the residual energy of the intermediate node, various types of data generated at an identical sensor node may potentially lead to the establishment of alternative transmission routes. Additionally, while choosing the final path, consideration is given to multipath balance, depending on the amount of energy used by neighboring nodes.

The secure multipath routing technique is proposed in [18]. "K-connectivity", expanded to "k-x-connectivity", is discussed there, where x represents the threshold value, signifying the maximum number of nodes shared between any two links from a set of k established links. This protocol is based on the demand routing approach that carries the threshold via a label in the datagram that is transmitted during route discovery. Paper [19] describes a method for identifying different routes between multiple sources and destinations to decrease the number of collisions. It uses a widespread placement of sensor nodes harnesses to look for divergent routes for several source nodes, with collision prevention being the final goal.

Article [20] presents a node-based disjoint multipath routing algorithm for WASNs that is of the energy-efficient and collision-aware type (EECA). The algorithm uses the location data to define two collision-free paths utilizing limited and power-adjusted floods, and then uses the protocol's power management component to send the data with the least amount of power necessary. In order to find multiple disjoint pathways between the destination and the originating node, a distributed, flexible, and localized multipath search protocol is provided in [21]. Multiple node-disjoint pathways can be identified by using the distributed multi-path routing approach. The load balancing algorithm seeks to distribute the flow of traffic to each path as efficiently as possible.

When building pathways, the REER algorithm proposed in [22] predicts the optimum next hop using the remainder of energy, the size of the usable buffer and the signal-to-noise ratio. Two traffic allocation strategies are examined. The first strategy transfers the data message along one route chosen from among all those found, switching to the following alternative route when the cost of that path drops below a predetermined threshold. The other technique involves breaking up the sent message into a number of equal-sized segments, adding XOR-based error-correcting codes, and then sending it down several different pathways.

Paper [23] shows a multipath routing technique for WASNs that consumes relatively little energy. This protocol aims to maximize battery lifespan by relying on the battery relaxation technique, thereby extending the entire lifespan of the sensor network.

In order to maximize throughput, reduce packet end-to-end delay, and balance energy consumption among numerous nodes, data is routed through various pathways. Hazard-aware multipath reliable routing techniques are presented in [24], as multipath non-agent and agent-based routing approaches. Numerous sensors are taken into account by the algorithms, including environmental factors.

3. Proposed Technique

In the proposed technique, some key components are taken into consideration, such as the operating node, the rising and falling angles, midpoint, node count, and agents. The operating node is used to detect the first transmission attempt. This node is triggering the process of discovering the route to the destination node. Each time, a random node is used as an operating node and informs the remaining nodes about exercising control, to prevent other nodes from gaining access as well. The angle between the operating node and the intermediate node, over and below the reference x axis, is called the rising angle and falling angle, respectively. Midpoint connects the operating node and destination node using a straight line. Intermediate nodes are placed either upon or below the midpoint. The total number of intermediate sensor nodes between the operating node and the destination node is called a node count. Generally, single agent and multi-agent systems are two different categories of agents. To carry out a certain task, a single agent interacts with resources, people, and other processes in single agent systems. Multi-agent systems are made up of a group of agents that work together to accomplish a variety of objectives through communication, cooperation, and coordination. Multi-agent systems are called mobile agents, as they move throughout the network and communicate with one another to complete the tasks [25].

3.1. Proposed Architecture

Figure 1 shows a network-oriented environment of the proposed scheme. Here, several sensor nodes are available and have the ability to sense audio data, with the nodes being

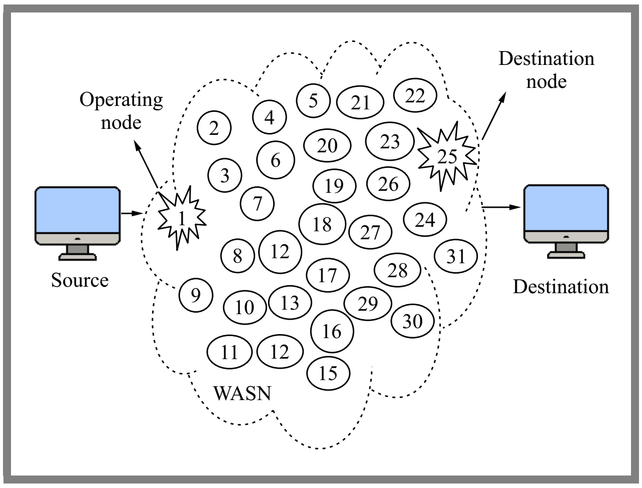

Fig. 1. Network configuration of the proposed system.

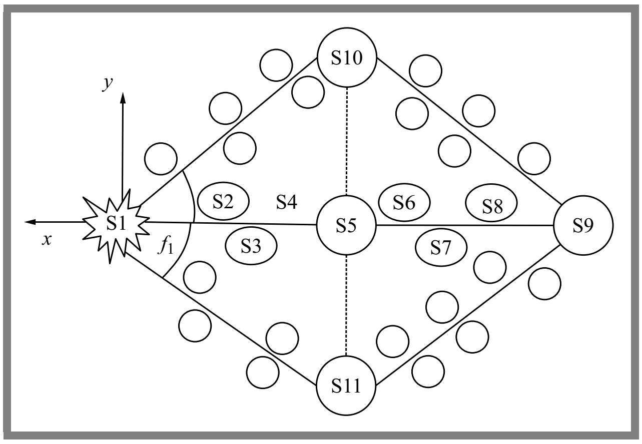

Fig. 2. Partial multipath discovery using the multipath routing topology in WASN.

distributed in a heterogeneous manner. From among the sensor nodes, based on the data transmission request, one node is dynamically selected as the operating node, and another is identified as the destination node using WASN multi-hop communication. It is assumed that all sensor nodes are dynamic in nature, some of them are also GPS enabled [26], [27] and establish the route using localization. The technique decreases the cost of the proposed system simultaneously generating the node's position and movement using GPS, thus achieving sub-centimeter levels of accuracy [28].

The proposed methodology is based on calculating such path- or route-related factors like efficiency, energy rate, and node distance. Cap is the capacity of a given channel, E_I is the total amount of energy consumed while transmitting one bit of data using link I, B is the bit rate of a given channel [29]. The capacity of channel I is measured by:

$$Cap_I = B \log_2(1 + \text{SNR}) \, . \tag{1}$$

The E_I parameter is calculated as:

$$E_I = E_T \cdot d \, , \tag{2}$$

where E_T is the total amount of energy consumed while transmitting data over distance d.

Link efficiency L_{eff} is computed by [30]:

$$L_{eff(I)} = \frac{Cap_I}{E_I} \, . \tag{3}$$

Based on the consideration of n number of links along the path, the path's efficiency is calculated using:

$$P_{eff} = \text{Minimum}\left[L_{eff(1)}, L_{eff(2)}, \ldots, L_{eff(n)}\right] . \tag{4}$$

In every path, the energy ratio from the operating node to the destination node is denoted as $ER(1)$, $ER(2)$ etc. up to the n intermediate node. The minimum and maximum energy consumption for the number of intermediate nodes n is calculated using Eqs. (5) and (6):

$$ER_{min} = \text{Minimum}\left[ER(1), ER(2), \ldots, ER(n)\right] , \tag{5}$$

$$ER_{max} = \text{Maximum}\left[ER(1), ER(2), \ldots, ER(n)\right] . \tag{6}$$

Also, the energy efficiency of a given path is computed as:

$$E_{eff} = \frac{ER_{min}}{ER_{max}} \, . \tag{7}$$

The node distance factor ND_f of a path is calculated using Eq. (8). P_d denotes the Euclidean path distance from the operating node to the destination node, while P_{nc} is the total number of nodes from the operating node to the destination node:

$$ND_f = \frac{P_d}{P_{nc}} \, . \tag{8}$$

Figure 2 shows the process of discovering multiple paths from the operating node S1 to destination node S9, using the partial topology technique. Sensor nodes S2, S3, S4, S5, S6, S7, S8 and S9 are situated at a 0° angle relative to the x axis. S5 is the mid-point node and S10 and S11 are intermediate nodes that are perpendicular to the reference value of the x axis. The operating node identifies the mid-point location of S4 using Eqs. (9), (10), where (X_o, Y_o) and (X_d, Y_d) are data concerning the location of the operating node and the destination node, respectively.

$$X_{midpoint} = \frac{X_d + X_o}{2} \, , \tag{9}$$

$$Y_{midpoint} = \frac{Y_d + Y_o}{2} \, . \tag{10}$$

The locations of intermediate nodes S10 and S11 are ($X'_{midpoint}$, $Y'_{midpoint}$) and ($X''_{midpoint}$, $Y''_{midpoint}$) respectively.

$X''_{midpoint}$ = $X'_{midpoint}$ =$X_{midpoint}$ because all of them are perpendicular to the x axis. Hence, midpoint values of the y axis have to be calculated using:

$$Y'_{midpoint} = n \cdot R + Y_{midpoint} \, , \tag{11}$$

$$Y''_{midpoint} = Y_{midpoint} - n \cdot R \, , \tag{12}$$

where n is the degree of nodes, R is the range among nodes. The rising and falling angle is calculated as:

$$\theta_{r1} = \text{tg}^{-1}\left[\frac{Y'_{midpoint} - Y_o}{X'_{midpoint} - X_o}\right] , \tag{13}$$

$$\theta_{f1} = 2\pi - \theta_{r1} \, . \tag{14}$$

3.2. Operating Node Management

The operating node is managed based on a node information agent (NIA), a path finding agent (PFA) and a multipath routing database (MRDB) used to store information about communication between several agents. Figure 3 shows the complete flow of managing an operating node.

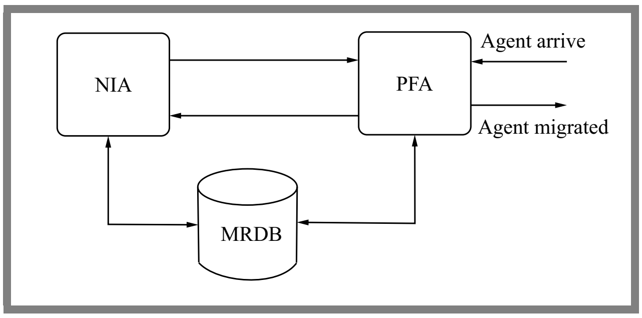

Fig. 3. Management of operating nodes – working flow diagram.

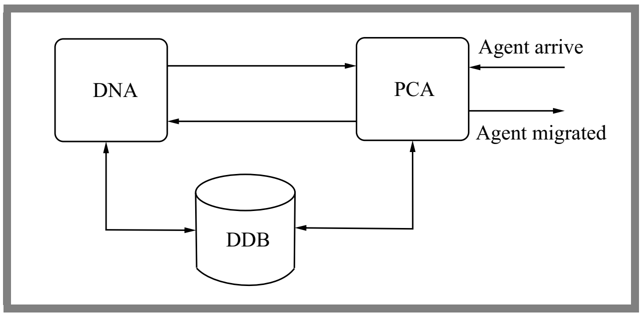

Fig. 4. Management of destination nodes – working flow diagram.

3.3. Destination Node Management

Figure 4 shows the process of managing a destination node, comprising a destination node agent (DNA), a path construction agent (PCA) and a database that stores information about the communication between multiple agents – destination database (DDB). The specific steps taken while relying on the proposed technique are as follows:

1. Initiate path construction scheme. When a data transmission occurred in the operating sensor node, NIA starts the scheme of constructing a path to the destination node.

2. Agent initiation. NIA initiates PFA, that replicates three copies of PFA.

3. Traverse nodes. These PFAs travel until they encounter the destination node and the intermediate nodes, respectively.

4. Disjoint multipath estimation. DNA of the destination node then estimates the disjoint multipath of the originating node. Then, it prepares a list of priority paths based on the path weight factor of each disjoint path.

5. Best path selection. After that DNA handover the access to PCA to consider the best path.

6. Alternative path selection for uninterrupted transmission. If the required data travel path may be altered for obtaining better (i.e. uninterrupted) transmission of data.

4. Experimental Setup

Matlab and the C programming language have been used to simulate the proposed scheme for various network scenarios and test their performance. The authors' approach is compared with the existing multipath routing scheme from [24]. This part presents the performance parameters and the analyzes the results obtained. For WASN, an area of $l \cdot b$ is taken. N static nodes that are positioned randomly within a specific area make up the network. For media access, the S-MAC protocol [31] is employed. Propagation constant b is utilized with the free space propagation concept. The R parameter is the WASN node's transmission range across a single step distance. Table 1 shows the simulation parameters. Arrival of traffic is judged based on the appearance of packets within a specific time period. Traffic volume relies on traffic intensity, size of packets and the intervals between packet arrival times [32].

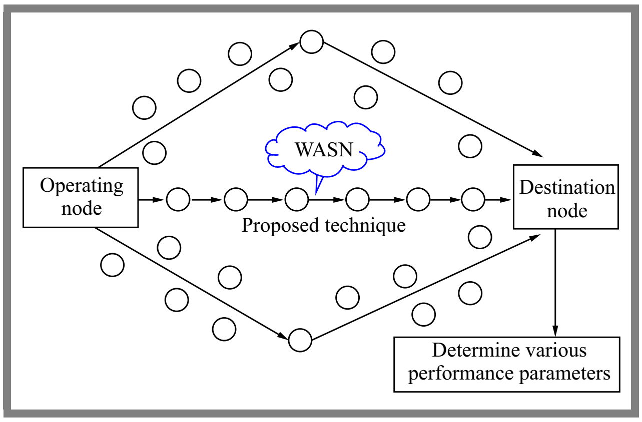

Fig. 5. Diagram of the network used in the simulation process.

Tab. 1. Simulation parameters used to analyze the proposed system.

Parameter	Value
Length l	4000 m
Width b	4000 m
Number of nodes N	160
Transmitted node N_t	20 to 160
Sensor node communication range R	300 to 500 m
Threshold value for the rising angle θ_{rth}	0 to 5°
Threshold value for the falling angle θ_{fth}	0 to 5°
Bandwidth per node BW	3 Mbps
Sensed data capacity of each node D_s	4 Kbytes
Initial energy of sensor node E_I	1 kJ

4.1. Simulation Process

The simulation process is shown in Fig. 5. Initially, a WASN-based network environment is developed and a sensor node is selected to serve as the operating node (depending on the task to be performed) that transmits topology-related information to the destination node using the multipath routing technique. Various performance metrics evaluated during the performance analysis are listed below.

- packet delivery ratio – the ratio of received packets to transmitted packets,
- latency – the total amount of time it takes to transfer data from the operating node to the destination node,
- energy consumption – the total amount of energy used for identifying and setting up a path and for transmitting data from the operating node to the destination node,
- overhead – the additional code that obtains the communication channel,
- path count – the total count of disjoint paths between the operating node and the destination node, also referred to as the number of paths.

4.2. Packet Delivery Ratio

Figure 6 shows the rate of the delivered packets. For both the existing and the proposed method, the PDR rises along with an increase in the number of transmitting nodes and decreas-

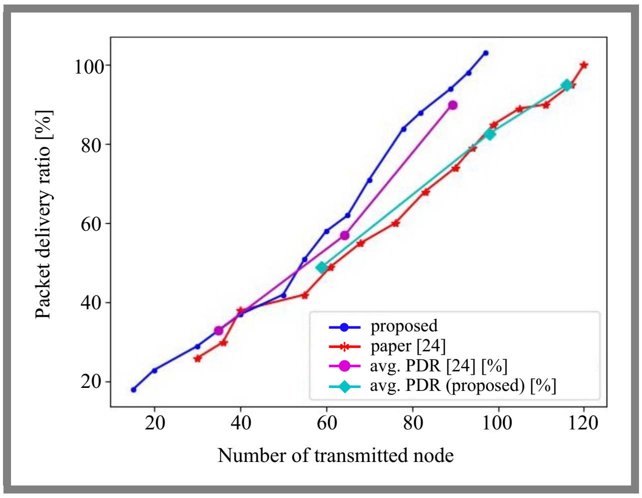

Fig. 6. Packet delivery ratio, in percentage rate, when communicating over a distance of 400 m.

es with an increase in the communication range. However, comparing to ABMR [24], the proposed system shows better a PDR result. This technique takes link efficiency into account in order to accurately compute the path. Hence, it offers better bandwidth availability than the existing technique. As fewer isolated nodes are available in the proposed system, PDR is better for transmitting packets over long distances. Table 2 presents a comparison of numerical PDR data for the proposed and the existing technique [24] used to transmit audio data via a WASN. It also shows the average PDR percentage rate with respect to the number of transmission nodes.

4.3. Energy Consumption

The amount of energy used vs. the number of transmitted nodes and the transmission range is shown in Fig. 7. Consumption of energy rises in both the existing and the proposed techniques with the number of nodes and the communication range. Compared with the existing technique, the proposed system performs better. It uses the partial topology approach, the node distance factor and energy efficiency-related information while calculating paths, to reduce energy consumption.

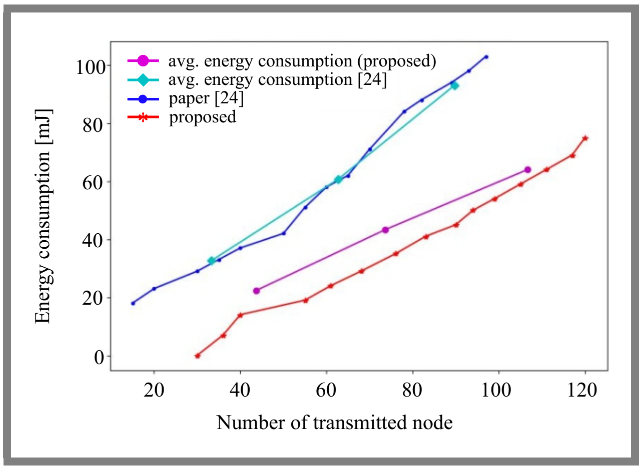

Fig. 7. Energy consumption when communicating over a distance of 400 m.

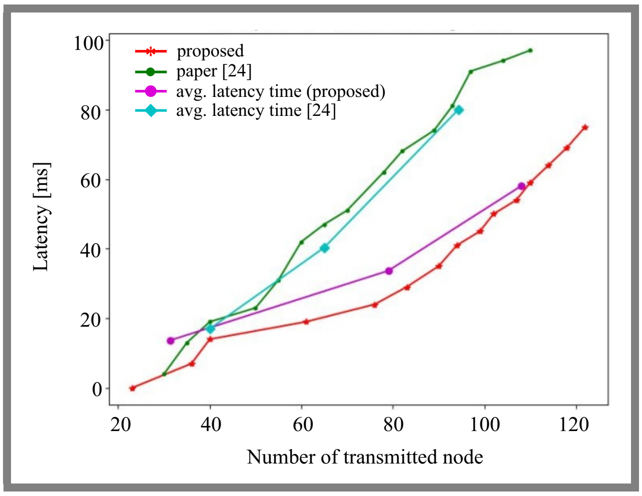

Fig. 8. Comparison of latency when communicating over a distance of 400 m.

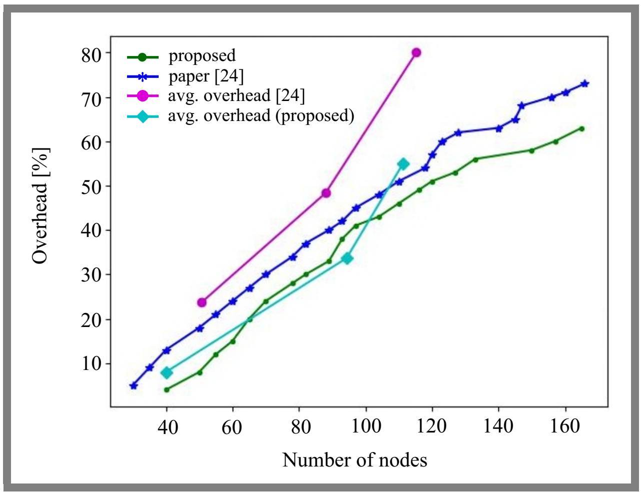

Fig. 9. Comparison of overhead when communicating over a distance of 400 m.

4.4. Latency

Latency for a specified number of transmission nodes and a given communication range is depicted in Fig. 8. The time needed to accumulate and determine the numerous disjoint

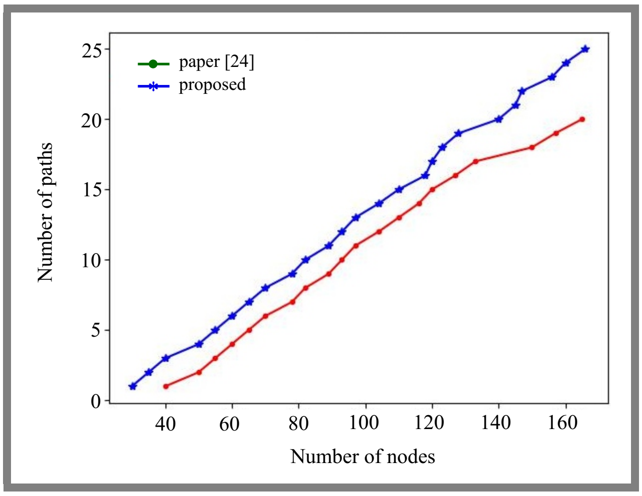

Fig. 10. Path count comparison.

Tab. 2. Comparison of packet delivery ratios based on the transmitting node.

Technique	No. of nodes	No. of nodes (avg.)	PDR [%]	Avg. PDR [%]
Paper [24]	30	62.9	29	60
	35		33	
	40		37	
	55		42	
	60		58	
	78		71	
	82		84	
	89		88	
	97		98	
Proposed	40	91	38	75.6
	61		49	
	76		60	
	90		74	
	99		85	
	105		89	
	111		90	
	117		95	
	120		100	

Tab. 3. Comparison of the amount of energy consumed based on the transmission nodes count.

Technique	No. of nodes	No. of nodes (avg.)	Energy consumption [mJ]	Avg. energy consum. [mJ]
Paper [24]	20	61.3	14	62.14
	35		33	
	50		42	
	60		58	
	78		84	
	89		94	
	97		101	
Proposed	36	80.3	14	44.29
	55		24	
	68		35	
	83		45	
	94		54	
	109		63	
	117		75	

paths will increase together with the number of transmitting nodes and the distance over which the communication takes place. The determination of pathways with the use of the proposed system requires less time than [24]. The existing technique relies on full topology information, whereas the proposed technique uses only partial topology information to determine the pathways, thus reducing latency.

Table 4 compares latency and average latency based on the number of transmission nodes.

Tab. 4. Comparison of latency based on the number of transmission nodes.

Technique	No. of nodes	No. of nodes (avg.)	Latency time [ms]	Avg. latency time [ms]
Paper [24]	30	67.3	9	49.43
	40		19	
	55		31	
	65		47	
	78		62	
	93		81	
	110		97	
Proposed	23	79	7	35.43
	40		14	
	76		24	
	90		35	
	99		45	
	107		54	
	118		69	

Tab. 5. Comparison of overhead based on the number of nodes.

Technique	No. of nodes	No. of nodes (avg.)	Overhead [%]	Avg. overhead [%]
Paper [24]	40	92.86	14	51.14
	78		26	
	89		31	
	97		47	
	110		62	
	116		81	
	120		97	
Proposed	30	81	2	34.143
	40		7	
	70		20	
	93		45	
	104		51	
	110		54	
	120		60	

4.5. Overhead

Figure 9 shows the overhead for data communication with a specified number of nodes and a given communication range. As the transmission range and the node count increase, the overhead rises as well. In comparison with the former technique, the proposed approach offers a lower overhead due to the fact that agent's movements in limited directions are required to obtain partial topological information, which reduces the number of transmissions needed to discover the multipath.

Table 5 illustrates the comparison of overhead and average overhead based on the number of nodes and range of communication.

4.6. Path Count

Figure 10 shows the number of disjoint pathways in the proposed system which are feasible given the network's node count and the range of communication. One may notice that an increase in the number of nodes causes an increase in the number of disjoint pathways for a given communication range. Agents are moving in three separate directions to gather data from neighboring nodes.

5. Conclusion and Future Scope

The proposed approach demonstrated a pilot agent-based WASN relying on a discontinuous multipath routing technique. It also enabled to determine a unique intermediary (dynamically), partial topology and the path weight factor. The proposed approach is characterized by better efficiency when compare with similar existing techniques, as well as by better PDR for long distance transmissions.

In the future, the solution's performance will be enhanced further by increasing the size of the WASN network and deploying other techniques tuned to account for the characteristics of specific audio signals.

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