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T-Tracking: An Energy-Aware Distributed Approach for Face-Based Target Monitoring

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ABSTRACT

In monitoring applications, detecting and tracking targets within mobile Wireless Sensor Networks (WSNs) is a critical and challenging task. This paper introduces a novel distributed tracking framework, known as Target Tracking (T-Tracking), designed to enhance monitoring accuracy while optimizing energy efficiency. The framework focuses on a specific concept termed the polygon face, where nodes are grouped based on their ability to communicate within defined boundaries. Within each polygon face, the brink detection algorithm is employed to identify edges formed by node pairs that offer the highest coverage. To ensure energy-efficient operation, nodes are dynamically selected based on their energy levels and sensing capabilities using a decentralized decision-making process. The proposed system effectively addresses common challenges such as coverage gaps, node failures, and energy depletion. When a target moves beyond the current coverage area or when monitoring nodes approach low energy levels, the tracking system activates a query mechanism to identify the optimal replacement node. This selection is based on a comparative evaluation of energy reserves and sensing range, ensuring continuous and reliable monitoring. By selecting the most suitable node in real-time, t-Tracking maintains high tracking quality (QoT), minimizes communication overhead, and extends the overall network lifetime. The framework is particularly beneficial for applications in surveillance, security, and mobile object tracking in complex environments.

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1. INTRODUCTION

A group of nodes in an interconnected network constitutes a distributed system of wireless detectors. An RF transceiver (usually with a single unidirectional antenna), computing power, multiple storage space forms (programmed, information, and flash memory), an energy source (such as batteries and solar cells), and the capacity to support a variety of sensors and actuators are all included inside every node. After being deployed in an ad hoc manner, the nodes interact wirelessly and often self-organize. 1000s or even 10,000 node systems are expected. The way of living and working can be revolutionized by such systems. Sensor networks that are wireless are now being deployed at an accelerated rate. It would be reasonable to expect autonomous sensor networks involving Internet connectivity to cover the entire world in 10-15 years. This can be regarded as a physical network becoming the Internet. This new technology is intriguing and has limitless application possibilities in a variety of industries, including biological, health, the soldiers, transport, entertainment, crisis management, national defense, and intelligent spaces.

Because an interconnected real-time framework is characterized by wireless sensor networks [5], one natural question is which options can be employed in these novel structures derived from scattered and real-time systems. Unfortunately, in many aspects of the system, little past research can be implemented, necessitating the development of new solutions. The primary reason is that there has been a dramatic change in the set of assumptions underlying a prior job.

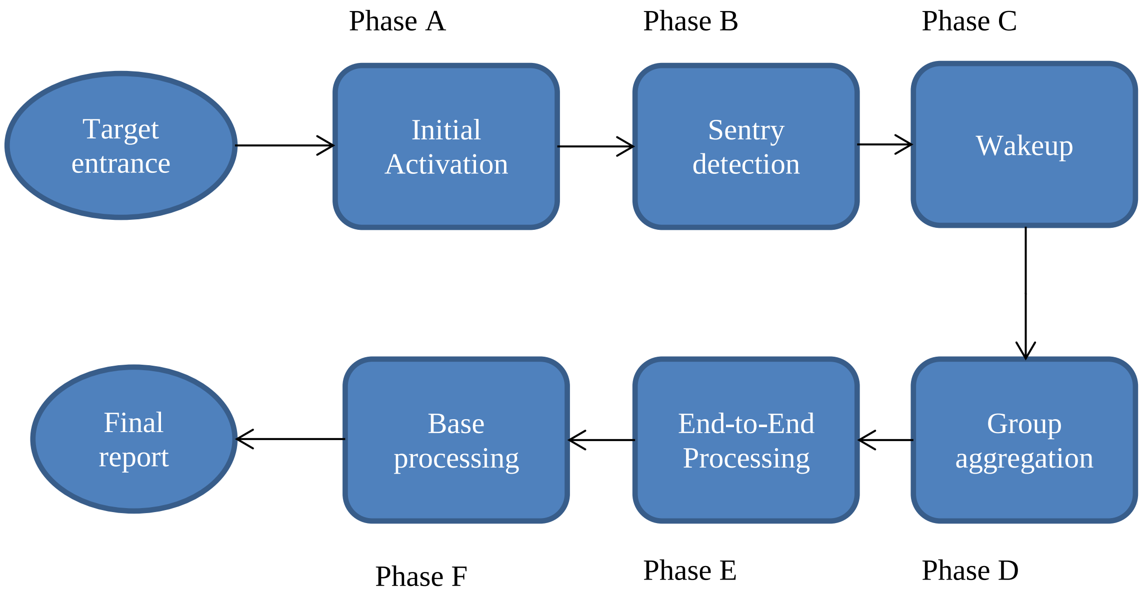

Figure 1. Breakdown tracking operation

The first sensor node that can confirm the detection is triggered when a target enters the area, as seen in Figure 1. Subsequently, other surrounding nodes are roused to form a group that will give the aggregated reports to the base.

Prior studies on distributed systems assumed that the systems were location-independent, connected, had infinite power, weren't in real-time, had user-facing devices like mice and monitors, had a fixed number of materials, and treated every point in the architecture as extremely important. However, for smart sensor networks, the devices are typically mobile, have limited energy, work in real-time, use both sensors and actuators as interfaces, have asset sets that are always changing, require collective behavior, and positioning is crucial. Low-capacity equipment is also a common feature of smart sensor systems, which further stresses the ability to employ previous methods.

2. LITERATURE REVIEW

A recipient is an affordable instrument for detecting and recording changes in the environment. Typically, it can detect, compute, and communicate. A wireless sensor network (WSN), which is made up of several sensors, may be utilized to efficiently examine wide areas. These sensor nodes are ad hoc wireless networks that are connected to the principal server (sometimes referred to as the sink) via one or more basin nodes that act like collection points and bridges. Every link in the network has the ability to generate information on a regular basis, either at the sink's request or in response to noteworthy events.

At the same moment, each node can transmit the information it gets to sink nodes, often numerous hops away. WSNs are increasingly intended to collect information from geographical fields of concern, such as physical or environmental characteristics. Numerous fields, such as military security (like battlefield observation), conservation efforts (like wildlife observing), technological tracking (like machining facility tracking), health care monitoring, employee monitoring, home automation, and more, use WSN applications. The monitoring of mobile objectives is one of the most significant fields where the benefits of WSNs can be utilized. Systems for monitoring mobile targets have grown in popularity because of their importance in the use of WSNs, which are wireless sensor networks, for monitoring applications. Sensors used in surveillance devices can deduce kinematic characteristics such as location, speed, and acceleration for either one or several interest objectives.

Quality of Tracking: The motions of a goal apply only to local fields and for a brief period in many comparable practical situations. This means that such a situation involves quick tracking and elevated tracking quality (QoT) as well. This QoT can serve as the quality of service (QoS) in a monitoring scheme. On the one hand, it becomes cost-effective to use sensor nodes that are already organized in local communities to monitor a destination before the system begins monitoring, as opposed to changing clusters or plants. Considering the primary monitoring connection on the server is not involved in such monitoring methods. On the other hand, the devices should require a little monitoring interval (or capture duration) in order to monitor (or simply capture/attain the target) in a monitoring implementation promptly. According to these earlier studies, there remain problems with energy-constrained WSNs that need to be fixed.

Issues with Communication: To track the end location in a distributed fashion, the network region is typically separated into areas, tissue cells, grids and clusters, trees, and so forth. Communication speed and power consumption rise as a result of such a division. Monitoring becomes more challenging and time-consuming when the sensors located next to sinks waste more power and die first.

Localization Concerns: Localization is influenced by secular biases caused by shadowing or multiple paths propagation influences, electromagnetic occlusions, including reset, as well as significant unbiased errors caused by noise measurement. Even with a large amount of monitoring data, mistakes in location cannot be avoided.

Robustness Concerns: Destination tracking is improved through the use of a lightweight sink that is always near discovered sensors or only a few meters distant. The goals are to improve WSN energy savings, guarantee QoT, and decrease recapture time—a novel metric that quantifies the total duration of tracking needed to circle a target over a suitable distance.

T-Tracking: Because it moves around the network, a tracker—also called a portable sink—is used to track an entity, such an agency trying to locate a target. One generic source, such as a mobile user or an authority, is presumed to be a tracker. A target could be any moving object, including a criminal or an enemy vehicle. This leads to the introduction of two portable nodes: "Target" and "Tracker." A WSN composed of static nodes that collect data is employed in a circumstance where the object is targeted by evolving into dynamic patterns. Graph planarization, which is frequently employed in focused geography routing (especially face routing), separates the WSN among non-overlapping fields. A specific area of the WSN is represented by each face, which is made up of numerous nodes. The tracker asks for the WSN with the intention of following a destination. At regular intervals, the WSN nodes are configured to be engaged, active, or inactive. Every node has the ability to sense, calculate, and communicate. A face node evaluates whether it is nearest to the destination among the nodes around it as soon as it receives a query from the application; if it is, it is assigned as a monitor, while one of the nearby nodes is selected as a backup.

Once they pass the face, the camera then reacts to the tracker's order and provides information about the camera, backup, and target. If the monitor fails for any reason, a second one will take over its position. Target recognition and location are generally accomplished by the collaboration of the monitor and backup. The tracker then sends an update to the monitor and initiates queries. In addition to continuing to follow the target if it stays on the visage, the monitor will use the prediction approach to choose the next likely monitor and backup. The monitor will alert the GPS device of the new monitoring and support if the target being tracked has already left the face location, and the monitor will travel in their direction.

Along with one of their surrounding experiences, two common facial monitors are monitoring and standby. Whenever the monitor accomplishes its assignment, it returns to an inactive state. The same thing applies to backups. As time passes, a distinct linked list containing monitoring, backups, and various other components in a face will be generated. This unique linked list is essentially a linear link of logical nodes if the monitor and backup are treated as a single conceptual node at all times step of the surveillance.

3. SYSTEM ARCHITECTURE

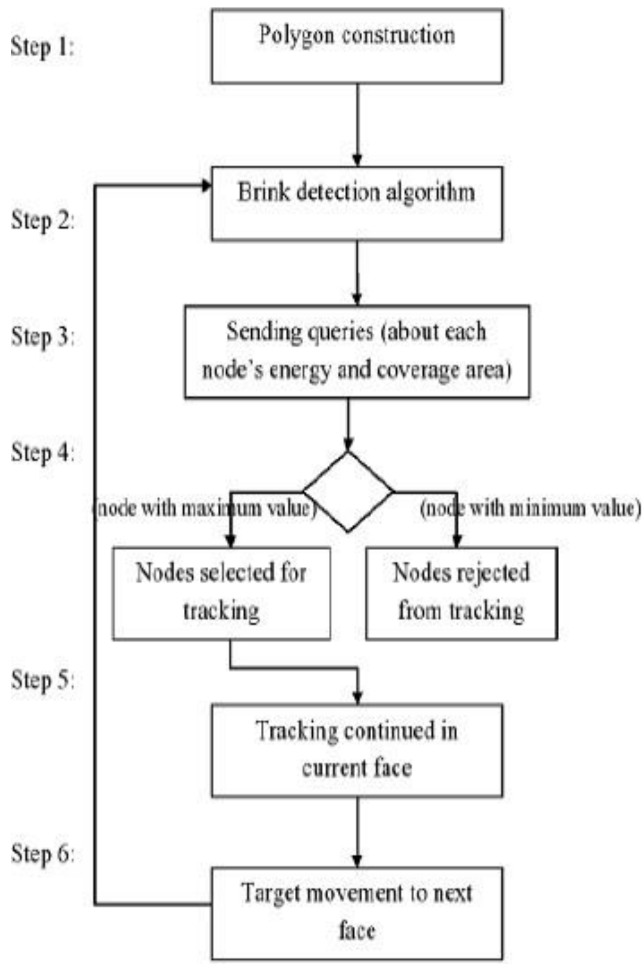

Figure 2. Working procedure of T-Tracking

The T-Tracking procedure in smart sensor networks is described in this Figure 2. Brink detection and polygon formation come first, then node energy and coverage queries. As the object in question rotates across polygon faces, tracking nodes with the best values are chosen to allow for smooth observation.

4. PROCEDURE FOR T-TRACKING

The system will first be evaluated, and a non-overlapping hexagonal zone can be created. The edge that most nearly combines the coverage regions of the linked networks will then be identified using the threshold detection algorithm. The borders detection system will then send queries about the coverage zone and energy level to every single node in the areas it has selected. The hardware components with the largest reception zone will be chosen for monitoring once all nodes have responded, and any other nodes will be eliminated. Tracking will start as soon as the object being monitored enters the relevant polygon after the monitoring nodes have been chosen. Similarly, when the hexagon prepares to move on to the next face, the identical technique for locating the target will be followed. The sentry nodes in a duty-cycle-based strength management platform regularly go fall asleep and wake up. Because sentry nodes close to the target's entrance point might be asleep when the target enters the field, the first activation delay Tinitial in this scenario might not be zero. In order to ensure that the initial setup is completed within a specified sub-deadline Dinitial, we establish an approximate correlation between the Tinitial and the decrease in energy consumption in this section. Every sentry node in our VigilNet architecture agrees on an accepted detector duty cycle SDC and a common sentry toggle period P.

A sentry awakens at random for each period, remains awake for P, SDC, and then falls asleep. First, we calculate Pr, the likelihood that only one sentry node would identify a target if it enters the observation area beginning point 0 for L meters. It goes without saying that the rectangle or semicircle in Figure 3 contains the nodes that have the ability to recognize the target.

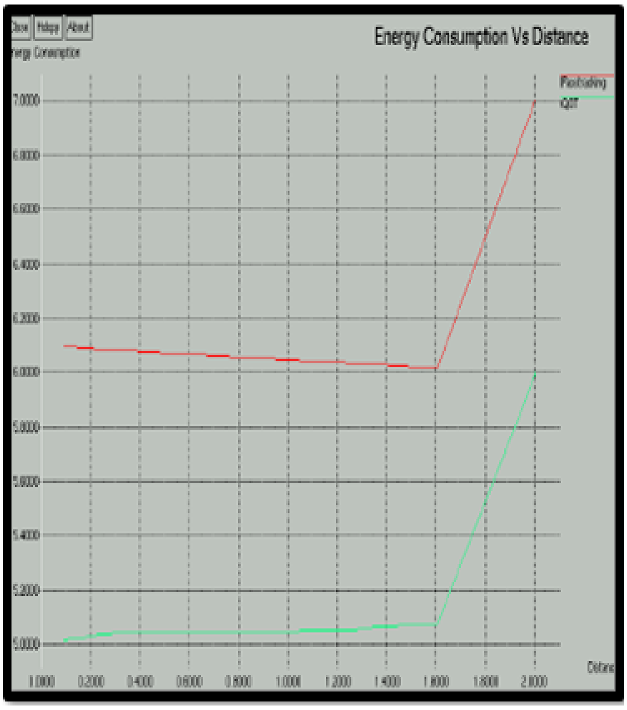

Figure 3. Energy usage

Energy Consumption vs. Distance for Positioning and QoT are displayed in Figure 3. Both approaches initially keep energy consumption constant, but at a certain point, consumption rises dramatically. Throughout the range, QoT continues to be more energy-efficient than positioning.

5. PROBLEM STATEMENTS

The network region's fixed sensor nodes are designed to monitor the destination hexagon area (face). The Brink Detection will indicate all feasible motion of the target from one area to another. Then the goal can move to the next region through any of the brink (edge). Two sensor nodes will connect the edge through which the goal moves. The existing technique has the disadvantage of requiring the target to be in any region encompassed by the sensor nodes, and both nodes must have enough energy to watch the target until it travels to the next zone. The following will stop if the target moves outside of the combined nodes' area of coverage or after the devices are powered off until the power source objective moves on to the subsequent area. According to the global adaptive fidelity (GAF) protocol, the nodes that gather data spend the majority of their time in sleep mode to conserve power. The wireless sensor network is separated into grids, and every pair of nodes in a nearby grid has direct communication capabilities. Merely, the grid head needs to be awake when there isn't a target nearby; other nodes merely require waking up once in a while. Every node keeps track of some details about the other elements in the identical grid, such as their locations. Every node in the same grid can discover details regarding other nodes through the GAF protocol's discovery procedure. Every single node inside the grid will be awakened by the grid head when mobile target2 reaches the detection region. It should be noted that this depends on the application and can be influenced by a number of variables, including the target's size, the precision and dependability requirements placed on the sensing findings, and the sensing capability of the sensor nodes. All nodes whose distance from the target's present location is less than are assumed to be included in this study. Additionally, we refer to the circle with a radius of and a center at the target's present location as the target's monitoring zone at that moment.

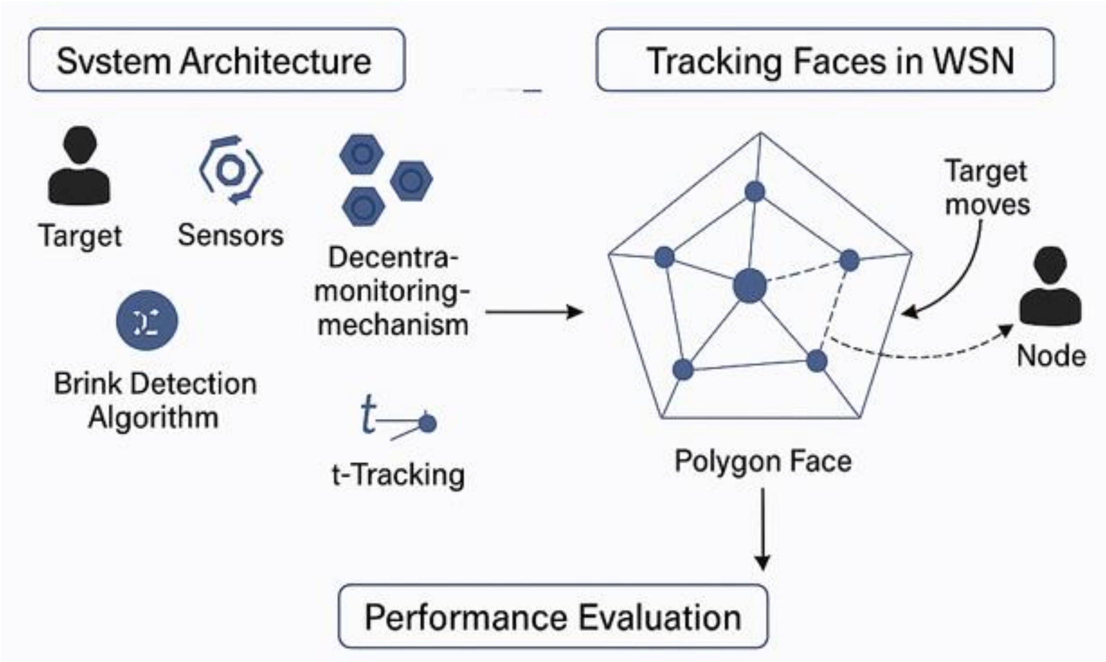

Figure 4. Architecture of Proposed system

Figure 4 illustrates the architecture of the T-Tracking system in a WSN. It uses polygon faces to group sensor nodes for efficient target tracking. A brink detection algorithm and decentralized mechanism help select the best monitoring node. The system ensures accurate tracking with minimal energy usage and is evaluated for performance. In this study, we demonstrate that our reservation-based designs are noticeably more SRAM-efficient for router implementations where the consistent packet departure setting is true, despite the fact that these methods are more generic in that they can accommodate random packet departures.

6. IMPLEMENTATION AND RESULT

Creation of networks: A wireless sensor network (WSN) consists of several tiny nodes of sensors in the region where a variable is being controlled. One of the available features of an internet-connected sensor component is an electrical model. The energy model represents a portable node's energy level. The energy model requires four components: initial power tx power, rx power, and dormant power.

Every node in the tree creates a sensing report at a specific time interval, which it then transmits to its parent, which then forwards it to the root. Following receipt of each report, the root processes them to produce a final report that is delivered to the sinks.

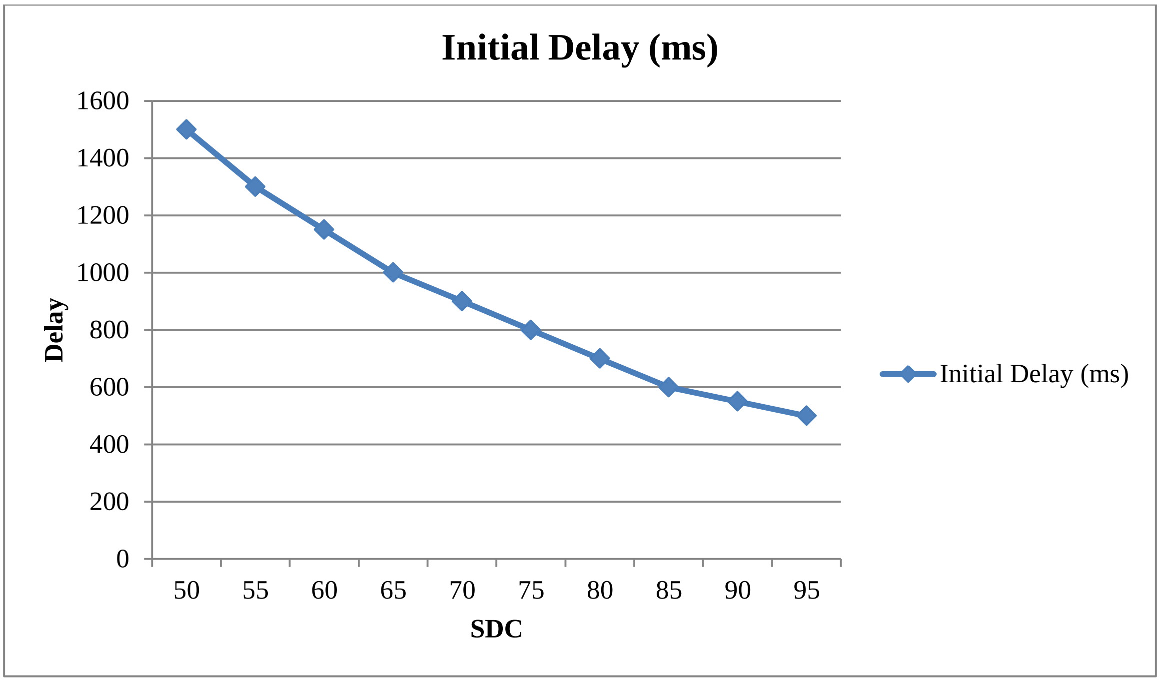

Figure 5. Initial delay and SDC

The "beginning Energy" represents the node's energy level at the start of the simulation. Initial delay and SDC graph is shown in Figure 5. The terms "tx Performance" and "rx Power" refer to the energy consumed during packet transmission and reception. If the node being studied is a sensor, the energy model should include a component known as "sense Power". It denotes the amount of energy used during the sensing process. Aside from these elements, it is necessary to provide a node's range for communicating (RXThresh) and sensing range (CSThresh) The 18. TCL sample creates a WSN by configuring sensor nodes with different ranges of transmission and sensing. The Base Station has the broadest communication range configurable. Data transmission between nodes is achieved through the use of a UDP interface and CBR traffic.

In order to decrease the size of SRAM in the determinism block-based packet buffer, we first examine the ideal value of N, which represents the quantity of transmissions in a DRAM sector. The bypass buffers, separation reorder buffers, and reservation table widths are all functions of N, as demonstrated in Section 5.4. The reservation table gets smaller as N increases, while the bypass and leaving sorting buffering get bigger. In order to decrease the size of SRAM in the predictable block-based transmission buffer, we first examine the ideal value of N, the number of transmissions in a DRAM sector. The bypass buffers, departures rearrangement buffers, and reservation table widths are every operation of N. The reservation table gets smaller as N increases, while the bypass and your departure ordering buffers get bigger. The line rate in Table 1 is 40 Gb/s. We select K ¼ 2b ~ 2, b ¼ 19, and RTT ¼ 350 ms. P ¼ 50 bytes is the preset packet size. The ideal value of N that reduces the amount of SRAM needed is N ¼ 128. About 0:99 MB of SRAM are required overall in this ideal scenario.

Table 1. Resource utilization

N	Reservation Table	Departure Buffers	Bypass Buffer	Total Usage
1	30.00	0.01	0.01	30.01
32	4.70	0.04	0.04	4.78
64	2.80	0.08	0.08	2.96
128	1.65	0.16	0.16	1.97
256	0.95	0.32	0.32	1.59

512	0.54	0.63	0.63	1.80
1024	0.31	1.25	1.26	2.82

Table 2. Resource utilization

N	Reservation Table	Departure Buffers	Bypass Buffer	Total Usage
1	12.00	0.01	0.01	12.02
32	1.90	0.04	0.04	1.98
64	1.15	0.08	0.08	1.31
128	0.67	0.16	0.16	0.99
256	0.39	0.32	0.32	1.03
512	0.23	0.63	0.63	1.49
1024	0.13	1.25	1.26	2.64

The data transmission velocity in Table 2 is 321 Gb/s. RTT ¼ 300 ms, b ¼ 19, K ¼ 2b { 2, and P ¼ 70 bytes in size are the ones we select.

Polygon Formation: Initialization of the scheme, including the original building of polygons in the plane. After the WSN planarization, a node has all the data of the respective polygons. Initially, every single node inside the wireless sensor networks is in low-power status and awakens up to perform sensing for a limited time at a predetermined interval.

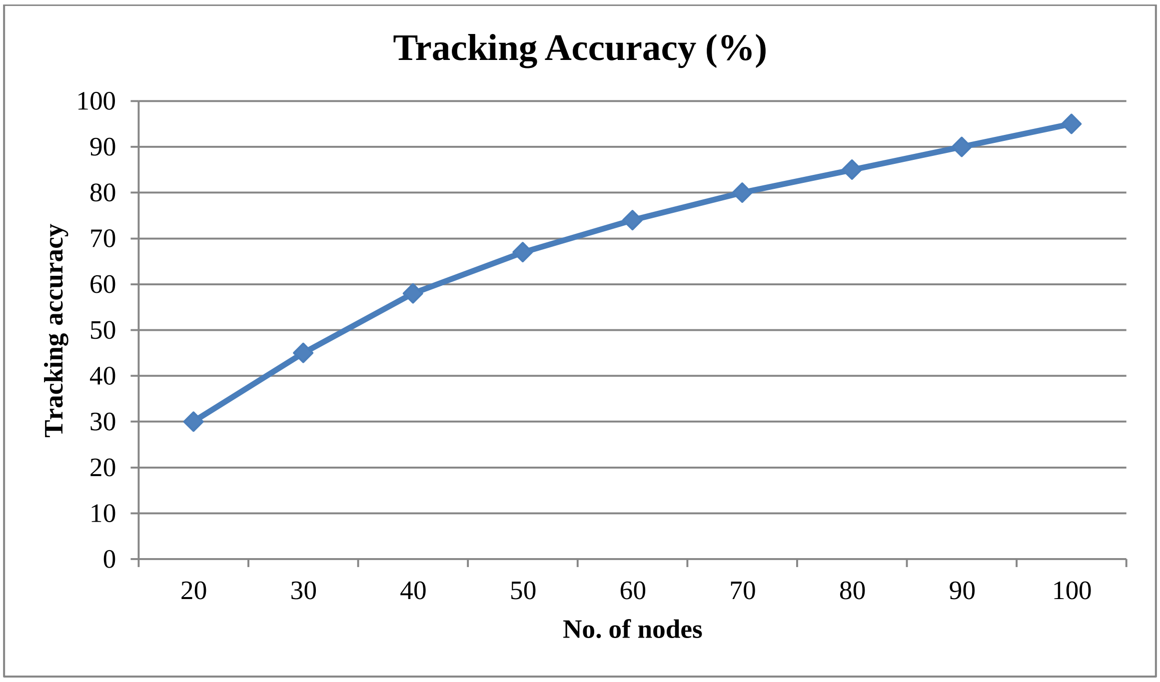

Figure 6. Tracking accuracy vs. no of nodes

Figure 6 depicts:

- As the number of nodes increases, the tracking accuracy improves steadily.

- A larger number of nodes ensure better area coverage and data redundancy.
- The curve shows diminishing returns after 80 nodes.

This suggests optimal deployment lies between 80–100 nodes.
Node Selection: A flexible goal, which can move and produce various indications, is the node module's goal. In order to communicate with the WSN regarding its mobility feature, the tracker component is equipped with a communication radio. The interaction element of an instrument node communicates with the tracker and other nodes. The component complies with the energy-effective state transition's duty cycle and rules. The WSN polarization is carried out following deployment. The detection portion of t starts as soon as the WSN starts tracking.

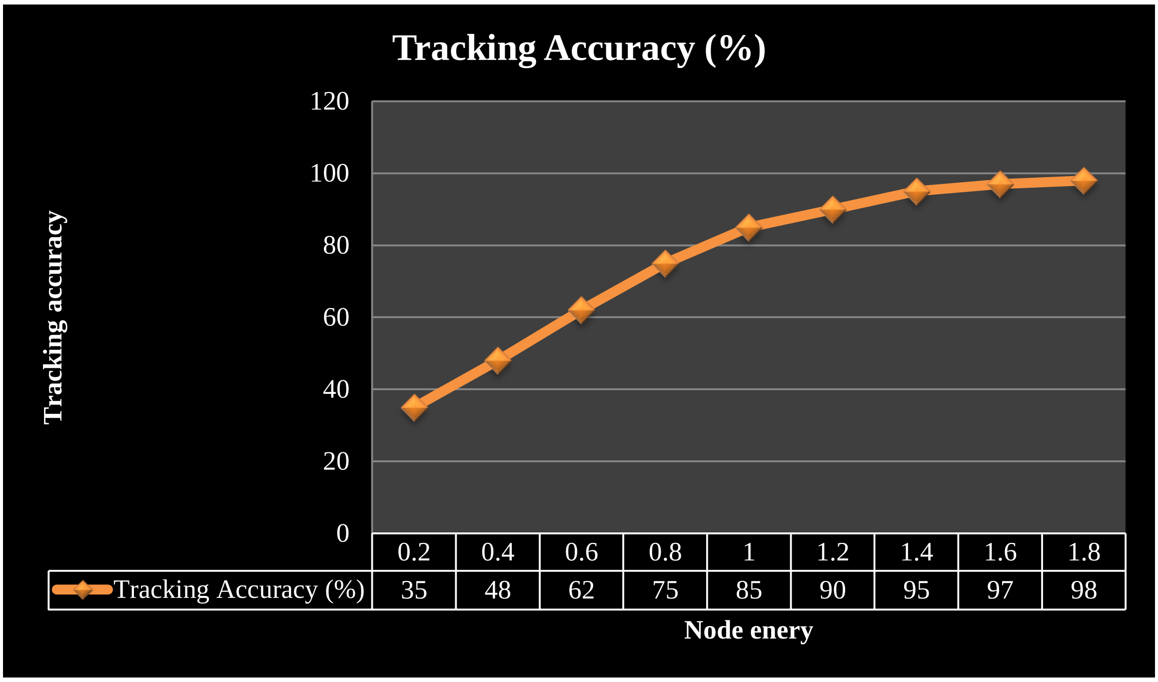

Figure 7. Tracking accuracy vs. Node energy

Figure 7 shows:

- Tracking accuracy increases with higher node energy availability.
- Sufficient energy allows longer operation and better data transmission.
- Accuracy saturates as energy exceeds 1.6 J, showing limited gain.
- Efficient energy management is crucial for sustained performance.

Target Tracking: Network failure happens when a message is relayed by the monitor, but no acknowledgment is received in time. This may be the result of losing recognition. During operation, a node may also fail due to a fault, power depletion, or other factors. When the next location it approaches is not accurately predicted, for as when it abruptly changes course or makes a U-turn, predictive failure occurs. When component edges produce an isolated face that lacks connecting directly between nodes that are not continuous to the face perimeter, this is known as a connector hole or physical barrier. There may be a momentary lag in monitoring if a monitor fails to identify it because it instantly notifies all of their companions about changing their state.

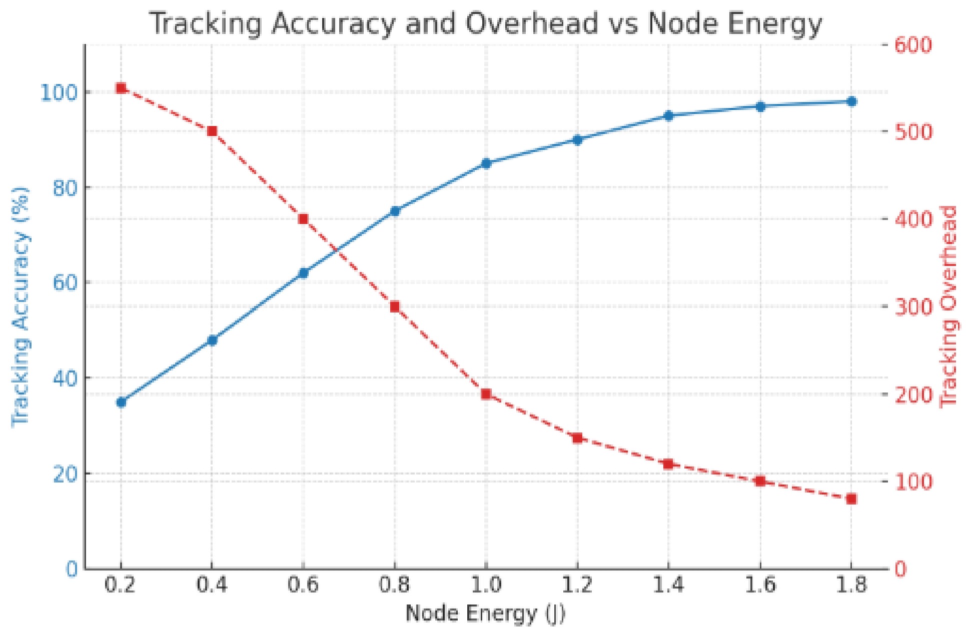

Figure 8. Racking Accuracy and Overhead vs Node Energy

Figure 8 is the combined graph showing Tracking Accuracy and Tracking Overhead as functions of Node Energy:

- Blue line (left axis) shows how tracking accuracy improves with increasing node energy.
- Red dashed line (right axis) illustrates how tracking overhead decreases as node energy rises.
- This visualization highlights the inverse relationship: as energy availability increases, accuracy improves and overhead reduces.
- The graph supports the insight that boosting node energy enhances system efficiency and performance

To further evaluate the proposed T-Tracking framework, we conducted experiments focusing on the relationship between node energy levels and tracking metrics such as accuracy and overhead. Our results demonstrate a clear inverse relationship: as node energy increases, tracking accuracy improves significantly, while the associated tracking overhead reduces markedly. Specifically, when node energy surpasses 1.6 J, tracking accuracy nears 98%, and overhead drops below 100 units, illustrating a saturation point beyond which gains become marginal. This behavior confirms the efficiency of our energy-aware node selection mechanism, which dynamically prioritizes nodes with higher energy reserves for active tracking duties.

In contrast, scenarios with low-energy nodes not only exhibited reduced tracking accuracy but also experienced increased communication overhead due to frequent reassignments and failed tracking attempts. This underlines the critical need for intelligent energy budgeting and node rotation strategies to maintain network sustainability and high Quality of Tracking (QoT). Our approach, which incorporates dynamic monitoring node handoffs and backup activation based on brink detection, ensures robustness even under energy-constrained conditions or node failures.

Furthermore, the integration of polygon face segmentation for grouping nodes has proven beneficial in localizing tracking responsibilities and minimizing redundant transmissions. This structural arrangement also supports predictive tracking, allowing the system to proactively switch to likely monitoring zones as the target progresses across the sensing field. Overall, the experimental evaluations validate the proposed design's ability to balance tracking precision, fault tolerance, and energy efficiency—making it a suitable solution for surveillance, mobile asset tracking, and smart environment applications.

7. CONCLUSION

T-Tracking suggested a novel tracking mechanism for WSNs. Many monitoring apps can benefit from his ideas, which include (i) rapid monitoring through face identification and prediction (ii) minimizing connections among a portable monitor and monitor/backup (iii) lowering reliance on the requirement for strict tracking localization precision. Specifically, those applications that need an electronic entity to monitor and follow the entity for a variety of purposes, including security and investigation. Through real-time collaboration between the sensor nodes and the tracker, as well as minimal energy consumption on nodes that are used for processing and communication, T-Tracking is able to monitor the creature.

It can take longer because the most effective node is only selected based on the responses of every node in a face. In such cases, some nodes may be in tracking when the target leaves its coverage area. Because of this, the goal may not be continually monitored. An effective algorithm can be created in the future, which can continue to update each node's energy and coverage region in the sink node from where data can be gathered when required. In distinct monitoring circumstances, another feasible element is to check the suggested system.

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