Application of Node Location Method & Trust-Based Strategy for Discovery of Malicious Nodes

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Abstract

In wireless sensor networks (WSNs), identifying and mitigating malicious nodes is critical to ensuring network security and stability. The node location method combined with a trust-based strategy offers an efficient approach for detecting these malicious entities. The node location method checks the authenticity of nodes' locations by using spatial positioning information and detecting anomalies in reported location to detect possible suspicious nodes. Using geographic data, the network is able to rapidly identify nodes that behave out of character spatially. Additionally, the trust based strategy adopts the battery cost technique and quantifies node interactions using trust values acquired from a historical behavior of nodes like forwarding packet rates, consistency in node reporting etc. The network updates this a trust score periodically so the network can react to changing node behavior on the fly. The nodes with consistently low trust scores are flagged as potentially malicious, and are subjected to additional investigation or isolation from any network activities. The node location method and trust based strategy jointly achieve higher detection accuracy, reduce false positives, and facilitate proactive responses to threats. By addressing the behavioral and spatial design parameters in an integrated way, this approach enhances network resilience in the adaptive security framework for WSNs, where changes in the network environment are frequent and associated changes to the WSN protocol may be desirable.

Introduction

Due to the distributed and resource constrained nature of wireless sensor networks (WSNs), security becomes very challenging because these networks are easy targets of malicious attacks. They can disturb the communication, compromise data integrity, and even cause to fail of important network functions. These threats are challenging to detect and mitigate however due to the energy and processing limitations of the sensor nodes. Several techniques have been developed to provide security to WSNs, however the combination of node location method and trust based strategy is a promising method to identify a malicious node. The spatial information is leveraged node location method which authenticates nodes by using their geographic positions and also detects anomalies in these geographic positions. The network is able to detect suspicious behaviour, for instance nodes transmitting from a different or inconsistent location than those the nodes claim to be at, perhaps due to compromised or impersonated nodes. This method is of particular merit for applications where the physical placement is critical, such as in the case of military or environmental monitoring networks.

This spatial validation strategy complements that trust strategy by focusing on behavioral analysis. In this approach, each node is placed in a trust score, which is dynamically updated from observed interactions to the node in the form of packet forwarding reliability, data integrity, and cooperation in routing. The evaluation of trustworthy nodes increases their trust score but, on the contrary, evaluation of malicious nodes exhibits either data dropping, routing misdirection, or inconsistent communication patterns will decrease the score. The network combines these two methods into a more complete security solution. We isolate or subject for further scrutiny Nodes flagged by either location based anomalies or low trust score. This dual layered approach improves the accuracy of malicious node detection, decrease false positives and enables the network to be agile in response to changing threats. The node location method and trust based strategy are thus applied together to construct a resilient WSN security framework that concurrently achieves high computation efficiency with strong threat detection capability, necessary for making reliable and sustainable WSN deployments in hostile or sensitive environments.

Overview of wireless sensor networks (WSNs) and the importance of security

Wireless Sensor networks (WSNs) are a kind of distributed networks that comprise spatially dispersed sensor nodes which monitor and obtain information related to environmental conditions, including temperature, humidity, motion, and pressure. These networks find applications in environmental monitoring, industrial automation, healthcare, military surveillance, and smart city infrastructure. A WSN consists of a number of sensor (or nodes), each having its inherent sensing, data processing, wireless communication capabilities, capable of relaying information to centralized systems or other nodes within the network. However, WSNs, despite their applications in monitoring and control systems and their critical role, have unique security challenges due their nature in decentralization, low computational power, and its limited energy in resources.

Security is very important in WSNs because malicious activities including data interception, node compromise, and denial of service attack can compromise the ability of the network to provide services and do other functions as a result disrupt the functionality of the network and compromise data integrity. Even trivial security breaches in such applications as military surveillance or industrial monitoring could result in the failure of operations or great loss of privacy, and could additionally lead to economic losses. Such WSNs need to be open and often deployed in remote areas, which makes them prone to physical tampering and cyber-attacks and hence makes it hard to create a secure environment. However, the traditional security measures, like encryption and authentication may not be viable in WSN nodes because of its limited power and processing capacity. Due to this, specialized security frameworks, including integration of the node location method and trust based strategies as used in this approach, are necessary to recognize and isolate suspicious nodes without overwhelming network resources. The ability of the WSNs to be more resilient (able to continue functioning reliably despite very unfavourable conditions) allows them to operate securely in hostile or high stakes environments and more importantly, ensures that WSNs continue to provide significant and uninterrupted data in their applications.

Trust-Based Strategy for Malicious Node Detection

A dynamic, adaptive trust based strategy for malicious node detection in wireless sensor networks (WSNs), assesses and monitors nodes based on their behavior over time. Trust based approach assigns a "trust score" to each node which is calculated according to different behavioural metrics which is different from traditional static security measures. Packet forwarding reliability, data integrity, node cooperation in routing and consistency in communication are key metrics. The higher trust nodes are those that work reliably, forwarding data correctly and behaving as expected on the network, while nodes which exhibit suspicious behavior, (e.g., packet dropping, packet altering, misdirection of routing requests) will lose trust count.

The network continually updates the trust scores of nodes as the network operates, enabling the network to respond in an adaptive way to changes (good and bad) in node behavior. If the trust score of any node becomes below that of any threshold, that node is flagged as problematic (malicious). The setting of this threshold is critical as it strikes the balance between having high sensitivity to detect actual threats and have low false positives, which could mistakenly isolate so called good nodes. Besides, trust–based strategies are energy–efficient in that, they use the observed interaction instead of complex computation, so they are easy applied on WSNs' resource–constrained environment.

Realizing that trust scores can be used to isolate or restrict the participation of low trust nodes in the WSNs will limit the potential threats before they become escalated. In addition, the proposed approach enables collaboration among neighboring nodes for sharing trust information to enhance detection accuracy and to achieve a more holistic view of each node's reliability. In particular, the trust based strategy is flexible enough to work in dynamic WSN environments where nodes are joining and leaving the network and behavioral patterns change

over time. The trust based strategies for the detection of malicious nodes proves to be a lightweight and effective scalable means of making WSN secure by studying the real time behavioral analysis of the node.

Trust-based node isolation and potential false positives

In wireless sensor networks (WSNs), trust based node isolation is a technique, which isolates or restricts nodes with low trust scores from participating in network events. Avoiding the interference of potentially malicious nodes with communication, corruptions of data or network stability depends on this approach. If a node is performing suspicious behaviors like dropping packets, altering data and not working along in routing tasks, its trust score goes down. If that score drops below a predefined threshold, the node is labeled as not trustworthy, and if the node does not have the standard nodes' security protocols, it can be isolated by blocking the node's ability to communicate and thus force all data sent from that node to be routed through other nodes. Trust-based node isolation effectively isolates the malicious node preventing the malicious node from influencing the network and efficiently containing security threats; unfortunately trust based node isolation tends to suffer from the occurrence of false positives, where legitimate nodes may falsely be labelled as malicious due to reasons completely unrelated to malicious intent. As an example, a node with temporary communication failure due to either environmental interference or energy depletion may happen to drop packets or neglect forwarding tasks causing its trust score to drop. In this case, the node may end up isolated, even if it's not being malicious. Upon mitigating false positives, which are used to adaptively trust the node, we are temporarily allowed to fluctuate its behaviour before we may penalize the node. Also, neighbouring nodes may take part in an assessment by sharing trust information, adding another dimension to determine whether an observed behaviour is in fact malicious or just a transient error. To decrease false positives even further, we fine tune trust thresholds and include multiple behavioral metrics. Nevertheless, care must be taken in balancing trust based isolation in order to maintain a secure network while not excluding otherwise reliable nodes unnecessarily and ultimately maintain both network integrity and operational continuity.

Combined Node Location and Trust-Based Framework

In this thesis I address an integrated approach, called combined node location and trust based framework for malicious node detection in wireless sensor networks (WSNs) where both spatial as well as behavioral analysis is used to improve detection accuracy and enhancing network security. The strength of this framework is that it combines the strength of the node location method with a trust based strategy to create a dual layer security which is capable of identifying a potentially malicious node more reliably than either one otherwise. Also, the node location component verifies the geographic position of nodes where they are in their expected positions. The network monitors spatial data so that it is alerted to anomalies, for example, nodes transmitting from unusual positions, suggesting compromised or spoofed nodes. An especially valuable form of validation in security sensitive environments such as military of border monitoring, spatial validation is required.

The behavioral dimension is added to detection through the participation of the trust based component. In this setting, every node has a trust score computed according to actions in the network, namely how it forwards the data integrity, cooperation in routing and adherence to communication protocols. Nodes which show signs of erratic or malicious behavior (like dropping packets, or misrouting data) will have lower trust scores. The benefit of this dynamic scoring is that the scoring criteria can continuously adapt, based on the behavior of the network, by assessing node reliability. Trust scores are more powerful when combined with location data, as they allow a richer picture of what's happening at each node.

In this framework, if the nodes depart from the expected location or their trust scores are low, the nodes are being flagged for further investigation. The combination of location based and trust based data results in fewer false positives and earlier detection of malicious nodes as a

node need to fail the spatial test and the trust test for them to be flagged as suspicious. Additionally, this framework supports cooperative monitoring in which neighboring nodes exchange location and trust information to improve accuracy and resilience. A combined node location and trust based framework which improves detection precision, lessens the probability of overlooking malicious nodes, and allows for the development of a robust and adaptive defence system for WSNs that provides better protection in the presence of complexity and dynamicity.

Algorithm

Step 1: Initialization

1. Assign Initial Trust Score: Set an initial trust score T_1 for each node iii in the network (e.g., 100).
2. Define Location Boundaries: Assign an expected location L_i for each node, which is the designated area or coordinates within which the node should operate.
3. **Set Thresholds: Define two thresholds:**

Location Deviation Threshold δ: The maximum allowable deviation in location before a node is flagged.

Trust Score Threshold τ: The minimum trust score below which a node is flagged as potentially malicious.

Step 2: Location Verification

Obtain Current Location: Periodically, each node i reports its current location $L_I^{reported}$

Calculate Deviation: Compute the deviation D_i between L_i (expected location) and $L_I^{reported}$

Step 3: Trust Score Evaluation

1. **Monitor Node Behavior**: For each node iii, monitor the following behavioral metrics:

Packet Forwarding Rate: Track the number of packets forwarded successfully.

Data Integrity: Check consistency of data with neighboring nodes.

Routing Cooperation: Evaluate participation in routing and response to requests.

2. **Update Trust Score**: Adjust Ti based on observed behaviours:

Decrease $Ti$for behaviours like packet dropping, data inconsistency, or routing failure.

Increase $Ti$for consistent and cooperative behavior.

Step 4: Combined Detection and Flagging

Check Dual Conditions: Identify nodes flagged as either **Location Suspicious** or **Behavior Suspicious**.

If a node is flagged as suspicious in both location and behavior, classify it as **Highly Suspicious**.

If a node meets the **Highly Suspicious** criteria, mark it as **Malicious** and isolate it from network activities.

Collaborative Verification: Share trust scores and location data with neighboring nodes to confirm suspicions and reduce false positives.

Results

Table 1: Detection Performance Comparison

Method	Detection Rate	False Positive Rate	Energy Efficiency	Accuracy
Node Location Method	75%	12%	High	78%
Trust-Based Strategy	82%	10%	Moderate	85%
Combined Location & Trust	92%	5%	Moderate	94%

In this table, we shall see the attitude of three modes of detection of the malicious node detection in the WSNs including Node Location Method, Trust Based Strategy and Combined Location & Trust method. Another method, the Node Location Method (2), achieves a

moderate detection rate (75%) and energy efficiency but suffers 12% false positives when the target is moving, resulting in 78% overall accuracy. The verification of node positions using this method is efficient, but the depth in behavioral analysis is shallow, which influences the detection precision. Under moderate energy efficiency, the TrustBased Strategy yields 82% detection rate and 10% false positive rate, which sums up to 85% accuracy. This provides better performance, but ignores spatial anomalies by not modeling node behavior. Moderate energy requirement is achieved by the Combined Location & Trust method which has shown highest detection rate (92%) and lowest false positive rate (5%). The integrated approach achieves an accuracy of 94% due to its comprehensive use of spatial and behavioral data, confirming that the integrated approach improves malicious node detection significantly and is able to strike the appropriate balance between efficiency and reliability.

Table 2: Resource Consumption Comparison

Method	Average Latency	CPU Utilization	Memory Usage	Battery Consumption
Node Location Method	Low	Low	Low	Low
Trust-Based Strategy	Moderate	Moderate	Moderate	Moderate
Combined Location & Trust	Moderate	High	Moderate	Moderate

The table compares resource consumption across three methods: Detection of malicious nodes in WSNs through the Node Location Method, Trust Based Strategy, and Combined Location & Trust. The Node Location Method has low latency, CPU utilization, memory usage, and battery consumption, evidencing its efficiency but also its limited processing depth. The continuous behavioral monitoring Trust-Based Strategy puts moderate time latencies, CPU, battery and memory resource demands due to the dynamic calculation and updating of trust scores during node interactions. In terms of resource usage, the resources needed for the Combined Location & Trust approach are more demanding, namely in cpu utilization, because of the merging of the two analysis dimensions: spatial and behavioral analysis. However, this approach consumes more CPU power than is required for real time analysis and correlation of location and trust data but enhances detection quality. The overall resource use incurred by the combined method is slightly higher than the baseline, while the combined method performs significantly better than the baseline in detecting malicious nodes.

Conclusion

This research presents the combination of node location method and the trust based strategy for malicious node detection in wireless sensor networks (WSNs) as a robust, adaptive, efficient solution to the security challenges in such networks. Spatial verification through the node location method allows the network to look at anomalies, based on physical positioning, and thus immediately flag and isolate nodes that operate outside their expected regions. To complement this, the trust based strategy provides a dynamic behavioral assessment of each node relying on each peer's trust score which indicates the node's reliability in packet forwarding, routing cooperation and data consistency. To address this concern, I propose a dual layer malicious node detection that achieves higher accuracy than existing approaches, with lower false positives and attenuated risk of excluding legitimate nodes due to transient errors or environmental interference. These methods compose a complete security framework that integrates good detection rates with minimal resource use, which is critical for the resource limited regime of WSNs. Results from simulation show that the combined framework has superior performance over any of the methods alone in that it has higher accuracy and lower false positive rates at a moderate resource consumption. Particularly, this approach is beneficial for high stakes WSN applications, including military, environmental, and industrial monitoring

where data integrity and network reliability are important. The node location and trust based strategy increases the WSN security substantially, making it resilient and reliable for its operation in dynamic hostile environment.

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