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Comparative Analysis of Multipath Routing Techniques and Design of Secure Energy Aware Routing Algorithm for Wireless Sensor Network

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Abstract

Due to the constrained communication range and high density of sensor nodes in wireless sensor network, forwarding packets in sensor networks is a important field of research over the past decade. At present, multipath routing approach is widely used in wireless sensor networks to improve network performance through efficient utilization of available network resources. Accordingly, the main aim of the survey is to present the concept of the existing multipath routing approach and summarizing the state-of-the-art multipath routing techniques from the network application point of view and proposing a secure energy efficient multipath routing approach for wireless sensor network.

Keywords

Wireless sensors; Protocol; Multipath Routing;Energy Efficient; Security; Fault Tolerant

1. Introduction

Recent developments in the wireless communication technology have pioneered economical low-power wireless sensor networks. Since the sensor nodes are easy to deploy and multi-functional, the wireless sensor networks have been used for a variety of applications [3] such as healthcare, target tracking, and environment monitoring. In each application, sensor nodes sense the target area [1] and transmit all the information to the sink node for further processing.

Due to the resource restrictions [5] of the sensor nodes and fallibility of low-power wireless links, many challenges in designing efficient communication protocols[2][8] for wireless sensor networks are imposed. Therefore appropriate routing protocols to fulfill different performance demands [6][11]of various applications is considered as an important issue in wireless sensor networking. In this perspective, several routing protocols have been proposed to get better performance through the network layer of wireless sensor networks protocol stack.

Most of the existing routing protocols [3] [15][16][19]in wireless sensor networks are designed based on the single-path routing approach without taking into account the effects of various traffic load intensities. In this approach, each source node selects a single path which can assure performance necessities of the intended application for transmitting its traffic towards the sink node. Even though, the route discovery through single-path routing method can be performed with minimum computational difficulty and resource utilization, the limited capacity of a single path highly reduces the possible network throughput. In addition, the low flexibility of this method because of node or link failures may considerably decrease the network performance in critical situations. Consider an example, if the active path fails to transmit data packets due to limited power supply of the sensor nodes or problems in wireless links, finding another path to carry on data transmission may cause extra overhead and delay in data delivery.

In order to handle the restrictions of single-path routing methods[20], another type of routing approach, which is called as multipath routing approach [16]has become a promising technique in wireless sensor networks. As the sensor nodes are deployed densely, the multipath routing approach can simply construct several paths from individual sensor nodes towards the destination. The discovered paths can be utilized simultaneously to make available adequate network resources in severe traffic conditions. Alternatively, each source node can use only one path for data transmission and switch to alternative path in case of node or link failures.

2. Objectives

While single path routing is not an effective technique due to the resource constraints of sensor nodes and the untrustworthiness of wireless links, the aim of the proposed research work is to develop a consistent, protected and load balancing multipath routing algorithm to determine & to distribute the traffic over

multiple paths between the sink and source nodes in a wireless sensor network.

The specific objectives of the research work include:

- To learn about the conventional routing algorithms in wireless sensor network.
- To create a reliable and secure multipath routing algorithm.
- Evaluate the performance improvements in terms of network lifetime and node energy efficiency by comparing with the existing routing schemes.

3. Literature Review

The routing methods for Wireless Sensor Network are classified as proactive, reactive, and hybrid [15][16]. The proactive routing method maintains the route information to all destinations by periodic updating. This method is expensive as network resources such as node energy and communication bandwidth are being consumed periodically. The reactive routing, on the other hand, retrieves routing information only when required. It saves the network resources in comparison with proactive routing, by reducing the time required for route discovery. The hybrid routing combines both the methods to balance the route detection time and the utilization of network resources. The other routing methods [21] [22] include location-based routing which creates the routing entries based on the location of nodes. The GPS (Global Positioning System) device attached to the nodes will be used to get the coordinates of nodes or the coordinates can also be obtained by exchanging messages with their neighbors. The distance information of the neighboring nodes is derived from the estimation of incoming signal strengths.

The details of the some of the existing routing algorithms are described below:

a. Directed Diffusion

The directed diffusion is a data-centric routing method [7] [23] which can be used to establish an energy-efficient data distribution path between the source and the sink. It makes use of the network aggregation, which merges the data coming from different sources for the same target in order to save energy and prolong the network lifetime by eliminating the redundancy. This method uses localized algorithms to enable flexible path construction and recovery in case of node failures. The steps of the algorithm are shown in the diagram below. In the initial phase, the interest messages are flooded in the network from the sink node (Figure1a). The interest message has low-level abstraction to provide the information requested depending upon the application. The gradients are set up within the network to connect the source node with the sink (Figure 1b). Each gradient contains value of attributes to sort out the information and the path to transmit the received data. The information about the gradients & their distinct interests is maintained in the interest cache by each node in the network. The source node transmits the

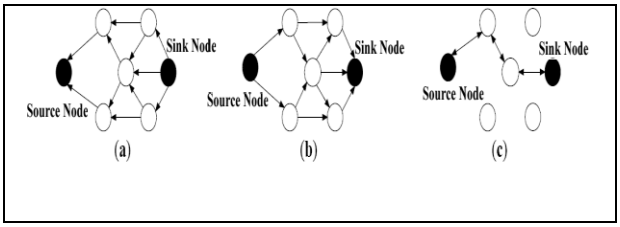

Fig 1: A simplified illustration of directed diffusion

exploratory data to the network at a low data rate at times. The routing decision is made based on the interest cache of each node. The attribute of the exploratory data received is matched with the gradient, if it matches then the exploratory data message is forwarded to the next hop. The sink sends a reinforcement message through a particular path after aggregating [12]the exploratory data arrived from different paths in order to inform the source node to transmit data at a higher rate (Figure 1c). Once the reinforced path is established, the sink still transmits periodically its interest to the network in order to refresh the interest cache at each node. The sink node also maintains the path generated by the reinforcement message. The negative reinforcement message is sent to the source in case of path degradation, so that the source can stop using it. This routing method could not be efficient in terms of resource utilization as the routing is performed based on the knowledge on neighboring nodes and sink node is not aware of the complete information on the existing paths.

b. Braided Multipath Routing Protocol

It is a decisive multipath protocol which provides fault-tolerant [14] routing in wireless sensor networks. It has a similar approach as Directed Diffusion to create several partially disjoint paths. The diagram below shows the established paths in this method.

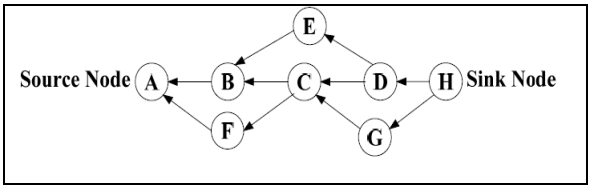

Fig 2: Braided multiple paths

In this method, two types of messages (primary path reinforcement and alternative path reinforcement) are used to construct partially disjoint paths. Initially, a primary path reinforcement message is sent by the sink node to its best neighboring node towards the source node. Consider for example, in Figure 2, the sink node sends the primary path reinforcement message to node D. An intermediate node between source & sink node, when receives a primary path reinforcement message, it forwards this message to its best next-hop neighboring node towards the source node. This process is repeated until the primary path reinforcement message reaches the source node.

After the primary path is created, source node and all the intermediate nodes along the primary path construct an alternative path around their next-hop neighboring nodes. It generally uses the neighboring nodes which are not included in the primary path to construct the alternative path. In order to create two paths, the sink and intermediate nodes send out both the primary path reinforcement message and alternative path reinforcement message to their next preferred neighboring node towards the source node. For example, in Figure 2, the sink node sends an alternative path reinforcement message to node G in order to create a backup path around node D. During this complete process of establishing paths, when an intermediate node which is not included in the primary path, gets an alternative path reinforcement message, it should forward this message to its best next-hop neighboring node. This process is continued till this message is received by one of the nodes in the primary path. Hence, each intermediate node along the primary path generates a backup path around its next-hop neighboring node on the primary path by transmitting an alternative path reinforcement message. The set of partially disjoint paths between the source and sink nodes can be used to prevent data transmission failure if the primary path fails to further transmit data packets towards the sink node.

The simulation results show that the braided multipath routing approach has lower overhead compared to the idealized node-disjoint multipath protocol. It is also verified that this approach provides about 50% higher resilience against path failures, compared to the idealized node disjoint multipath protocol. However, the end-to-end throughput [23] is limited to the capacity of a single path as this method uses only one path for data transmission. Since this approach is designed based on the principles of Directed Diffusion, the disadvantages of Directed Diffusion can also be applied to this protocol.

c. Reliable and Energy-Aware Multipath Routing

Reliable & energy aware multipath routing [4][10][17]is designed to provide reliable data transmission by maintaining a backup path from each source node towards the sink node to diminish the energy efficiency requirement of wireless sensor networks. The routing operation in this protocol is also initialized by the sink node. So, when the sink node receives an interest message from a source node and if there is no active path towards the source node, then it floods a service path request message to initiate a service-path discovery process. The source node when receives the service-path request message, then it transmits a service-path reservation message towards the sink node (through the reverse path) to validate the discovered path. As the service-path reservation message moves from the source node towards the sink node, a node receiving this message reserves a part of its remaining battery level for data transmission over this path.

The process is continued till the sink node receives the service-path reservation message. Thus, the data transmission between source node and the sink node can be performed through the constructed path. The sink node can now initiate another path discovery process to establish a backup path towards the same source node by flooding a backup path discovery message. The intermediate nodes, which are not a member of the discovered service-path, broadcast the received backup path discovery message to their neighbors. Hence, a node-disjoint path is constructed to provide fault tolerance when the service-path fails.

This protocol provides energy-efficient and reliable data transmission, but it has the drawback of the alternative path routing strategy: the end-to-end capacity is limited to the capacity of a single path. More notably, this protocol does not consider the effect of wireless interference and link unreliability [13] for successful data transmission.

d. Sensor Protocols for Information via Negotiation (SPIN)

Sensor Protocols for Information via Negotiation (SPIN)[18] are a family of protocols that broadcast all the information at each node to every node in the network considering that all nodes in the network are potential base-stations. Therefore a user can query any node and get the required information immediately. These protocols apply the property that nodes which are close have similar data, and hence only the data that other nodes do not posses needs to be distributed. These types of protocols make use of data negotiation and resource-adaptive algorithms. The nodes assign a high-level name to completely describe their collected data (called meta-data) and perform meta-data negotiations before transmitting any data. This guarantees that the data sent throughout the network is not redundant. The syntax of the meta-data format is application-specific and is not specified in SPIN. For instance, unique IDs of sensors might be used to report meta-data for a certain known region. SPIN also has access to the current energy level of the node and adjust the protocol it is running based on the energy remained.

These protocols periodically distribute the information all over the network, even when a user does not demand any data. The SPIN family is developed to deal with the drawbacks of classic flooding by negotiation and resource adaptation. The SPIN family of protocols is based on two basic ideas:

1. Sensor nodes only send data that describe the sensor data instead of sending all the data in order to perform more efficiently and conserve energy; for instance, the changes in the energy resources must be monitored by image and sensor nodes.
2. Protocols like flooding or gossiping waste the energy and bandwidth when sending extra and un-necessary copies of data by sensors covering overlapping areas.

The advantage of SPIN is that topological changes are confined to a small area since each node knows only its single-hop neighbors. The energy savings in SPIN is more than flooding and the redundant data is also reduced due to meta-data negotiation. But, the data advertisement mechanism of SPINs cannot assure the delivery of data. Consider the instance, if the nodes interested in the data are placed far away from the source node and the nodes between source and destination nodes are not interested in that data, then such data will not be transmitted to the destination.

4. Comparison of Existing Techniques

The multipath routing algorithms are compared based on parameters such as traffic distribution, no. of paths etc. The table shown below gives the summary of the comparison.

Table 1: Comparison Table

Algo.	Advantages	Disadvantages
Reliable and Energy-Aware Multipath Routing	1.It provides energy-efficiency & reliable data transmission by maintaining a backup path from each source node towards the sink node.	1.It suffers from the main disadvantage of the alternative path routing strategy in which the end-to-end capacity is restricted to the capacity of a single path. 2. The effects of wireless interference & link unreliability for successful transmission is neglected.
SPIN	1. SPIN is adaptive protocol which uses data negotiation and resource-adaptive algorithms. 2. It is a data centric routing protocol. 3. The changes in the topology can be localized as each node knows its single-hop neighbors. 4. SPIN provides much more energy savings than flooding. 5. The meta-data negotiation mechanism	1.SPINs data advertisement mechanism cannot guarantee the delivery of data.

	halves the redundant data.	
Directed diffusion	1. Directed diffusion is a application-aware and data-centric protocol in which the sensor nodes are named by attribute-value pairs. 2.Directed Diffusion can save energy by selecting optimal paths through caching and processing data in the network.	1. Data aggregation technique needs time synchronization which is not very easy to achieve in WSNs. 2.The cost of a sensor node is increased due to recording the information.
Braided Multipath Routing Protocol	1.It is a seminal multipath routing protocol which provides fault-tolerant routing in wireless sensor networks. 2. The overhead of braided multipath routing approach is low as compared to the idealized node-disjoint multipath protocol. 3. It also provides about 50% higher resilience against path failures, compared to the idealized node disjoint multipath protocol.	1. As this protocol utilizes only one path for data transmission, the end-to-end throughput is limited to the capacity of a single path.

5. Research design

A secure multipath routing algorithm is proposed to create alternative paths that connect the sink and source nodes. The path selection is based on the estimation of the node residual energy level and its neighbors distance to the destination in order to increase energy efficiency and to reduce the data transfer delay. The multipath routing protocol provides newly discovered paths to transmit data packets from the source to the sink. The sink node also monitors the path conditions in order to distribute the traffic properly in real-time.

The path cost is the main factor which is used to give the cost of transmitting data through a path. It is calculated by the residual and initial energy levels of nodes along the path and their hop distance to the destination. The sink node applies the load balancing algorithm to dispense the traffic over multiple paths depending on their "path cost". The algorithm solves the optimization problem of traffic allocation to extend the network lifetime and maintain a reasonable packet delay.

The concept of public & private key is also applied in the proposed algorithm for security purpose. The RSA algorithm will be used to generate public key & private key. The public key will be used for encrypting the data & private key will be used for decrypting the data.
The steps for the proposed algorithm are as follows:

The steps for deciding multipath in hierarchy fashion are:

1) In the initial phase, the sink node transmits a hello message to its neighboring nodes including its identity, cost & public key.
2) When this hello message reaches at the neighboring nodes, then the cost of the path from sink to that node is calculated and the node having more energy is selected to transmit the message
3) The message is encrypted using the public key & again transmit it to its neighbors.
4) The process in step 2,3 is repeated till the message reaches at the source node.

Let Ni is ith Node, Ci is cost of ith node calculated as C=1/remaining energy of node. Pkey is public key of ith node, Pj1 is path 1 from jth node, pj2 is path 2 from jth node. Cj1 is cost of path 1 from jth node; Cj2 is cost of path 2 from jth node.

Proposed Data Transmission
For Data transmission path is alternately selected from Path 1 and Path 2. Every data transmitted should be encrypted with public key of next node on path for security e.g. if path 1 is selected for transmission then data should be encrypted with public key pjkey1.(for decryption private key is required and kept secret at node so nobody can decrypt data except next node on

the path). Every node on path receives data, decrypt with own private key, encrypt again with next nodes public key. Finally data reach to sink node.

6. Conclusion and Future Work

Designing efficient routing protocol in sensor networks is a novel area of research. In this paper, a comprehensive survey of existing routing techniques in wireless sensor networks is specified.
A secure & energy aware multipath routing algorithm is proposed which will securely transmit the data by encrypting it. The proposed algorithm will also take into account the energy of the node while transmitting the data. Further, the algorithm can be modified to become fault-tolerant.

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