Postprint: A Routing Protocol for Mobile Wireless Sensor Networks Based on Active Regions

Authors: Ran Yong, Li Fang

Date: 2018-08-13T00:00:00+00:00

Abstract

To address energy efficiency issues in mobile wireless sensor networks, an activity-region-based routing protocol for mobile Wireless Sensor Networks (WSN) is proposed. This method utilizes the relative positions of source and sink nodes to form the activity region for routing, and mobile nodes in the network employ a sleep-wake pattern to conserve energy. Mobile vector information (such as current position, direction, and velocity) as well as the residual energy of nodes are used to select neighbors that can provide maximum connection retention time, and mobile vector information is also used to wake up mobile nodes within the activity region. Experimental results demonstrate that, compared with other routing protocols, the proposed method achieves higher reliability in the packet transmission process.

Full Text

A Mobile Wireless Sensor Network Routing Protocol Based on Active Regions

Ran Yong[1], Li Fang[2]
[1]Dept. of Mechanical & Electrical Engineering, Chongqing Three Gorges Vocational College, Chongqing 404155, China;
[2]School of Computer Science, Chongqing University, Chongqing 400044, China

Abstract

To address energy efficiency challenges in mobile wireless sensor networks, this paper proposes a mobile wireless sensor network (WSN) routing protocol based on active regions. The method utilizes the relative positions of source and sink nodes to form an active region for routing. Mobile nodes in the network employ a sleep-wake pattern to conserve energy. Motion vector information—including current position, direction, and velocity—along with residual node energy, is used to select neighbors that can provide maximum connection retention time. This motion vector information is also employed to awaken mobile nodes within the active region. Experimental results demonstrate that compared with other routing protocols, the proposed method achieves higher reliability in packet transmission.

Keywords: energy efficiency; active region; wireless sensor network; routing protocol; mobility vector

0 Introduction

Conventional routing protocols use routing tables to forward data toward destinations [7]. However, in mobile wireless sensor networks (MWSNs), frequent routing table updates become inevitable due to dynamic topology. The network must repeatedly perform route discovery while optimizing energy consumption, latency, and bandwidth. Dynamic topology also causes frequent link disruptions that affect ongoing communications.

With the advancement of wireless sensor network technology [1], mobile wireless sensor networks have gained increasing attention for their low-power, low-cost advantages, finding applications in health monitoring, vehicle tracking, and area surveillance [2]. As mobility increases, nodes must continually adapt to frequent topology changes, leading to higher energy consumption per node [3,4]. Energy efficiency in MWSNs is crucial for determining both node lifetime and overall network longevity.

To mitigate increased node energy consumption, nodes need to enter sleep mode to avoid unnecessary active time unless activation is required [5]. Determining when to place sensor nodes into sleep states presents a challenge, as sleeping nodes cannot receive any communications. Conversely, keeping a node active continuously—even when it has no sensing or communication tasks—results in unnecessary energy waste. Introducing mobility into network protocol stack design poses significant challenges [6].

This paper proposes a region-based routing protocol for mobile wireless sensor networks (MWSNs). For mobile data routing, an active region is created around the source and sink nodes, with only nodes within this region participating in route selection while remaining nodes follow a sleep-wake pattern. Data routing is performed such that participating nodes stay close to the Euclidean distance connecting source and sink nodes. The proposed method utilizes node sleep-wake patterns to conserve energy while ensuring reliable packet transmission through active region participation.

1 Proposed Routing Protocol

For a sensor network with n mobile nodes, each mobile node moves randomly within region A at speed v (angle). The base station is positioned at location B. All nodes follow a sleep-wake pattern to improve energy efficiency. These mobile nodes can determine their positions using GPS or similar technologies and can navigate freely.

The sleep-wake pattern reduces energy consumption, with each node sleeping for time T and waking for time T, where $T > T$. Communication between source S and base station B is established by creating a rounded rectangular region R. The proposed method selects optimal nodes for data packet forwarding based on contact time calculated using mobility vector information. The neighbor selection protocol consists of two phases: a signaling phase and a data transmission phase.

1.1 Signaling Phase

The signaling phase initiates when a node has data to transmit. Its objective is to form an active region between source and base station where all sensor nodes remain awake. During this phase, nodes use source and destination position information to create a virtual region connecting them. As illustrated in [Figure 1: see original paper], this region forms a stadium shape, where circles of radius r are cut in half through their centers, with the ends separated by a rectangle of side length a.

The area of the formed region is $A' = r^2 + 2ra$. Nodes are classified as either outside or inside the region based on their positions relative to the defined area. Nodes within region R are classified as inside nodes. If a node $x \quad A'$, it is classified as an outside node. Node classification is shown in [Figure 1: see original paper], with source and base station located at the centers of the circular regions.

Initially, each node starts as an outside node. All outside nodes follow a sleep-wake pattern, transmitting participation request (*reqP*) messages when awake. If any inside node receives a *reqP* message, it sends a participation reply (*reqP*) message after a random wait time less than T. Source and destination information contained in *reqP* messages enables nodes to determine whether they belong to region R. Nodes maintain their wireless active state until they move outside region R.

1.2 Data Transmission Phase

The data communication phase begins after the signaling phase. During data communication, only active nodes participate. The signaling phase awakens all nodes in region R, which then forward data during the communication phase. Each data packet header contains *posS* and *posD* fields to store source and sink node positions, which mobile nodes use to dynamically recalculate the active region.

If a node has data to transmit, it must find a neighbor for communication. The sender node broadcasts a data request packet to all neighbors, and all active nodes receiving the packet reply to the sender after a short time t. The t value is inversely proportional to each neighbor's priority value. Priority is determined by how long a node remains within the transmission range of the neighbor node sending the packet and its position relative to the destination. The neighbor with the highest priority will avoid sending its own reply message, and data is subsequently transmitted to the selected mobile node. This process can send data for up to $\hat{t}$ time units and repeats at each node with data to transmit.

The contact time calculation determines how long two nodes remain within transmission range. For two mobile nodes n and n, the contact time represents the duration they stay within transmission range r. Let *X (t)* be node n' s position vector at time t, and *X (t)* be node n' s position vector at time t. The scenario of two mobile nodes moving at velocities v and v is shown in [Figure 2: see original paper].

Assuming time t as the reference time for calculation, the initial distance between nodes is d, which is less than the transmission range r. Let t' be the time when nodes move out of communication range. The contact time $\hat{t}$ for mobile nodes n and n is expressed as:

The relative velocity is v = v - v, with velocity components along x and y directions:

$$\begin{cases} v_{rx} = v_1 \cos\theta_1 - v_2 \cos\theta_2 \\ v_{ry} = v_1 \sin\theta_1 - v_2 \sin\theta_2 \end{cases}$$

The relative velocity magnitude is:

$$|v_r| = \sqrt{v_{rx}^2 + v_{ry}^2}$$

The relative velocity direction can be determined from these components. The Euclidean distance between nodes n and n at time t is given by:

$$d_0 = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

The contact time represents when nodes exceed range r. With relative velocity separating them at magnitude */v /*, the contact time is:

$$\hat{t} = \frac{r - d_0}{|v_r|}$$

A more precise calculation solves the quadratic equation derived from relative motion. Let *a = v cos - v cos* , *b = v sin - v sin* , *c = x - x* , and *c = y - y* . The contact time is obtained by solving:

$$(a^2 + b^2)\hat{t}^2 + 2(c_x a + c_y b)\hat{t} + (c_x^2 + c_y^2 - r^2) = 0$$

This yields:

$$\hat{t} = \frac{-(c_x a + c_y b) + \sqrt{(c_x a + c_y b)^2 - (a^2 + b^2)(c_x^2 + c_y^2 - r^2)}}{a^2 + b^2}$$

The method’ s algorithm comprises three parts. Algorithm 1 checks whether a node has data to transmit:

```
procedure START(node)
    if node has data then
        Call CALCULATE_NEXT_HOP(node)
    end if
end procedure
```

If no data requires transmission, the node enters sleep state outside the active region. If the destination lies within the sender’s range, it forwards data directly. Otherwise, the sender selects a node with the highest $\hat{t}$ value to forward data. Algorithm 2 implements the CALCULATE_NEXT_HOP(node) function used in Algorithm 1:

```
procedure CALCULATE_NEXT_HOP(node)
    max_contact_time = NEGATIVE_VALUE
    for all neighbors i do
        contact_time = CONTACT_T_CALC(node, i)
        if contact_time > max_contact_time then
            max_contact_time = contact_time
            nexthop = i
        end if
    end for
    if d(node, destination) < r then
        nexthop = destination
    end if
end procedure
```

Contact time calculation is presented in Algorithm 3, which uses the equation above to compute contact time. Mobile ad-hoc networks employ similar methods to predict contact time. Once a mobile node moves out of the active region, it enters sleep-wake state to preserve energy.

The algorithms used in this protocol do not retain data about neighboring nodes. Only the positions of source and destination nodes are stored in memory. Consequently, the protocol’ s algorithms have constant space complexity. For each node participating in data transmission, contact time calculation must be performed. In the worst case, a node may have n neighbors, where n is the total number of nodes. To calculate the next-hop neighbor for data transmission, the algorithm requires $O(n)$ time. Neighbor computation occurs at regular intervals, giving the protocol linear time complexity.

2 Experimental Results and Analysis

To validate and analyze the performance of the proposed mobile wireless sensor network routing protocol, simulations were implemented using the OMNeT++ framework on an Intel Core i7 system at 2.69 GHz with 4 GB RAM running Windows 10. Wireless sensor network simulation parameters are listed in .

Table 1. Simulation Experiment Parameters

Parameter	Value
Area size	200m × 200m
Packet size	128 bytes
Sink node	(0, 0)
E_elec	50 nJ/bit
_fs	20 pJ/bit/m²
_mp	0.013 pJ/bit/m

The proposed protocol' s efficiency is evaluated by comparing the number of nodes within mutual contact range while varying velocities. Experiments run for 300 seconds, with averages from multiple iterations used for analysis. Results are shown in [Figure 5: see original paper], demonstrating that the number of nodes participating in overall data communication is smaller compared to ROF. This occurs because the proposed protocol selects neighbor nodes with maximum contact time. Additionally, as velocity increases, the number of contacting mobile nodes also increases due to highly dynamic topology.

To demonstrate the proposed algorithm' s superiority, comparisons were made with existing protocols. Few protocols in current literature support energy-efficient routing in WSNs through mobile relays. This study selected Receiver-Based Opportunistic Forwarding (ROF) and Greedy Perimeter Stateless Routing (GPSR) for comparison. Due to low complexity, neither requires global tables (both use local topology information to select direct neighbors for communication).

The ROF protocol does not require establishing global routes between source and destination. ROF selects neighbor nodes relative to the sender to compete for forwarding rights. The protocol optimizes forwarding priority calculation and designs a dual-channel-based forwarding contention mechanism to handle data conflicts and forwarding delays. GPSR uses information about the sender' s direct neighbors in the network topology to make decisions. In GPSR, when greedy forwarding becomes impossible, the algorithm recovers by routing around the region' s perimeter. For dynamic topologies with mobile nodes, GPSR can quickly find correct new routes.

Simulations assume a single source-destination pair. A random waypoint mobility model determines node positions. Analysis is performed by varying the number of source nodes, data rates, and node velocities. Packet size is set to 128 bytes.

[Figure 3: see original paper] shows the packet delivery ratio (PDR) for the proposed protocol, ROF, and GPSR. Nodes move at 0.5 m/s, with sender rates varying from 10 pps to 200 pps. Results indicate that the proposed method achieves better PDR compared to other protocols, with GPSR showing the lowest PDR.

For further analysis and validation, node velocity is varied from 0.5 m/s to 10 m/s, with packets transmitted at 20 pps. The PDR for each method is calculated and displayed in [Figure 4: see original paper]. The results demonstrate that the proposed protocol delivers superior performance.

[Figure 5: see original paper] illustrates the relationship between the number of data communication nodes and velocity. [Figure 6: see original paper] presents the average contact time per node compared with the ROF protocol. The proposed protocol achieves the highest average contact time due to its neighbor selection algorithm that preferentially chooses optimal neighbors.

3 Conclusion

This paper proposes a region-based routing protocol for mobile relay nodes in wireless sensor networks. The protocol supports topology control through an improved sleep-wake node mechanism. The static node's sleep-wake approach ensures network-wide energy efficiency without adding time synchronization overhead. Comparative experiments with ROF and GPSR protocols demonstrate that the proposed protocol achieves superior packet delivery ratio with fewer participating nodes.

Current work focuses on communication between a single source and static receiver. Future work will extend the protocol to support multiple sources communicating with mobile receivers.

References

[1] Xu Hongyan, Guo Hong. On fault diagnosis algorithm in wireless sensor network nodes [J]. Journal of Southwest China Normal University: Natural Science Edition, 2016, 41(9): 126-133.

[2] Chang Jie, Zhang Ling. Optimal path planning for mobile sink in random distributed wireless sensor networks [J]. Computer Science, 2017, 44(2): 147-151.

[3] Al-Jemeli M, Hussin F A. An energy efficient cross-layer network operation model for IEEE 802.15.4-based mobile wireless sensor networks [J]. IEEE Sensors Journal, 2015, 15(2): 684-692.

[4] Velmani R, Kaarthick B. An efficient cluster-tree based data collection

scheme for large mobile wireless sensor networks [J]. IEEE Sensors Journal, 2015, 15(4): 2377-2390.

[5] Boubekri A, Ajib W, Boukadoum M. EAM: Energy Aware Mobility over wireless sensor networks [C]//Proc of the 30th Canadian Conference on Electrical and Computer Engineering. IEEE Press, 2017: 1-6.

[6] Sreejith V, Suriyadeepan R, Anupama K R, et al. DS-MMAC: dynamic schedule based MAC for mobile wireless sensor network [C]//Proc of the 31st Annual ACM Symposium on Applied Computing. ACM Press, 2016: 738-741.

[7] Zhao Yue, Meng Bo, Chen Lei, et al. Routing protocol in wireless sensor networks based on energy aware [J]. Computer Engineering and Design, 2016, 37(1): 16-20.

[8] Luo J, Hu J, Wu D, et al. Opportunistic routing algorithm for relay node selection in wireless sensor networks [J]. IEEE Trans on Industrial Informatics, 2015, 11(1): 112-121.

[9] Kumar A, Shwe H Y, Wong K J, et al. Location-Based Routing Protocols for Wireless Sensor Networks: A Survey [J]. Wireless Sensor Network, 2017, 9(1): 25-72.

[10] Pantazis N A, Nikolidakis S A, Vergados D D. Energy-efficient routing protocols in wireless sensor networks: A survey [J]. IEEE Communications Surveys & Tutorials, 2013, 15(2): 551-591.

[11] Gaddour O, Koubâa A, Rangarajan R, et al. Co-RPL: RPL routing for mobile low power wireless sensor networks using Corona mechanism [C]//Proc of the 9th IEEE International Symposium on Industrial Embedded Systems. 2014: 200-209.

[12] Wang Kaibin, Cheng Lianglun. Wireless sensor network redundancy sensor node state schedule method [J]. Journal of Application Research of Computers, 2018, 35(4): 1227-1230.

Note: Figure translations are in progress. See original paper for figures.