Energy-efficient network reprogramming scheme with Raptor code by using transmission power control in WSNs

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Abstract: In wireless sensor networks, the necessity of reprogramming becomes more and more important for variety of purposes. However, the reprogramming produces a large amount of data and causes large energy consumption and interference. In this Letter, we propose an energy-efficient reprogramming scheme with Raptor code by using transmission power control. By selecting proper relay nodes, relay nodes' transmission power and Raptor code overhead, the proposed scheme minimises energy consumption while guaranteeing reliable transmission. This is verified by comparing it with conventional schemes.

1 Introduction

In general, wireless sensor network (WSN) consists of hundreds of small-sized battery-powered sensor nodes that integrate sensing, computing and communication capabilities. WSNs are employed in various applications such as disaster protection, security surveillance, battle field observation and healthcare infrastructure [1]. In many applications, WSNs are deployed in inaccessible areas. Thus, reprogramming is required to enable new functionalities.

Reprogramming of WSN should be supported not only with 100% accuracy of the disseminated data, but also in an energy-efficiency manner. A Traditional method is to perform manual reprogramming; however, it is costly and impossible since certain nodes cannot be accessed physically. Another conventional reprogramming method is multicast/broadcast schemes [2–5] which perform reprogramming with fixed transmission power. However, this can cause redundant energy consumption and interference. In addition, reprogramming methods with variable transmission power are proposed in [6–8] where transmission power is decided according to the received signal strength indication (RSSI). However, they are unsuitable for applications generating large traffic such as reprogramming because of control overhead of each node. Furthermore, [6–8] lead to unreliable transmission because of reducing transmission power. In this Letter, we propose new reprogramming scheme with Raptor code which optimises transmission power while guaranteeing reliable transmission.

2 Protocol description

The proposed scheme encompasses two phases: topology discovery phase and transmission power control phase. After discovering current topology in the first phase, relay node (RN) and transmission power of RNs are decided in the second phase. After then, sender node transmits reprogramming data by pre-calculating transmission power.

3 Topology discovery phase

In this Letter, WSN consists of beacon nodes (BNs) which have an inherent knowledge of their own position and normal sensor nodes (NSNs). BNs broadcast their location information and NSNs determine their location based on the RSSI and BN's location information using (1)

$$P_i(x, y) = \frac{\sum_{k=1}^{l} \left(\mathrm{WC}_{ik}\, B_k(x, y)\right)}{\sum_{k=1}^{l} \mathrm{WC}_{ik}} + \frac{\sum_{j=1}^{n} \left(\mathrm{WC}_{ij}\, P'_j(x, y)\right)}{\sum_{j=1}^{n} \mathrm{WC}_{ij}} \quad (1)$$

where $P_i(x, y)$ represents the position of node i given by its two-dimensional coordinates. The known position of beacon k is given by $B_k(x, y)$ and the estimated position of node j is given by $P'_j(x, y)$ which is calculated by other BN's location information and other known NSNs location information. l and n indicate, respectively, the number of BNs and estimated number of known nodes that are within the communication range of the considered unknown node. In addition, WC_{im} is the weight cost between the node i and the known position of node m which is defined as

$$\mathrm{WC}_{im} = \frac{\alpha}{\mathrm{LQI}_{im}} \quad (2)$$

where LQI_{im} is the link quality indicator value between i and m and α is proportional factor between BN and estimated location information node that is determined as follows

$$\alpha = \begin{cases} 1, \quad \text{location information from BN} \\ \min(1 + \text{number of estimation location, } 5), \\ \text{location information from estimation nodes} \end{cases} \quad (3)$$

After calculating the location coordinate, each node can be aware of its own position. This information is transmitted to the sink that will be piggybacked in transmitted data. In this Letter, we assume that the reprogramming is performed after a given time of network deployment, thus the sink node recognises the network topology.

4 Transmission power control phase

When the network reprogramming triggers, based on the estimated node location information in topology discovery phase, RNs and their power are determined in transmission power control phase. In the proposed scheme only specific RNs transmit reprogramming data with pre-calculated transmission power.

First of all, the sink node calculates normalised transmission power (NpP) and it is defined as

$$NpP = \frac{P_i}{k} \quad (4)$$

where P_i is the adjusted transmission power based on node i and adjusted transmission power is calculated by Friis formula with location information. k is the number of nodes within P_i.

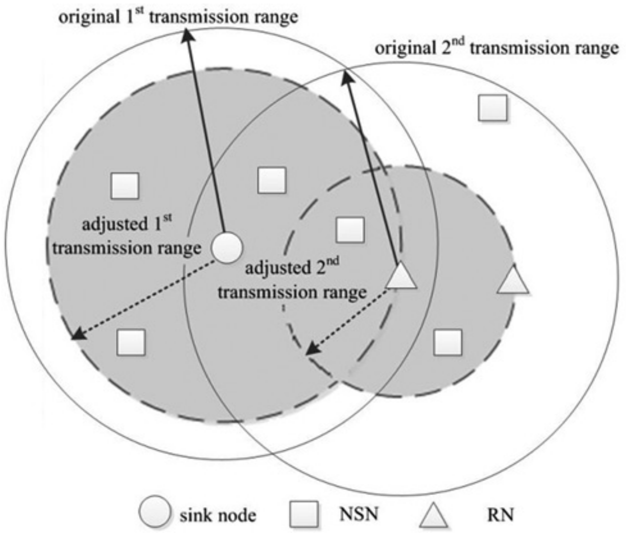

Fig. 1 *Coverage area of proposed scheme*

After then, the sink node selects the RN node that has the minimum *NpP* value. However, if RN is only selected based on *NpP*, the same node will be consecutively selected as RN, which quickly exhausts its energy. To overcome this side effect, the number of cumulative selection is considered when selecting the RN as described by the following formula

$$\text{RN\_ID}(i,\ l) = \min\left(NpP_1\, m_l,\ \ldots,\ NpP_i\, m_l,\ \ldots,\ NpP_n\, m_l\right) \quad (5)$$

where m_l is the cumulative selecting number as RN at lth reprogramming and its default value is 1.

Fig. 1 shows coverage area of the proposed scheme. The original transmission range indicates the transmission range for a fixed transmission power. The adjusted transmission range represents the optimal transmission range that can cover the node.

Furthermore, we utilise Raptor code, which is a famous application layer forward error correction (AL-FEC), to compensate for unreliable transmission by reducing transmission power. After applying Raptor code, we obtain reliability gain described as

$$P_f(n,\ P_e) = 0.85 \times 0.567^{n-k-P_e n} \quad (6)$$

where P_f is the expected received symbol erasure probability in AL, n is the output Raptor symbol length, k is the input source symbol length and P_e is the input symbol erasure probability in medium access control (MAC) layer. The relation between n and k is defined as Raptor code overhead and it is described as

$$\varepsilon = \frac{n-k}{k} \quad (7)$$

In addition, P_e is calculated using (8)

$$P_e(l) = 1 - \left(1 - 0.5 \times \operatorname{erfc}\left(\sqrt{\frac{P_r \times W}{N \times f}}\right)\right)^l \quad (8)$$

where P_r is the received power, W is the channel bandwidth, N is the noise power, f is the transmission bitrate, erfc is the complementary error function and l is the symbol length [9].

After determining the first RN_ID, its transmission power, and its Raptor code overhead, sink node determines the second RN's parameter based on the first ones. The calculation for selecting RNs is performed until the final target node is covered by RN node.

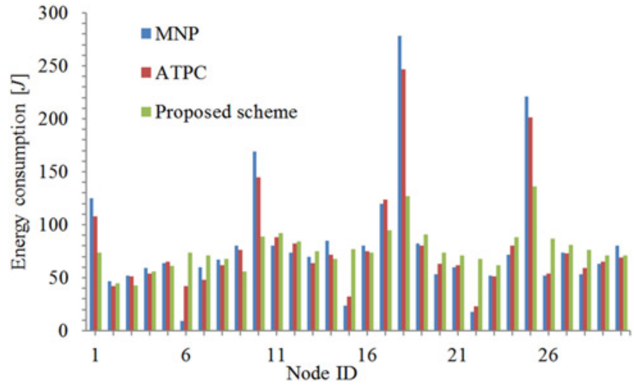

Fig. 2 *Energy consumption comparison*

Finally, the determined parameters are to be transmitted to RNs being piggybacked in data. Eventually, by selecting proper RN, RN's transmission power and Raptor code overhead, the proposed scheme reduces energy consumption while guaranteeing reliable transmission.

5 Simulation results

For the performance evaluation, we use OMNeT++ [10] which is a widely used network simulator and allows the performance evaluation in WSNs. We assume that the new programme size is 30 Kb corresponding to the code size for an operating system such as TinyOS [11].The new programme is divided into 32 pages; each page consists of 30 packets with 32 byte of data payload. The 30 sensor nodes are randomly deployed in a 500×500 m field. We assume that the node, positioned at the bottom-left edge, initially floods the new program. In the simulation, the radio characteristics are of CC2240 transceiver [12] and the MAC protocol is based on IEEE 802.15.4 [13]. The proposed scheme is compared with the multi-hop network reprogramming protocol (MNP) [4] and adaptive transmission power control (ATPC) [7]. In the MNP, each source node calculates the number of neighbour requesters that sent the request packets to it. By exchanging messages including its number of neighbour requesters with other sensor nodes, one of the source nodes in their hop range is selected as the sender which has the most neighbour requesters. On the other hand, in the ATPC, every node broadcasts several beacons to measure the RSSI value at diverse transmission powers. Every node then learns the relationship between the RSSI value and the various transmission powers.

Fig. 2 shows the energy consumption of the MNP, ATPC and the proposed scheme. As it can be observed, the proposed scheme has lower energy consumption than the two others. By using both adjusting transmission power and Raptor code, the proposed scheme restrains unnecessary retransmission by transmission errors. The average energy consumption of MNP, ATPC and the proposed scheme are 82.7, 78.6 and 74.3 J respectively. Furthermore, in MNP and ATPC, the node is positioned at the middle of the network; it has a high probability to transfer the received new programme because it has many receiver nodes around its neighbour. However, the proposed scheme selects RN by considering *NpP* and cumulative RN selection number and the proposed scheme has low energy consumption that is distributed equally to all nodes.

6 Conclusion

The proposed scheme aims to design an energy-efficient reprogramming method with Raptor code using transmission power control. Based on *NpP*, cumulative RN selection number, the sink node decides RNs, their transmission power and Raptor code overhead. Additionally, unreliable transmission by adjusting transmission power is compensated by Raptor code. Comparing with MNP and ATPC, we demonstrate the proposed scheme outperforms them both.

7 References

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