Energy Optimization in Wireless Sensor Network

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Abstract. Energy consumption is a major challenge in wireless sensor network (WSN). Most of the routing algorithms focus on energy efficient paths, For the analysis of such algorithms at low cost and in less time; we believe that, simulation gives the better approximation. Therefore, in this paper, we are proposing a simulation model for WSN. Literature survey is done on energy-aware routing protocols, in which, it is found that, Minimum Total Transmission Power Routing (MTPR) and Minimum Battery Cost Routing (MBCR) Protocol, most comprehensively captures tradeoffs of energy efficiency and network lifetime respectively. Proposed simulation model is implemented using Qualnet 4.5 and applied to MTPR and MBCR to analyze its performance. Through this study, we lay a foundation for further research work on enhancements in extending the network lifetime of WSN. Experimental result shows that there is always a tradeoff between energy efficiency and network lifetime.

Keywords: Energy Aware Routing Protocol, Wireless Sensor Network, Quality of Service, Power Aware Routing, Qualnet 4.5.

1 Introduction

Traditional routing protocols are not designed as per the specific requirement of WSN. Therefore, energy efficient routing paradigms are an area of active research [1]. Power aware routing protocols make routing decisions based on power, energy related metrics to optimize the performance of routing protocol. The two routing objectives of “minimum total transmission energy” and “total working time of the network” can be mutually contradictory. For example, when several minimum energy routes share a common node, the battery power of this node will quickly run into depletion, shortening the network lifetime. In WSN, excessive energy conservation, neglecting energy consumption at individual nodes, speeds up network partition by draining batteries of the energy critical nodes in the network. In effect, it shortens the network lifetime. On the other hand, not considering overall energy consumption, this commits to paths with large number of hops and longer total distance. Consequently, the total energy dissipated is high and on an average, the battery power decays faster. In effect, it also shortens the network lifetime. The above observations suggest that both battery level and transmission energy needs to be considered while designing energy aware routing protocols.

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The paper is organized as follows: Section 2 presents related work. Proposed simulation model is discussed in section 3. Section 4 presents experimental set-up. Results are discussed in section 5 and finally, conclusion is given in section 6.

2 Related Work

This section gives the brief information of research in routing protocols for WSN. In [1], the authors have said that the Traditional routing algorithms are not optimized for energy conservation; therefore energy efficient routing paradigms are an area of active research. Ian et al. [2] present a survey of sensor networks. W. R. Heinzelman et. al. [3] have proposed LEACH (Low Energy Adaptive Clustering Hierarchy), a clustering based protocol that utilizes random selection of cluster head. Itanagonwiwat et al. [4] have presented Directed Diffusion Protocol [DDP]. In this protocol, a sink requests data by sending interests for named data. Data matching the interest is then drawn toward that node. Intermediate nodes can cache or transform data, and may direct interests based on previously cached data. Ganesan et al. [5] present Multi path Routing algorithm. The focus of this algorithm is to extend the working time of network. A family of protocols called Sensor Protocols for Information via Negotiation (SPIN) is proposed in [6]. SPIN is a source initiated directed diffusion scheme, developed at the Manchester's Institute of Technology (MIT). SPIN uses negotiation and resource adaptation to address the deficiencies of flooding. N. Chilamkurti et. al [7], have exploited cross-layer optimizations technique that extends the DSR to improve its routing efficiency by minimizing the frequency of reforming routes. In [8], Nadeem Ahmed et. al, have proposed a multi hop routing protocol for ZigBee based WSN that considers the interference caused by WiFi networks and uses multiple channels at different frequencies to increase the network throughput. Hui Wang et. al. [9] investigates a cross-layer design approach to minimize energy consumption and maximize network lifetime (NL) of a multiple source and single sink (MSSS) WSN. C.-K. Toh [10] has discussed Minimum Total Transmission Power Routing and Minimum Battery cost routing along with the Network Performance Parameters. In [11], S. Singh, M. Woo and C. S. Raghavendra have presented a new power aware matrics for determing routes in Ad-Hoc network.

2.1 Minimum Total Transmission Power Routing (MTPR) [10]

This protocol focuses on end-to-end energy efficiency. Generally, the route selected for conserving energy is the shortest distance path or minimum hop path, the end-to-end shortest path naturally leads to conservation of energy in transmission. In a non-partitioned network, there exists at least one path for communication with any other node. So theoretically, any node can reach any other node in the network through a random forwarding path. However, the energy consumption along different paths differs, due to its dependence on variations of distance between directly communicating nodes and noise interference levels. The greater the values of these parameters, larger the amount of energy required for transmission. Successfully transmission of packets requires the Signal-to-Noise Ratio (SNR) at the receiver to be greater than a predetermined threshold ψ_j that is closely related to the Bit Error Rate (BER). Mathematically, this is expressed as:

$$SNR_j = \frac{P_i G_{i,j}}{\sum_{k \neq i} P_k G_{k,j} + \eta_j} > \psi_j (BER) \tag{1}$$

where P_i is the transmission power of node n_i, $G_{i,j}$ is the path gain, inversely proportional to the distance d between nodes n_i and n_j (i.e., $G_{i,j} = 1 / d_{i,j}n$, usually n = 2 for short distance and n = 4 for longer distance) and η_j is the thermal noise at n_j.

Minimization of the power consumption can be obtained by selecting a routing path with minimum total transmission power. The transmission power P (n_i, n_j) between nodes n_i and n_j are used as the metric to construct such routing path. The total transmission power for a possible path l, P_l can be derived from:

$$P_l = \sum_{i=0}^{D-1} P(n_i, n_{i+1}) \qquad \text{For all nodes } n_i \text{ on route l} \tag{2}$$

Where n0 and n_D are the source and destination nodes. Hence, a path k will be selected if it satisfies:

$$P_k = \min_{l \in A} P_l \tag{3}$$

Where A is the set of all possible routing paths.

2.2 Minimum Battery Cost Routing (MBCR)[10]

Though the transmission power is an important metric to consider, if multiple minimum total power paths pass through some common node, then this common node will soon experience battery exhaustion. MTPR has a drawback in violating fair distribution of power consumption among nodes. It does not reflect the lifetime of individual nodes. This indicates that, as an alternative, node's residual energy can be used as a cost metric in route selection. MBCR is such a scheme that minimizes the path battery cost so as to maximize the total network life time. The cost function f in MBCR is defined such that the lower the remaining battery capacity c of a node i, the more reluctant the node is to receive and forward the packet. One possible function f is

$$f_i(c_i) = \frac{1}{c_i} \tag{4}$$

This shows that as a node's battery power decreases, the cost to include the node into the routing path increases.

By using residual power as a cost metric, MBCR avoids excessive usage of network nodes, and attempts to evenly distribute battery capacity over the network to delay network partitioning. However, it has a drawback, again because only the end-to-end consideration is taken. Although the total battery cost achieves minimum, some weak links where nodes have little residual power can still exist in the paths, which may lead to early network partitioning.

3 Proposed Simulation Model

Fig.1. shows that, the proposed simulation model has six major components: Network Scenario Designer, Network Animator, Packet Generator, Static/Mobile Scenario Generator, Routing Protocol Engine, and Statistics Analyzer.

The module Network Scenario Designer states the space boundary, number of network nodes, their location and the maximum transmission range as an input parameter. The network animator is the simulation ground for packet delivery and mobile node movement events. The number of active communicating parameters including mobility speed, pause time can be varied.

The routing protocol engine includes MTPR, MBCR, AODV, and other routing protocols whose performance is to be analyzed. MTPR, MBCR are on top of AODV, in which MTPR, MBCR handles the route selection whereas AODV manages route discovery, route maintenance and route refreshments through in cooperation with

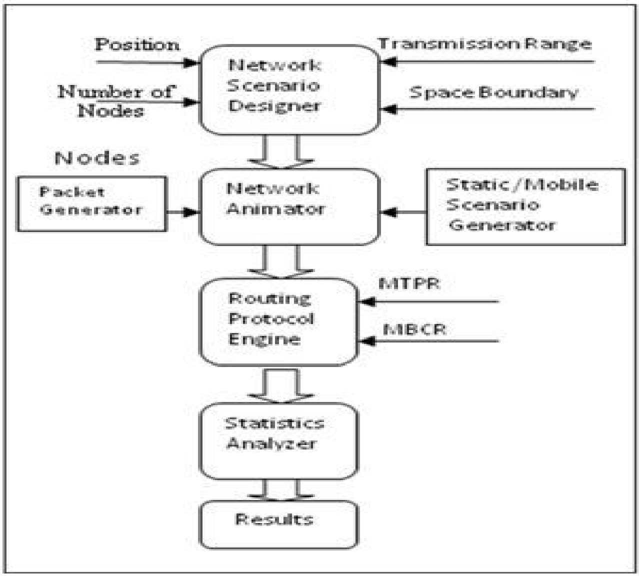

Fig. 1. WSN Simulation Model

MAC and physical layers in the TCP/IP stack. When the routing protocol engine processes packet transmission or node movement events, statistics such as energy consumption, node dead time, and other QoS parameters are recorded. Statistics analyzer examines the recorded data and draw out specified analysis results.

4 Experimental Setup

The proposed simulation model is implemented using Qualnet 4.5[12] and the performance of MTPR and MBCR is tested for the simulation of 16 nodes, forming a grid of 4*4 cells with 200M distance between every pair of nodes. IEEE 802.11 protocol is used at MAC and Physical layer. Constant bit rate (CBR) is used to apply data traffic over User Datagram Protocol (UDP), a connection between source and destination node. The simulations parameters used are as shown in table1.

Table 1. Simulation Parameters

Parameters	Values
No. of Nodes and Area	16 and 1500m*1500m
Simulation time	240 simulation units
Channel frequency	2.4GHz
Transmission range	300 meter
TX-Power	15dBm
Path Loss Model	Two Ray Model
Phy and MAC Model	802.11
Energy Model	MICAZ Mote
Battery Model	Simple Linear,1200 mAhr,
Data Rate	0.1,1,2,5,10
Payload Size	512 bytes

5 Results and Discussion

This section provides the experimental results to compare and validate the effectiveness of MTPR, MBCR. We have implemented the MTPR and MBCR algorithms in “C” and used the environment of Qualnet 4.5 for simulation.

Fig. 2 shows the residual energy of nodes after the completion of simulation using MTPR and MBCR. In MTPR, It is an end to end consideration to selects the shortest path for routing and does not consider the energy critical nodes along the path. MBCR considers node’s residual energy as a cost metric in route selection but it is again a end to end consideration. Results showed in Fig. 3 to 6 shows the effect of path selection metric used in MTPR and MBCR. Fig. 3 shows the comparative analysis of network lifetime of MBCR and MTPR. Experiment is repeated for different data rate values such as 0.1, 1, 2, 5, and 10. Fig. 3 shows that for high data rate, MTPR has low network lifetime than the MBCR. Fig. 4 shows that the amount of data received (bits/Sec) at destination node. For all data rate values, throughput obtained using MTPR is higher as compared to that of MBCR. It can be easily judged from Fig. 3 and 4 that there is always a tradeoff between energy efficient path and network life time. Fig. 5, and 6 shows end to end delay and jitter observed for the given scenario using MBCR and MTPR respectively.

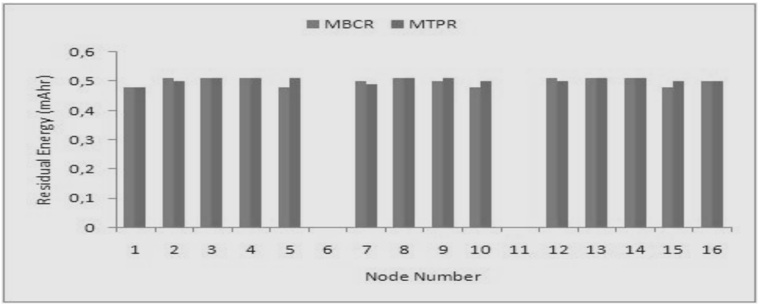

Fig. 2. Residual Energy

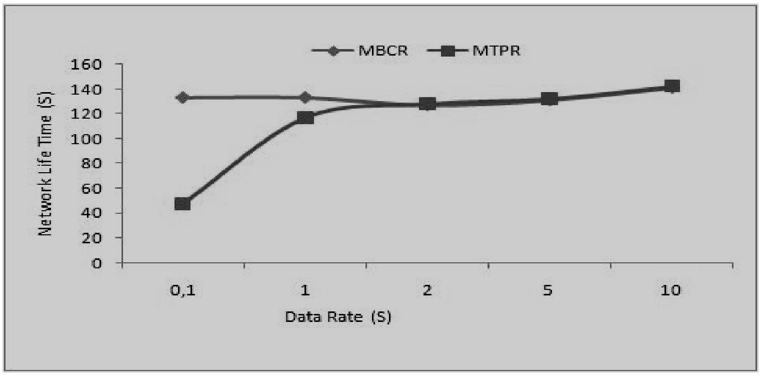

Fig. 3. Network Lifetime

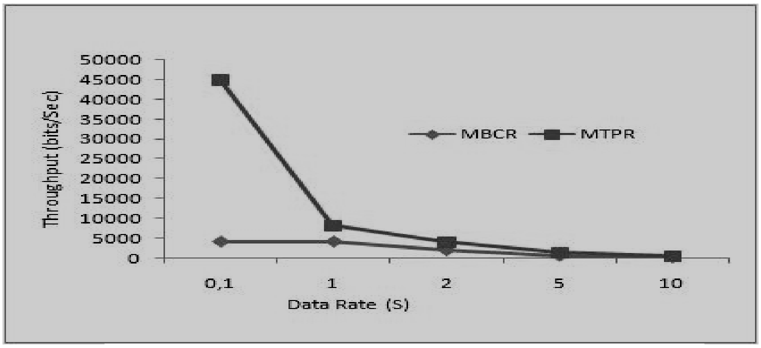

Fig. 4. Throughput

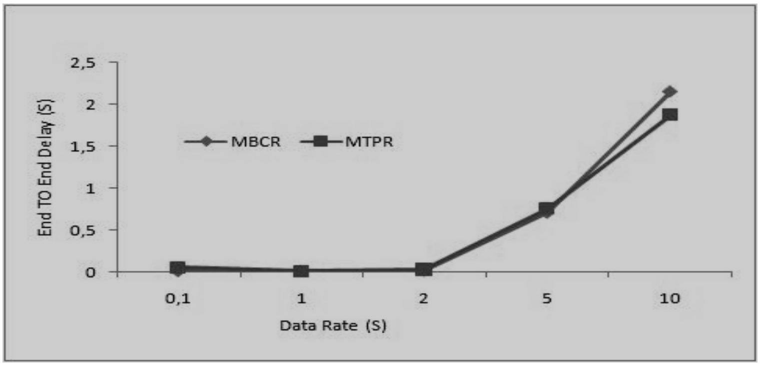

Fig. 5. Comparative Analysis of End TO End Delay

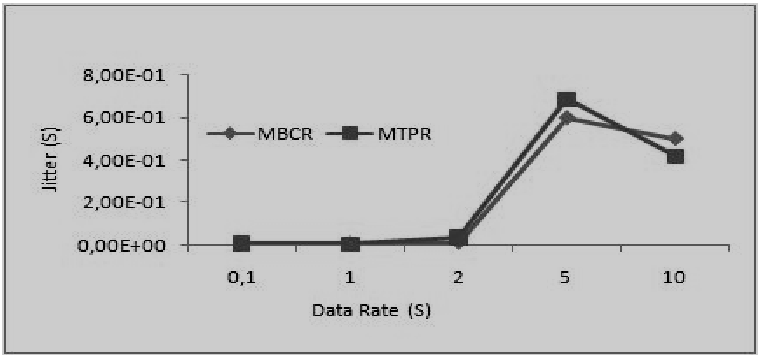

Fig. 6. Comparative Analysis of Jitter

5 Conclusion

In this paper, we have proposed a simulation model for the analysis of routing protocols and also presented some energy aware routing protocols such as Minimum Total Transmission Power Routing (MTPR) and Minimum Battery Cost Routing (MBCR) that are prominent in the research community. Proposed simulation model is applied to MTPR and MBCR, to investigate the performance they provides on energy saving, network lifetime and other Quality of Service (QoS) parameters. It is found that, as MTPR focuses on shortest distance path or minimum hop path, the total battery consumption achieves minimum, However, some weak links where nodes have little residual power can still exist in the paths, which may lead to early network partitioning. MBCR avoids excessive usage of network nodes, and tries to balance battery capacity over the network to delay network partitioning. However, because of end to end energy consideration, some weak links where nodes have little residual energy can still exist in the paths, which may lead to early network partitioning.

Future Work: Energy aware routing protocols are energy-saving strategies designed at the network layer. These are effective in power saving, but are still limited in the ability of making use of strategies or parameters designed at other layers. Through cross layering, Making use of the parameters defined at various layers such as MAC, physical, application layers and network layer are expected to bring improvements. Therefore, our further work will be based on cross layer design for enhancements in extending the energy efficiency and network lifetime of Wireless Sensor Network.

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