ENERGY EFFICIENT ROUTING ALGORITHM FOR MAXIMIZING THE MINIMUM LIFETIME OF WIRELESS SENSOR NETWORK: A REVIEW

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ABSTRACT

In wireless sensor network, devices or nodes are generally battery powered devices. These nodes have limited amount of initial energy that are consumed at different rates, depending on the power level. The lifetime of the network is defined as the time until the first node fails (or runs out of battery). In this paper different type of energy efficient routing algorithms are discussed and approach of these algorithms is to maximize the minimum lifetime of wireless sensor network. Special attention has been devoted for algorithms formulate the routing problem as a linear programming problem, which uses the optimal flow path for data transmission and gives the optimum results. Advantages, limitations as well as comparative study of these algorithms are also discussed in this paper.

KEYWORDS

Battery power, Lifetime of wireless sensor network, Minimum energy cost routing, Optimal flow, Linear programming problem.

1. INTRODUCTION

In recent years, wireless communication has experienced exponential growth caused by the need for connectivity. Wireless networking has followed a similar trend due to the increasing exchange of data in services such as the Internet, e-mail and data file transfer. The capabilities needed to deliver such services are characterized by an increasing need for data throughput. Other applications in fields such as industrial, agricultural, vehicular, residential, medical sensors and actuators have more relaxed throughput requirements. This type of network consists of a group of nodes and each node has limited battery power. There may be many possible routes available between two nodes over which data can flow. Assume that each node generated some information and this information needs to be delivered to set of destination nodes. A node can easily transmit data to a distance node, if it has sufficient battery power. A node transmits its data to other node without any interference, if node lies in its vicinity. A large battery power is required to transmit the data to a node which is situated far from source node. After few transmissions a node reaches to its threshold battery level and it may exclude from network path and there will come a condition that no node is available for the data transmission and overall lifetime of network will decrease. Whereas network lifetime is define as the time until the first node in the network dies.

For maximizing the lifetime of network, the data should be forwarded such that energy consumption is balanced among the nodes in proportion to their energy reserved, instead of routing to minimize consumed power. The minimum energy routing is proposed as in [1]

DOI : 10.5121/ijasuc.2011.2203

approach in this work is to minimize the energy consumption to reach the destination by sending the traffic to same path but if all the traffic follows the same path then all the nodes of that path will drain out there energy quickly. Instead of trying to minimize the consumed energy the main objective is to maximize the lifetime of the system. Chang and Tassiulas define the maximum lifetime problem is a linear programming problem and solvable in polynomial time [2]. In this work considers the single commodity version of the problem but [3] the problem is extended to multicommodity case, where each commodity has its own set of destinations. [2],[3] proposed maximizing the lifetime of a network when message rate is known but Q. Li, J. Aslam and D. Ras proposed online, hierarchical and scalable algorithms [4] that do not rely on knowing the message rate and optimize the lifetime of network.

Routing algorithms [2],[3],[4] consider energy consumption on sender side only, but as in [5] the maximum lifetime routing problem is extended to include the energy consumption at the receiver during reception. The relation of maximizing the minimum lifetime of the nodes to minimizing the cost per packet was defined as in [2],[3],[4],[5] but this relation take one step further to provide a delay guarantee in the time the packets reach their destination, while maximizing network lifetime [6].

In [7] C.K. Toh discovered that if nodes in an ad hoc wireless network expend most of their power on communication-related applications, then power aware routing protocols like minimum battery cost and min-max battery cost schemes can prevent nodes from being unwisely overused. This extends the time until the first node powers down and increases the operation time before the network is partitioned. Investigations reveal that these two goals (to use each node fairly and to extend their lifetimes) are not compatible. A trade-off between them is needed. C.K Toh proposed conditional maxmin battery capacity routing (CMMBCR) scheme which chooses the shortest path if all nodes in all possible routes have sufficient battery capacity. When the battery capacity for some nodes goes below a predefined threshold (τ), routes going through these nodes will be avoided, and therefore the time until the first node power-down is extended. By adjusting the value of τ, either the time when the first node powers down or the lifetime of most nodes in the network can be minimized.

K. Kar, M Codialam, T. V. Lakshman and L. Tassiulas provided routing algorithm for network capacity maximization in energy constrained ad hoc network [8]. C. Pandana and Ray Liu proposed the Keep Connect algorithm along with flow augmentation or with Minimum Total Energy algorithm and these combine algorithm provided maximum connectivity of the network as well as maximize the lifetime of network [9].

In [10] LEACH (Low-Energy, Adaptive Clustering Hierarchy) is given by W.R.Heinzelman, A.Chandrakasan and H. Balakrishnan. LEACH is a clustering-based protocol that utilizes randomized rotation of local cluster base stations (cluster-heads) to evenly distribute the energy load among the sensors in the network. LEACH uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data fusion into the routing protocol to reduce the amount of information that must be transmitted to the base station. H.Hsu and Q.Liang extend the work of LEACH [11]. They extend LEACH stochastic cluster-head selection algorithm by a deterministic component to reduce energy consumption.

In [12] an energy efficient routing in ad hoc disaster recovery networks is given by Gil Zussman and Adrian Segall. Their network model is based on the model for energy conserving routing in a wireless sensor network, presented by Chang and Tassiulas [2]. Formulated as an anycast routing problem, in which the objective is to maximize the time until the first battery drains-out. They present iterative algorithms for obtaining the optimal solution of the problem. Then, they derive an upper bound on the network lifetime for specific topologies and describe a polynomial algorithm for obtaining the optimal solution in such topologies. Finally, numerical results regarding the upper bound and the algorithm are presented.

G. Anastasi, M. Conti, M. D. Francesco and A. passarella discussed various energy conservation schemes in wireless sensor network. To reduce power consumption in wireless sensor network, they identified three main enabling techniques namely duty cycling, data-driven approach and mobility [13]. Distributed energy balanced routing is proposed in [14]. This routing algorithm uses the energy balance path for data transmission. It firstly calculates the total energy cost of all the paths from source node to base station and then select energy efficient path for data transmission.

The organization of the rest of the paper is as follows. Section 2 describes the various energy efficient routing algorithms and section 3 describes the comparison of various energy efficient routing algorithms. Finally in section 4, some concluding remarks are made.

2. ENERGY EFFICIENT ROUTING ALGORITHMS

A key challenge in ad hoc wireless sensor network is achieving a long lifetime of nodes that carry limited amount of battery energy. It could be impossible or inconvenient to recharge the battery in the remote location therefore, the crucial requirement is to prolong the network life time.

Need to Prolong the WSN Lifetime

- Devices are generally battery powered.
- Devices may be embedded inside structures.
- Failure of some devices may result in the failure of entire network.
- Sensor nodes cooperatively perform a single task so they must be alive for same amount of time.
- Sensor nodes are use for application where they monitor particular region so they must go down in a fashion that the overall task may be accomplish

In wireless sensor networks the main objective is to maximize the minimum lifetime of each node. Lifetime is maximized by balancing the energy consumption of each node, using energy efficient routing. To maximize the objective function, it is appropriate for an emergency network in which every node is critical.

Assumption for energy efficient Routing Algorithms

- Consider a directed graph G (N, A) where N is the set of all nodes and A is the set of all directed links (i, j) where i,j Є N.
- Let Si be the set of nodes that can be reached by node i with a certain power level in its dynamic range, where link (i,j)exists, if j Є Si.
- A set of origin nodes O where the information is generated
- A set of destination nodes D among which node can be reached in order for the information transfer be considered done.
- Let each node i have the initial battery energy Ei
- Let Qi be the rate at which information is generated at node i.
- The transmission energy required for node i to transmit a bit to its neighbouring node j is eij,
- The rate at which information transmitted from node i to node j is called the flow qij.

So based on the above [2] Assumptions, various energy efficient routing algorithms maximize the lifetime of network. These routing algorithms are

2.1. Energy Efficient Routing Algorithm for Single Destination [2]

2.1.1. Flow redirection algorithm (FR)

Definition:
Largest longest length path (Lp): largest longest length path is the path in which has largest capacity in terms of battery power and have less energy consumption per bit transmission than all other nodes in network.
Smallest longest length path (Sp): smallest longest length path is the path in which has minimum capacity in terms of battery power and have higher energy consumption per bit transmission than all other nodes in network.

Flow redirection algorithm (FR) is the redirection based algorithm where some amount of flow is redirected from smallest longest length path (Sp) to largest longest length path (Lp). In this algorithm firstly Determine the two paths from node i to the destination which are to be involved in redirection second step calculate the amount of redirection (€) and in the final step add € amount of flow to the largest longest length path Lp. After adding € amount of flow algorithm checks one or possibly more loops in the path and then loops are removed link by link along the path so in this step properly increment or decrement the flows of the two paths.

2.1.2. Maximum Residual Energy Path Routing (MREP)

In MREP algorithm let P be the set of all paths from node i to the destination node d. For a path p Є P, define the path length lp as a vector whose elements are the reciprocal of the residual energy for each link in the path after the route has been used by a unit flow. We assume that the routing path is calculated for each unit flow. The idea was to augment the flow on the path whose minimum residual energy after the flow augmentation will be longest.

2.1.3. Advantages

According to simulation result of [2] compare with Minimum Total Energy (*MTE*) on an average Flow Redirection (FR) and Maximum Residual Energy Path Routing (MREP) were both close to optimum, while Minimum Total Energy (*MTE*) [1] was not as good as the two. The ratio Rx (where the ratio $Rx=T^{x}_{sys}/T^{o}_{sys}$, is used as the performance measure of algorithm x and o defines the optimal lifetime of the system) of FR and MREP were over (Rx>0.9) of the true optimum in 84% and 89% of the case respectively, while that of MTE was true optimum in only 37% of the case and perform arbitrarily bad in worst case, simulation results were in favor of MREP and FR.

2.1.4. Limitations

As in [2] topology of the network is static. Hence the results are applicable to networks which are either static like sensor network or whose topology changes slowly enough, but not applicable for ad hoc network whose topology changes very frequently.

2.2. Energy Efficient Routing Algorithm for Multicommodity case [3]

2.2.1. Flow augmentation algorithm (FA)

The objective of this algorithm is to find the best link cost function which will lead to the maximization of the system lifetime so at each iteration, each origin nodes $o \in O^c$ of commodity c calculates the shortest cost path to its destination nodes in D^c Then the flow is augmented by an amount of λQ_i^c on the shortest cost path, where λ is the augmentation step size. After the flow augmentation, the shortest cost path is recalculated and the procedure are repeated until any node $i \in N$ runs out of its initial total energy E_i. As a result of algorithm, we obtain the flow which will be used at each node to properly split incoming traffic.

2.2.2. Flow Redirection algorithm (FR)

This flow redirection algorithm is define for multicommodity case where each node i belongs to set of all nodes $N – D^c$, for each commodity. For node i firstly select two paths and redirect the flow from smallest longest length path Sp to largest longest length path Lp. So need to assign more flows to Lp path as compared to any other path. After that, algorithm calculate amount of redirection $€_i^{(c)}$. In final step add amount of redirection in to the longest length path, after adding flow redirection amount algorithm checks one or possibly more loops from the path and then loop or loops are removed link by link along the path. So in final step algorithm can properly increment or decrement the flows of the two paths.

2.2.3. Advantages

FA algorithm iteratively augments traffic flow along the shortest cost path, which will lead to maximization of the system lifetime, as well as in flow redirection algorithm redirects some amount of flow from one path to another path and lifetime of later path is better than all other paths in the network belongs to same commodity so Flow Redirection algorithm is also lead for the maximization of the system lifetime.

2.2.3. Limitation

Proposed algorithms used fixed information generation rates and required a priori knowledge of future information generation, means FR and FA algorithms [3] provides optimal flow rates based on knowing the complete topology and packet generation rate at each node.

2.3. Online Power aware Routing Algorithms

2.3.1. Max-Min zPmin algorithm

This algorithm combines the benefit of selecting the path with the minimum power consumption and the path that maximize the minimal residual power of the node in the network. This algorithm first finds the minimum transmission energy path Pmin and then removes all edges whose residual energy fraction after use is smaller than or equal to the minimum residual energy fraction on the minimum transmission energy path. It then repeats the same procedure on the sub graph until just before the total transmission energy of the chosen path exceed z times Pmin, where $z \geq 1$.

2.3.2. Zone Based Routing

Zone based routing organize the network structurally in geographical zones, and hierarchically to control routing across the zones. Each zone contains various nodes and treats the zones as an entity in the network and allows each zone to decide how to route a message across. In this algorithm each zone has a global controller node for message routing manages the zones and this node has highest power. Each zone uses the max-min zPmin algorithm to route a message within a zone.

2.3.3. Advantages

An online approximation power aware routing optimizes the life time of the network. The max-min zPmin algorithm combines the benefits of selecting the path with the minimum power consumption and the path that maximize the minimal residual power in the nodes of the networks. Whereas the zone based routing is to divide the network in to small number of zones and calculate the optimal path for each message across the zone as well as computing the best path for the message within each zone.

2.3.4. Limitations

Proposed max-min zPmin algorithm requires information about the power level of each node in the network. In small network knowing this information accurately is not a problem but for large network it is difficult to aggregate and maintain this information. So it is very hard to implement max-min zPmin algorithm for large networks. In zone based routing each zone has many nodes and thus a lot of redundancy in routing a message through it.
In the analysis of max-min zPmin algorithm, authors assume that the message are generated in constant rate means it is assumed message generated cyclically, or in each interval of time the set of message are same [4].

2.4. Algorithm for energy conservation in multicommodity case with energy consumption at the receivers [5]

2.4.1. Flow augmentation algorithm (FA)

The objective of this algorithm is to find the best link cost function which will lead to maximize the system lifetime and also consider the energy expenditure for unit data transmission at receiver end also. Each iteration every origin nodes o Є Oc of commodity c calculates the shortest cost path to its destination nodes in Dc Then the flow is augmented by an amount of λQic on the shortest cost path, where λ is the augmentation step size. After the flow augmentation, the shortest cost paths are recalculated and the procedure are repeated until any node i Є N runs out of its initial total energy Ei. As a result of this algorithm, we obtain the flow which will be used at each node to properly split incoming traffic.

2.4.2. Advantages

In proposed flow augmentation (FA) algorithm which iteratively augments traffic flow along the shortest cost path which will lead to the maximization of the system lifetime and according to simulation result [4] in multicommodity case the ratio Rx (where the ratio $Rx=T^{x}_{sys}/T^{o}_{sys}$, is used as the performance measure of algorithm x and o defines the optimal lifetime of the system) of FA were over (Rx>0.9) of the true optimum in 88%, while that of MTE and MREP was so in only 17% and 49% respectively in constant information generation process, simulation results were in favor of flow augmentation.

2.4.3. Limitation

2.4.3.1. In proposed work the performance of algorithm is depend on the value of 'λ'. If augmented step size 'λ' becomes larger the performance deteriorated. So the larger 'λ' means less frequent update on the routing information.
2.4.3.2. Flow augmentation algorithm assumes that sensor have global information about the topology of networks to find the sufficient energy path, so this algorithm is not sufficient for large size networks and is not adaptive to dynamic network environment.

2.5. Energy Efficient Routing Algorithm with Delay Guarantee [6]

2.5.1. Centralize energy efficient routing

The objective of this routing algorithm is to determine the optimal path from each sensor node to Access Point (AP) based on the topology of the network and the packet generation rates at the sensor node. In this algorithm, author propose a routing protocol for centralized implementation of the Linear Programming solution means in this protocol LP solution is decompose in to multiple routing tree. The algorithm decompose the network with optimal flow in to multiple routing trees then the nodes in the network will schedule using Time Division Multiple Access (TDMA) protocol such that all the packet reach the destination (AP) before deadline.

2.5.2. Distributed energy efficient routing

There are two distributed routing algorithms presented by the author namely least sum-cost path algorithm and least max-cost path algorithm, to be implemented for each period. The objective of these algorithms is to minimize the cost of routing paths from each sensor node to Access Point (AP). This algorithm calculate the shortest path from AP to all other nodes in the network where the cost of the path from one node to another is the sum and maximum of the costs of the links for least sum-cost algorithm and least max-cost algorithm respectively.

2.5.3. Level restricted energy efficient routing (LR-ENR) with delay guarantee

This routing algorithm aims to give delay guarantee on the arrival of packets at the Access Point (AP) while generating energy efficient path. This algorithm firstly execute Bellman-Ford algorithm to find minimum cost paths from each node to AP, then the routing algorithm is same as the distributed implementation with inclusion of a counter and tree construction packet, where counter is initialize to zero at the AP and increased by one at each transmission and this counter is contained by tree construction packet and this packet also contained nodes on routing path starting at the AP with node cost and cost of the transmission node in the routing tree.

2.5.4. Hop restricted energy efficient routing (HR-ENR) with delay guarantee

In this routing protocol, the time is divided into time frames. At the beginning of the frame, the AP floods a tree construction packet in to the network which contains the counter, its routing path, node cost and the cost of the transmitting node in routing tree. Upon reception of a tree construction packet, the node checks whether the cost of the path is smaller than that of previously learned paths of the same length. If, so it updates its minimum cost path for that length, and broadcast the packet. At the end of flooding each node knows about the minimum cost path of each length. They then send only the cost of the paths corresponding to each length, not the path themselves, to the Access Point (AP). The AP finds the optimal path length for each node based on the Integer Programming model, and sends it back to the nodes in the network. The nodes then use the routing path of the optimal length until the end of the frame.

2.5.5. Advantages

Energy Efficient Routing may choose path that are much longer than the shortest path to the Access Point while avoiding nodes with small residual energy and longer paths may prevent the system from meeting the delay guarantee but the proposed algorithm [6] Energy Efficient Routing with Delay Guarantee generate energy efficient paths and gives a delay guarantee on the arrival of packets at the Access Point.

2.5.6. Limitation

3.5.6.1. According to simulation result [6] LR-ENR and HR-ENR required more memory and CPU cycles then centralize and distributed energy efficient routing algorithm. For algorithm implementation CPU requirement of LR-ENR and HR-ENR were O(deg max $|V|$ 2) and for centralize and distributed algorithm its O(deg max $|V|$).

3.5.6.2. HR-ENR algorithm uses the Integer Program iteratively for finding the optimal flow but it is much time consuming then linear programming problem [5].

2.6. Algorithm for maximum connectivity and maximum lifetime of wireless sensor network [9]

2.6.1. Keep connect algorithm (KC)

The keep connect algorithm finds the weight of node based on how many components are connected with this node. The weight of node can be thought as the importance of the node. Most important node is the node that results in large number of disconnected component as it dies.

2.6.2. Minimum Total Energy-keep connect (MTE-KC)

This algorithm firstly find the minimum total energy path with edge cost e_{ij}.w(i) where w(i) is the weight of node i. After that algorithm transmit the data on MTE path. If any node die because of low battery power, then algorithm recomputed the remaining nodes weight using keep connect algorithm and also recomputed the minimum total energy path using MTE.

2.6.3. Flow augmentation-keep connect (FA-KC)

Firstly In every update time find the minimum total energy path using flow augmentation algorithm with w(i). In second step if node dies, recomputed the remaining nodes weight using keep connect algorithm and also recomputed the energy efficient path using FA algorithm.

2.6.4. Advantages

The proposed KC algorithm along with flow augmentation or with Minimum Total Energy algorithm provide the best result such as these combine algorithm provide maximum connectivity of the network as well as maximize the lifetime of network.

2.6.5. Limitation

The main limitation of proposed algorithm is that when it work alone then maximum lifetime routing in network is not possible because KC alone can only calculate the weight of node based on how many connected component.

2.7. Distributed Energy Balance Routing (DEBR) [14]

This algorithm balances the data traffic of networks in a decentralized manner and prolongs the lifetime of the system. The routing algorithm uses a path that achieves energy balance for entire network. For energy balancing this algorithm calculates the energy cost of all paths and select a path having minimum energy cost. For calculating energy cost it considers not only energy efficiency but also the amount of energy remaining in each node.

2.7.1. Advantages

2.7.1.1. This algorithm maintains the energy efficiency for networks while keeping an energy balance.
2.7.1.2. This algorithm is robust to various event generation functions.

2.7.2. Limitations

Distributed energy balanced routing algorithm considers a general multi hop scenario where few nodes can communicate with base station. For large network DEBR algorithm is not works properly, a more specific routing algorithm and problem definition is required for this kind of scenario.

3. COMPARISON OF VARIOUS ENERGY-EFFICIENT ROUTING ALGORITHMS

3.1. FA, FR, max-min zPmin and centralize energy efficient algorithms use linear programming problem for finding the optimal flow data rate whereas HR-ENR uses Integer Programming model for path length optimization.
3.2. FA, FR and MREP algorithms maximizes the network lifetime when message rate is known whereas max-min zPmin and zone based routings are not rely on knowing the message rate.
3.3. HR-ENR and LR-ENR algorithms [6] provide a delay guarantee for the packet to reach their destination, while maximizing the network lifetime but FR, FA, max-min zPmin, KC and DEBR routing algorithms discussed did not provide delay guarantee.
3.4. routing algorithms [2]-[6] use the time until the first node in the network dies as the definition of network life time but [8] defines that the network lifetime as the time until the network become disconnected.
3.5. Performance comparison of some algorithm in the single commodity case.

Table1. Performance Comparison of Algorithms

Algorithm X	**Average** R_x	**minimum** R_x	Pr $\{R_X > 0.9\}$
MTE	0.7310	0.1837	33%
FR	0.9596	0.6878	88%
MREP	0.9572	0.8110	89%
FA	0.9744	0.7347	94%

According to simulation results [3] the performance of algorithms are presented in Table I. average and worst cases of the algorithms are compared. The ratio Rx (where the ratio $Rx=Tx_{sys}/To_{sys}$, is use as the performance measure of algorithm x and o defines the optimal lifetime of the system) of FA were over (Rx>0.9) of the true optimum in 94%, while that of MTE, FR and MREP was only 33%, 88% and 89% respectively. The average lifetime of FR, MREP and FA were above 95% of the optimal, while the average of RMTE was about 73%.

MTE and FR can perform arbitrarily bad in worst case, simulation results [5] were in favor of flow augmentation.

4. CONCLUSION

There are various challenges for deploying wireless sensor network like " type of service", "quality of service", " scalability", " programmability", "maintainability", "fault tolerance" and "lifetime of the network". For increasing the lifetime of the network, the efficient utilization of energy is very important. So battery energy is the most important resource, and route the traffic through the minimum energy path to the destination is fatal for the network because all the nodes in that path will drain out their battery power quickly. So it's not a feasible solution and instead of this solution route the traffic such that energy consumption is balanced among the nodes. In this paper, various energy efficient routing algorithm have reviewed to increase the lifetime of wireless sensor network. The lifetime of wireless sensor network is defined as the time until the first node fails (or runs out of energy). All the energy efficient routing algorithms discussed in this paper balance the energy consumption rates among the nodes in proportion to their remaining energy. Finally paper concludes with insights for research direction about various energy efficient routing protocols.

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