Power Control-based GRACE (PC-GRACE) Routing Protocol for Wireless Sensor Networks

Mohsin Raza, Ghufran Ahmed, Noor M Khan
ACME Center for Research in Wireless Communication (ARWiC)
Department of Electronic Engineering, Mohammad Ali Jinnah University
Islamabad, Pakistan
mohsinraza119@gmail.com, ghufran@arwic.com, noor@ieee.org

ABSTRACT: *This paper investigates an Adaptive Power Control based Energy Efficient Routing scheme, referred to as PCGRACE, which takes advantage of both efficient energy utilization and transmission power control strategy. Thus, transmission power control strategy is incorporated with energy efficient routing. Experimental results are obtained by using the Sun SPOT-based wireless sensor test bed. The experimental results show that the routing technique results in an increase in the energy efficiency of the network and thus, an improvement in the network lifetime.*

Keywords: Energy efficient routing, Energy utilization, Power Control, Routing protocols, Wireless Sensor Networks

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1. Introduction

Efficient energy utilization has always been a challenge for the researchers in the field of wireless sensor network. This is due to the fact that sensor node have very limited battery power. These batteries are unattended and it is not possible to recharge them. Moreover, the small size of a sensor node restricts embedding high power battery with it, leaving only one solution in order to achieve long network lifetime of wireless sensor network i.e. efficient energy utilization. Hence, reliable data transmission with energy efficiency becomes is a challenging task. The proposed routing scheme not only focuses on the link quality by establishing efficient routes, but also emphasis on the efficient power utilization by establishing a favorable transmission power control mechanism. The proposed scheme keeps the nodes alive for much longer duration of time without compromising the quality of links between the communicating nodes on the selected routing path. Thus, reliable links are established on a path from source to sink without draining nodes' energy. The practical observations of the proposed scheme appears much more stunning as it succeeds to overrule the existing energy aware routing schemes in terms of better lifetime along with reliable link establishment. Figure 1 shows a typical wireless sensor network.

The rest of the paper is organized as follows: section II discusses the related work. Section III discusses the importance of utilization of energy efficiently. Section IV presents the system model. Section V discusses basic routing and power control scheme of the proposed approach. Section VI presents the experiments and results. Finally, section VII concludes the paper.

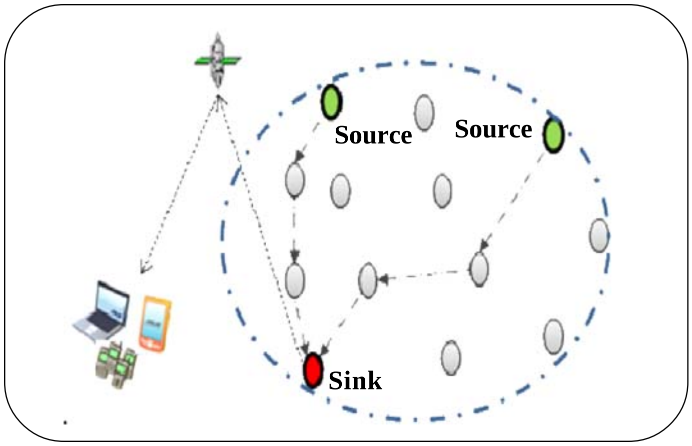

Figure 1. A Typical Wireless Sensor Network

2. Related Work

In the past few years, the network lifetime has been appeared to be a major hurdle in the field of wireless sensor networks. Throughout the period, researchers have been working to improve network lifetime by exploiting various dimensions in the field of sensor networks. The primary motive of this research is to maximize the network lifetime without degrading the link quality. In certain rare circumstances, tradeoffs can be made between the network lifetime and the desirable link efficiency. Various routing protocols present various schemes to improve the network lifetime without degrading the link quality. Many reviewed routing protocols in the field of wireless sensor networks can widely be distributed into two categories: Reactive Routing Protocols (RRP) and Proactive Routing Protocols (PRP). In reactive routing, a route from source to sink is evaluated at runtime. This is achieved by a route request message which is generated when there appears to be a need of route for data transfer. On the other hand, the proactive routing protocols use a preliminary phase in which all the nodes in a network establish a routing table on the basis of which the route is established. Though in case of proactive routing, the routes are pre-defined and route selection delay is avoided, yet the proactive routing protocols add a reasonable overhead to the communication. In some networks where the nodes are closely located near the sink, communication can be established in either of the two ways: in a single-hop manner by increasing the transmission power of a node so that the source node directly communicates with the sink node or in a multi-hop fashion. Both of the techniques have their own advantages. In case of direct communication, the path delay of the packet is reduced to great extent, but on the other hand, the power consumption increases exponentially. While hop by hop or multihop transmission induces much more delay than the direct transmission but results in huge power saving. Usually the energy efficient routing protocols prefer indirect (multi-hop) transmission. This is because the direct or shortest path transmission causes more energy consumption and nodes especially the low energy nodes along the shortest path are drained of their battery resulting in topological changes in the network. Some of the routing algorithms are discussed in the upcoming passages.

Adaptive On demand Distance Vector (AODV) [1] routing protocol can be represented as a good example of RRP. In AODV, depending on the route requirements the source broadcasts a packet for route request. This packet propagates until it reaches the node in neighborhood of the sink. This node at receiving the route request packet, replies with route acknowledgement that follows the same route back from which it reached to this node. The very same route is later on used for all the data communications routed by that particular source. Power aware routing (PAR) [34] is one of the energy efficient routing protocols which select the routes with lowest power cost. However, the problem with this scheme is that if a node is located at a junction it would be selected for multiple times, resulting in energy depletion, hence forming network gaps. Lifetime Prediction Routing (LPR) [2] is another scheme which considers the network energy distribution. In this scheme, the path selection takes into account the battery life and hence, forms the route having maximum power nodes. The life time of every node on a path is estimated and on the basis of these evaluated lifetimes, the network lifetime is predicted from the node with minimum battery lifetime in a path.
Though the LPR offers more stable network, however, the cost of the selected path may be high. Cost Effective Maximum Lifetime Routing (CMLR) [3] offers an improvement. It not only considers the high energy nodes but also takes in to consideration the routing cost. The CMLR scheme tries to establish harmony among the network lifetime and power awareness.

Some routing protocols require geographical location of the nodes to establish the routes. In such protocols, the nodes exchange their location information within the network [4]. Such protocols usually require a GPS device to be attached to the nodes or the deployment is non-random with the nodes having the information of their position with respect to some reference point. Such protocols are not good solution to routing problems as they add extra budget and still are applications limited as GPS are not functional under covered roofs and if placement is fixed then they fail to work in dynamic atmosphere.

Local Update based Routing Protocol (LURP) [5] offers another routing scheme that works with a mobile sink. The need of a mobile sink rises from the fact that the neighboring nodes of the sink are the nodes most frequently used. Due to this reason, these nodes die out at quite earlier stages leaving network broken and nonfunctional. This issue is resolved by using a mobile sink. In LURP, the sink is considered mobile and whole network is divided in to subsections called local areas and a sink only updates its position to the nodes in that particular local area until the mobility of the sink is bounded by the boundaries of that local area. When the sink moves out of a local area the information is propagated in the entire network. This scheme appears attractive but its applications exclude remote operations.

Hierarchical routing is also a notable scheme used for data routing in wireless sensor networks. In hierarchical routing, a network is divided into clusters and data activity within each cluster is managed by a particular node known as cluster head. The sensor nodes falling in a particular cluster, communicate their information to their respective cluster head which in turn routes this information to the sink. The cluster head communicates with the sink either directly or indirectly via other cluster heads. The cluster heads and other sensor nodes are either homogeneous or heterogeneous. Figure 2 shows some examples of routing models.

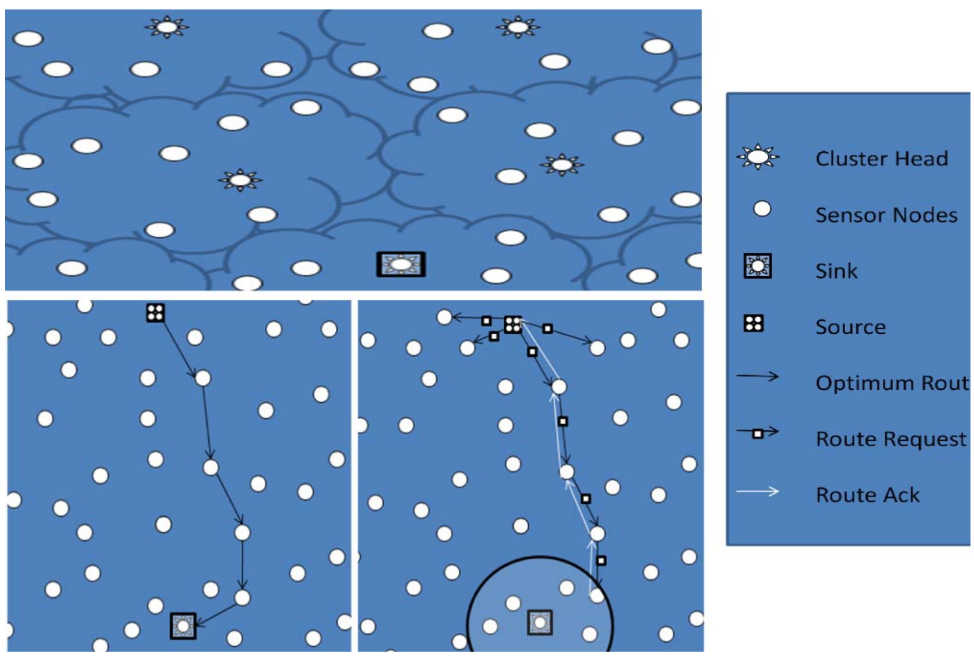

Figure 2. Examples of Routing Models

3. Importance Of Energy Efficient Utilization

As stated earlier, energy is one of the most critical resources in the field of wireless sensor networks especially when the nodes are unattended. It is, therefore, worth investigating different aspects of WSNs which could help extending the lifetime of wireless sensor nodes.

In a wireless sensor node, the contributing factors for the power consumption are sensing, processing and communicating. The communication or data transfer serves as a major contributor among these three. This is a reason why most of the research focuses on the efficient utilization of energy while routing the data. This paper investigates an Adaptive Power Control based Energy Efficient Routing (PC-GRACE) scheme which takes advantage of both efficient energy utilization and transmission power control strategy. The paper also discusses the practical results obtained by using the Sun SPOT-based wireless sensor test bed.

4. System Model

In this section, the general architecture and implementation methodology of PC-GRACE is presented.

4.1 General Architecture

Before discussing the precise details of the architectural model used by PC-GRACE, a more generalized model is discussed. In Figure 3, a general model of the wireless sensor network is shown where wireless sensor nodes are randomly deployed with a single source. The source generates information packets which in turn relayed to the sink through coordinated data transfer sequence. A test-bed comprising of

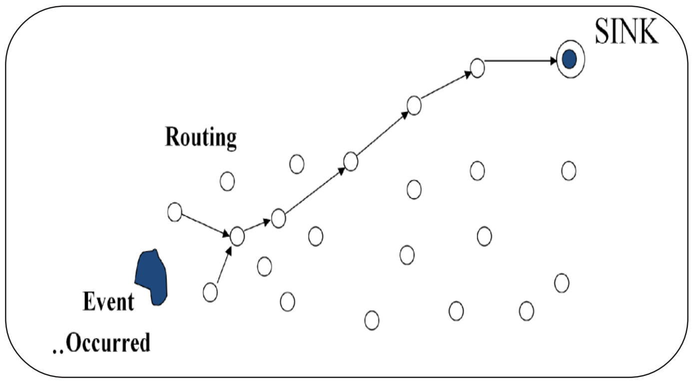

Figure 3. A Generalized Architecture

Sun SPOT motes is used to evaluate the performance of PCGRACE. The path selection and transmission power control mechanisms are the same as followed in GRACE [6] and MODTPC [7] respectively. A more detailed discussion on the path selection procedure is covered in the following section.

5. Basic Routing and Power Control Scheme of PC-grace

One of the advantages of PC-GRACE is that along with an efficient routing protocol, it also embeds a transmission power control mechanism. The working mechanism of PCGRACE can be distributed into two phases: setup phase and data communication phase.

5.1 Setup Phase

The setup phase is used to establish the cost field in the entire network. Before the setup phase is initiated, cost of all nodes except the sink is set to infinity and cost of the sink is set to zero. The setup phase is initiated from the sink exactly the same way as the GRACE [6] follows. Sink broadcasts a control packet with zero cost value. After receiving this cost value by neighboring nodes of the sink, these neighboring nodes set their cost by taking into account the link cost, their battery level and received cost. After establishing their own cost, the updated cost factor is propagated in the network establishing the gradient cost field.

5.2 Data Communication Phase

Once the cost fields are established throughout the network in the setup phase, any node can send its data to the sink through the least-cost path. In the data communication phase, the lowest cost path is used to transmit multiple packets until its cost becomes higher than the other nodes or till the setup phase is re-initiated. In this span, along with the efficient route selection, a process also adjusts transmission power at each of the node on the routing path through the feedback mechanism. The feedback is based on the received RSSI. In the data communication phase, the extra transmission power is catered on point to point basis, resulting in high energy savings. For communication between any two nodes, the transmission power is decreased consistently until the received RSSI is within the threshold level, however, if the received RSSI crosses the threshold, a feedback message is generated, on the basis of which transmission power is adjusted. As the motes for implementing the protocol use CC2420 radio [8], a maximum of 8 different power levels can be adjusted. These levels are shown in Table I.

After the delivery of a pre-defined number of packets to the sink, the sink re-initiates the setup, thus updating the cost field.

6. Experiments and Results

This section presents the performance evaluation of GRACE and PC-GRACE. The results are obtained by evaluating both the protocols using similar test-bed setup. The test-bed comprises of Sun SPOT wireless sensor nodes.

6.1 Experimental Setup

The deployment of wireless sensor nodes is shown in Figure 4. Each of these communication nodes can transmit data and control packets using transmission power levels ranging from 0dBm to -25dBm. It has also been evaluated that in order to receive data packets successfully, RSSI must be within the acceptable range.

The basic aim of these experiments is to evaluate the lifetime of the network. Lifetime is defined as the time till the network is able to maintain the links from source to sink. The evaluated network lifetime for both GRACE and PC-GRACE are shown in Figure 5. The comparison of the GRACE and PC-GRACE shows that both the protocols observe similar trends, however, use of PC-GRACE results in an extended network lifetime. From the obtained results, it can be clearly stated that the improvements in the network lifetime of PC-GRACE is a direct outcome of the efficient adjustment of transmission power. The use of the Transmission Power Control (TPC) strategies

Transmit Power Level	RF Output Power (dBm)	Current Drawn (mA)
31	0	17.4
27	–1	16.5
23	–3	15.2
19	–5	13.9
15	–7	12.5
11	–10	11.2
7	–15	9.9
3	–25	8.5

Table 1. Transmission Power Levels Of Cc2420 [8]

helps tuning the transmission power according to current propagation environment in order to utilize energy efficiently and transfer data successfully. In order to ensure successful data transfer, a minimum RSSI threshold level is defined and if received signal strength falls below the minimum threshold, maximum transmission power is used. For rest of the cases, PC-GRACE uses optimized transmission power levels.

The TPC mechanism of PC-GRACE tries to minimize the transmission power level along with ensuring suitable RSSI. In the experiments, it is observed that most of the time TPC module tries to keep the transmission power at minimum possible level i.e. between -15 to -25 dBm. It was also ensured that the nodes use high transmission power levels at startup in order to maintain good link quality. After sometime, nodes start decreasing the transmission power level gradually until the threshold is reached to a level where it could not be further decreased. The number of occurrences of the transmission power levels is shown in Figure 6.

One of the desired goals of this work is to increase the number of transmitted packets by each node before its death. GRACE in comparison with PC-GRACE, has short lifetime since the GRACE uses maximum transmission power level for data transmission. Therefore, GRACE faces quick energy depletion, resulting in less number of packets transmitted before network dies out. In contrast, PC-GRACE uses transmission power control mechanism which results in transmitting more data packets. Figure 7 shows a comparison of number of packets transmitted by using GRACE and PC-GRACE with same initial network energy. While Figure 8 shows the experimental results of overall network energy consumed. From Figure 8, it can be seen that there is not much difference in the network energy consumed by both the protocols, GRACE and PCGRACE.

As the experimental results show that the difference betweenthe network energy consumed by GRACE and PC-GRACE is just

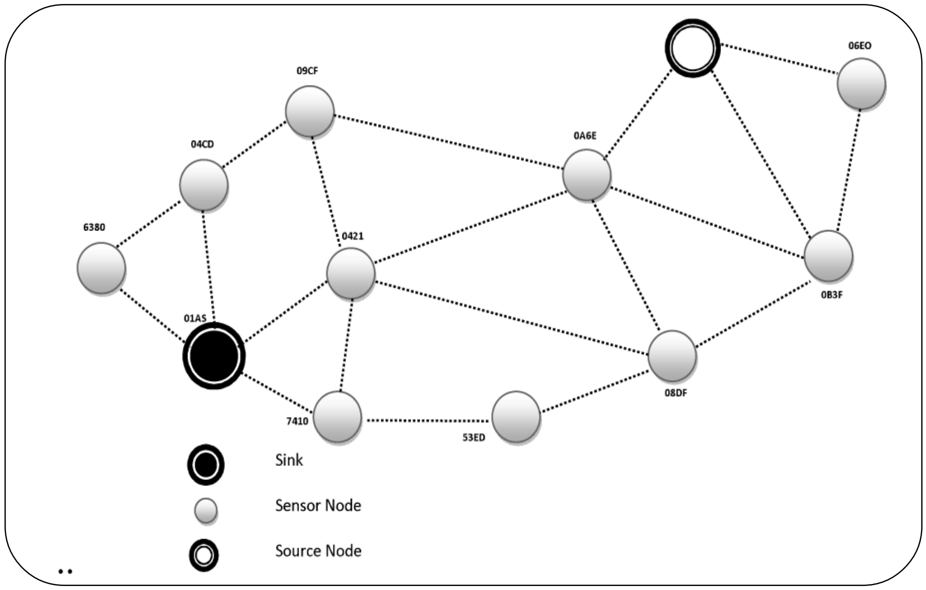

Figure 4. Nodes Deployment

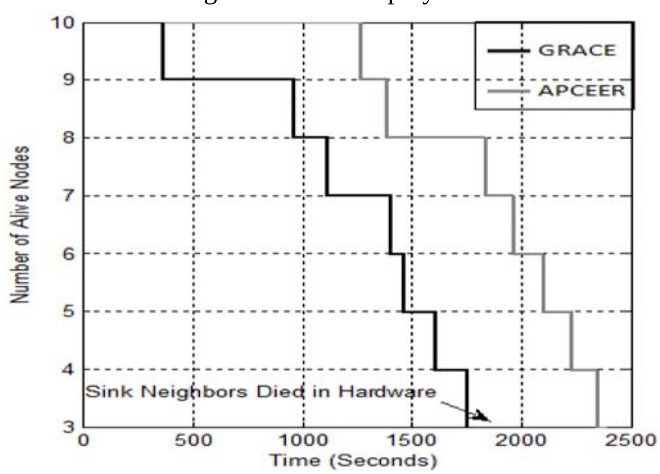

Figure 5. Network Lifetime

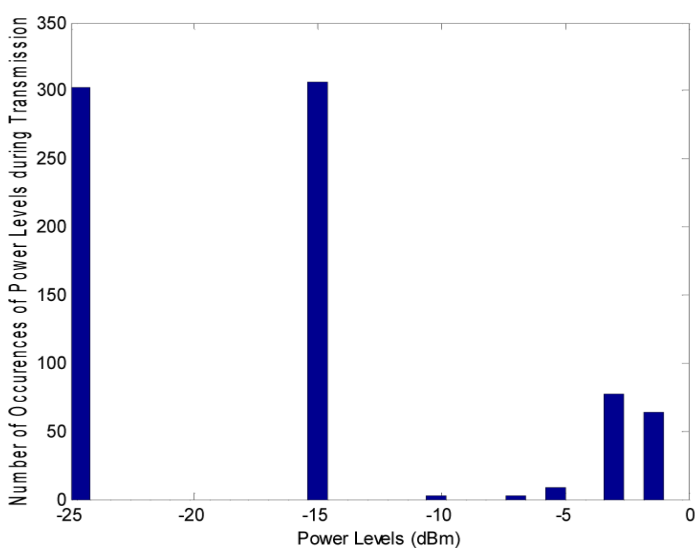

Figure 6. Number of Occurrences of the Transmission Power Levels

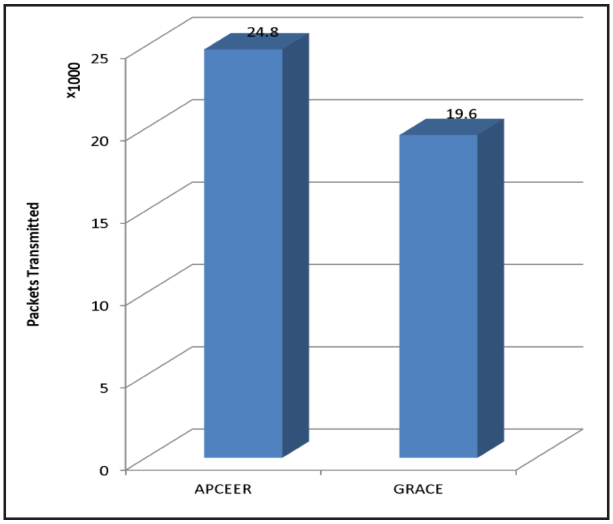

Figure 7. Number of Packets Transmission

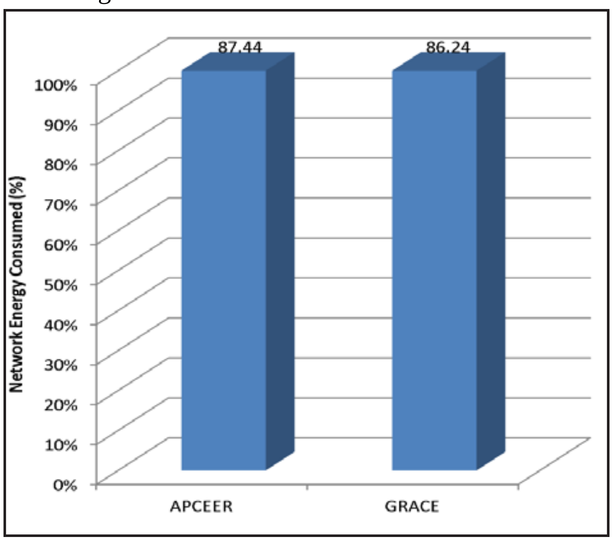

Figure 8. Network Energy Consumed

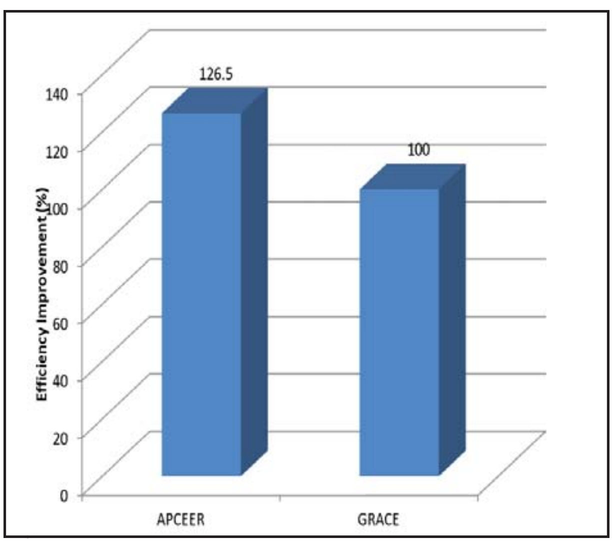

Figure 9. Efficiency Improvement

1.2%, one may ask about the savings claimed in the PC-GRACE. The reduction in energy consumption is due to the power control strategy used by PC- GRACE to extend the network lifetime. The overall energy efficiency of both the protocols is depicted in Figure 9. Figure 9 shows that PCGRACE has an enhanced packet delivery efficiency of 26.5% from the efficiency obtained by GRACE.

7. Conclusion

The proposed routing scheme, PC-GRACE, has observed to provide with ample improvements in the energy efficiency of the wireless sensor networks. By incorporating the transmission power control strategy with the energy efficient routing scheme, an appreciable improvement in the network lifetime has achieved. The network lifetime improvement of the PC-GRACE supersedes its predecessor routing scheme, GRACE.

The focus of the research is to practically implement and test the simulation-based notable protocols using a wireless sensor test-bed for their performance bounds. The primary aim is to identify the factor contributing in the globally accepted performance parameter, the network lifetime. However, in some cases the improvements in the network life lifetime is directly derived from sacrificing link quality. As a future work, further research can be done to ensure that the improvement in the network lifetime must not affect the link quality. Moreover, there are many other dimensions yet to be explored to improve the performance of the routing protocols in terms of efficient energy utilization, network lifetime, link reliability, packet reception rate and timely data-deliverance.

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