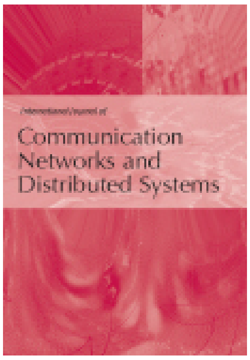

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Grey prediction-based energy-aware opportunistic routing in WSN

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Abstract: Opportunistic routing (OR) protocol is widely applied for wireless sensor network (WSN) for maximising energy as well as network lifetime. OR selects the capable forwarder set of node for multi-hop forwarding, based on residual energy and transaction history. This selection process using the forwarding set will continue for every hop, till the destination is reached. This paper proposes a new routing protocol, namely grey prediction-based energy-aware OR protocol for WSN. The grey-prediction model is a proven model which needs minimum data for prediction and is used to select the nodes for the forwarding set used in every hop. The new protocol is simulated and compared with existing ones for performances. The observations suggested that the advocated protocol shows superior performance as against the already accepted protocols about network lifetime, throughput, and energy consumed and remaining.

Keywords: opportunistic routing; wireless sensor network; WSN; grey prediction; energy efficiency.

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1 Introduction

Opportunistic routing (OR) protocols (Fradj et al., 2019; Zhang et al., 2017; Shelke et al., 2018; Chithaluru et al., 2019) are widely applied in wireless sensor network (WSN) (Ogundile et al., 2020; Akyildiz et al., 2002; Raghavendra et al., 2006; Akyildiz and Vuran, 2010) to maximise energy and network duration. OR selects the capable forwarder node set for multi-hop forwarding, based on residual energy (RE) and transaction history. The main aim behind choosing a forwarder set and prioritising it is reducing the amount of energy utilised by the nodes of a network. This selection process using the forwarding set will continue for every hop, till the destination is reached (Jadhav and Satao, 2016).

WSN contains many sensor nodes to monitor military applications, weather forecasting, traffic surveillance, etc. (Boukerche and Darehshoorzadeh, 2015). The sensor nodes present in the network gather and import data to the sink node through multi-hop communications. Achieving energy efficiency in such a network is challenging as the nodes are very tiny and operated using small-sized batteries (Boukerche and Darehshoorzadeh, 2015; Chakchouk, 2015).

The literature presents several categories of energy-efficient protocols, namely OR protocols (EXOR, EEOR), data-centric protocols (SPIN, COUGAR), hierarchical protocols (LEACH, PEGASIS), and geographical protocols (GEAR, GAF) (Chakchouk, 2015). Of the above, OR is characterised by higher network lifetime and energy efficiency in routing. In traditional routing, energy efficiency is very less because the pre-selected set of nodes is used to transfer packets and loss of battery energy by one node will result in a reduction in network lifetime. By contrast, in OR, factors such as distance and transactions count play a role in the selection of forwarder set nodes. If a prioritised node in a selected set loses packet or energy, another node characterised by greater priority performs the packet-transferring task (Soua and Minet, 2011; Fradj et al., 2019).

OR protocol uses both prediction-based and non-prediction-based methods for energy-efficient routing. The former protocol allows higher energy efficiency and network lifetime based on current value and future value of certain parameters like a number of transactions (NTRs), distance, RE, etc. In prediction-based OR, the grey prediction is best for WSNs due to the minimum data requirement for prediction.

Herein, we have elaborated a novel protocol for routing – energy-aware opportunistic routing protocol (EEGPOR) for WSN using a grey prediction model. The concept of the grey system was described first in the year 1982 by Professor Deng Julong (Fradj et al., 2019). The traditional prediction model needs more data for prediction, but grey theory will work for small datasets and unfortunate information (Julong, 1989; Yu and Lu, 2012; Lu, 2015; Xie and Liu, 2009; Mi et al., 2018). Compared to the traditional prediction-based routing protocol, the grey prediction-based OR protocol gives more accurate prediction values with less amount of data (Lee and Lee, 2018; Safaldin et al., 2020; Engmann et al., 2020; Adama and Asutkar, 2021; Chen et al., 2021). Existing OR protocols like EXOR, EEOR, and ENS-OR (Biswas and Morris, 2005; Mao et al., 2009; Luo et al., 2014) select the capable forwarder set (CFS) based on present context values namely RE, distance, and many more but the proposed EEGPOR protocol uses a grey prediction-based OR method to select an energy-efficient capable forwarding list based on current context values and future context values namely NTRs, RE. The grey prediction-based OR selects and prioritises more accurate relay nodes to improve energy efficiency and network lifetime in a WSN. We consider this point as a special feature of our proposed model.

In the proposed EEGPOR, grey prediction is used for selecting and prioritising the forwarder set. Forwarder set is formed with nodes that have a smaller NTRs. The grey model (GM) estimates the transactions count of each node of a network for making an ideal forwarder set and prioritising the node based on its RE. This is especially useful for prediction-based OR, due to the minimum data requirement for prediction.

Section 2 of this paper describes the work performed. Section 3 elucidates the background and developed protocol. Section 4 discusses the findings of the simulation. Section 5 provides final comments.

2 Literature review

We carried out a detailed literature survey to analyse the existing energy-efficient opportunistic protocols and grey prediction models. The most preferred protocols are described in this section.

Biswas and Morris (2005) proposed an Exclusive opportunistic multi-hop routing protocol or EXOR for application in WSNs. EXOR involves the transfer of packets from one place to another place through batches. It groups the nodes into batches, which will reach the destination. Each batch has a batch ID and based on the batch ID packet; it will be sent through a high-priority node to another node. The batch contains a batch map to travel correctly, and at each period the map will be updated. It uses the integrated routing and MAC protocol for enhancing the network's throughput. The drawbacks of the EXOR protocol are it does not care about un-updated data of nodes. So, the incorrect data of nodes will cause packet duplication in a network. It leads to packet overhead due to seeking coordination among all nodes. EXOR protocol did not reuse the data.

Mao et al. (2009) developed EEOR, which picks up forwarder lists about the rate measure of lowest energy use while broadcast to reach the destination in the WSN. This method determines the expected cost of all nodes for choosing a forwarder list to forward data. This presumed cost of the newly created forwarding list must be lower than that of the previous forwarding list. This is the basic concept for selecting the forwarder list. The Bellman-Ford algorithm is used for determining the expected cost updating of all nodes in a forwarder list. The drawbacks of the EEOR protocol is the consumed energy was high than the proposed EEGPOR protocol.

Luo et al. (2014) recommended an energy-aware routing protocol (ENS-OR), choosing the energy-efficient nodes (EEN) in light of RE. Considering RE as well as distance to reach the destination, the forwarder list is prioritised in ENS-OR. It uses the best hop distance to select the forwarder list. The drawbacks of the ENS-OR protocol is less throughput than the proposed EEGPOR protocol.

Chithaluru et al. (2020) put forth 'adaptive ranking-based energy-efficient opportunistic routing (AREOR)'. It deals with the cluster concept, and through OR, an ideal cluster head is picked up in light of ranking. This system was developed to select forwarder nodes. The ranks are computed on the basis of the RE as well as the geographic location of each node. Their observations confirmed the lower energy expenditure of this protocol.

Chithaluru et al. (2021) advocated ‘adaptive ranking-based improved opportunistic routing in wireless sensor networks (ARIOR)’. The adaptive ranking uses a volunteer node for energy efficiency in OR. This mechanism works according to the RE, spatial density, as well as distance of each node of a network.

Al-Kahtani et al. (2020) proposed ‘opportunistic density cluster-based routing (ODCR)’. During crisis conditions, the routing procedure sends data from one node to another node opportunistically. It allows good energy consumption than LEACH, TEEN, and LORA protocols.

Mhatre and Khot (2020) proposed the extension of ‘energy-saving opportunistic routing (ENS-OR)’ with an algorithm of sleep scheduling for improved energy efficiency in a network. ENS_OR, with sleep mode, is used to compute the current flow of data in optimum sleep intervals for increasing the energy efficiency and network lifetime. In ENS-OR protocol, energy loss occurs due to idle listening of nodes, but this disadvantage is overcome in sleep scheduling algorithm.

Bangotra et al. (2020) proposed the ‘intelligent opportunistic routing (IOP)’ protocol. It uses the Naïve Bayes theorem for choosing potential forwarder nodes among several ones for higher energy efficiency as well as increased network duration. RE and distance are used for the selection of the next-hop forwarder.

Kumar et al. (2020) proposed ‘adaptive prediction strategy with clustering (APSCT)’. It exploits the spatial and temporal correlations using grey prediction and a data-driven clustering model. APSCT allows energy efficiency by considering the intervals of upper bound and lower bound prediction. It also decreases message transfer in a network.

Lee and Lee (2018) proposed prediction-based transmission power control (TPC) which works based on grey fuzzy logic (grey-FTPC). This is used to maintain the packet delivery ratio and lower the energy utilisation of nodes. GM is applied for predicting forthcoming received signal strength indications (RSSI) variations. RSSI is adopted by the GM, and the new transmission level is determined by fuzzy inference. Recently, Markov-based OR protocol has been reported by Nagadivya and Manoharan (2020).

Shanmugam and Kaliaperumal (2021) proposed ‘cross-layer-based opportunistic routing (CORP)’ for application in WSN. This protocol improves network performance based on clustering and routing techniques and reduces the energy consumption based on optimal traversal paths. Sensor nodes are clustered based on K-medoid by Harris Hawk optimisation. The cluster head is selected based on energy condition, distance as well as sensing node locus.

Lu et al. (2020) developed ‘energy-efficient depth-based opportunistic routing algorithm with Q-learning (EDORQ)’ for under-water WSN for achieving energy-efficient and definitive data transfer. EDORQ protocol detects void nodes and reduces energy consumption based on factors such as void detection, remaining energy, and candidate nodes’ depth.

Venkatesh et al. (2019) proposed an energy-efficient opportunistic routing protocol (THGOR). It selects 2-hop neighbour nodes based on higher RE and packet reception ratio. It also selects 1-hop neighbour nodes, that should contain good network coverage for 2-hop nodes.

Singh and Pant (2017) proposed a teaching-learning algorithm to deploy and schedule the sensor nodes to improve network lifetime in a WSN. The sensor node’s location is predicted based on the network lifetime’s upper bound.

Logambigai and Kannan (2018) proposed a hybrid optimisation system to prolong the network lifetime in WSN. A hybrid optimisation system uses the bacterial swarm optimisation (BSO) method for energy-efficient routing. The relay node selection is based on the distance between the base station to relay node.

Nwadiugwu et al. (2019) proposed a path tracking algorithm to place mobile sensor nodes in a disaster-prone location. Mobile sensor node deployments results are investigated concerning less consumed energy, end to end system threshold.

Engmann et al. (2020) proposed an energy conservation model based on reducing the data transmission in WSN. GM and autoregressive integrated moving average are the time series models used to predict the active and inactive periods of nodes in a network. here, duty cycling and data-driven approaches are used to support the grey prediction model to predict active and inactive nodes in a network. Based on the predicted data, the GM is used to control the data transmission to save energy in WSN.

The above survey represents existing energy-efficient protocols that contain more energy consumption, very less network lifetime, and network delay. Based on the survey of existing protocols the objectives of the proposed protocols are energy efficiency and network lifetime. It can be stated that grey prediction-based OR ensures higher energy efficiency and network lifetime compared to OR protocols that are not prediction-based.

3 Background and proposed scheme

This section is structured as mentioned. Subsection 3.1 elucidates OR and GM (1, 1). Subsection 3.2 discusses the details of the advocated protocol. Subsection 3.3 provides a flow chart of the protocol. Subsection 3.4 presents the related algorithm.

3.1 Background of OR and GM

3.1.1 Opportunistic routing

OR works completely different from the conventional routing process. In traditional routing, the relay node will be pre-selected by the source node along the path based on routing protocol. The retransmission process starts when the packet is discarded or if there is any routing disconnection. Since the WSN is deployed in a hostile environment, traditional routing will increase the data transmission cost due to retransmission. However, in OR, the source node selects the relay node during packet relaying. It chooses the appropriate forwarder set, followed by packet transfer to all capable forwarder nodes. Node characterised by higher priority will play the role of packet forwarder node, while others leave out the packet. Then, the next greater-priority node serves as a forwarder when the first node of high priority leaves out the packet. So, the cost of packet retransmission will be less in OR (Fradj et al., 2019; Zhang et al., 2017; Shelke et al., 2018).

Figure 1 represents the workflow of OR. It depicts the following steps for packet forwarding from the source (S) node toward the destination (D) node.

Step 1 The S node picks the CFS among the neighbour nodes based on some parameters like distance, cost, energy, and the NTRs occurring in a node.

Step 2 Relay node prioritisation from CFS based on some parameters like RE and distance.

Step 3 The CFS selection and prioritisation will continue till the packet is forwarded to its destination (Jadhav and Satao, 2016; Boukerche and Darehshoorzadeh, 2015; Chakchouk, 2015).

Figure 1 Opportunistic routing

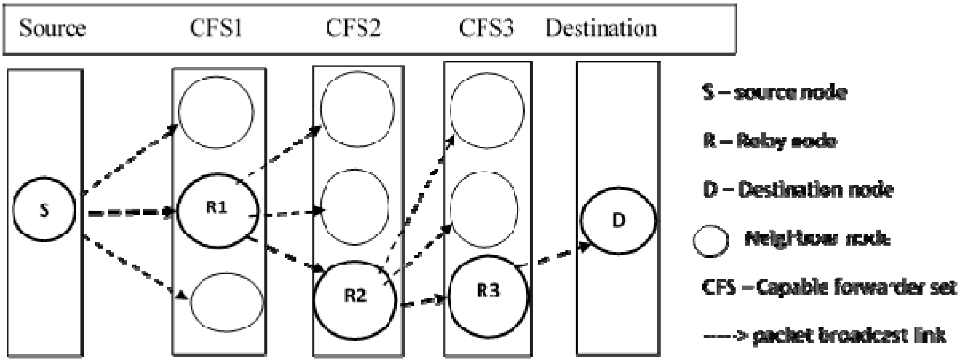
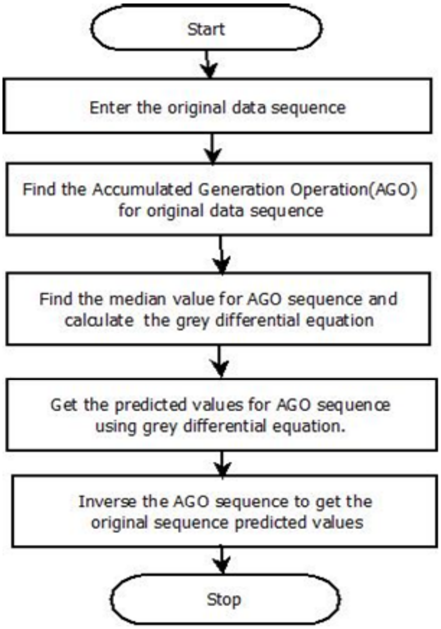


Figure 2 Traditional GM (1, 1) model flow chart



3.1.2 Traditional GM (1, 1) model flow chart

Grey theory is used to predict uncertain data, and it is successfully utilised in many application areas such as agriculture, sports, medicine, geography, etc. (Julong, 1989). The primary model is named GM (1, 1) model, that is, the one-variable first-order GM (Lu, 2015; Xie and Liu, 2009). Generally, traditional prediction models require more data to predict the values but this model needs only four data points. Figure 2 represents the traditional grey (1, 1) model flow chart. Grey prediction will collect the original data sequence and find the accumulated generation operation (AGO) for the original sequence. AGO can convert the grey system into white and allow monitoring the development of grey data (Yu and Lu, 2012). Thus, it calculates the median values of grey parameters and deals with the differential equation enabling it to obtain AGO sequence prediction values. The AGO sequence should be inverted to get the prediction values for the original sequence (Mi et al., 2018; Lee and Lee, 2018).

3.2 Proposed EEGPOR protocol

The proposed EEGPOR protocol uses the grey prediction model to give energy efficiency in WSNs. Compared to protocols not based on prediction, this provides higher energy efficiency as well as improved network duration in WSN. Grey prediction gives better values than other traditional prediction methods. The EEGPOR protocol contains the following two steps:

3.2.1 CFS selection

In WSN, the S node directs the packet toward the D node through OR. In other words, the source node first picks a CFS among neighbour nodes and later transmits the packet to the selected node. The node of high priority plays the role of a relay node, while other nodes in the set refrain from the process. The prediction-based OR uses transactions count (number of packets transmitted and received by a node) and distance (relay node distance to reach the destination) as parameters for the selection of CFS (Engmann et al., 2020).

3.2.1.1 GM to predict a node's NTRs

In EEGPOR, the S node selects a capable forwarder node-set taking into account of neighbour nodes' transactions to reach the destination node. The NTR value will be the number of packets transmitted (NP_{TR}) added to the number received (NP_{RE}) on a particular node,

$$NTR = NP_{TR} + NP_{RE} \tag{1}$$

Source node selects the node with a lower NTR as forwarder node. In the EEGPOR protocol, the source node uses a grey prediction model to predict the NTR of the neighbouring nodes. Source and neighbour nodes contain a current NTRs history. Based on that history, the grey prediction model estimates the future transactions count for all nodes. Node with fewer transactions is selected as a capable forwarder node due to the remaining energy existing in that node. Compared with other traditional prediction models, grey prediction allows high-accuracy prediction with minimal data. Grey prediction predicts the node's transactions count as follows.

1 Original *NTR* of a data sequence: The data on the original transactions count of a node collected to generate a cumulative sequence should be entered. The accuracy of the GM is increased based on accumulated generating operations.

$$NTR^{(0)} = NTR^{(0)}(1), NTR^{(0)}(2), NTR^{(0)}(3), \ldots, NTR^{(0)}(n), n \geq 4 \tag{2}$$

Here, $NTR^{(0)}$ is an original transactions data sequence.

2 Accumulated generating operator (AGO) sequence for original *NTR* sequence: AGO sequence is used to reduce the unpredictability and noise of the original data sequence.

$$NTR^{(1)}(u) = \sum\nolimits_{i=1}^{u} NTR^{(0)}(i),\ u = 2, 3, \ldots, n \tag{3}$$

$NTR^{(1)}(u)$ is an AGO for the original data sequence.

3 Median value for AGO sequence:

$$M^{(1)}(u) = \frac{1}{2}\left(NTR^{(1)}(u) + NTR^{(1)}(u-1)\right),\ u = 2, 3, \ldots, n \tag{4}$$

$M^{(1)}(u)$ is a median value for the AGO.

4 Grey differential equation for NTR:

$$\frac{\partial NTR^{(1)}(u)}{\partial u} + pM^{(1)}(u) = q \tag{5}$$

Here, the quantity $M^{(1)}$ represents the average value of $NTR^{(1)}$ obtained from equation (4). p is the progress coefficient and q is a control variable which can be estimated using least-squares method as,

$$[\hat{p}\ \hat{q}]^T = (K^T K)^{-1} K^T X \tag{6}$$

where

$$K = \begin{bmatrix} -M^{(1)}(2) & 1 \\ -M^{(1)}(3) & 1 \\ \vdots & \vdots \\ -M^{(1)}(n) & 1 \end{bmatrix} \text{ and } X = \begin{bmatrix} NTR^{(0)}(2) \\ NTR^{(0)}(3) \\ \vdots \\ NTR^{(0)}(n) \end{bmatrix} \tag{7}$$

5 NTRs prediction values for AGO sequence: The differential equation (5) can be solved as,

$$\widehat{NTR}^{(1)}(u) = \left(NTR^{(0)}(1) - \frac{\hat{p}}{\hat{q}}\right)e^{-\hat{p}(u-1)} + \frac{\hat{q}}{\hat{p}},\ u = 2, 3, \ldots, n \tag{8}$$

$\widehat{NTR}^{(1)}(u)$ is a predicted NTR values for accumulated generating operation.

6 Inverse AGO to get prediction values for original NTR sequence: Finally, the NTRs is predicted by our prediction system. The GM (1, 1) model equation is

$$\begin{aligned} \widehat{NTR}^{(0)}(u) &= \widehat{NTR}^{(1)}(u) - \widehat{NTR}^{(1)}(u-1) \\ &= (1 - e^{\hat{p}})\left(NTR^{(0)}(1) - \frac{\hat{q}}{\hat{p}}\right)e^{-\hat{p}(u-1)},\ u = 2, 3, \ldots, n \end{aligned} \tag{9}$$

$\widehat{NTR}^{(0)}(u)$ is a predicted NTRs values for the original data. The inversion of predicted AGO sequence provides original sequence predicted values.

3.2.2 Relay node prioritisation

The relay node prioritisation is done after the CFS selection according to forwarder set nodes' RE and distance to reach destination. The packet is sent to each and every node of a CFS by the source node, but in a set only one node will act as a relay node. Considering a node's RE (N_{RE}), the relay node is chosen in a forwarder set. The grey prediction method is applied to a CFS nodes to predict N_{RE}.

$$N_{RE} = N_{TE} - N_{CE} \tag{10}$$

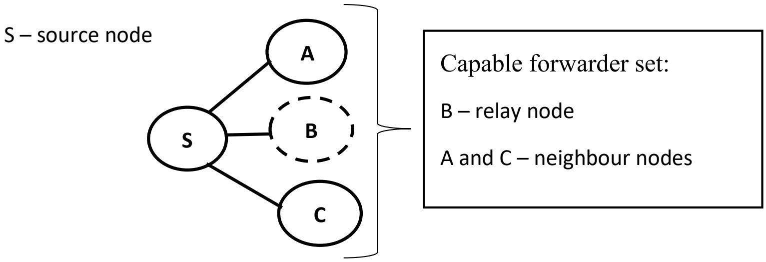
The N_{RE} is determined from the node's total energy (N_{TE}) and its consumed energy (N_{CE}).

In EEGPOR protocol consumed energy (N_{CE}) of the node is determined from energy consumed for NTR (N_{NTR_e}) of that node, i.e., energy consumed for number of packet transmission (N_{TX_e}), packet reception (N_{RX_e}), idle mode (N_{IM_e}) and sleeping mode (N_{SM_e}) of a node based on equation (1).

$$N_{CE} = N_{NTR_e} = N_{TX_e} + N_{RX_e} + N_{IM_e} + N_{SM_e} \tag{11}$$

In Figure 3, the source node(s) selects the CFS (A, B, C) using grey prediction model and will broadcast the packet to all nodes. The prioritisation process will start to select high-priority node as a relay node. The grey prediction model selects high-priority node considering the predicted RE as well as distance of each node to reach destination in a forwarder set. Finally, relay node takes the packet for transferring it to another node, while the remaining nodes of the set skip the packet. In EEGPOR protocol, packet retransmission process is completely avoided because if the packet is skipped by highest-priority relay node the next node of high priority will transfer it. Due to the elimination of packet retransmission, routing in WSNs will use less energy.

Figure 3 Relay node prioritisation



Finally, the RE prediction values for nodes A, B and C (Figure 3), are determined by, same as in equation (9),

$$\begin{aligned}\widehat{RE}^{(0)}(u) &= \widehat{RE}^{(1)}(u) - \widehat{RE}^{(1)}(u-1) \\ &= \left(1-e^{\hat{p}}\right)\left(RE^{(0)}(1) - \frac{\hat{q}}{\hat{p}}\right)e^{-\hat{p}(u-1)}, u = 2, 3, \ldots, n\end{aligned} \tag{12}$$

If node B (drawn as dashed circle in Figure 3) gets high RE compared to the other nodes (A and C) after grey prediction, then it is considered to be a relay node and the latter nodes are discarded.

3.3 Workflow for EEGPOR protocol

The workflow of EEGPOR protocol is presented in Figure 4. In a WSN, EEGPOR protocol allows higher energy efficiency and increased network duration. It operates in two steps for energy-efficient packet forwarding, viz., selection of CFS and prioritisation. Using grey prediction model, the NTR of neighbour nodes is determined. Selection of relay node will continue until the destination is reached by the packet (Figure 4).

3.4 Algorithm for EEGPOR protocol

The algorithm represents two phases of EEGPOR protocol; Algorithm 1 represents electing the CFS. It needs the data about how many nodes are present in a network; neighbouring nodes count and the initial NTR to select CFS through grey prediction. During Algorithm 2, capable forwarding sets are prioritised to choose the forwarder node from parameters namely distance and remaining energy. These two phases will continuously work till the packet reaches the sink.

Algorithm 1 Electing the CFS

```
Input: Network parameters are source node, transactions, neighbour nodes (n), sink node, CFS
    FOR(j = 1 to n)
        $N_{TR}^{(j)}(u) = 0$                                  !1st AGO set to zero
        FOR(k = 1 to u)
            $N_{TR}^{(j)}(u) = N_{TR}^{(j)}(u) + N_{TR}^{(j)}(k)$
        END FOR
        $M^{(j)}(u) = [N_{TR}^{(j)}(u) + N_{TR}^{(j)}(u-1)]/2$
        $dN_{TR}^{(j)}(u) + pM^{(j)}(u) = q$                   !first-order differential equation
        least-squares method( );                              !to extract p and q values
        $\hat{N}_{TR}^{(j)}(u-1) = \hat{N}_{TR}^{(j)}(u) - \hat{N}_{TR}^{(j)}(u-1)$
    END FOR
    $AVG\_N_{TR} = \frac{\sum_{j=1}^{n} F\_N_{TR}}{n}$
    FOR(j = 1 to n)
        IF($F\_N_{TR}[j] < AVG\_N_{TR}$)
```

```
            $CFS < N[j]$                        !Node ID added to CFS
        END IF
    END FOR
    !CFS → CAPABLE FORWARDER SET
```

Algorithm 2 Prioritisation

Input: Network parameters are CFS, node broadcast, node reception, initial (total) energy of the node

```
    FOR($j$ = 1 to COUNT(CFS))
        $N_{Ce}[j] = N_{TXe} + N_{RXe}$                !Designed using equation (11)
        $N_{Re}[j] = N_{Te} - N_{Ce}$
    END FOR
    Starting_Val = $N_{Re}[1]$
    PRIORITIZED_NODE = $N[1]$
    FOR($j$ = 1 to COUNT(CFS))
        IF($N_{Re}[j]$ > Starting_Val)
            PRIORITIZED_NODE = $N[j]$
        END IF
    END FOR
```

4 Assessment of performance and simulation findings

4.1 Simulation

Network simulator NS-3.25 is used to conduct simulation with 100 nodes. Here, node ‘0’ is the one and only sink node and remaining nodes are considered as source nodes. The nodes are organised in a 1,080 m × 960 m network extent. The maximum transmission distance is 100 m. Every node is assumed with starting energy of 5–30 Joules. Node’s mobility is determined by random waypoint model. The nodes move freely without any restrictions. Table 1 lists the numerical variables of simulation.

Table 1 Numerical parameters used in the EEGPOR simulation within the NS-3 tool

Parameter	*Parameter’s value*
Node’s placement area	1,080 m × 960 m
Mobility	Random waypoint model
Nodes	100
Sink node	1
Interval between neighbouring nodes	4–50 m
Longest transfer distance	100 m
Transmitting rate	1 packet/s
Packet measurement	512 bits
Node’s starting energy	5–30 Joules

4.2 Experimental results

The capability of EEGPOR protocol has been analysed and compared with that EXOR, ENS_OR and EEOR, OR. Experimental results are assessed by considering the following parameters: energy consumed and remaining, throughput and network lifetime. To examine the protocol's efficiency, the simulations were done in two different scenarios. First, the NTR of the nodes is changed and the nodes count is kept constant, while for the second the vice versa is followed.

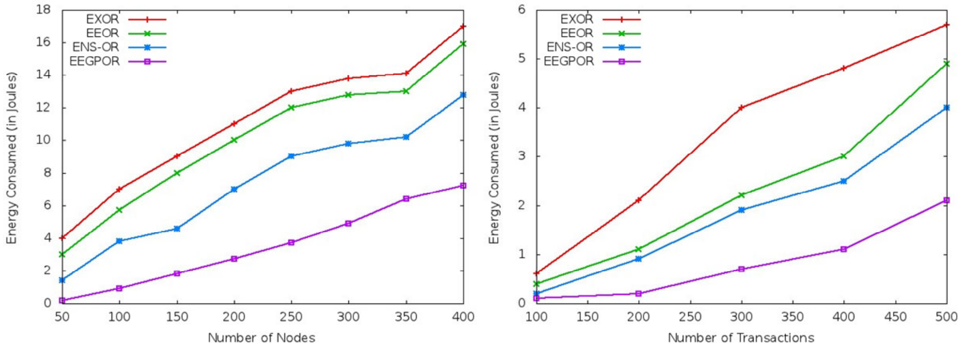
4.2.1 Consumed energy

Consumed energy is the energy spent by a node for packets transmission and reception (Nagadivya and Manoharan, 2020). It is measured using different protocols with reference to the nodes count and transactions count as in Figures 5(a) and (b), respectively. In the first scenario [Figure 5(a)], the consumed energy is calculated by assuming fixed NTRs, i.e., 100, whereas [Figure 5(b)] a fixed number of nodes, i.e., 50, is used in the later scenario. In each case, the average amount of energy used for EEGPOR is

1. 89.4% lower compared to EXOR protocol
2. 84.5% lower compared to EEOR protocol
3. 68.6% lower compared to ENS_OR protocol.

Overall, the energy utilised by EEGPOR protocol is lesser than others, concluding that the EEGPOR protocol is highly energy-efficient.

Figure 5 Consumed energy (a) scenario 1 and (b) scenario 2 (see online version for colours)



(a) (b)

4.2.2 Residual energy

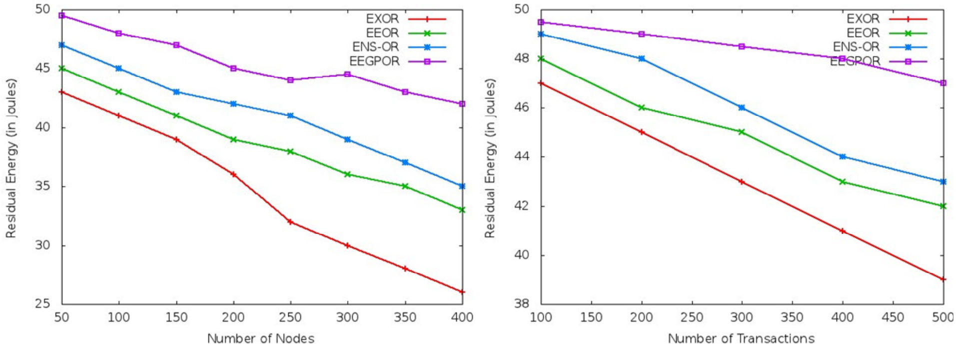
In WSN, a node's RE plays a critical role in prolonging the network lifetime. The variable N_{RE} is calculated using energy at the beginning and final energy (Nagadivya and Manoharan, 2020). The relay node in a CFS is chosen taking into account the amount of energy remaining. Figure 6(a) shows the RE with reference to the number of nodes for a constant NTR value, and Figure 6(b) shows the same with reference to the NTR for a constant number of nodes. Similar to consumed energy, RE is also obtained by using a constant NTR value (100), and a fixed value of nodes count (50). Selection of a relay node by EEGPOR protocol is related to high RE. In both scenarios [Figures 6(a) and 6(b)], high RE of EEGPOR is observed using grey-prediction model compared to other three protocols. To mention, the EEGPOR protocol shows

1 26.4% more RE than EXOR protocol

2 15.9% more than EEOR protocol

3 12.5% more than ENS_OR protocol.

Figure 6 Residual energy (a) scenario 1 (b) scenario 2 (see online version for colours)



(a) (b)

4.2.3 Network lifetime

Network lifetime refers to the duration at which the first sensing node of the network completely loses its energy (Nagadivya and Manoharan, 2020; Dhurandher et al., 2018). Figure 7 shows the network lifetime performance of EEGPOR protocol in comparison to the three analysed protocols. For the first scenario [Figure 7(a)], the lifetime is estimated by changing the number of nodes for a fixed NTR value. It can be seen from the figure that for the choice of number of nodes and transactions, (n, NTR) = (100, 100), the lifetimes estimated using the EEGPOR protocol are

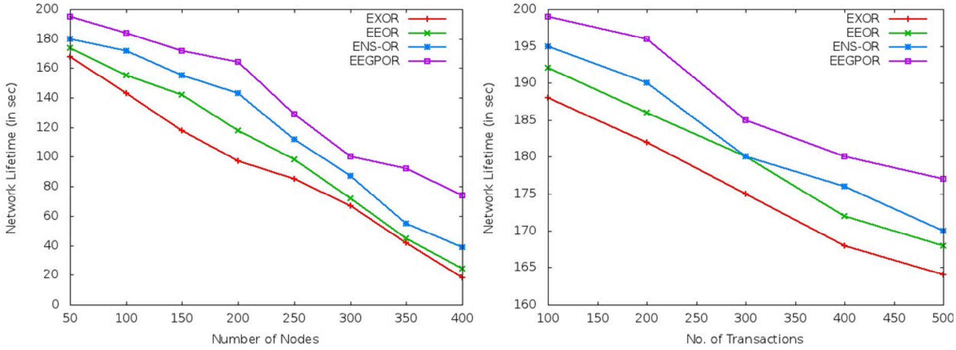
1 22.3% more than the EXOR

2 15.8% more than the EEOR

3 6.5% more than the ENS_OR protocols.

For the second scenario [Figure 7(b)], the lifetime is estimated by varying the value of NTR for a fixed nodes count. For the choice of (n, NTR) = (100, 100), the EEGPOR protocol shows only 5.5% more lifetime than the EXOR and only 2.0% more than the ENS_OR protocol. Considering both scenarios [Figures 7(a) and 7(b)], the average lifetime estimated for a given choice of (n, NTR) = (400, 400) by EEGPOR protocol using grey prediction model is maximum of 41.2% more than EXOR, 36.0% more than EEOR, and minimum of 24.8% more than ENS_OR.

Figure 7 Network lifetime (a) scenario 1 (b) scenario 2 (see online version for colours)



(a) (b)

4.2.4 *Throughput*

Quality of service of EEGPOR protocol is represented by a parameter called throughput. It refers to the number of data successfully transferred from the S node toward the D node in network per unit time. EEGPOR protocol prevents data retransmission to increase throughput in a network (Nagadivya and Manoharan, 2020).

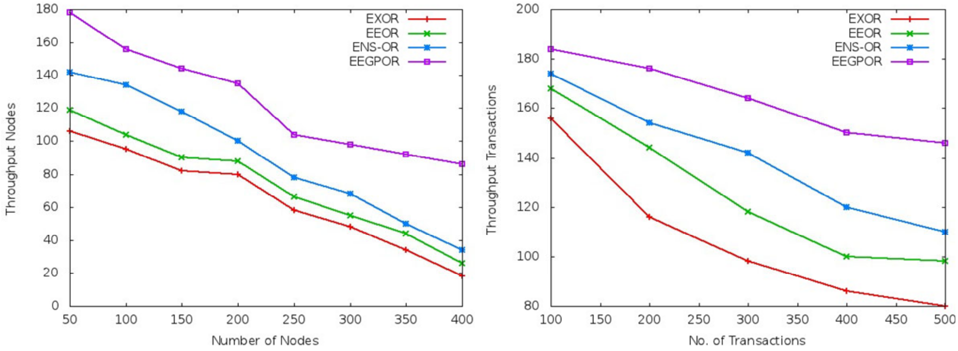
Same as the results discussed above, the throughput estimated for EEGPOR and other three protocols is presented in Figure 8, considering the nodes count [Figure 8(a)] and transactions count [Figure 8(b)]. For both scenarios, the average throughput of EEGPOR protocol is

1 60.9% higher compared to EXOR

2 51.6% higher compared to EEOR

3 40.3% higher compared to ENS_OR, indicating EEGPOR has comparatively better throughput.

Figure 8 Throughput nodes (a) scenario 1 (b) scenario 2 (see online version for colours)



(a) (b)

5 Conclusions

The need of low-energy routing for WSNs is a major issue due to the low energy battery present in the sensor nodes. In this work, EEGPOR protocol is presented which works by effectively choosing a CFS taking into account the predicted transactions count with the neighbours using grey prediction model. Among the predicted nodes, those with a smaller NTRs and higher energy will be selected as a capable forwarder and then, relay node is prioritised. In EEGPOR protocol, if any high-priority node ignores packet, then next node of high priority becomes forwarder node. To observe the whether the protocol functions effectively, experiments were done using a simulator and findings were compared with currently existing ones. Simulation results have shown that EEGPOR performs better than the compared protocols with respect to energy utilised as well as remaining, network lifetime, and throughput. The future work is based on additional parameters like transmission error, noisy propagation for prediction of OR forwarder set.

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