Energy Harvesting in a Modified Opportunistic Routing Protocol, a New Approach in Wireless Sensor Network

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Abstract: We proposed a modified opportunistic routing protocol that is based on cross layer design and mainly focus on energy harvesting principles named as modified energy harvesting opportunistic routing protocol (MEHOR). In the cross-layer design, parameters are exchanged in between the different layers to optimize the energy use. Apart from the traditional opportunistic routing protocols like Hybrid energy efficient protocol(HEEP), power-efficient gathering in sensor information (PEGASIS), Extremely opportunistic routing (ExOR), MEHOR focus on energy constraints at a sensor node because it requires recharge once their energy level depleted. Basically we give the importance on regioning to overcome the multipath routing problems, specially the energy availability. We minimize retransmission rate and reduce collisions, considering data packet received in a linear multi-hop energy harvesting wireless sensor networks (EH-WSN). We compare the MEHOR with the traditional protocols and achieve good performances with larger coverage area and EH-WSN also reduces the cost.

Keywords: WSN-HEAP, EHOR, Performance, PEGASIS, Regioning , Goodput.

Introduction

In wireless sensor network (WSN) the sensor nodes are densely deployed. The neighbor nodes may be close to each other, therefore multihop communication is one of the most efficient way to consume less power. Mostly all the sensor networks are data centric in nature. The data centric routing protocols are mainly depends on the data aggregation and data association, which helps to solve the overlap problems with implosion. The protocols associated with WSN are also data centric in nature as well as it requires attribute based naming. The data centric approaches are performed by two cases.

i) Sensor node broadcast the advertisement for the available data and wait for a request
ii) Sinks broadcast the information to all nodes associated with it

Sink node collect the information from all the sensor nodes and used as a gateway to other networks as well as a backbone to other network. The routing protocol are perceived as a reverse multicast tree, where the sink collect the aggregated information from multiple sensor nodes as they are using the same routing way back to sink[1]. In the depicted Fig. 1, A, B, C….G are different sensor nodes and H is considered as sink node. E aggregates A & B, F aggregates C & D .Data aggregation is also called data fusion, which contains a set of automated techniques and combining all the relevant data and meaningful information that comes from different sensor nodes.

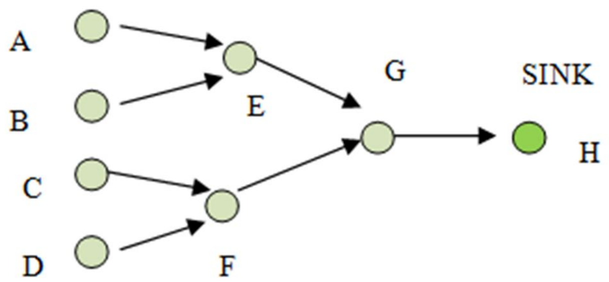

Figure 1. Network model for a node to sink

Basing on cross layer designing we mainly focus on energy harvesting principles with energy harvesting opportunity called modified energy harvesting opportunistic routing protocol (MEHOR).The rest of the paper is structurally organized by: We introduce opportunistic routing, in Section II. Then, we present related work in Section III. Model of MEHOR under various scenarios are presented in Section IV. We compare MEHOR with other exiting routing protocols in Section V and conclude the chapter in Section VI with some references.

Opportunistic Routing (OR)

Opportunistic Routing (OR) [2] is a typical example of routing which has been put forward for wireless network. It uses the broadcasting features of wireless sensor networks so that transmission from one node can be discovered by multiple nodes. This technique helps the OR to select the next node dynamically at the time of transmission rather than selecting the next node ahead of time. The node which is nearest to the destination is selected for forwarding. Choosing the forwarder set and prioritizing it is the prime job of the OR. The OR selects all the intermediate nodes for data routing between source and destination rather than selecting a single node which is done in Traditional routing. After that all the intermediate nodes who receives the packet data runs a coordination protocol to set a perfect way to transmit the packet.

Advantages of Opportunistic routing:

i. High efficiency
ii. Maximum throughput
iii. More reliability
iv. Reducing data redundancy
v. Increase utilization of the each elements of network

Disadvantages of Opportunistic routing:

i. Limited battery power of sensor networks
ii. Critical resource allocation

The OR routing is divided into main steps:

A : Node Selection
B : Co-ordination method

Node Selection

This step deals with selecting the appropriate node for the packet transmission after data packet is transmitted from source node [3]. The nodes are assigned with priorities. Nodes near to destination are assigned with higher priority and nodes closer to source are assigned with lower priority. Node Selection has two subparts as node filtering and node ordering.

Node Filtering

Node filtering is done to maximize the performance of the system. The number of the nodes participating in the algorithm must be minimized to reduce the work load. Node filtering is done to reduce the data redundancy.

Node Ordering

Node ordering tries to order the node according to their distance from the destination. Coordination method helps to pick the suitable best candidates to forward the packets. This coordination method depends upon the 3 factors. These are ‘Timer’, ‘Token’, ‘Network coding’. In Timer it is lead to duplicate transmission and in Token it prevent duplicate transmission and higher control overhead and in Network coding it has no coordination overhead . Mainly coordination method depends upon the three factor i.e. timer (lead to duplicate transmission), token (prevent duplicate transmission and higher control overhead), and network coding (no coordination overhead). Ordering of nodes depends on various factors i.e. hop counts, connective link state, expected number of transmission (ETX), expected transmission time (ETT) and cost computation [4].

Co-ordination Method

This is required because the data packet transfer from source to destination moves smoothly across the path. The nearest node to the destination receives the packet and sends acknowledgement to all the other nodes that it has received the data packets. This reduces the packet duplication rate as other nodes don’t sends that packet data because they know through acknowledgement that the respective data packet has already been received. A good coordination method should select the best candidate without replication of transmissions. Existing coordination methods are divided into three categories based on the mechanisms: timer, token, and network coding.

Related Work

C. J. Hsu et al. [4] have reviewed in details how the co-ordination method helps to find out the best relay to generate the candidate selection and overhearing in OR. Author also describes how opportunistic routing can completely exploit the potential of the wireless medium and compare their protocols with other different routing protocols. Zhi Ang et al. [5] analyzed the concept of ambient energy harvesting i.e. WSN-HEAP. The author mainly focus on multihop OR. Choosing an optimal power in EHOR they clearly described about the rate of charging in a sensor node is directly dependent upon the ambient sources. M. M. Ajmal et al. [6] have coined the term co-ordinate opportunistic routing protocol for wireless medium networks (CORP-M) which eliminates a key challenge of opportunistic routing where it suffers from computational overhead and without using pre-selected list of potential relay candidates. Z. A. Eu et al. [7] evaluated AOR (Adaptive OR) protocol using regioning in the networks. In a multihop EH-WSNs depending upon the availability of the energy the event driven and monitoring throughput increases depending upon the energy harvesting and sensor node densities. Qi Yang et al. [8] have represented a utility-based opportunistic router in this paper. Utility energy helps OR for optimization of the fairness of energy expenditure among the candidates. R. Negishi et al. [9] describes how to enable the sensor nodes and auto-build networks like Internet of Things (IoT) and Machine to Machine (M2M). In Energy Harvesting WSNs the nodes harvest energy through ambient sources. The ambient sources may be sunlight, wind, heat and vibrations. The authors proposed a light weight relay a slot which contains a grid based energy harvested concept. They divided the network virtually and apply the concept of square shaped grid in the network. Lin Longbi. et al. [10] describes about the energy aware and how to harvest in sensor networks. Static routing is a simple static multi-path routing which is optimal in nature. Here the author exploits the static routing with traffic patterns and energy replenishment outputs. They also developed a multihop routing protocol to find the optimal distributed solution. Yoshida Masya et al. [11] explain how to reduces the energy by applying two approaches i.e. data collection protocol probabilistic retransmission (PRT) and PRT with collision consideration. The main concept behind this protocol is to reduce the retransmission packets with active intervals. The goal is to achieve high reliability & efficiency in data collection in the protocol following energy harvesting. Meng J. et al. [12] reviewed the ambient energy harvesting technology & approaches the new adaptive energy harvesting aware clustering routing protocol. The basic idea behind this protocol is to find the node state by applying election algorithm. Changing the regular factor ρ the available alive node gives high throughput as compare with other protocols. M. Shaoba et al. [13] introduces the optimal energy allocation (OEA) techniques in the sensor nodes for energy harvesting. Rechargeable battery is one of the solution in a sensor node aims to maximize the throughput in a time dependent system. D. Singh et al. [14] further studied about cluster based routing protocols and their energy management capabilities. The author focus on improved cluster based routing protocol in wireless sensor network .In this protocol design, exchange of messages can be done by time setting & nodes can be prioritized by applying geographic al locations.

MEHOR System Model

We considered a WSN consists of homogeneous set of static sensor nodes with fixed transmission range R, distributed over a 2-D region and a sensing range S. Each sensor node has same initial energy E which is depleted at each occurrences of transmission and receives. Assuming a simple first order radio model [14], each sensor node consumes the energy while receiving and transmitting an *l*-bit packet. In MEHOR model each sensor node performs sensing and data transmission with repeated charging and transmitting the data transmission after getting power by energy harvesting source. In our protocol design we considered as solar energy as the ambient sources. Initially the stored energy (battery) is low, when the sensor nodes are powered by photovoltaic cells through sunlight the sensor nodes are active. Pre charged nodes broadcast their locations to all other nodes during deployment. Afterwards other deployed nodes also keep the information and broadcast to other neighbor nodes using the node selection process. Each sensor node operates in three states: *charge*, *transmit* and *receive*. After the energy harvesting process completed, enough energy can be harvested and stored in the energy storage devices i.e. capacitors. At that time the transceiver and microcontroller are on and broadcast data till the energy level goes down certain level and again both are off. A node returns to the charging state after it completes receive or transmit state as presented in Fig. 3. At the charging state, the node charges up to the maximum amount of energy, denoted by E_{max}, that may be the sufficient for receive and transmit a packet. But the storage device required repeating the process again because; to receive and transmit the data from different nodes we require the energy. The average energy harvesting rate λ(mW) in different time intervals are show in Fig. 4.

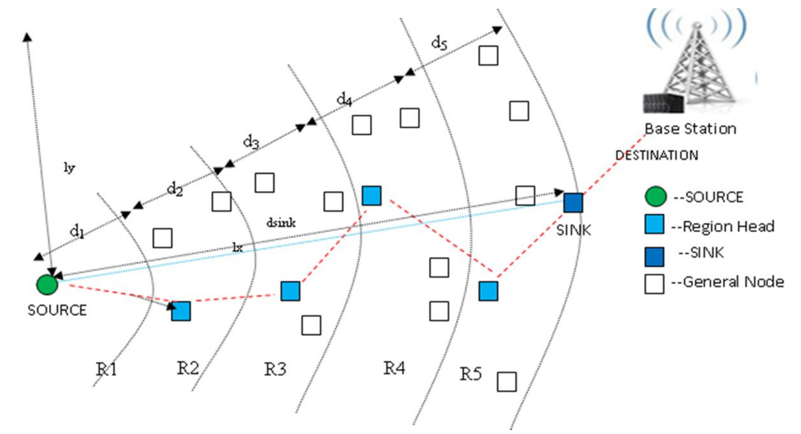

Figure 2. Illustration of region concept in MEHOR where region K=5

EHOR (Energy Harvesting in Opportunistic Routing) gives high performance over opportunistic routing. Although the performance is high (high throughput) it did not considered the concept of regioning and residual energy at the sensor nodes. Our model MEHOR considered the above concepts which are depicted in figure 2. In the figure 2 source and sink are there. The distance from source to sink is d_{sink}. Each region contains a region head, through region head the data can transmitted from source to the sink. The sink is near the base station. The network structure can give high throughput because

(a) In between the regions the data packets can easily interchanged and required fewer amounts of energy as well as the time. The time required to receive at the destination is also decreases. The harvested energy optimizes the data packets to be sent or receive.

(b) If we consider the residual energy the life time of the sensor node is increases as well as the battery power also increases. The probability of receiving packets increases due to the use of more short-range links.

(c) It is two times efficient as normal Routing Protocol. Its delivery time is one fourth times of other ad-hoc network. This protocol accumulates large blocks of data for transmission.

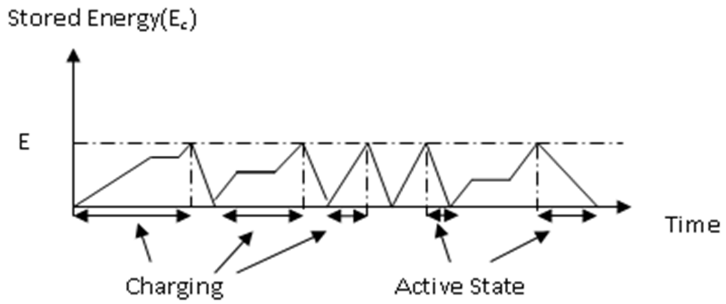

Figure 3. Simple Energy Management scheme at a sensor node

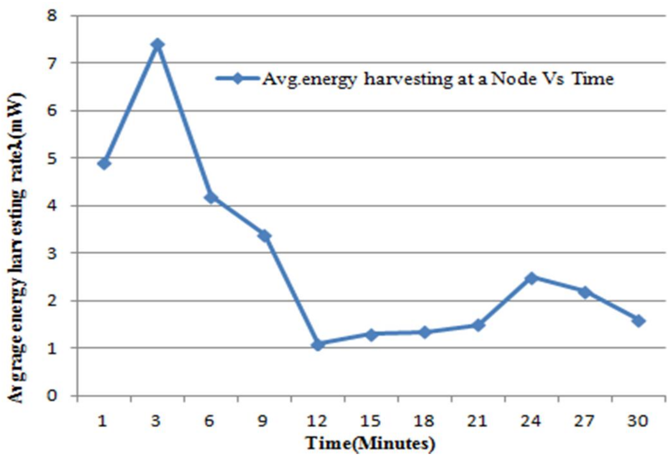

Figure 4. Average energy harvesting rate different time intervals
(Data collected from IMT, BBSR in the period of March-2017)

Objective of a cross layer Techniques

A cross layer Techniques [15] is a kind of interaction between different layers .It can be used to make intelligent decisions about power saving, QoS routing, enhanced scheduling and bandwidth allocation algorithms in multihop networks[24]. Cross-layer information exchange is to optimize network usage and resource by communicating different layers. Cross-layer design can determine the best method of performance calculation (in terms of throughput) and energy requirements.

1. Information can be interchanged between two or more non-adjacent regions.
2. The new interface in between the two regions helps in functionality as well as reduces the overhead.
3. Design coupling between regions, i.e. one region assumes information arriving from another
4. Vertical calibration between different regions.

The basic idea of MEHOR is as follows: Out of all sensor nodes one considered as sender which send the data forward and backward region. Forwarded data is in forward region as well as backward data is in backward region. We must consider as sink is in the forward region. Receiving the data from sender node the sensor nodes forwarded it with j^{th} time slots to other neighbor nodes provided it has sufficient energy. For each sender, the forwarding region is partitioned into k regions and upon receiving the data packet from the sender, each node in region j, 1≤ j ≤ k.

Regioning in MEHOR

The MEHOR determines the best forwarding node and find the suitable path. Sending the data packets to the neighbor nodes reduces the retransmission capabilities and less coordination overhead. MEHOR divides the forwarded area into different regions in the network. In the depicted Figure 2 the network is partitioned as different region named as *k*, where *k* = 5 which contain the sink, is in last region nearest to base station. If the sink is outside the transmission range we must considered as another additional region [16].

Determination of k

For a sender node in the network, let A be the area of the forwarding region that is within its transmission range, as illustrated in Fig. 2. Since there are *n* sensor nodes, in the covering region R, the average number of relay nodes within the forwarding region for each sensor node, $n1 = \frac{R}{l_x l_y} n$, where l_x, l_y are distance from source to sink in *x* and *y* direction. To reduce the probability of retransmissions which may occurs a collision, we have to consider the awake node (who can receive and transmit the data simultaneously) in each region [17]. Let P_{rx} be the probability that a node can receive a data packet from a source. Now the value of k may be represented as in equation (1).

$$k = [n1P_{rx}] + 1 \qquad (1)$$

As maximum time the sensor nodes are in active mode and also receive mode, P_{rx} can be approximated using $P_{rx} = \lambda\, P_{rx}$, where λ is the average energy harvesting rate [18][19]. We compute A by considering the intermediate area between two region where d_{sink} is the distance from the sender to the sink.

Assumptions

- Total no of nodes =20
- Deployment area ,A=300m
- Nearest node transmission =Total deployment area(A)/Total no of nodes(n)=300/20=15m
- Maximum distance cover to sent a data=70m
- Initially all the nodes are in sufficient and constant energy(Maximum=100)
- Once accepting a packet & send to the other node they are considered as active state

After energy loses they are move to charging state.

N1= (d*n)/A, where N1 is the number of region takes in active role. Considering Prx is the receiving probability of a node m= ceil (N1*Prx), where m is the actual number of regions at the deployment area .Now K= m+1, Where K=Total no of region.

Therefore, our assumption contains four queues (Q) for each sensor node in the network.

Q 1: When the sensor node acts as a sender it can transmit the data (new) as well as receive the data. Q 2: In active mode each sensor node saves the transmitted data from the source. If the source node receives a same ACK message from any two or more neighbor nodes, then the data will be discarded; and again the source retransmit the data in the forwarding region. Q 3: receiving the data from source nodes when the sensor nodes are active and act as a relay node. Q 4: for retransmitting the data to other sensor nodes when the node acts as a relay.

Total Power consumption in a node

Total Power consumption in a node = P(Q 1)+ P(Q 2)+ P(Q 3)+ P(Q 4) , where P(Q i)- is the total required power for transmitting the data in the i-th queue in a certain time interval. Power consumption in a sensor node can be calculated be determining the harvested energy. Let the output power of the harvesting device with any sensor node of the model can be represented as $P_{Harvested}$. Let $E_{Initial}$ be the initial energy of a storage device and $P_{Co\ \ sume}$ be the power consumed by a harvesting device. For transceiver operation, the amount of power required can be expressed as $P_{Transive} = P_{Transmit} + P_{Recive}$, where $P_{Transmit}$ is the transmitting power of a node and P_{Recive} is the receiving power of that node [12]. The output power P_{Output} can be represented as in equation (2).

$$P_{Output} = P_{Intial} + P_{Harvested} - P_{Transciver} \qquad (2)$$

$$\Rightarrow P_{Harvest\ \ d} = P_{Output} - P_{Intial} + P_{Transciver}$$

By the transceiver the available harvesting energy is represented in equation (3).

$$E_{Harvested}(t_1, t_2) = \int_{t_1}^{t_2} P_{Harvested}(t)dt \qquad (3)$$

Duty cycle (k):- the time taken by a node in which it is transmitting a data packets in active time period [20-23]. Energy harvesting rate (λ) = The total amount of energy consumed during a sensor node operation cycle =

$$\lambda = \frac{E_{total}}{t_c + n_{pkt} * t_{tx}} \quad where E_{total} = n_{pkt} * t_{tx} * P_{tx} \qquad (4)$$

Wheren_{pkt} is the average number of data packets transmitted in between the charging cycle, t_c is the average charging time for each cycle and t_{tx} is the total transmitted time, taken for data packets?

Redundant packets reduction in MEHOR

Duplicate packets transmission can be reduced or avoided in the network by the help of coding packets. When the packets are transmitted from source(S) to destination (D), a flow between them is divided into batches and subdivided into several native packets. The native packets are without coding and are original packets. All the packets are randomly broadcasts with linear combinations. If there are x native packets in the batch, and the destination has received y coded packets, where y >= x. Considering the Figure 5, S and D are source and destination respectively. S transmitting two native packets np1 and np2 through the relay R1, R2 and generates two coded packets P1 and P2. Let R2 received both P1 and P2 where as R1 missed the second one. However R1 and R2 generate coded packets P3 and P4 at D and decoded the packets and restore np1 and np2 respectively. From this network structure we can conclude that less coordination overhead may occurs. To reduce the redundant packets in the networks, we considered the following example.

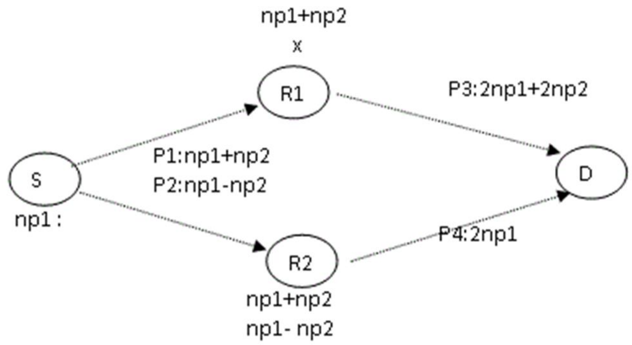

Figure 5. Network coding approach

In Figure 6 : a source broadcast one coded packets p2 and p3 are linearly independent. So they both generate two different coded packets. If we compare the two packets they are not the same, but one of them is redundant which does not contain any additional information.

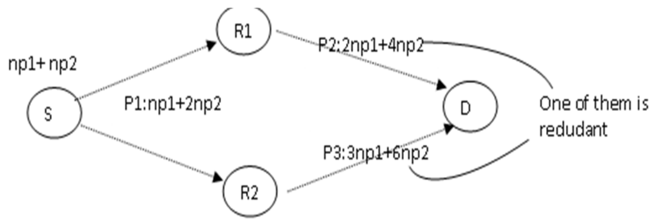

Figure 6. Redundant packets scenario 1

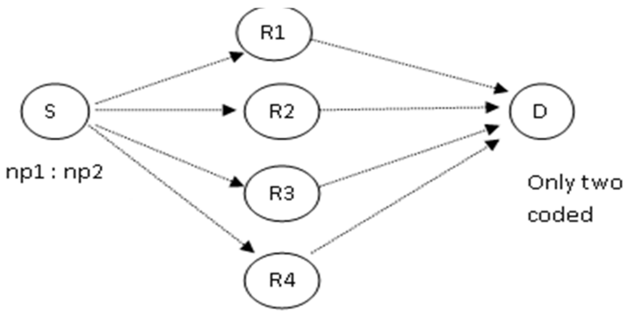

Figure 7. Redundant packets scenario 2

In Figure 7: If we consider two native packets two linearly independent coded packets are required with coordination. So four relay may generated and four coded packets generated. Out of four two are linearly dependent, so they are redundant. At destination, D only two coded packets are valid.

Result Analysis

Our proposed protocol evaluated rigorously through MATLAB 9.1 simulator. In the simulation result 20 numbers of nodes are densely deployed in the area size 15m×20m. The sink is located at the center and it is powered by power supply. We assume there are no packet losses in the communication range. In opportunistic routing protocol maximum author use weak links which covers a long distances, so the threshold value is less. But here we considered the transmission data rate of the node is 250 kbps and the threshold value is 0.1. From our simulation result Table 1 describes about the shortest path and no of partitions depends on the no of nodes and Table 2 describes about the packets variation with respect to changing the deployment area. In MEHOR we use short range communication and transmit more data packets. In our protocol as the number of regions (k) increases the relay nodes also increases and SR decreases because data transmission rate is directly proportional to the covering region.

Table 1. Determination of shortest path and no of partitions depends on the no of nodes

No Of Nodes	No Of Partitions	Shortest Path From Sender To Receiver
20	3	1-7-14-19-20
50	5	1-10-20-30-40-49-50
100	8	1-13-26-39-52-65-78-91-99-100
150	12	1-13-26-39-52-65-78-91-104-117-130-143-149-150
200	15	1-14-28-42-56-70-84-98-112-126-140-154-168-182-196-199-200

Table 2. Packets variation with respect to changing the deployment area

Deployment Area	No of Packet Received	No of Packet Lost
200	79	0
300	79	0
500	79	0
600	30	49
700	25	54
1000	14	65
1500	9	70

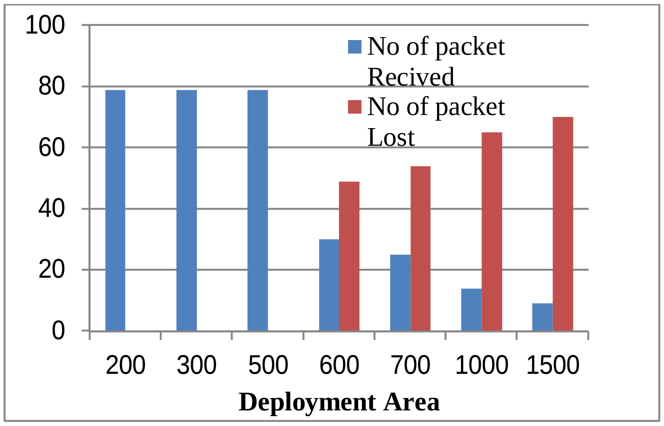

Figure 8. Packets variation with respect to changing the deployment Area

Figure 8: shows the number of packets receive or lost with respect to change in the deployment area. Increasing the deployment area in the network may be directly proportional to the lost packets.

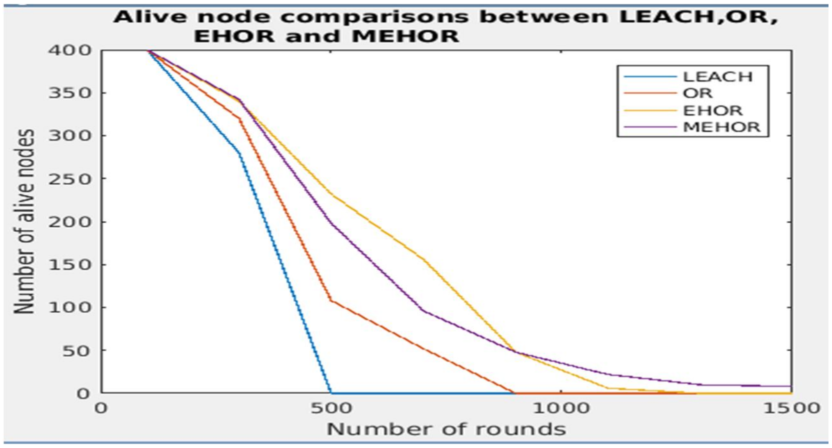

Figure 9.Number of live nodes comparisons in increased traffic scenario

Figure 9: describes the number of alive nodes with respect to time period. We compared the protocols by considering 400 alive nodes in the network. This simulation result compares with the traditional protocol, LEACH [20] (more balanced routing cluster based protocol) with other advanced protocol OR and EHOR. From the result analysis we can say with increased in number of rounds with traffic MEHOR exits with respect to others. It is observed, that after 480 rounds the LEACH comes to an end, OR comes to an end at 780 rounds, EHOR comes to an end with 1120 rounds, where as even after 1500 rounds the MEHOR exits. The amount of data received within a period of time by the destination nodes is known as throughput. To increase the received data packets at base station we should think about the throughput of the MEHOR in the network. So we compare MEHOR with other advanced routing protocols in terms of performances. When we compared MEHOR with OR and EHOR, we get the higher probability of energy harvesting sensor nodes in MEHOR, which increases the throughput as depicted in Figure 10.

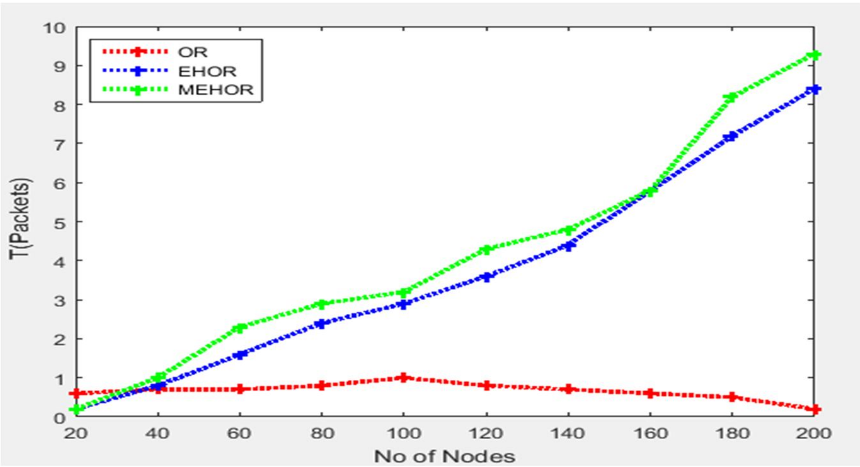

Figure 10. Throughput comparisons in OR, EHOR, MEHOR

Conclusion

MEHOR mainly focus on how to minimize the delay and maximize the throughput. The efficiency of a sensor node depends on the energy harvesting rate. Mainly these sensor nodes are depends open the ambient energy, receiving and transmitting the data depends upon the energy of the storage devices. So from the above performance analysis MEHOR perform better as compare to OR and EHOR. Regioning helps to group all the sensor nodes together in a region where MEHOR helps to reduce the time required in the receive state. As we considered the residual energy our protocol helps to send more data packets and optimize energy with increasing the throughput as well as the goodput.

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