Enhancing Multihop Routing Protocols in Wireless Sensor Networks using LEACH-1R

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Abstract—**Energy consumption is one of the most important factors in wireless sensors networks (WSN). In fact, many protocols have been modified to enhance the lifetime of deployed sensors networks. In our work, we are investigating multihop clustering protocols such as MR-LEACH and MH-LEACH as well as their modified version that integrate the LEACH-1R protocol that which aids to stabilize the network at the phase of clustering. Experimental results shows a clear advantage when LEACH-1R was integrated in both MR-LEACH and MH-LEACH in term of energy consumption, life time, and stability of the network when compared to their original version.**

Keywords—Wireless sensor networks; LEACH-1R; MR-LEACH; MH-LEACH; efficient energy consumption.

I. INTRODUCTION

Wireless networks are composed of infrastructured networks such as cellular wireless network and infrastructure-less network such as ad hoc and wireless sensor networks (WSNs). WSNs are sets of sensor nodes with limited lifetime or residual energy. So the energy consumption of sensor nodes is the main challenge of protocols that govern WSNs. When a sensor node transmits data to a nearby node or a base station (BS), it requires energy relative to the square of distance between the sender and the receiver [1][2]. The problem appears when the residual energy is insufficient for large transmission, yet quite enough for nearby communications. In order to handle such problem, different energy-aware protocols were designed. Sensors' clustering is class of protocols that spatially divides the WSN into clusters after electing a node as a cluster head (CH). Many factors can intervene in such decision, but the residual energy is the most important one. The CH has ability to aggregate information from its cluster members and transmits it to the BS. In fact, single-hop protocols rely on the fact that a packet is passed from a sensors node to its CH, then passed directly to the BS. However, in multi-hop protocols, a packet may travel through different CHs before reaching the base station. Therefore, in multi-hop transmission, a CH hierarchy is to be defined (from nearest to farthest) until reaching the BS. The multi-hop strategies aims at reducing distances of single transmission so that the energy is lesser consumed.

There are many WSNs protocols that are based on clustering hierarchy. LEACH (low energy adaptive clustering hierarchy) is one of the first protocols that used clustering hierarchy in order to reduce energy consumption. However, this well-known protocol suffers from many deficiencies; simply because CHs use a single-hop transmission to send information to the BS. Therefore, too much energy will be lost in the long term. Other protocols are based on multi hop cluster hierarchy such as multi-hop LEACH protocol, and multi-hop routing LEACH (MR-LEACH). These protocols are designed to improve LEACH in term of energy consumption. The objective of our work is to enhance the MR-LEACH protocol once more by combining it with bio-inspired techniques.

The rest of this paper is organized as follows. Section II highlights general concepts of WSNs, their challenges, and their characteristics. In Section III, we present different protocols that are based on multi-hop clustering hierarchy. The enhanced version of LEACH (LEACH1R) is presented in section IV. Simulation results along with interpretations and analyses are given in Section VI. Section VII is the conclusion.

II. WIRELESS SENSOR NETWORK TOPOLOGIES

There are many applications of WSNs. Two fields that broadly utilize them are surveillance and fire detection [3]. Typical WSNs consists of a large number of small, inexpensive, resource constrained sensor nodes that communicate wirelessly in a multi hop network [4]. These sensor nodes collaborate together to accomplish a common task and serve a certain application; for example, environment monitoring, battlefield surveillance, Intelligent Transportation Systems (ITS), home applications for domestic devices and users interaction, and industrial process control [5]. The difference between wireless sensor networks and ad-hoc networks is that the number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network. Moreover, sensor nodes are densely deployed, prone to failures, and more importantly limited in power, computational capacities, and memory.

A. *Architecture design of sensor node*

Architecture of node focuses to reduce cost, increase flexibility, provide fault tolerance, improve development process and conserve energy [4]. Each sensor node is divided into five major blocks where each block performs with specific mission.

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1. Power supply.
2. Communication block (transceiver).
3. Processing block with memory.
4. Sensing unit.
5. Software block provides

B. *Energy consumption*

The sensor node lifetime typically exhibits a strong dependency on battery life [6]. In many cases, the wireless sensor node has a limited power source, and replenishment of power may be limited or impossible altogether. The function of a sensor node in a sensor field is to detect events, perform local data processing, and transmit raw and/or processed data. Power consumption can therefore be allocated to three functional do mains: sensing, communication, and data processing, each of which requires optimization.

C. *Data aggregation*

Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmission is reduced [7]. Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g., duplicate suppression, minima, maxima and average. This technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols. Signal processing method can be used for data aggregation. In this case, it is referred to as data fusion where a node is capable of producing a more accurate output signal by using some techniques such as beam forming to combine the incoming signals and reducing the noise in these signal. In clustering routing scheme, data aggregation helps to dramatically reduce transmission data and save energy. Moreover, clustering with intra-cluster and inter-cluster communications can reduce the number of sensor nodes performing the task of long distance communications, thus allowing less energy consumption for the entire network [8].

D. *WSN clustering*

Clustering is a process of dividing a network into no overlapping groups of sensor nodes [9]. Each cluster is managed by a chosen Cluster-Heads (CHs). Cluster members send data packets to the cluster heads which communicate with each other and send the aggregated packet to the Base Station BS.

Clustering is one of the best ways to extend the lifetime of a sensor network by reducing energy consumption and to provide stability of network in wireless sensor networks. It can be a useful solution to the problems like routing loops or unbounded delay. Also, clustering can help us to use data aggregation methods.

The major benefits of clustering in wireless sensor networks consist of spatial reuse of resources to increase system capacity as well as reducing the number of transmissions performed for distributing information [10]. However, node mobility would make clustering very challenging since the node membership will dynamically change, forcing clusters to evolve over time [11].

III. Related work: Multi-hop hierarchy clusters in WSNs

Routing protocols in WSNs are for setting up one or more paths from sensor nodes to the sink [12]. Since sensor nodes have limited resources, routing protocols should have a small overhead, which may result from control message interchange and caching. Therefore, the traditional address centric routing protocols for Internet do not meet the requirements of WSNs. Data centric routing is more suitable for WSNs because it can be deployed easily, and due to data aggregation, it save s energy. Generally the routing protocols are classified into two classes: one is based on the network structure and the second is depending on protocol operation. The network structures are further classified as flat network routing, hierarchal network routing, and location based routing [1][2].

A. *WSN protocol types*

1) Multipath based protocols

In this case, the network derives benefit from the fact that there could be multiple paths between a source node and the destination. The fault tolerance (resilience) of a protocol is measured by the likelihood that an alternate path exists between a source and a destination when the primary path fails. This can be increased by maintaining multiple paths between the source and destination at the expense of increased energy consumption and traffic generation [1][2].

2) Query based protocols

In this kind of routing, the destination nodes propagate a query for data (sensing task) from a node through the network, and a node with this data sends the data that matches the query back to the node that initiated the query [2].

3) Negotiation based protocols

The nodes here exchange a number of messages between themselves before transmission of data. The benefit of this is that redundant data transmissions are suppressed [1].

4) QoS based protocols

QoS based protocols have to find a trade-off between energy consumption and the quality of service. A high energy consumption path or approach may be adopted if it improves the QoS. So when interested in energy conservation, these types of protocols are usually not very useful [1].

B. *Multi-hop hierarchy clusters in WSN*

There are several protocols in WSN based on multi-hop communication in order to reduce energy consumption. Clustering and hierarchical clustering were widely used to perform such goal.

1) Low Energy Adaptive Clustering Hierarchy (LEACH) protocol

LEACH [13] is the first hierarchical cluster based routing protocol for wireless sensor network which divided the nodes into clusters, in each cluster a dedicated node with extra privileges called Cluster Head (CH) is responsible for creating and manipulating a TDMA (Time division multiple access) schedule and sending aggregated data from nodes to the BS where these data is needed using CDMA (Code division multiple access) [14]. The operation of LEACH is broken up into rounds, where each round begins with a setup phase, when the clusters are organized, followed by a steady state phase, when data transfers to the BS occur. In order to minimize overhead, the steady state phase is long compared to the setup phase [15].

In the advertisement phase, the decision of each node to elevate as a CH is made for the current round. This decision is made by choosing a random number r between 0 and 1. The node becomes a CH if the randomly obtained value is less than a threshold T(n) [14]. Then, each nominated CH starts advertise their own status to the rest of the nodes in the network. The non CH nodes must keep their receivers on during this phase to hear the advertisements of all the CH nodes [7] and choose the CH which sent the message with the largest signal strength heard. This fact means the election of the CH to whom the minimum amount of transmitted energy is needed for communication [16].

After receiving all messages from the non CH nodes, each CH include them to their respective cluster. For each node the CH creates TDMA schedule which indicate that they can transmit data [16]. When the TDMA schedule is fixed for each node, then according to the allocated schedule each node can transmit data to their respective CH. The CH nodes must keep its receiver on to receive all the data from the nodes in the cluster. When they receive all the data from the nodes, they perform aggregation mechanism to compress the amount of data, and next this data is sent to the BS.

2) Multi hop Routing LEACH (MR-LEACH) protocol

In MR-LEACH, there are three steps that compose the protocol [17]. First, clusters are formed, then, the hierarchical structure of clusters is defined, and finally the phase of sending data in hierarchal manner to the base station.

a) Clusters formation

In order to form clusters in the network, each node broadcasts the HELLO message to its neighboring nodes within its transmission radius [17]. Once the cluster is formed, sensor node will save the node ID of CH and all other data will be discarded. If certain node has the largest residual energy among all its neighboring nodes, it elects itself as a CH. Afterwards, it broadcasts a header message (HEAD_MSG). When no CH node receives multiple HEAD_MSG, a node will select the CH whose HEAD_MSG has the highest Received Signal Strength. Once, a node selects the CH it changes the status of CH node to "Cluster Head" and similarly CH will change the status of all its member nodes status to "Members".

b) Cluster hierrachy formation

When clusters are formed, the second phase starts to determine the hierarchical relation between CHs to reach the BS as shown in Fig. 2 [17]:

1. The BS broadcasts a message with its ID over the common control channel to all CHs. The broadcasted signal should be of low strength to reach closer CHs only.
2. CHs near to BS acknowledge the reception and form the first hierarchical layer; these CHs are single hop away from BS.

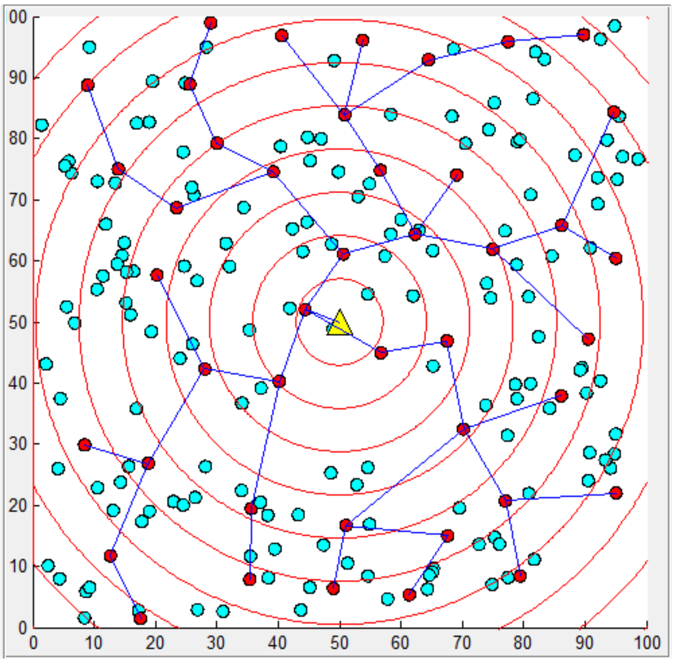

Fig. 1. Hierarchical structure of WSNs using the MR-LEACH protocol

3. BS broadcasts a control packet of discovered CHs IDs with higher transmission range to find new CHs and build a hierarchical links with the old CHs, and thus, building the second layer CHs.
4. The process is repeated until no new CH is discovered.

c) Scheduling

Time Division Multiple Access (TDMA) is the preferred scheduling scheme in sensor networks because it saves lot of energy compared to contemporary medium access tetchiness for wireless networks. Upper level cluster heads will allocate longer time slots to their member low level CHs because they have more data to send compared to simple members [17].

3) MULTI-Hop LEACH protocol

When the network diameter is increased beyond a certain level, LEACH becomes inefficient. In this case energy dissipation of CH is not affordable. To address this problem, the Multi-Hop LEACH protocol aims to increase energy efficiency of a WSN [18]. Multi-Hop LEACH forms clusters like LEACH in the setup phase. In steady state phase, a CH collects data from all nodes in its cluster and transmits data directly or through other CHs (closest with strong signal and closer to BS) after aggregation. Multi-Hop LEACH allows two types of communication operations. First one is intra-cluster communication, when the whole network is divided into multiple clusters. CH receives data from member nodes at a single hop distance and aggregates and transmits the data directly to the BS, or through intermediate CH(s). the second one is inter-cluster communication, when the distance between the CH and the BS is large, the CH uses intermediate CH(s) to communicate to the BS [18].

IV. ENHANCING MULTI-HOP PROTOCOLS IN WSNS USING LEACH-1R

LEACH-1R (LEACH One Round) is based on the LEACH protocol where the clusters of the first rounds are maintained [19]. In fact, the clusters are set based on LEACH. However, the selection of a new CH is done only if the current one runs out of energy. Moreover, the new CH is selected directly among the members of the cluster; hence, the regular process of selection is avoided for better performance.

In order to achieve our goal of enhancing the WSNs clustering phase, more control of the clustering process is needed, i.e., detecting CHs and their members. In fact, such operation is based on two phases. In the first phase (Fig. 2 (a)), CHs are selected upon the first round of LEACH mechanism. In fact, we can use any of the first $\frac{1}{P}$ rounds since the percentage P is more or less respected. In the second phase (Fig. 2 (b), the clusters are preserved and a new CH is selected only if the current one ran out of energy, i.e., the battery level beyond certain threshold). In this case, a new CH is selected among the cluster members only taking in consideration the strength of the last received signal.

V. SIMULATIONS AND RESULTS

Through several experiments, we analyzed the performance of the old version of MR-LEACH and MH-LEACH as well as our modified version MR-LEACH-1R and MH-LEACH-1R where LEACH-1R is integrated in the setup phase. The simulations where conducted using MATLAB. Since energy conservation is the primary objective of our work, performance metrics such as network lifetime, energy consumed per round, and the residual energy level of sensor nodes are of particular interest.

A. Network Configuration

In our analysis, we use the same radio model as in [4]. In order to transmit k bits through a distance d the required transmission dissipated energy E_{Tx} and reception dissipation energy E_{Rx} are obtained as follows:

$$E_{Tx}(k,d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2 & d \le d_0 \\ E_{elec} * k + E_{mp} * k * d^4 & d > d_0 \end{cases} \quad (1)$$

$$E_{Rx}(k,d) = E_{elec} * k \quad (2)$$

Where:

E_{elec}: per bit energy dissipations for transmission and reception.

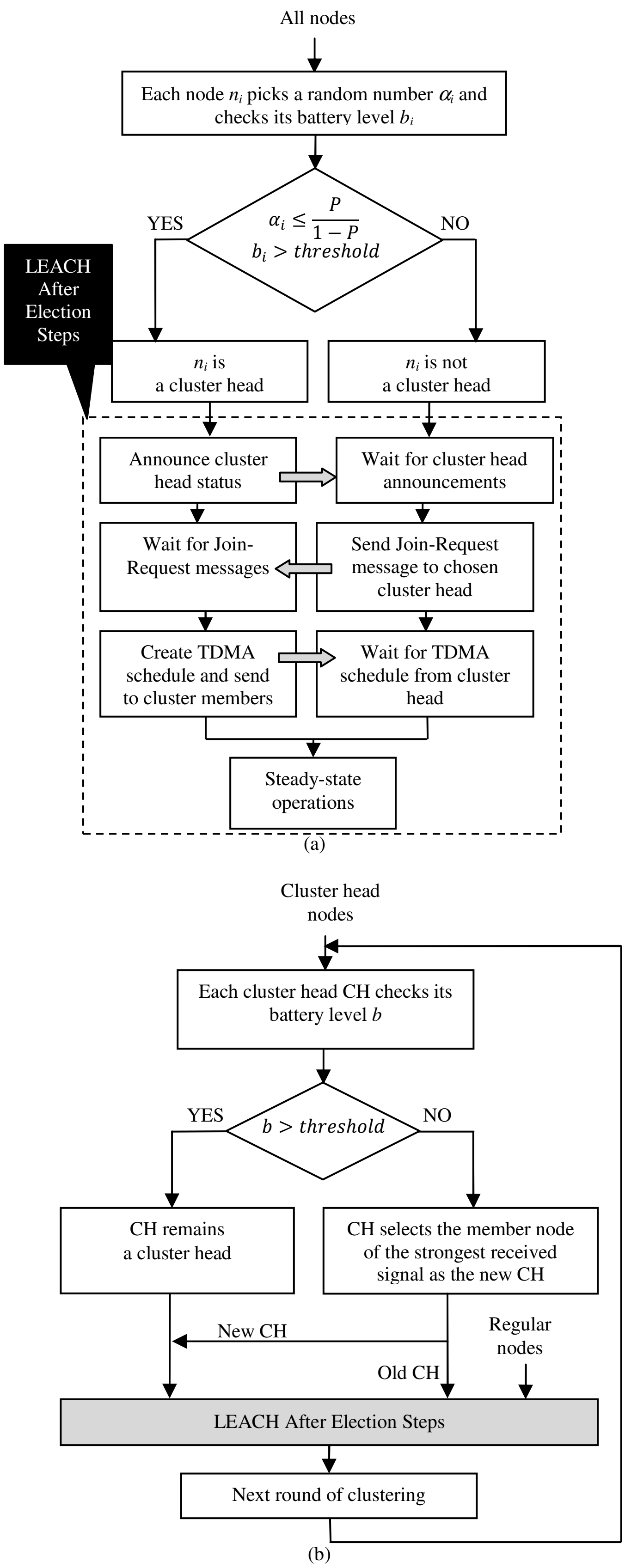

Fig. 2. The LEACH-1R protocol: (a) first clustering round (b) other rounds

E_{fs}: the fading space energy required by the transmission amplifier to maintain an acceptable signal-to-noise ratio in order to transfer data messages reliably when the distance is below certain threshold distance d_0.

E_{mp}: the multi path energy required by the transmission amplifier to maintain an acceptable signal-to-noise ratio in order to transfer data messages reliably when the distance exceeds the d_0 threshold.

In our simulation, we used a network operation model as shown in Table 1. The reference network consists of 200 nodes randomly distributed over an area of 100x100 meters with an initial energy of 0.1 Joule. The base station is located at the coordinate 50, 50.

TABLE I. SIMULATION PARAMETERS

Parameters	Values
Zone Height	100 meters
Zone Width	100 meters
Number of Sensors	200 nodes
Base Station Position	50, 50
Cluster Head Percentage (P)	0.1
Initial Energy (E_0)	0.1 Joule
Transmission Energy (E_{elec})	50 nJoule/bit
Propagation Energy (fading space E_{fs})	10 pJoule/bit/m^2
Propagation Energy (multi path E_{mp})	0.0013 pJoule/bit/m^4
Data Aggregation Energy (E_{da})	5 pJoule/bit/signal
Threshold distance (d_0)	10 meters
Packet Size	500 bytes
Packets per Round	1

B. Results and Analysis

Fig. 3 shows the number of clusters through clustering rounds. It is clearly seen that MH-LEACH was very instable due to the use of the instable LEACH protocol at the setup phase where it quickly jumped between low and high numbers of clusters wasting lot of energy. However, MH-LEACH-1R maintains a steady level of 21 clusters and then decreases slowly when nodes ran out of energy. On the other hand, MR-LEACH-1R was more stable than MR-LEACH maintaining 14 clusters up to 200 rounds.

Fig. 4 shows the number of live nodes through clustering rounds. Although MR-LEACH and MH-LEACH kept almost all nodes alive in the first 100 rounds, a free fall took place between rounds 200 and 300. However, MR-LEACH-1R as well as MH-LEACH-1R maintained a gradual decrease of live nodes.

Fig. 5 shows the total residual energy of the sensors. As in Fig. 4, MR-LEACH and MH-LEACH showed a free fall between rounds 200 and 300. However, MR-LEACH-1R as well as MH-LEACH-1R maintained a gradual decrease of residual energy.

Fig. 6 and Fig. 7 show the entire data flow of the network, i.e., data sent from sensors to CHs and from CHs to base station. MH-LEACH showed a high data flow in the network in the first rounds before nodes ran out. On the contrary, MH-LEACH-1R succeeded to maintained a proportional data flow vis-à-vis the current live nodes.

VI. CONCLUSION

In this paper, we presented a modified version of the sensor network hierarchical clustering protocols MR-LEACH and MH-LEACH. The idea was to integrate the LEACH-1R protocol in their setup phase instead of the obsolete LEACH. In LEACH-1R, the first round of LEACH as a basis for clustering instead of re-clustering, aiming to achieve a better clustering stability and thus saving network energy.

Simulation results were presented to demonstrate the performance of the MR-LEACH-1R and MH-LEACH-1R over MR-LEACH and MH-LEACH as well as the effects on energy conservation and network lifetime. We used residual energy and live node parameters per round to evaluate the behavior of the old and new protocols. Simulation experiments were conducted using many different values of initial energy and number of nodes. Our experiments showed that MR-LEACH-1R and MH-LEACH-1R achieved significant energy savings and enhances network lifetime compared to MR-LEACH and MH-LEACH protocols. Moreover, MR-LEACH-1R and MH-LEACH-1R showed a better distribution of clusters formation over different clustering rounds.

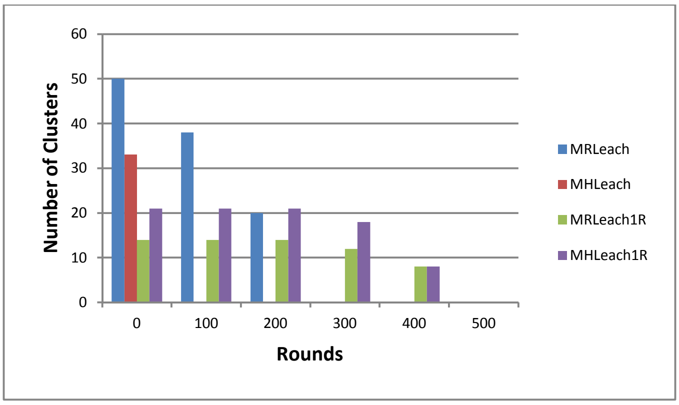

Fig. 3. Protocols comparison vis-à-vis the number of clusters.

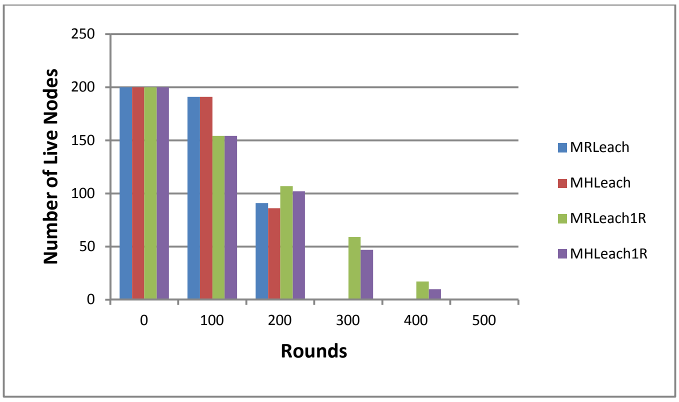

Fig. 4. Protocols comparison vis-à-vis the number of alive nodes.

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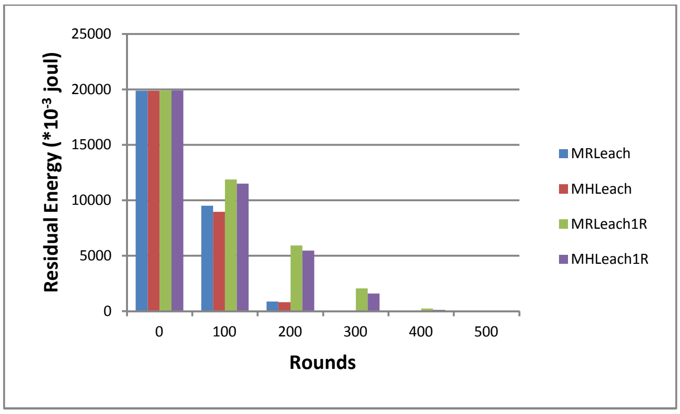

Fig. 5. Protocols comparison vis-à-vis the network’s residual energy.

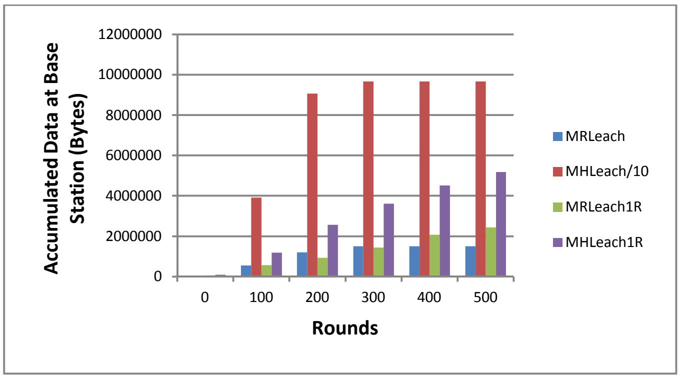

Fig. 6. Protocols comparison vis-à-vis the data volume received by the base station.

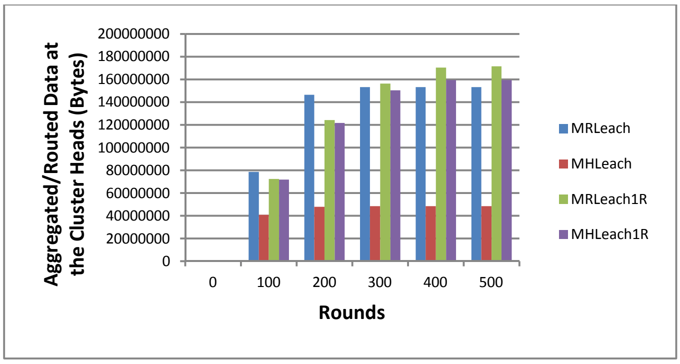

Fig. 7. Protocols comparison vis-à-vis the aggregated and routed packets at the cluster head nodes.

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