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RESEARCH ARTICLE

Pizzza: A Joint Sector Shape and Minimum Spanning Tree-Based Clustering Scheme for Energy Efficient Routing in Wireless Sensor Networks

SARA NASIRIAN[1,2], PAOLA PIERLEONI[1], ALBERTO BELLI[1], MARCO MERCURI[1], AND LORENZO PALMA[1], (Member, IEEE)

[1]Department of Information Engineering, Universitá Politecnica delle Marche, 60131 Ancona, Italy
[2]Department of Information Engineering and Mathematics, University of Siena, 53100 Siena, Italy

Corresponding author: Lorenzo Palma (l.palma@staff.univpm.it)

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ABSTRACT The widespread employment of wireless sensor networks in various fields necessitates the urgent creation of methods for prevailing over known shortcomings of this network category. Energy shortage as one of the most restrictive deficiencies of the employed sensors in this network category has encouraged many researchers from both academic and industry communities to propose efficient solutions to contribute to efforts done with the aim of decreasing energy consumption and consequently increasing the wireless sensor networks' lifetime. Among bunches of schemes proposed in this regard, cluster-based routing protocols have demonstrated promising results so far. Plenty of these schemes have improved network communication and minimized delay, however, they still need to be improved in the crucial aspects for which they were proposed, namely energy consumption reduction and network lifetime prolongation. Considering all these pivotal points, a novel cluster-based hierarchical routing protocol, named Pizzza, is introduced in this paper. Pizzza is creatively designed by forming minimum spanning trees among communicating nodes in each sector-shape cluster, where only eligible nodes from the first level of the architecture can undertake cluster head leading role. Employment of this innovative scheme has concluded in the prolongation of the network lifetime through the reduction in energy wastage resulting from the elimination of reverse data flow from BS, data transmission to the nearest neighbors, and balanced energy consumption in the network. The efficient energy consumption in Pizzza has resulted in a 65.52% prolongation in the network lifetime and a 77.05% enhancement in the residual energy of the network compared to a selected set of popular and efficient protocols.

INDEX TERMS Wireless sensor network, clustering, hierarchical routing, energy, cluster head.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are widely used in several application fields such as agriculture, military, environmental surveillance, healthcare, disaster prediction, industry, transportation, etc. [1], [2], [3]. In many cases, these tiny sensors improve the quality of life of human beings by taking over tasks in hazardous regions, and in other cases, their performance has resulted in significant decreases in the downtime and related costs of various equipment types [4]. All of this is possible only by profiting from the trinary capabilities of sensors, namely sensing, processing, and communication [5]. Moreover, being equipped with memory, processor, and transceiver, the performance of the wireless sensor nodes is strongly affected by their limited power supply [6]. Therefore, handling this deficiency is the only way out of this problem, which in turn leads to improving the performance of the wireless sensor networks by prolonging their lifetime.

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With the aim of improving energy efficiency, enhancing network communication, prolonging network lifetime, and minimizing delay, the clustering technique is introduced. Clustering organizes nodes into a set of groups called clusters based on a set of pre-defined criteria such as supporting Quality of Service (QoS), optimizing resource consumption, network load balancing, etc. [7]. Then, in each cluster, a node is selected as a Cluster Head (CH). CH is in charge of collecting data from the sensors of the same cluster and passing it to the BS after imposing data aggregation and fusion to the collected data. Selecting the cluster head in each cluster is considered an essential step that enables energy-efficient routing with minimized transmission delays in the network. Thus, clustering can be considered a super useful mechanism in the routing of WSNs with plenty of achievements some listed as follows:

Energy consumption reduction:

Nowadays energy efficiency and greenness are indispensable goals for both wired and wireless networks [8], [9], [10]. The intrinsic power scarcity in wireless sensor networks pushes us to put more stress on such a pivotal fact in WSNs. Being considered a cluster member, a node devolves a major part of its energy-consuming tasks, such as data gathering, data aggregation, and high-range base station-destined data transfers to the corresponding cluster head. Such a policy can also decrease energy wastage in the network by eliminating the amount of transmission of redundant information [11].

Delay reduction:

Instead of directly transmitting the sensed data to the base station (BS), the cluster nodes generally use the best possible routes to send their data to the cluster head. Successively, the cluster head sends just a single message to the base station that is consisted of the aggregated format of all the received messages. Therefore, the employment of the optimal routes for data transmission to the cluster head and forwarding just one aggregated packet by the cluster head to the base station (instead of several packets) drastically decrease the amount of experienced latency in the network [12].

Network lifetime prolongation:

Network lifetime prolongation: The major goal of clustering is certainly the prolongation of the network lifetime. All the adopted policies aiming at equilibrating the distribution of load in the network can have an effective contribution to increasing the network lifetime. Also avoiding energy dissipation by evading the direct long-range transmission of packets or transfer of duplicate and redundant content significantly increases the network lifetime [13].

Data redundancy reduction:

Usually, the nodes located in the near vicinity of each other sense almost the same amount of the assessment indicator, and therefore, transmitting all these redundant messages can be considered a significant waste of the network energy. Clustering methods, however, prevent this energy dissipation by imposing data aggregation techniques on the gathered information from the cluster whole [14]. Therefore, the information will be transferred from the cluster head to the base station in the form of a single packet instead of several redundant ones. This technique, therefore, saves a notable amount of energy in the network.

Robustness improvement:

To overcome network flaws and failures and with the aim of managing the integrity of the network, shaping dynamic clusters is essential. The formed clusters must be maintained in an efficient way so that they can strongly withstand the occurrence of any alteration in the network topology or death of the nodes [15]. Therefore, generally, a periodical change of cluster head is vital to prevent the energy depletion of some nodes and the advent of hot spots in the network.

By considering all the privileges of the cluster-based schemes over other routing protocols, in Section II, a plentiful selection of cluster-based routing protocols is gathered, and some of their pros and cons are discussed. After gaining a comprehensive background about the cluster-based routing protocols, the employed radio energy dissipation model is introduced in Section III, which makes everything ready for introduction of a novel cluster-based routing scheme, named Pizzza, in Section IV. In Section V, the performance of Pizzza is studied and compared to some well-known and efficient cluster-based routing protocols. In Section VI, it is discussed that how the main design requirements of an energy-efficient cluster-based wireless sensor network was achieved through the novelties in the design of the proposed Pizzza scheme. Finally, Section VII concludes the paper.

II. RELATED WORKS

Various routing protocols have been proposed in order to decrease energy dissipation and increase network lifetime. With all this, it is still widely accepted that clustering routing protocols are among the best-performing protocols in energy conservation [16], [17]. In this section, it is tried to present a short review of some of the hierarchical routing protocols in which the researchers try to achieve energy conservation goals.

LEACH [18] is one of the most popular hierarchical and one of the first instances of dynamic clustering protocols as well. The random selection of the cluster head in LEACH is done by producing a random number by each node and comparing the produced number by a threshold, which was in turn calculated based on the percentage of cluster heads in the total sensor population, and round number. Only if the produced random number is less than the threshold, the node will be elevated as a cluster head. Therefore, the cluster head selection will be done without any interference from the base station. Thanks to the reduction of direct transmission to BS and balancing sensor loads, LEACH achieves a factor of 8 times improvement compared to direct transmission. On the other hand, the random cluster head selection policy, employed in LEACH, selects the cluster heads neglecting the amount of their residual energy, which can result in the elevation of even low-energy nodes as cluster heads and subsequently early death of the selected cluster heads which can notably degrade the robustness of the network [19], [20].

LEACH-MAC [21] was presented to modify the randomness in the LEACH's nature, which may result in variations in the cluster head count. This approach employs a fixed number of cluster heads. Based on this scheme, each node first generates a random number, in a similar way as LEACH, and if the generated number is less than a threshold the node can be considered an eligible candidate for further processing. Each eligible candidate then randomly elects a time slot for advertisement. The actual advertisement time slot, however, can be calculated by dividing the elected time slot by the residual energy of the node. Therefore, energy scarcity postpones the advertisement time slot and instead energy abundance anticipates the advertisement time slot. Finally, each node can only advertise its candidacy during the calculated time slot only if it has not already received a predefined number of advertisement messages, which is equal to the optimal number of cluster heads. Although this scheme enjoys stability in terms of CH count, the cluster selection process is still based on the threshold value, and many other critical factors are mostly neglected.

Improved-LEACH [22] considers cluster head percentage, neighbor number, residual energy, and distance to the base station as effective factors in the generation of the employed threshold in the cluster head selection process. The unique threshold of the I-LEACH is used in the same way as the LEACH threshold. In this way, to become a cluster head each node needs to produce a random number less than the mentioned threshold. This scheme improves the life span and load distribution of the network; however, it inherits the random nature of the LEACH, which introduces it as a scheme with a significant need for amelioration.

LEACH-Fuzzy [23] Clustering (LEACH-FC) is proposed to improve the energy efficiency of various types of wireless sensor networks. It is designed based on the implementation of a fuzzy logic-based cluster head selection and cluster formation and with the aim of maximizing the lifetime of the network. In this scheme, the cluster head selection and the cluster formation are done based on a centralized approach. A fuzzy logic centralized approach is also used in the vice cluster head selection process. LEACH-FC improves the reliability of the network by balancing the energy load of the nodes. This scheme, however, does not show its full performance in the energy consumption and network lifetime aspects of homogenous networks. Other extensions of LEACH [24], [25], [26] and some related fuzzy-based schemes [27], [28] were proposed to increase the network lifetime of wireless sensor networks.

UCRA [29] was proposed with the aim of solving the imbalanced energy consumption and the hot-spot advent in wireless sensor networks. UCRA is proposed in the form of an unequal clustering routing algorithm (UCRA) in which the whole span of the network must be divided into a few levels, where the widths of the levels increase by getting further from the base station position. The nodes of the network can advertise their role as the cluster head at precise moments. Generally, the nodes with higher residual energy and lower distance to the base station have the possibility to advertise their role as a cluster head sooner. So, each node will join the cluster head, which has a shorter back-off time compared to its own back-off time. Each cluster member can directly communicate its sensing to its elected cluster head. A cluster head instead communicates its fused data to the base station through its other peers to decrease the total communication cost. UCRA improves the network energy consumption and the number of surviving nodes, however, it still needs to be improved in the aspect of energy wastage through reverse data flow from the base station.

In order to achieve the goal of energy conservation, WPO-EECRP [30] considers multiple energy-related clustering factors for selecting cluster heads, such as residual energy, node distance to the base station, neighbors, and the number of neighbors through weighting. Moreover, the clustering parameter of neighbor communication range, R, and weight coefficient W of clustering factors used to control clustering in each round are both optimized. Thus, the network is divided into clusters under the configuration of optimal amounts of R_{opt} and W_{opt} and operates until it completes data communication. Simulation results show that this protocol can extend the network lifetime over two representative clustering protocols published recently and significantly reduces energy consumption. However, its performance is only proven for small-scale networks, while nowadays, the need for the employment of huge wireless sensor networks cannot be denied.

GBCHS [31] presents a grid-based cluster head selection mechanism by dividing the network field into a certain number of uniform-size partitions. This scheme is designed for minimizing the energy dissipation of sensor nodes and enhancing network lifetime. To balance energy consumption within the grids, the CH role rotates between the sensor nodes in a round-robin fashion. Thanks to the elimination of the re-clustering procedure after the end of the regular intervals, GBCHS reduces communication overheads and energy consumption. Also, based on the minimum distance, a multi-hop path is adopted for forwarding the data to the destination. The simulation results show that the proposed GBCHS mechanism outperforms the standard LEACH protocol in terms of several parameters. However, its performance needs to be improved by grouping the sensor nodes to form energy-aware and balanced clusters.

EEHCHR [32] is recently proposed as an adaptive and hybrid clustering for minimizing the usage of the energy of the nodes using the Euclidean distance parameter, Fuzzy C-Means (FCM) technique, BS location, and the nodes' residual energy of the nodes. Performing the clustering process only in a few rounds results in energy consumption reduction. EEHCHR selects the cluster heads profiting from the energy-efficient fitness function that is still adaptive, regarding the fact that the residual energy of the nodes is involved in the process of the cluster head selection.

By adopting a hierarchical packet routing strategy, different cluster head types, namely Direct Cluster Head and Central Cluster Head, selected based on different fitness functions, are employed as relays for other CHs. EEHCHR improves network energy consumption, however, its coverage ratio drops suddenly and drastically, and its network lifetime needs to be improved.

EECMHR [33] is proposed to support effective data collection in wireless sensor networks. The method splits the entire network area into an arrangement of cluster regions in each a single node plays the role of the cluster head. The nodes are hierarchically grouped up in levels and routing is performed through the cluster heads. The cluster head selection process is done according to a likelihood scale and based on the nodes' power level which results in the rotation of the cluster heads at each timestamp according to energy conditions. With all this, the cluster head selection phase of EECMHR does not result in balanced energy consumption between the nodes. On the other hand, EECMHR slightly improves the performance of the network.

A novel fully connected energy efficient clustering mechanism named FCEEC is proposed in [34], which facilitates optimum CH-BS shortest path discovery for full connectivity of nodes. The electrostatic discharge algorithm is employed in the FCEEC scheme to establish a fully connected network with shortest-path multi-hop routes from various nodes to the cluster head. The employed ESDA algorithm prolongs the network lifetime and achieves energy-efficient full connectivity between sensor nodes as well. The employment of this scheme, however, cannot result in a very significant reduction in the number of dead nodes. Therefore, energy efficiency is the factor that demands dedication of more attention.

EECA [35] is proposed with the aim of prolonging the network lifetime via the reduction of the energy consumption in the network nodes. The EECA model uses Artificial Neural Network (ANN) to select a cluster head in each region. For the CH selection process, ANN qualifies the nodes based on parameters, such as residual energy, number of events detected, distance to the base station, and number of neighbors. EECA also defines the maximum size of the cluster to prevent the formation of huge clusters. Moreover, with the aim of preventing the transmission of redundant data to CHs, only the sensor nodes located in the proximity of an event can send updates to the CH. Furthermore, each CH turns its radio off in case of not receiving any signal at the beginning of the slot dedicated to the incoming transmissions. This rule decreases energy wastage provoked by idle listening in CHs. All these measures can improve the energy efficiency in EECA, however, for achieving better performance, some solutions to many deficiencies should be devised yet. As an instance of these deficiencies, one can refer to energy-exhaustive single-hop data communications to the BS by various nodes of the network, instead of the employment of multi-hop paths.

GA-UCR [36] is a genetic-algorithm-based clustering scheme that employs non-equally sized clusters in wireless sensor networks, in which the size of the cluster changes in proportion to the cluster head's distance from the base station to prevent the advent of energy holes or hot-spots in the network. For the CH election phase, genetic algorithm is used with three fitness functions, namely the remaining energy of CHs, CH-BS distance, and inter-cluster separation. For inter-cluster data transfer towards the BS, once again genetic algorithm is employed with three fitness functions, namely residual energy of the next hop, CH-next hop node distance hop counts. Although based on the simulation results this scheme has achieved good energy consumption, and a prolonged network lifetime, its complexity can be considered a hindrance to its practical employment.

Some inspiring works adopting concentric clustering [37] or track-sector clustering [38] were proposed in the classical literature of the work, which have still kept some of their superiorities compared to recent schemes. In addition to the schemes proposed for the homogenous [39] and static wireless sensor networks [40], which are generally the most widespread types of wireless sensor networks, some outstanding schemes are proposed for improving the load balance and network lifetime enhancement in mobile [41], [42], [43] and heterogenous [44], [45], [46], [47] wireless sensor networks. In the section IV, a novel cluster-based routing protocol is proposed for homogenous and static wireless sensor networks, which can be adapted to the case of mobile and heterogenous networks without requiring a lot of modifications or effort.

III. RADIO ENERGY DISSIPATION MODEL

The radio and energy model used in this paper is in complete compliance with the most widely employed model used by LEACH [18], SEP [48], MCR [49], EEMHR [50], and many more schemes. The mentioned model is exhibited in Fig. 1, where the energy consumption of both transmitter and receiver is modeled based on the equations collected in this section. First, the transmission energy consumption can comply with one of the free space or multipath models based on the distance between the transmitter and the receiver and whether the mentioned distance exceeds a preset threshold denoted as d_0 equal to $\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$ or not. The exact values of the ε_{fs} and ε_{mp} constants can be found listed later in the performance evaluation section. Therefore, the transmission energy consumption is calculated based on (1):

$$E_{T_x}(k,d) = k \times E_{elec} + k \times \varepsilon_{amp} \times d^{\gamma} \tag{1}$$

in which k is the packet size. Moreover, the path loss component, denoted as γ, and the amplification factor, denoted as ε_{amp} (ε_{fs} or ε_{mp}) should be selected based on (2):

$$E_{T_x}(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times k \times d^2, & (d < d_0) \\ k \times E_{elec} + k \times \varepsilon_{mp} \times k \times d^4, & (d \geq d_0) \end{cases} \tag{2}$$

In (2), E_{elec} is the electronic energy dissipation per bit.

Second, the receiving energy is calculated as mentioned in (3):

$$E_{R_x}(k, d) = k \times E_{elec} \tag{3}$$

IV. PROPOSED PIZZZA SCHEME

In this section, the architecture, and details of the proposed Pizzza scheme are described. In addition, some preventive measures adopted with the aim of stopping network fragmentation occurrence are introduced here as well. Pizzza is a novel cluster-based routing scheme that is proposed with the aim of prolonging the network lifetime via reducing the energy dissipation mainly by eliminating the reverse data flow from the BS and transmitting data to the nearest neighbors. Employing sector-shaped clusters in Pizzza makes it very similar to the shape of a pizza. Therefore, the proposed scheme is nominated as Pizzza to highlight the similarity of its appearance to the pizza while not neglecting its obvious difference from a real one by inserting an additional z letter to the selected name!

Briefly, Pizzza is a cluster-based routing scheme that accommodates bi-level sector-shape clusters, where only the nodes from the first level, which is the nearest level to the BS are considered eligible nodes to become CH. In each operational round, both sector assignment and level assignment will occur dynamically, based on the number of alive nodes and even the amount of residual energy in the network. Moreover, in each sector, a Minimum Spanning Tree (MST) structure will be shaped, selecting a root node, designated from the first level. Using an MST structure will guarantee that each cluster node will send its data to its nearest neighbor (its precedent node in the tree structure), where the mentioned neighbor will fuse the received data with its own data and then will transmit it to its one-hop neighbor, which is actually its precedent node in the tree structure. Finally, the cluster head, which is the root of the tree as well, will transmit the final form of data, which is the fused and aggregated data of the whole cluster, to the BS. Therefore, partitioning the area of the network into some sectors, devising a tree structure in each sector, and assigning two levels to the whole area of the network will absolutely decrease redundant data transmission and reduce the energy consumption, resulting from large distances between CHs and the BS. The newly proposed protocol consists of 3 major steps:

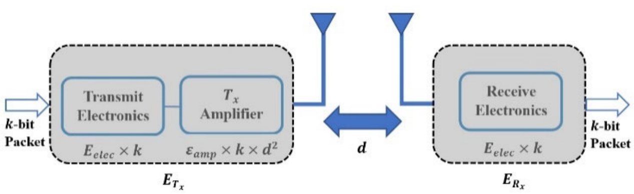

FIGURE 1. Employed radio energy dissipation model.

- *Network Setup Phase*
- *Schedule Creation and Code Assignment Phase*
- *Data Transmission Phase*

A. NETWORK SETUP PHASE

In the network setup phase, different steps of clustering, head node selection, and routing path construction will be accomplished. These steps are discussed in more detail in the following.

1) ENCIRCLING THE NODES

As the first step of the cluster formation phase, the BS encircles all the networks in an imaginary circle, in which the BS location is considered as the circle's center and the distance of the farthest node from the BS is considered as the circle's radius. In that way, all the nodes would be enclosed in an imaginary circle. As clear, there is no obligation, necessity, or constraint for the placement of the BS inside or outside of the sensing terrain. It is also assumed that the nodes are equipped with GPS, and therefore, they have the possibility to communicate their position to the BS after the placement phase.

2) SECTORIZATION

11Sectorization'' refers to the process of dividing the whole span of the imaginary circle into some sectors. In that way, the network span would look like a Pizza, and as already mentioned that is the reason why the proposed scheme has been named in this particular manner. In the initialization phase, before the calculation of the desired number of sectors, the number of sectors would be set to 2, which is the smallest even number. The actual desired number of sectors should be calculated based on the rules described in subsection VI in the same section and should be used for the sectorization phase and its following steps from scratch. As in the proposed scheme, the sector count is equal to the cluster count, and due to the fact that dividing the network to the optimal number of clusters is of paramount importance, it is tried to find the optimal number of clusters.

The optimal cluster number depends on several parameters, such as the network topology and the relative costs of computation versus communication. To improve the efficiency of the network, sectorization can be also done dynamically during the network lifetime, and even the number of sectors could be changed facing the death of the nodes to avoid maintaining an unnecessarily large number of clusters in the network. However, it may impose an extra overhead on the network. The optimal number of clusters in the network can be calculated based on some formulae proposed in some related works [51] or based on the heuristic method proposed by the authors exclusively designed for the Pizzza scheme. Thus, as mentioned, before finding the optimal number of sectors, the initial sector number can be set equal to the smallest even number, 2. Then, it can be updated to the optimal number calculated based on the provided information in subsection VI of the same section.

3) LEVEL ASSIGNMENT

By dividing the whole circular span of the network into two levels, each node would be assigned a level number based on its locating position to the base station. In that way, the nodes located at the nearest distance to the BS are considered first-level nodes, while the rest of the nodes are considered second-level ones. Leveling is done with the aim of introducing only the first-level nodes as eligible candidates for the CH selection phase. This act can highly decrease the amount of reverse data flow from BS since the cluster data needs to be received by one of these near nodes to be sent to the BS. Therefore, the energy of the nodes would not be wasted for sending data away from BS instead of sending it toward that. The leveling threshold can be varied in different networks, and it can dynamically increase during the network lifetime by encountering the death of certain nodes and alteration in the network topology. The leveling threshold can be calculated based on the density of nodes, their distance from each other, the node count, and some other similar criteria.

4) CLUSTER HEAD SELECTION

To select a cluster head in each sector, all the first-level nodes need to calculate their eligibility factor based on (4):

$$EF = \alpha \times \left(\frac{E_{res}}{E_{init}}\right) + \beta \times \left(\frac{R_{L1} - D_{BS}}{R_{L1}}\right)^2 + \gamma \times \left(\frac{D_{CH}}{2R_{L1}}\right)^2 \tag{4}$$

The above equation consists of three normalized fractions. Where in the first part, two of the most efficient parameters in the calculation of EF namely E_{res} and E_{init} are considered. E_{res} and E_{init} are respectively the residual energy of the node and the initial energy of the node. Clearly, considering the first part of the formula in its current form $\left(\frac{E_{res}}{E_{init}}\right)$ is only recommended for the calculation of EF in homogenous networks in which all the nodes have the same consumption pattern and initial energy. In the next normalized fraction, R_{L1}, which is the radius of the first level, and D_{BS}, which is the distance of the given node to the BS are considered. This fraction facilitates the selection of the closer nodes to the BS and can efficiently contribute to the cancellation of reverse data flow from BS. Finally, in the third fraction, the distance of the current candidate and the last CH in the same sector, denoted as D_{CH}, is considered as a determining factor, which reduces the likelihood of hotspot occurrence in the network by avoiding the selection of near nodes as CHs in a consecutive manner.

The weighting coefficients of α, β, and γ should be selected in the range of $[0, 1]$ and they must meet the following condition:

$$\alpha + \beta + \gamma = 1 \tag{5}$$

By considering the significantly higher importance of the energy factor in the cluster head selection, proved in bunches of related research conducted in the field [52], α should be assigned a notably higher value compared to β and γ. On the other hand, due to the relatively high significance of the distance to the BS and its effect on energy wastage [53], β should be assigned a higher value compared to γ. In the small networks containing a limited number of nodes, assigning small values to γ is necessary and will lead to prevents the unnecessary increase in the level assignment threshold. Therefore, in general, the coefficients should be assigned in the following manner $\alpha > \beta > \gamma$, to result in the selection of the top CH candidate.

Therefore, the base station uses Eq. 4 to select the most suitable cluster heads among the eligible candidates. BS updates its information about the remaining energy of eligible nodes not only by sending push notifications to certain nodes once in a while but also based on residual energy estimations considering the role of the nodes and their distance to their corresponding CHs. Therefore, this method tries not to impose much overhead on the network in the CH selection phase, however, it is still tried to select the most suitable candidates for the cluster head role by considering the most important factors that contribute to an efficient energy consumption distribution and equilibration.

5) PLANTING TREES

The term "planting" refers to the process of forming a Minimum Spanning Tree (MST) in each sector, which connects all the alive nodes of the same sector with the minimum possible total edge weight. To keep the energy consumption of the nodes over the links as limited as possible, the square of the distance between nodes is considered as the link cost. However, the most important point about the formed MST is its root. To form the mentioned tree, therefore the selected cluster head of each sector in the previous step should be considered as the root of MST in that sector. Employing the tree structure will guarantee the lowest level of energy wastage in data transmission especially considering the fact that the root node or in other words the CH is one of the nodes located in the nearest position to the BS. Thus, Pizzza employs an MST structure in which the square of the distance between nodes is considered as the link cost. Hence, by employing an MST structure in each sector all the nodes enjoy the opportunity of sending their data to a near neighbor, and the total energy consumption in each sector would be kept as low as possible.

6) OPTIMAL NUMBER OF CLUSTERS (SECTORS)

To calculate the optimal number of sectors, first, the initial number of clusters should be set to 2 in the previous steps and an MST should be formed in each sector. Then, each edge of each tree, which is a vector connecting each node to its parent node, is projected to the vector which connects BS to the given node $\left(\vec{\mathbf{BSV}}\right)$ and the perpendicular vector of the mentioned one. The projections of the ith node's vector, respectively on the former and the latter vectors are as follows:

$$\vec{V}_1^i = Proj_{\vec{\mathbf{BSV}}}\left(\vec{V}^i\right) = \left(\frac{\vec{V}^i \cdot \vec{\mathbf{BSV}}}{\left\|\vec{\mathbf{BSV}}\right\|}\right) \tag{6}$$

$$\vec{V}_2^i = \vec{V}^i - \vec{V}_1^i \tag{7}$$

Hence, the BS, which is aware of the locating position of the nodes and has already formed 2 MSTs in 2 sectors, calculates these vectors for all the nodes. Then, by calculating the magnitude of these reflected components for each edge vector, the following values can be achieved as well:

$$a_1 = \frac{\sum_{i=1}^{n}\left|\vec{V}_1^i\right|}{n} \tag{8}$$

$$a_2 = \frac{\sum_{i=1}^{n}\left|\vec{V}_2^i\right|}{n} \tag{9}$$

where n is the total number of nodes in the network. After calculating the mentioned average amounts, the BS starts to increase the desired number of sectors by a step size of 2 until the following inequality is satisfied:

$$a_1 > a_2 \tag{10}$$

The above inequality can be satisfied only after achieving the desired number of sectors. After accomplishing this initialization step and in other words, after achieving the desired number of sectors, all the steps mentioned in subsections II to V in the current section should be repeated to make the network ready for both schedule creation and data transfer phases.

B. SCHEDULE CREATION & CODE ASSIGNMENT PHASE

In order to avoid both intra-cluster and inter-cluster interfaces a joint employment of TDMA scheduling and CDMA code assignment is devised in the network. This combination uses an intra-cluster TDMA scheduling, which prevents the occurrence of intra-cluster interferences, and consequently results in energy conservation and performance improvement thanks to the packet collision and retransmission cancellation. In such a manner, each node of the cluster in the MST structure sends its data to its parent node in its allocated timeslot and goes back to sleep mode until its next turn of transmission. Then based on the organized schedule, the turn will come to the mentioned parent node. In such a manner, time intervals are passed one after the other until it is finally the CH's turn to send the final comprehensive message of the whole cluster to the BS. Therefore, by employing an intra-cluster TDMA scheduling in each cluster, there would be no chance for intra-cluster inferences. The process of data transmission can be also accelerated by employing local or neighbor-aware TDMA schedules. On the other hand, for avoiding inter-cluster interferences, CDMA code assignment has been used. In such a manner, a unique code for both intra-cluster and extra-cluster transmissions (transmissions to the BS) is allocated to all the nodes of each cluster. Finally, the joint use of TDMA and CDMA will guarantee collision-free data transmission.

C. DATA TRANSMISSION PHASE

After accomplishing the configuration of the clusters, it is the ripe time to transmit data to the BS. Each node sends its data to its one hope precedent node in the tree structure during its allocated time slot and using its dedicated CDMA code. There, the mentioned precedent node fuses the received data with its own data and then transmits the resulting one to its own precedent node. This process will be repeated until the whole data of the sector arrives at the CH; there the CH will merge its data with the received data and finally will send the total aggregated data to the BS, which is located in the relatively nearest distance to it.

Fig. 2 illustrates partly the aforementioned steps of the proposed algorithm on the whole span of the network and Fig. 3 shows one sector of the network, and in particular the projections of the i^{th} node's vector on the perpendicular vectors as mentioned in subsection A.6.

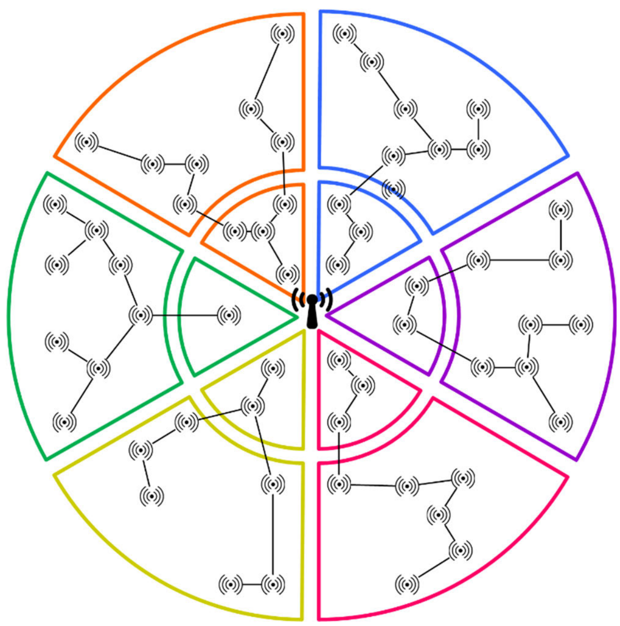

FIGURE 2. Configuration of the network after cluster formation phase.

Algorithm 1 describes *PizzzalgorithmBS* which includes all the required tasks to be done by the BS for the setup, scheduling, and data setup phases of Pizzza scheme in a wireless sensor network. The BS needs to receive the locating position and the residual energy of all the wireless nodes of the network, i.e., $\{x_i, y_i, E_i\}$, to execute some calculating processes and in turn providing them with a setup message which inform each node its predecessor and descendent nodes in the MSTP structure, its assigned time slot as well as the CDMA code assigned to its referring cluster.

Taking a look at Algorithm 1, more details can be figured out about the tasks done by BS in the Pizzza scheme. In line 1, BS broadcast a push message to all the wireless sensor nodes

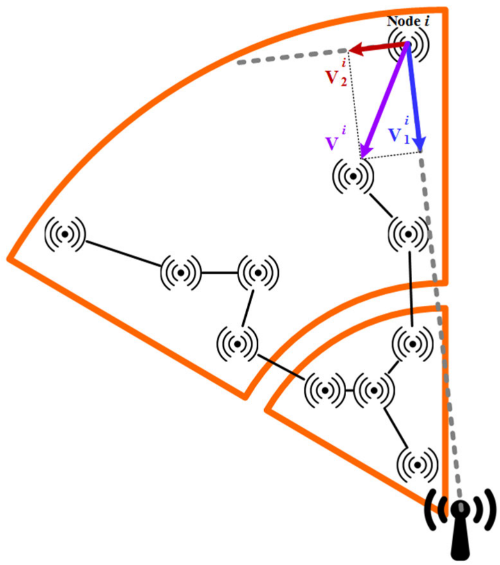

FIGURE 3. Projection of each MST edge on two perpendicular components.

inviting them to send their position and energy level info back. In lines 2-6, the received messages containing the position and energy info from various nodes are processed, and consequently in line 5 the radius of the network is set to the distance of the farthest node to the BS. In lines 6, the initial sector count is set to 2. This value will be updated later, after some further calculations, for finally achieving the suitable number of sectors, i.e., clusters. Furthermore, in line 7, the leveling threshold can be set to a constant value which can be calculated based on some already discussed factors. In lines 8-9 sectorization and leveling is done based on the rules already discussed in this section. In line 10-12 a cluster head selection process takes place for each cluster and select the most suitable eligible candidate as the cluster head. Then in lines 13-15, minimum spanning tree structures are established between all the nodes of the same cluster, where the selected cluster heads in the previous step take the role of MST root. In line 16, the projected components of all the MSTs' edges are calculated and are employed in the two successive lines (lines 17-18) for calculation of $a_1$and a_2 factors. Then, in lines 21-24 the sector number and as a result the tree structures keep updating until $a_1 > a_2$. Later if lines 25-28, each node will be assigned a TDMA time slot and CDMA code based on the cluster to which it belongs. In line 29, a setup message is formed for each sensor, from which it can get informed of its predecessor and its descendent nodes in the tree structure as well as the allocated TDMA time slot and CDMA code. In line 30, the formed messages are sent to the network nodes. And after this setup phase, the base station waits to receive the messages and updates from the nodes via selected CHs. For the sake of conciseness, the cluster head and MST structural update phase is skipped. Clearly, with the aim of equilibrating the energy consumption, once

Algorithm 1 *PizzzalgorithmBS* $([\{x_i, y_i, E_i\}])$

1: $SendMsg\ (InitPushMsg, Broadcast)$;
2:**if** $((RcvMsg == 1)\ \&\&\ \{x_i, y_i, E_i\} == 1)$
%Receivingtherequiredpiecesofdatafromallthennodes $(1 \leq i \leq n)$%
3: $\{x_i, y_i\} = CollectPosition$;
4: $E_i = CollectPosition$;
5: $D_i = CalculateDistance\ \{x_i, y_i\}$;
6: **end if**
7: $Radius = max\ ([D_i])$;
8: $SectorNumber = 2$; % Initial Sector Number
9: $LevelingThreshold = const.$;
10: $Sectorization\ (\{x_i, y_i\}, SectorNumber)$;
11: $LevelAssignement\ (D_i, LevelingThreshold)$;
12: **for** $(s = 1 : SectorNumber)$
13 $\quad [CH_s] = ClusterHeadSelection\ ([\{x_i, y_i, E_i\}])$;
14: **end for**
15: **for** $(s = 1 : SectorNumber)$
16: $\left[\vec{V^i}\right] = MSTShaper\ ([\{x_i, y_i\}], [CH_s])$
17: **end for**
18: $\left[\left\{\vec{V_1^i}, \vec{V_2^i}\right\}\right] = ProjectedComponentCalculator(\left[\vec{V^i}\right])$
19: $a_1 = \frac{\sum_{i=1}^{n}\left|\vec{V_1^i}\right|}{n}$;
20: $a_2 = \frac{\sum_{i=1}^{n}\left|\vec{V_2^i}\right|}{n}$;
21: **while** $(a_2 \geq a_1)$ **then**
22: $\quad SectorNumber = SectorNumber + 2$;
23: $\quad Return2Line\ (10)$;
24: **end while**
25: **for** $(s = 1 : SectorNumber)$
26: $\quad TDMAProgramming$;
27: $\quad CDMAAssignmnet$;
28: **end for**
29: $[SetUpMsg_i] =$
$\left[\left\{PredTreeNode^i, DecsendNode^i\right.\right.$,
$\left.\left.AssignedTimeSlot^i, AssignedCDMACode^i\right\}\right]$;
30: $SendMsg([SetUpMsg_i], [Node_i])$;
31: **if** $((RcvMsg == 1)\ \&\& Update == 1)$
32: $\quad ExtractInfo$;
33: **end if**

in a while the BS sends push messages to the eligible nodes from the first level with good residual energy level in the last push replies, asking them about their current energy level. These pieces of information will be used for selecting new cluster heads. The push messages can be occasionally sent to second level nodes as well with the aim of total reform of the MSTs after facing some dead nodes in the MST structures and experiencing some defects in the network.

Algorithm 2 instead describes the simple and straightforward tasks that need be done in wireless nodes in the network for completing network setup and data transmission phases. Each node reacts to the events of receiving messages whether from BS or other wireless nodes, and also receiving initial push message and setup message with a series of actions which make the data setup phase and data transmission phase possible.

Algorithm 2 ***PizzzalgorithmWN* (*RcvMsg*, *InitPushMsg*, *SetUpMsg*)**

1: **if** $((RcvMsg == 1)\ \&\& InitPushMsg == 1)$
2: $SendMessage\left(\left\{x^{i}_{BS}, y^{i}_{BS}, E^{i}_{Current}\right\}, BS\right);$
3: **end if**
2: **if** $((RcvMsg == 1)\ \&\& SetUpMsg == 1)$
3: $[PredNode, DecsendNode, AssignedTimeSlot,$ $AssignedCDMACode] = UpdateTable;$
4: **end if**
5: **if** $((RcvMsg == 1)\ \&\&\ (Src == DecsendNode))$
6: $Update = MergeMsg\,(Update, RcvMsg);$
7: **end if**
8: **if** $((CurrentTime == AssignedTimeSlot)$ $\&\&\ (Update == 1))$
9: $SendMsg\,(Update, PredTreeNode);$
10: $Update = 0;$
10: **end if**

As already stated, Algorithm 2 has gathered most of the tasks for which the nodes are considered responsible. Based on lines 1-3, each node should provide the BS with its current location and energy in case of having received and initial push message. In case of receiving the setup message from the BS, as written in lines 2-4, the node should update its information about its predecessor and descendent nodes in the MST structure as well as its allocated TDMA time slot and CDMA code. In lines 5-7, each node will merge the received data from its descendent nodes in the tree structure with its own data. And then as mentioned in lines 8-10, the final fused data will be sent to the predecessor of the given node in the MST structure. Also here, for the sake of conciseness and being in line with Algorithm 1, some more lines are skipped. Wireless nodes occasionally receive push messages inviting them to send their current energy level, which can be used for reforming MSTs after facing dead nodes in the tree structures before experiencing a drop in the network performance.

V. PERFORMANCE EVALUATION

The Current section is dedicated to the performance evaluation of the proposed Pizzza scheme. Therefore, to study the characteristics of the Pizzza scheme, the network lifetime and energy consumption of the network which has employed Pizzza as the routing protocol is compared with three other networks employing three distinguished cluster-based routing protocols, namely LEACH, GBSC, and UCRA. Definitely, the mentioned schemes have been selected from a wide range of possible choices with relatively good network lifetime and energy consumption. Therefore, for the sake of a comprehensive selection, one noticeably famous, another relatively recent, and one highly efficient protocol are included in the collection of comparing schemes.

With the aim of unveiling the performance of Pizzza diverse scenarios were simulated, and the obtained results are carefully studied and analyzed. Considering the random placement of the nodes in each scenario and with the aim of achieving reliable results, in which the randomness effects are neutralized, each scenario has been repeated for 50 iterations. This means every single point in the figures or each number in the tables is achieved by calculating the average of the outcomes of all these independent iterations, which has resulted in more reliable curves and tables. Furthermore, to investigate the effect of the BS positioning on the network energy consumption and lifetime, two different positions have been attributed to the BS. In half of the scenarios, the BS is placed in the center of the network, however, in the other half, the BS is located at the border of the network. Conducting various scenarios with diverse BS positions can result in achieving a thorough image of the network lifetime and power consumption. Moreover, all the mentioned scenarios have been repeated once for the networks containing 100 sensor nodes and another time for networks containing 200 nodes. Considering the confirming similarity of the results and for the sake of conciseness and without sacrificing the generality of the outcomes, the result of the bigger networks containing 200 nodes are gathered in this section. Table 1 collects various parameters involved in the simulations.

For simulating various scenarios, 200 nodes are deployed in a round area with a radius of 200 m. The initial energy of each node is set to 0.5 J, so the total initial energy of all the nodes in the field is 100 J. The message size is set to 4000 bits. The energy consumption to run both receiver and transmitter circuitry is set to 50 nJ/bit, and the energy required for data aggregation is set to 5 nJ/bit/signal. The energy dissipation to amplify one bit is set to 10 pJ/bit/m^2 or 0.0013 pJ/bit/m^4 depending on the distance between the transmitter and receiver, as discussed in Section III. The mentioned values are widely used in the evaluation of many other schemes in the same research field. The radios have power control and can expend the minimum required energy to reach the intended recipients. The radios can be turned off to avoid receiving unintended transmissions and save

TABLE 1. Variables used for network simulations & numerical analysis.

Parameter	Value
Initial Number of Nodes	200
Diameter of monitoring area	200 m
Position of the BS	Center, Border
Message Size (k)	4000 bits
Initial Energy of Each Node (E_0)	0.5 J
E_{elec}	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_{DA}	5 nJ/bit/signal
Number of Tries	50

energy. All the employed scalar quantities, such as the initial energy of each node, the required energy for reception and transmission processes, the data aggregation energy, the data size, and the transmitter amplifier energy have been set so, in order to achieve logical and comparable results with those of other protocols. Many other well-known protocols that use the first-order radio model or any other radio models, set the same scalar values to achieve their simulation results. Since clustering is a technique proposed with the aim of tackling the energy scarcity in wireless sensor networks, employed with the intention of prolonging the lifetime of such systems, the residual energy of the network, as well as the number of dead nodes, should be accurately observed during the lifetime of the network. Besides, it is important to be aware of the remaining percentage of the residual energy in each round to get a better idea of how fast the network energy is consuming. Therefore, these aspects are examined in plenty of already-discussed related articles [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47]. Moreover, to achieve a comprehensive view of the energy efficiency of the proposed scheme, the rounds in which the death of the first node, the half node, and the last node (respectively abbreviated as FND, HND, LND) occur are evaluated.

Clearly, the later occur these rounds, the more energy-conserving the network is. Besides, it is highly desired that FND, HND, and LND rounds be very close together, which is a sign of equilibrated energy consumption in the network. These enlightening aspects were also examined in many articles [54], [55], [56], [57], [58].

A. CENTRALLY-LOCATED BS SCENARIO

Figures 4 and 5 illustrate the qualities of the Pizzza scheme in both the aspects of efficient energy consumption and prolonged network lifetime. As already discussed, the proposed scheme prevents wasting energy to an appreciable extent via the reverse data flow cancellation, and establishment of short-length data transmission hops profiting from the MST structure in each sector of the network. Furthermore, the equilibrated and balanced energy consumption of Pizzza has resulted in a considerable network lifetime enhancement. As clear in Fig. 5, unlike other methods the death of the nodes happens in the form of a couple of steps in the Pizzza scheme. Such a death pattern is one of the most desirable node death patterns in wireless networks, which is a result of balanced energy consumption of the nodes and prevents network hotspots or network fragmentations, and the network performance deteriorations and energy wastages. Clearly, with the appearance of these steps due to the death of the nodes, the radius of the first network level increases to encircle more nodes in the first level and give them the possibility of becoming cluster heads and to balance the energy consumption of the nodes in various network regions.

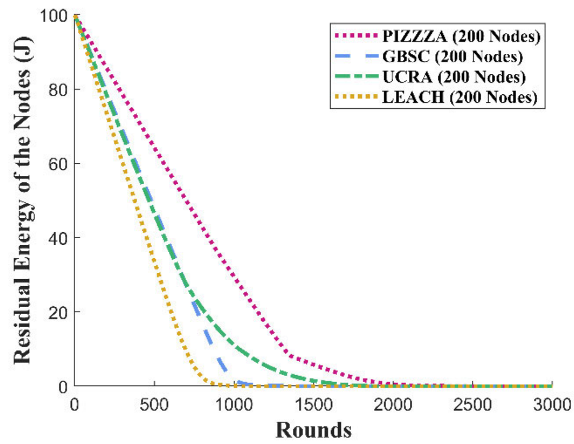

FIGURE 4. Total residual energy of the nodes per round (BS @ center).

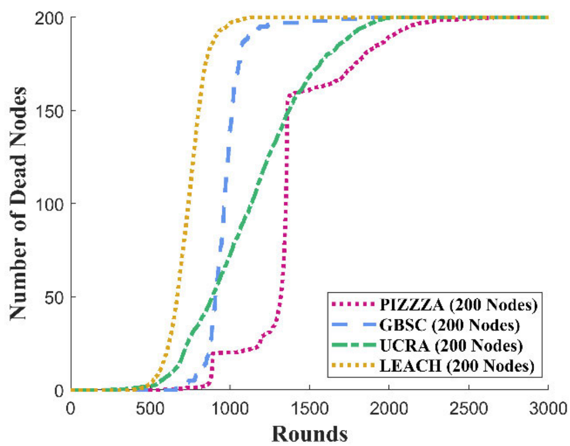

FIGURE 5. Number of dead nodes per round (BS @ center).

Fig. 4 confirms that Pizzza consumes energy more efficiently compared to other comparing schemes in the centrally-located BS scenarios. The mentioned figure reveals the fact that the devised strategies for canceling the reverse data flow and directing the messages to the nearest neighbors have been successful in decreasing the energy dissipation in the network and enhancing the network lifetime. Table 2 presents more details about this scenario type in a numeric manner. As demonstrated, in the first 500 rounds of the lifetime Pizzza consumes around 35.74% of its initial energy, while the other schemes use much more than half or at least around half of their initial energy. The same trend is kept during the lifetime of the network, where for instance, after 1000 rounds the residual energy of the Pizzza is 3 times that of UCRA, and the energies of the other two schemes are almost depleted. This superiority is repeated once again in the last column of Table 2, after 1500 rounds, where the residual energy of the proposed scheme is still considerably more than the comparing networks.

Fig. 6 provides more detail about the node death rate in various comparing networks in the centrally-located BS

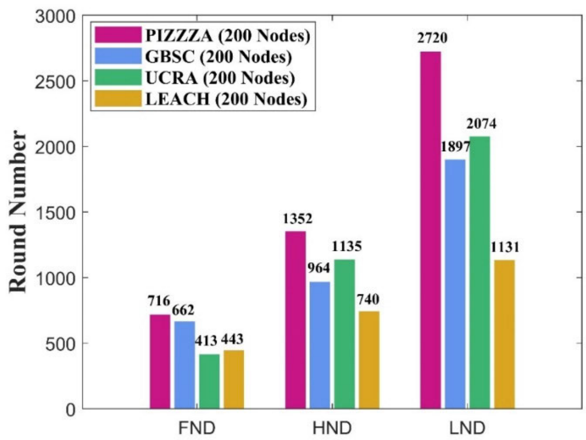

FIGURE 6. Round number of FND, HND & LND occurrences in various networks (BS @ center).

TABLE 2. Residual energy percentages after R rounds in various networks (BS @ center).

Scheme Name	N = 500	N = 1000	N = 1500
PIZZZA	64.26 %	29.53 %	5.80 %
GBSC	47.95 %	1.85 %	0.02 %
UCRA	46.57 %	11.14 %	1.46 %
LEACH	33.66 %	0.08 %	0.00 %

scenario. Clearly, the death of the first node occurs about 41.50% later than in other networks. Moreover, the network lifetime in which Pizzza has more than half of its nodes alive lasts 42.65% longer than other networks on average. Finally, the death of the last sensor, which can be translated to the definitive death of the network, happens on average 59.93% later than the other comparing networks.

So far, all these results have approved the excellence of the Pizzza scheme in energy saving and network lifetime enhancement in the scenarios with a centrally-located BS. On the other hand, with the aim of making sure that the performance of the network remains untouched even in the scenarios without a centrally located BS, another comprehensive set of simulations has been conducted in which BS is located on the border of the network farther than any sensor to the center of the sensing area. As follows, the results of the mentioned scenarios confirm the advantages of Pizzza achieved in the previous set of simulations.

B. NON-CENTRALLY-LOCATED BS SCENARIO

Clearly, the scenario in which the BS is located at the center of the sensing terrain is not the only prevalent scenario type and the energy consumption of the network can be affected by this positioning and distance alteration. Besides the central positioning of the BS, there are definitely various positions in which the BS can be found, namely BS located at the corner of the sensing terrain [59], [60], [61], [62], on the edge of the sensing terrain [63], outside the sensing terrain but still close to the sensors [64], or even the cases in which a moving sink is employed and can be found in any point of the terrain [65], [66]. In this subsection, another common scenario in which the BS is located at the corner of the network is considered, and another set of simulations is done with the aim of realizing whether Pizzza can keep its prominence over other methods, similar to what has been achieved in the case of centrally-located BS scenarios.

Figures 7 and 8 illustrate the outcomes of the scenario conducted by the assumption of the BS located on the border of the network. Once again, similar to the previous scenario, Pizzza outperforms other comparing protocols by prolonging the network lifetime and dissipating a lower energy level.

Clearly, due to the placement of the BS in the border of the network in the second scenario, the optimal number of clusters is different from the first scenario, in which the BS is located at the center of the network. Generally, in the scenario with non-centrally located BS, the optimal number of clusters is normally less than those with centrally-located BS. In such networks, fewer clusters but with more number of participants would be formed. Hence, a more frequent increase of the radius of the first level helps to an equilibrated energy consumption in the network just similar to the case of the Pizzza network with a centrally-located BS. That is the reason for that the step pattern can be observed slightly more in the second scenario compared to the first one. What counts, however, is the better performance of the Pizzza scheme compared to all the three comparing protocols in both the aspects of network lifetime and the residual energy.

In Table 3, the residual energy percentages of the networks employing various schemes were collected. As it can be seen, after 500 rounds, the residual energy percentage of Pizzza is about twice that of the best comparing scheme. After 1000 rounds while other schemes have almost finished their energy, Pizzza has still a considerable amount of energy to continue its activity without any hindrance. After 1500 rounds, the proposed scheme has still residual energy, which impressively is even more than the remaining energies of GSBC and LEACH in 500 previous rounds.

Fig. 9 demonstrates that the death of the first node in the Pizzza scheme occurs on average about 104.83% later than in other schemes. Furthermore, the completion of the death of 50% of the nodes in Pizzza occurs after 1346 rounds, which is 70.88% later than other schemes on average. Finally, employing the Pizzza scheme in a network with the BS on the border prolongs the network lifetime on average by 47.05%.

C. COMPARISON OF THE CENTRALLY-LOCATED & NON-CENTRALLY-LOCATED SCENARIOS

As discussed and demonstrated in the previous subsections, the Pizzza scheme has achieved notable improvements compared to the comparing schemes of GBSC, UCRA, and LEACH, in terms of both network lifetime and energy consumption, regardless of the BS locating position. For instance, Pizzza has achieved a lifetime of 71.67% and

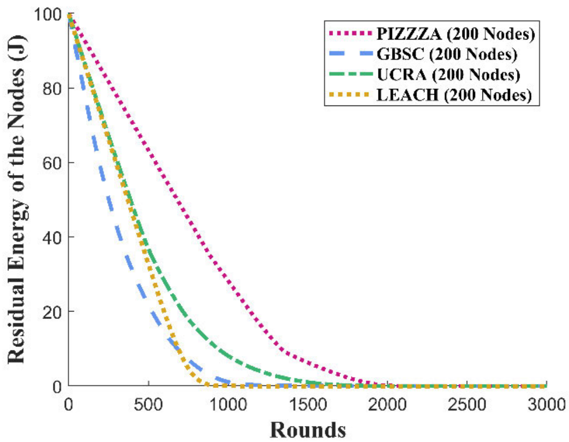

FIGURE 7. Total residual energy of the nodes per round (BS @ border).

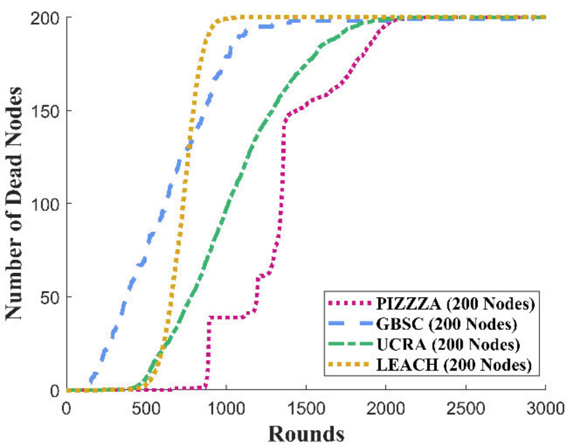

FIGURE 8. Number of dead nodes per round (BS @ border).

59.37% longer on average than other comparing networks, respectively in the scenario with centrally and non-centrally-located BSs. Moreover, the proposed scheme has achieved 60.82% and 93.28% enhancements on average in the amount of residual energy in the whole span of the lifetime of the selected schemes. In short, Pizzza has reached an average of 65.52% and 77.05% compared to other protocols, respectively in lifetime and residual energy aspects.

Tables 4-5 collect more information about the improvements achieved by Pizzza over the selected schemes from the residual energy and lifetime points of view. Obviously, the presented scheme has achieved significant ameliorations in both the scenario types over all the comparing schemes.

VI. DISCUSSION

In this section, it is briefly summarized what are the main design requirements of an energy-efficient cluster-based wireless sensor network and how these requirements were answered in the design of the proposed Pizzza scheme. Furthermore, a short summary of what architectural novelties have distinguished Pizzza from other related works is recollected in this section.

Clearly, to make any limited resource type last as long as possible and to be consumed as efficiently as possible, two key factors should be considered: 1) Making the best out of what is available by consuming it in an intelligent efficient fashion and decreasing the wastage as much as possible. 2) Use the available resource in the most equilibrated manner possible, with the aim of not facing resource depletion in some parts and not being able to make the best out of what remains. In the following paragraphs, it is briefly discussed how the mentioned goals are achieved in the special case of

TABLE 3. Residual energy percentages after R rounds in various networks (BS @ border).

Scheme Name	N = 500	N = 1000	N = 1500
PIZZZA	63.27 %	28.24 %	6.30 %
GBSC	21.73 %	1.07 %	0.09 %
UCRA	36.81 %	8.09 %	1.02 %
LEACH	32.72 %	0.01 %	0.00 %

TABLE 4. Achieved Pizzza IFs in the network residual energy compared to the other schemes.

BS Location	GSBC	UCRA	LEACH
(BS @ Center)	51.12 %	40.33%	91%
(BS @ Border)	129.65 %	58.52 %	91.68 %

TABLE 5. Achieved pizzza IFs in the network lifetime compared to the other schemes.

BS Location	GSBC	UCRA	LEACH
(BS @ Center)	43.38 %	31.15 %	140.50 %
(BS @ Border)	60.50 %	5.84 %	111.78 %

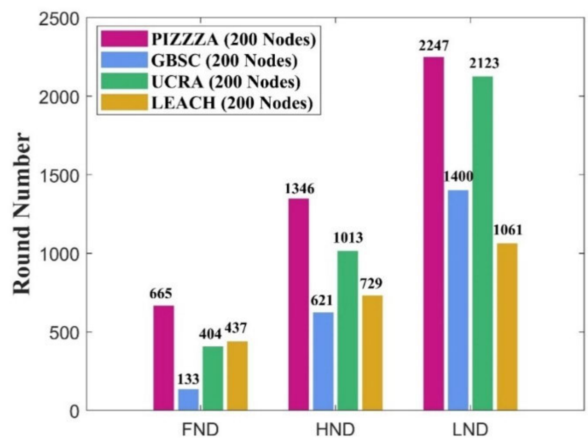

FIGURE 9. Round number of FND, HND & LND occurrences in various networks (BS @ border).

energy scarcity in wireless sensor networks, employing the novel cluster-based proposed Pizzza scheme.

A. MAKING THE BEST OUT OF THE AVAILABLE ENERGY

To keep the wireless sensor lifetime as long as possible all energy wastage factors should be omitted or strictly controlled. One of the most drastic energy wastage factors in many other cluster-based routing protocols, such as LEACH [18], TEEN [67], BCDCP [68], and HGMR [69], is the reverse data flow from BS, where the transmitted data is unintentionally pushed away from the sink in some hops, resulting in considerable energy wastage. In Pizzza, however, by employing a minimum spanning tree architecture in each cluster, in each hop, the data gets necessarily closer to the cluster head, which is already selected from the nearest level to the BS and nominated as the root of the tree. This is done by transmitting the data to one of the nearest neighbors, which is closer to the BS compared to the current node, consuming only a trivial amount of energy. Furthermore, thanks to the unique strategy devised for setting the suitable number of clusters and by enclosing each minimum spanning tree in a sector shape cluster, the energy is majorly used for directing the data toward the BS and not in the lateral directions, unlike PEGASIS [16] and CCS [37]. Another source of energy wastage is the data collision and retransmission of what has already been transferred but could not be received correctly, due to the lack of a solid transmission and access program. The joint usage of TDMA and CDMA in Pizzza clusters will guarantee collision-free data transmission, and therefore, relieves the need for retransmission of already transmitted data and prevent any related energy dissipation. Moreover, the employment of a suitable local or neighbor-aware TDMA schedule gives the nodes the possibility to get back to sleep mode until their next turn of data transmission, which will definitely result in a great amount of energy conservation. In addition, forwarding the data in the formed tree architecture, hope by hope, provides the opportunity for the nodes not to transmit lots of redundant repeated data, via performing data aggregation in each hope. Thus, the waste of energy for redundant transmissions can be highly controlled.

B. KEEPING THE NETWORK ENERGY EQUILIBRATED

Pizzza divides the whole network span into two levels and following this leveling policy, only the first level nodes, which are located in the vicinity of the BS, have the authorization to be upgraded as cluster heads in case of satisfying some other criteria, which in turn omits the need for any long-range communication different from LEACH [18], TL-LEACH [20], UCS [70], EECS [71], BCDCP [72], and DWEHC [73]. Moreover, considering the dynamic nature of the cluster head selection scheme in Pizzza, the energy of the current cluster head should not be considerably dropped before another cluster head selection process is performed. This measure, similar to the previous measure, fortifies the equilibration of the energy consumption in the Pizzza scheme, in contrast with other methods such as TL-LEACH [20], UCS [70], ACE [71], CCS [37], and EEUC [71]. Moreover, different from many other schemes, such as HGMR [69], which tolerates unbalanced energy consumption around access points, the proper cluster head selection criteria used in Pizzza reduces the probability of hotspot occurrence in the network by assuming the short physical distance between the consecutively-selected cluster heads as a negative factor in the process of the cluster head node selection. Moreover, due to the employment of a minimum spanning tree architecture the nodes only need to receive data from a few child nodes located closely and forward it to a near parent node. Therefore, whether the nodes are located close to the BS or far away, they only need to communicate with their near nodes, and therefore a relative energy consumption equilibration can be achieved in the network.

Satisfying these two criteria in Pizzza by employing a bi-level sector enclosed minimum spanning tree data communication architecture alongside an efficient cluster head selection and cluster number calculation process, unlike many other schemes such as HEED [72] with a surplus number of CHs, has resulted in satisfying the vital energy conservation goal in wireless sensor network and prolonging the network lifetime, compared to a set of well-known and efficient cluster-based routing protocols. The simulation results achieved via carrying out various scenarios have revealed that Pizzza can result in a desirable step pattern in the death of the nodes in relatively late rounds of the network lifetime, which is a result of the well-equilibrated energy consumption and the excellent functionality and efficiency of the network even till the last rounds of its lifetime. Hence, Pizzza can be considered an eligible candidate in all the applications in which profiting from a long-lasting, efficient, and functional wireless sensor network is of paramount importance.

VII. CONCLUSION

The widespread employment of wireless sensor networks in various applications and their substantial role in improving the quality of life has encouraged many researchers to struggle with the deficiencies of these networks, especially those of energy scarcity and short lifetime. Having this in mind, and with the aim of reducing energy consumption, decreasing energy wastage, enhancing the network load balancing, and prolonging the network lifetime, the cluster based Pizzza routing scheme is proposed in this paper. Pizzza employs a minimum spanning tree structure among communicating nodes in each sector-shape cluster, where only eligible nodes from the first level of the architecture can be selected as cluster heads. Shortening the communication distance between the communicating nodes, canceling the reverse data flow from the BS, balancing the energy consumption between all the network nodes, and avoiding the hotspots in the network lead to a successful energy conservation mechanism in Pizzza, which in turn results in decreasing energy consumption and consequently increasing the network lifetime. Pizzza improves the network lifetime by 65.52% and enhances residual energy of the network by 77.05%, comparing to a selected set of popular and efficient protocols. These achievements introduce Pizzza as a superior cluster-based routing scheme where efficient energy consumption and prolonged network lifetime are of paramount importance.

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SARA NASIRIAN was born in Esfahan, in 1991. She received the B.Sc., M.Sc., and Ph.D. degrees in telecommunication engineering from Islamic Azad University, Najafabad Branch, Najafabad, Iran, in 2013, 2015, and 2020, respectively.

She was a Postdoctoral Research Fellow with Universitá Politecnica delle Marche, Ancona, Italy, and the University of Applied Sciences and Arts of Southern Switzerland, Lugano, Switzerland. She is currently a Postdoctoral Research Fellow with the University of Siena, Siena, Italy. She has won the Swiss Government Excellence Scholarship. Her research interests include wireless sensor networks, data center networks, and non-terrestrial networks.

PAOLA PIERLEONI received the master's degree in electronic engineering and the Ph.D. degree in electrical engineering from Universitá Politecnica delle Marche, Ancona, Italy, in 1991 and 1995, respectively.

In 1991, she joined the Department of Information Engineering, Universitá Politecnica delle Marche, where she is currently an Assistant Professor of telecommunications. Her research interests include network protocols, wireless sensor networks, the Internet of Things, signal processing, and embedded devices development.

ALBERTO BELLI received the master's degree in telecommunications engineering and the Ph.D. degree in biomedical, electronic, and telecommunications engineering from Universitá Politecnica delle Marche, Ancona, Italy, in 2012 and 2016, respectively. He is a Technician with the Department of Information Engineering, Universitá Politecnica delle Marche. His research interests include wireless sensor networks for the Internet of Things, data fusion algorithms for array sensors, and wearable sensors.

MARCO MERCURI received the master's degree (cum laude) in electronic engineering from Universitá Politecnica delle Marche, Ancona, Italy, in February 2019, where he is currently pursuing the Ph.D. degree with the Department of Information Engineering.

His research interest includes bluetooth mesh architectures for IoT applications based on the bluetooth 4 protocols and later versions.

LORENZO PALMA (Member, IEEE) received the master's degree (cum laude) in electronic engineering and the Ph.D. degree in information engineering from Universitá Politecnica delle Marche, Italy, in 2012 and 2017, respectively. He is currently an Assistant Professor (RTD-B) with Universitá Politecnica delle Marche. His main research interests include the IoT, artificial intelligence, wireless sensors networks, embedded systems, communication networks, and the Internet of Medical Things.

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