A Two-Levels Hierarchy for Low-Energy Adaptive Clustering Hierarchy (TL-LEACH)

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Abstract— **Wireless sensor networks with thousands of tiny sensor nodes are expected to find wide applicability and increasing deployment in coming years, as they enable reliable monitoring and analysis of the environment. In this paper we propose a modification to a well-known protocol for sensor networks called Low Energy Adaptive Clustering Hierarchy (LEACH). This last is designed for sensor networks where end-user wants to remotely monitor the environment. In such situation, the data from the individual nodes must be sent to a central base station, often located far from the sensor network, through which the end-user can access the data. In this context our contribution is represented by building a two-level hierarchy to realize a protocol that saves better the energy consumption. Our TL-LEACH uses random rotation of local cluster base stations (primary cluster-heads and secondary cluster-heads). In this way we build, where it is possible, a two-level hierarchy. This permits to better distribute the energy load among the sensors in the network especially when the density of network is higher. TL-LEACH uses localized coordination to enable scalability and robustness. We evaluated the performances of our protocol with NS-2 and we observed that our protocol outperforms the LEACH in terms of energy consumption and lifetime of the network.**

Keywords-component: Sensor Networks; LEACH; TL-LEACH;

I. EXTENDED ABSTRACT

Recent advances in sensor technology have enabled the development of inexpensive and low-power wireless micro-sensors [1]. The low costs make it possible to have a network of hundreds or thousands of sensors, enhancing the reliability and accuracy of data. A big advantage of sensor networks is represented by ease of deployment, reducing installation cost, possibility to distribute the tiny sensors over a wide region, a larger fault tolerance because the failure of a single node not affects the network operation. Another important characteristic of sensor networks is represented from the capability to self-configuring. There are a few of limitations of wireless sensor networks such as low bandwidth, limited resources as energy, etc. Usually these sensor networks are deployed in places where it is very difficult replace the individual nodes and for this reason it is desirable to realize communication protocols that increase the longevity of the network and it is preferable that nodes die together to replace all the nodes (the whole network). The traditional routing protocols for wireless ad hoc networks [2] are not well suited for sensors networks. Estrin et. al [3] discuss a hierarchical clustering method with emphasis on localized behavior and the need for asymmetric communication and energy conservation in sensor networks. Huang et al. [4] propose a new multicast communication paradigm called “spatiotemporal multicast” for supporting spatiotemporal coordination in applications over wireless sensor networks. Another routing protocol has been proposed in [5].

There are many possible models for micro-sensor networks. Here we consider micro-sensor networks where:

- The base station is fixed and localized far from the sensors
- All nodes in the sensor are homogeneous and energy-constrained.
- There are no “high-energy” nodes through the communication can proceed.

As in the original protocol (LEACH) [6, 11] in TL-LEACH is used the concept of *data-fusion* [8, 9] in order to avoid the overload of data. Large energy gains can be achieved by performing the data fusion, thereby requiring much less data to be transmitted to the base station. The TL-LEACH uses the following techniques to achieve energy and latency efficiency:

- Randomized, adaptive, self-configuring cluster formation
- Localized control for data transfers

These key features are maintained in our version of protocol called TL-LEACH. Also in our protocol we consider a randomized rotation of the cluster-heads and the corresponding clusters. As we will see the main difference between our protocol and LEACH consists in the set-up phase.

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The set-up phase is the phase in which the clusters are created and a node can be primary cluster-head, second cluster-head or simple node (SN) (see Figure 1).

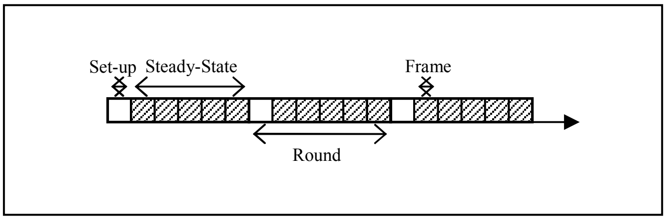

Figure 1. Time-line showing TL-LEACH operation. Adaptive cluster are formed during the set-up phase and data transfers occurr during the steady-state phase.

In section II research issues in sensor networks are considered. In section III is presented a resume of original LEACH. Section IV discusses the details of our approach and the difference between this and the original LEACH. Section V presents simulation results and in section VI conclusions are done.

II. RESEARCH ISSUES IN SENSOR NETWORKS

Different from traditional networks, sensor networks do impose a set of new limitations for the protocols designed for this type of networks. Devices in sensor networks have a much smaller memory, constrained energy supply, less process and communication bandwidth. Topologies of the sensor networks are constantly changing due to a high node failure rate, occasional shutdown and abrupt communication interferences. With such a vast difference between traditional networks and sensor networks, it is not appropriate and inefficient to port previous solutions for ad hoc networks into sensor networks with only incremental modifications. For instance, the sheer number of sensor nodes makes flooding-based standard routing schemes. Data aggregation techniques are proposed to address multiple issues. Data aggregation performed among a group of nodes can effectively reduce total amount of application data shipped out, thus reduce network congestion and energy consumption. The low-cost deployment is one acclaimed advantage of sensor networks, which implies the resources available to individual nodes are severely limited. Low processing speed, limited memory, constrained energy supply and bandwidth make the designs that abuse these resources not applicable in sensor networks. The highly unpredictable nature of sensor networks necessitates a high redundancy. Nodes are normally deployed with a high degree of connectivity. With such a redundancy, the failure of a single node has a negligible impact on overall capacity of the sensor networks. High confidence in data can also be obtained through the aggregation of multiple sensor readings. Redundancy is one of few positive characteristics that sensor networks have, therefore it should be fully utilized and exploited in the protocol designs.

III. LEACH PROTOCOL

LEACH is an energy-efficient communication protocol, which employs a hierarchical clustering. In LEACH, nodes organize themselves into clusters using a distributed algorithm. Periodically both the cluster membership and the cluster-head (CH) change to conserve energy. Once the clusters are formed, the CH node create TDMA schedule. The CH collects and aggregates information from sensors in its own cluster and passes on information to the BS. The use of clusters for transmitting data to the base station leverages the advantages of small transmit distances for most nodes, requiring only a few nodes to transmit far distances to the base station. LEACH outperforms classical clustering algorithms by using adaptive clusters and rotating cluster-heads, allowing the energy requirements of the system to be distributed among all the sensors. LEACH is able to perform local computation in each cluster to reduce the amount of data that must be transmitted to the base station. In this way it realizes a large reduction in energy dissipation, as computation is much cheaper than communication. Details of how to form a cluster and how can be found in [6].

IV. OUR EXTENSION PROPOSED: TL-LEACH

We considered the original version of LEACH protocol [6, 11] and we evaluated the possibility to better exploit the *data fusion* mechanism already introduced in the original LEACH maintaining the same characteristics of the original protocol. Introducing a new level of hierarchy we permit to elaborate the information to transmit to a Base Station (BS) over two different levels and this permits to better use the energy in the network.

The cluster formation protocol is a local process that realizes, where it is possible, a two-level hierarchy as shown in the Figure 2. In this way each node can decide, in a way that is autonomous, to result in a good cluster. The use of two-levels of clusters for transmitting data to the base stations leverages the advantages of small transmit distances for more nodes more than in the original LEACH. In this way less nodes are required to transmit far distances to the base station and it is particularly true in networks where the density of nodes is high. The use of clusters for transmitting data to the base station leverages the advantages of small transmit distances for most nodes, requiring only a few nodes to transmit far distances to the base station. We think that this advantage is higher if a bigger number of hierarchy levels is used and for this reason we introduce two-level hierarchy: a top cluster-head called here primary cluster-head (CH_i), a second level represented from secondary cluster-head (CH_{ij}) and finally simple node, indicated as SN. In this way we introduce partial local computation in each cluster-head at the second level and we complete the local computation at top level where data will be transmitted to the base station directly. We conducted simulation with NS-2 [10] and we obtained a significant improvement in energy consumption using our technique.

Our protocol is composed from 4 fundamental phases: 1) Advertisement Phase; 2) Cluster Setup Phase; 3) Schedule Creation; 4) Data Transmission. In the first phase each node decides if wants to be, in current round (where the term round is the same in LEACH), primary cluster-head (at top level, CHi), secondary cluster-head (called CHij) or simple node (SN). A node that has elected itself as primary cluster-head has to advertise other nodes. The mechanism used in this phase is the CSMA. Subsequently secondary cluster-head nodes send the advertisement to the simple nodes (SN). This phase consists of two parts (there is a fundamental difference between our approach and original LEACH): 1) Each secondary cluster-head decided to which primary cluster-head it belongs, then each secondary cluster-head sends a message to "advertise" its primary cluster-head 2) Each simple node has decided which it will be its secondary cluster-head and informs it through an apposite message.

SN	**S**ensor **N**odes
CH_{ij}	**C**luster **H**ead to **second level**
CH_i	**C**luster **H**ead to **first level**
BS	**B**ase **S**tation

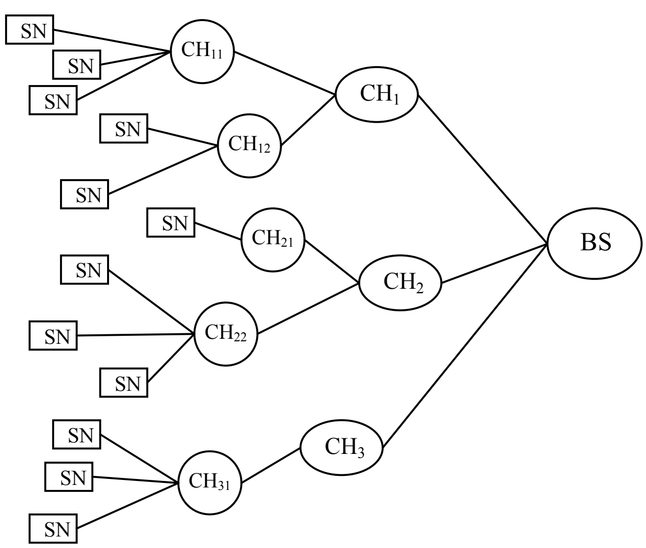

Figure 2. The topology network after the setup cluster phase is complete.

The third phase consists of two sub-phases: 1) the generic primary cluster-head knows which nodes are in its group (either simple nodes and secondary cluster-head) and each primary cluster-head (CH_i) creates a TDMA schedule assigning each node a slot to transmit. Each primary cluster-head chooses a CDMA code and informs all the nodes at second level in its group to transmit using this code.

Each secondary cluster-head can transmit this information to SN in its group, both the code to use to transmit and the schedule (given from the primary cluster-head). Finally in the last phase clusters are created and each node can transmit in respect to the TDMA schedule decided by its primary cluster-head (assuming node always have data to transmit). Naturally also this phase is characterized from two sub-phases. Initially each SN sends its data to the respective secondary cluster-head. When this phase is completed, each secondary cluster-head can send the aggregated data to its primary cluster-head. In this sub-phase SN can turn off in sleep mode. We considered simulations with 100 nodes. Results of simulations shown that there is a reduction in energy dissipation compared to the original protocol (where is considered only a level of hierarchy). For our experiment we considered that each node is initially given 2 Joule of energy. We considered other experiments with different energy thresholds but we obtained similar results: our version of protocol, TL-LEACH, with two levels of hierarchy, permits to reduce the energy consumption in the network.

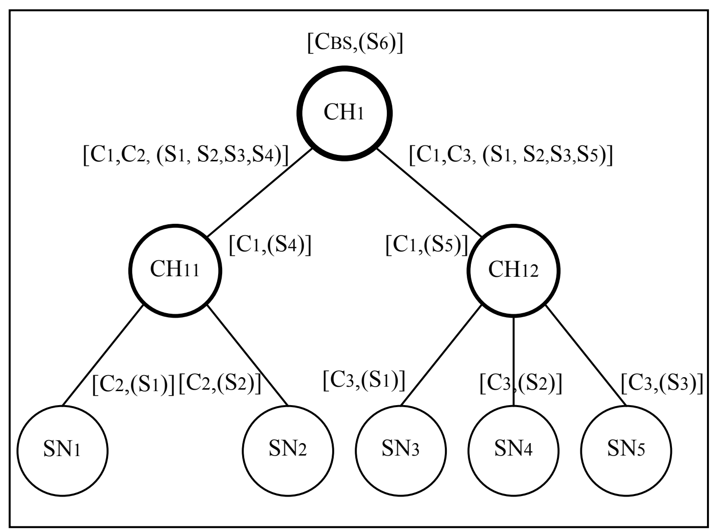

Figure 3. Construction of a tipical cluster in TL-LEACH. The nodes CH_{11} and CH_{12} represent cluster-head at an intermediate level. They process the data receiving by sub-cluster (or simple nodes) (SN_1, SN_2) and (SN_3 ,SN_4 ,SN_5) respectevely. After intermediate cluster-head send data processed to the primary cluster-head CH_1

In Figure 3 is shown as extension proposed works. There is an exchange of different messages between nodes on the network that permits to build a more complex structure to the respect to the original LEACH. Naturally the messages exchanged in the set-up phase to build a two-level structure have been taken into account in term of energy spent in the network.

V. SIMULATION RESULTS

The experiments described in this section have been conducted with the aid of the well known tool of simulation NS-2. For the experiments described in this dissertation, both the free space model and the multi-path fading model were used depending on the distance between the transmitter and receiver, as defined by the channel propagation model in NS. Instead, as it regards the radio energy model, in this work we assume a simple model where the transmitter dissipate energy to run the radio electronics and the power amplifier and the receiver dissipate energy to run the radio electronics. For the simulation we set the energy dissipated per bit in the transceiver electronics to be $E_{elec} = 50\ nJ/bit$ for $1 Mbps$ transceiver. Finally, computation energy for beam-forming is set to $5\ nJ/bit/signal$.

We ran wireless micro-sensor networks simulations using NS-2 to determine the benefits of TL-LEACH in comparison to LEACH in terms of:

- throughput (data signals received at the BS)
- energy dissipation
- lifetime (number of nodes alive over time)

For these experiments a random, 100-nodes networks has been used. The base station was placed 75 meters from the closest node, at location (x=50, y=175). For the following set of experiments it is supposed that each node begins with only 2 J of energy and an unlimited amount of data to send to BS. We tracked the rate at which the data are transferred to the BS and the amount of energy required to get the data to the BS. Since the nodes have limited energy, they use up this energy during the course of the simulation. Once a node runs out of energy, it is considered dead and can not longer transmit or receive data. For these simulations, energy is removed whenever a node transmits or receives data and whenever it performs data aggregation. We do not assume any static energy dissipation, nor do we remove energy during carrier-sense operations.

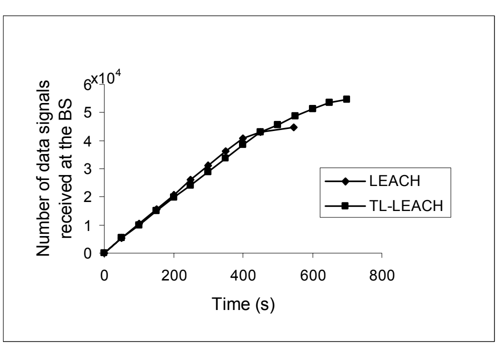

Figure 4. The total amount of data received at the base station over time

Figure 4 shows the total number of data signals received at the base station over time. As can be noticed, TL-LEACH sends much more data to the base station than original LEACH and therefore achieves lower latency than original LEACH. Such result can be justified from the use of a suitable politics of scheduling TDMA that has allowed the increase of frequency of data transmission. These aspects, mainly connected to the fact that the nodes are forced to transmit to smaller distances in comparison to how much expected by LEACH thanks to the introduction of a new hierarchical level, have allowed the attainment of this result.

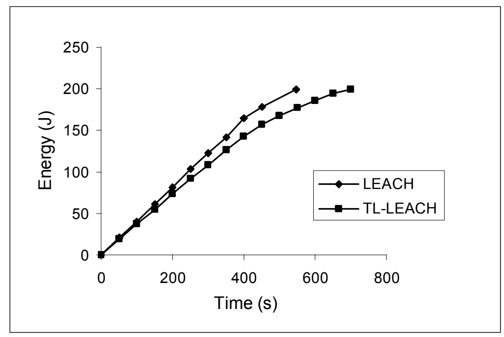

Figure 5. The total amount of energy dissipated in the system over time

In figure 5, instead, is shown the total energy dissipated over time. Both the LEACH and the TL-LEACH use up all the energy available in the network (2 Joule/node x 100 nodes = 200 J). The TL-LEACH shows a more gradual energetic consumption that at the end it will bring to an increase of the lifetime of the network. This could be brought back to the fact that while in the LEACH there is only a level before sending to the base station, in the TL-LEACH architecture two levels can be exploited for decreasing the distances of transmission and therefore the relative consumptions.

Figure 6 shows the number of node alive over time.

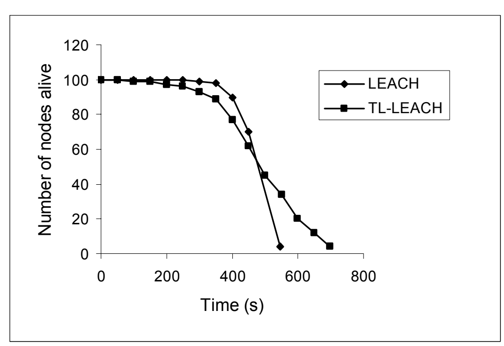

Figure 6. Number of nodes alive over time

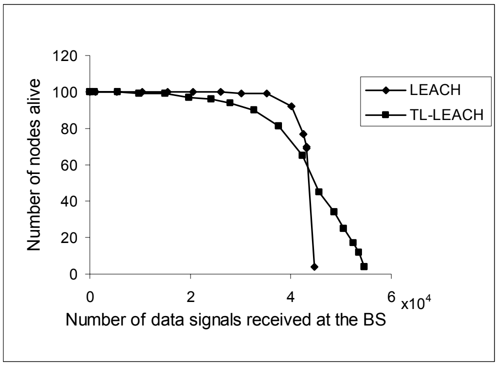

Figure 7. Number of nodes alive per amount of data sent to the base station

Finally, in figure 7 is shown the number of data alive over data received at the BS. To confirmation of our choices, while the LEACH arrives to a point in which it almost immediately degrades to zero in terms of delivered packets, the TL-LEACH, also having some inferior performances in the initial phase of evolution of the network, at the end it clearly overcomes the performances guaranteed by the LEACH.

We can conclude saying that the TL-LEACH has allowed us to reach a 20% increase as it regards the delivered packets and an increase of even the 30% of the lifetime of the network, in comparison to how much guaranteed by the LEACH.

VI. Conclusions

In this work we considered a well-known protocol for sensor networks called LEACH. We proposed an extension to this protocol adding another level in the cluster (we considered two levels in our version of protocol) to the respect of LEACH that considers only a one level. Trough simulations we demonstrated that last choice outperforms in energy consumption and lifetime the original protocol. We obtained that our protocols is able to deliver more data packets than the original LEACH protocol. Particularly, the TL-LEACH has allowed us to reach a 20% increase as it regards the delivered packets and an increase of even the 30% of the lifetime of the network.

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