Performance Analysis of LEACH, CTP, ECTP Using Castalia Simulator

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***Abstract*—Due to an uncontrolled dynamic physical environment and spatiotemporal nature of traffic, Wireless Sensor Networks require energy-efficient routing protocol for routing and data processing. This dependency influences all aspects of WSN including topology. In this paper the simulation and performance evaluation of three protocols namely LEACH,**
CTP and its variant E-CTP will be presented. Collecting data at a base station is a common requirement of sensor network applications. The general approach used is to build one or more collection trees, each of which is rooted at a base station. When a node has data which needs to be collected, it sends the data up the tree, and it forwards the collection of data that other nodes have sent to it. The simulation results will be analysed and compared with respect to the chosen performance parameters using Castalia Simulator.

Keywords: Castalia Simulator, Collection Tree Protocol (CTP), Energy-balanced CTP (ECTP), LEACH, Wireless Sensor Networks.

I. INTRODUCTION

Wireless Sensor Network (WSN) is composed of large number of small sensing and computing devices which are called motes. These devices have stringent resource constraints. Due to uncontrolled and dynamic physical environments & spatiotemporal nature of traffic, wireless sensor networks require distributed algorithms for efficient data processing, while individual sensing devices motes require highly concurrent and reactive behaviour for efficient operation. The data sensed by these motes are collected in one or more sinks (i.e., a centralized collection point), where it is processed and analysed afterwards. The main aim of hierarchical routing is to efficiently maintain the energy consumption of the nodes by involving them in multi-hop communication within a particular group and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink.
Further, outline of the paper is as follows: Section 2 discusses about the working of protocols namely LEACH, CTP, ECTP, in brief. Section 3 discusses about the simulation results and performance comparisons against chosen parameters namely, the energy consumption of each node, transmitted packets, receiver packets breakdown and application level latency.

II. RELATED WORK

A. *Low-Energy Adaptive Clustering Hierarchy (LEACH):*

LEACH [10] is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or *cluster-head*. LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the battery of a single sensor. In addition, LEACH performs local data fusion to "compress" the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime.

Sensors elect themselves to be local cluster-heads at any given time with a certain probability. In this protocol when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold T(n) the node becomes a cluster-head for the current round.

The threshold is set as:

$T(n) = P/(1-P*(r \bmod 1/P))$ if $n \in G$; else $T(n) = 0$

Where P = the desired percentage of cluster heads (e.g. P=0.5), r= the current round, and G is the set of nodes that have not been cluster-heads in the last 1/P rounds.
After each node has decided to which cluster it belongs, these nodes inform back to the cluster head using a CSMA MAC protocol. Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This schedule is based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcasted back to the nodes in the cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except during its transmit time, thus minimizing the energy dissipated in the individual sensors. Once the cluster-head has all the data from the nodes in its cluster, the cluster-head node aggregates the data and then transmits the compressed data to the base station. Being a cluster-head drains the battery of that node. In order to spread this energy usage over multiple nodes, the cluster-head nodes are not fixed; rather, this position is self-elected at different time intervals. Being a cluster-head, it

drains the battery of that node. In order to spread this energy usage over multiple nodes, the cluster-head nodes are not fixed; rather, this position is self-elected at different time intervals. The decision to become a cluster-head depends on the amount of energy left at the node.

B. Collection Tree Protocol (CTP):

The Collection Tree Protocol [6] [8] [9] is one of the most relevant routing protocols for WSNs. These routing algorithms base their routing decision on tree structures built at runtime rather than routing packet by using distance vectors. In the collection tree protocol, nodes form routing tree topologies in which packets are forwarded to the sink, the root of the tree. Every node of the collection tree selects its parent from a list of candidate neighbors, sorted according to a performance metric that measures how likely is that the neighboring node can forward the packet to the closest sink. In CTP, this metric is the estimated number of Transmissions (ETX), which consists on the expected number of transmissions required to deliver the packet to a sink. By definition, the sinks have an ETX equal to zero. The 1-hop ETX measures the quality of the link that connects a node to its neighbor. Therefore, the ETX of a node, i.e. *multihop ETX*, is recursively computed by summing of the 1-hop ETX to its parent. Every node of the tree is then in charge of forwarding packets received from its children, together with its own packets, to its parent. The algorithm constructs and maintains the routing tree topology by using beaconing: the nodes broadcast beacons to their neighbors to inform them about routing ability (expressed in terms of ETX). The neighbors use that information to update their neighbor table and select the best parent.

The implementation of CTP in TinyOS consists of three main modules that interact among themselves to provide the whole protocol functionality:

1) Link Estimator (LE): takes care on computing the link quality for each neighbor node based on the information received by beaconing;

2) Routing Engine (RE): takes care of the beaconing process to exchange routing information with neighbors. It keeps a list of candidate neighbors and selects a parent whose multihop ETX is the lowest from its neighboring nodes;

3) Forwarding Engine (FE): embodies the logic for sending packets to the parent. It manages packets queues, packet retransmissions, duplicate packet suppression and loop detection.

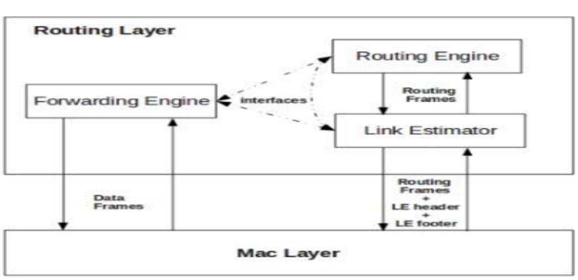

Fig. 1. **Message flow and modules interactions [8].**

The three modules interact among themselves by interfaces that they provide to each other.

4) Interfaces: The three components RE, FE, and LE do not work independently but interact through a set of well-defined interfaces. For instance, the RE needs to pull the 1-hop ETX metric from the LE to compute the multi-hop ETX. On the other side, the FE must obtain the identifier of the current parent from the RE and check the congestion status of the neighbors with the RE. As schematically depicted in figure 1, these interactions are managed by specific interfaces.

C. An Energy-balanced Collection Tree Protocol (ECTP):

In Wireless Sensor Networks (WSNs), the network consists of energy constraint sensor nodes with finite battery power. Hence in order to prolong the lifetime of the network, energy efficient strategies must be applied for data transmission. It is important to minimize the total energy consumption in each round so that the network lifetime is maximized. This new energy efficient protocol E-CTP [4] is based on the Collection Tree Protocol (CTP) which takes into account the power available to the whole network and single node. The Expected Transmission Value (ETX) is updated according to the proposed protocol. In ECTP voltage information is also taken into consideration when estimating the link quality to prolong the lifetime of the WSN.E-CTP also makes improvements by considering the residual energy as an important factor to evaluate the quality of the link in addition to the original 4 Bit estimator.

In E-CTP, the algorithm recalculates a new node to balance the energy consume of the entire network when there is a large difference between the neighbor node and the next node. Based on the 4Bit estimator the energy balance procedure could be divided into parts, which would be explained in details as follows:

1) Getting the Remaining Energy of each Node: In this part, we use the characteristic of the device which is the Voltage of the battery to get the value of sensor's available power.

2) Evaluate the Energy: Considering characteristics of each node , there exists a voltage $\mathbf{V_L}$ .When the node's voltage is under V_L the data collected would be meaningless though the node is still able to collect information,. Therefore we define the interval between operating voltage V_{max} and V_L as the normal operating voltage .Meanwhile a threshold, $V_T = (V_{max}+V_L)/2$ is set as the alert voltage .Also, we define a coefficient to maintain a better voltage balance.

$$\delta = \left| \frac{U-\mu}{\sigma} \right| \qquad (1)$$

Where δ is the convergence coefficient, μ is the average value of all nodes, U is the voltage of the particular sensor node, and σ is the variance. If the voltage value we got is less than V_T, we multiply the 4 bit estimator by the coefficient δ to get the ETX.

III. Simulations And Results

Among the currently available frameworks the Castalia WSNs simulator is used for the comparison as it emerges for its quality and completeness. Castalia provides a generic platform to perform "first order validation of an algorithm before moving to an implementation on a specific platform" [3] [4]. It is based on the well-known OMNeT simulation environment, which mainly provides for Castalia's modularity. OMNeT++ is a discrete event simulation environment that has an excellent modularity, particularly suited to support frameworks for specialized research fields [5]. OMNeT++ is written in C++, is well documented and features a graphical environment that eases development and debugging. The comfortable initial training, the modularity, the possibility of programming in an object-oriented language (C++), are among the reasons that led us to prefer the OMNeT++ platform, and thus Castalia, over other available network simulators .For our work, we make use of version 3.2 of Castalia[7], which builds upon version 4.3 of OMNeT. In this version, Castalia features advanced channel and radio models, a MAC protocol with large number of tunable parameters and a highly flexible model for simulating physical processes. The simulation is run for 300 seconds for 100 nodes. The three protocols are compared for following parameters: Energy consumed in joules, Application level latency in milliseconds (ms), Transmitted packets and Rx breakdown.

A. ***Consumed Energy**:* The comparison for energy consumed by each node in the network for LEACH, CTP, ECTP is shown in figure 2 and figure 3 shows energy consumed by CTP and ECTP.The energy consumed is measured in joules.

B. ***Application Level Latency***: Latency at application level refers to time taken by the data packets to reach from source to destination and is measured in ms(Milliseconds). Figure 4 shows the latency comparison where latency is nearly constant for LEACH.

C. ***Transmitted packets:*** Transmitted packets refers both data and control packets**.** Figure 5 shows the number packets transmitted by each node of LEACH, CTP, ECTP.

D. ***Receiver packets breakdown:*** Receiver packets breakdown can be influenced by packets failed with interference, with no interference, received with and with no interference, failed below sensitivity threshold of the sensor .Figure 6,7,8 shows the receiver packets breakdown for LEACH, CTP, ECTP.

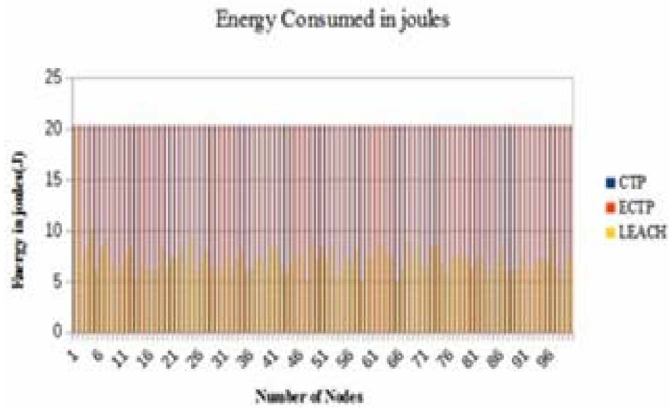

Fig. 2. Energy Consumed by each node in joules Of LEACH, CTP, ECTP.

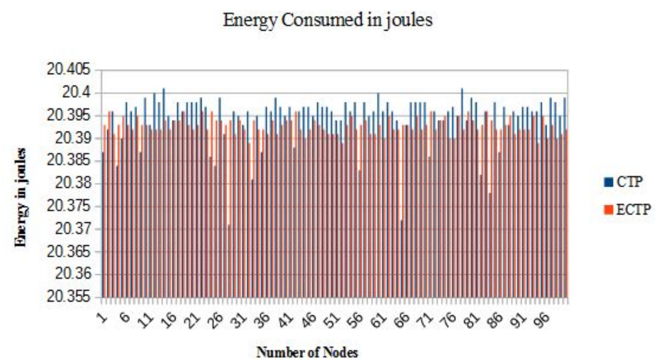

Fig. 3. Energy Consumed by each node in joules of CTP, ECTP.

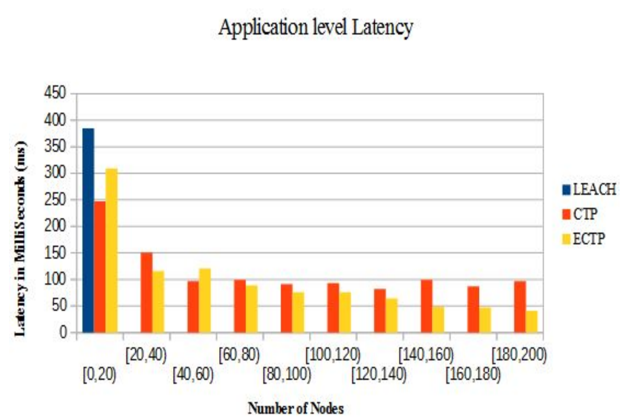

Fig. 4. Application Level Latency

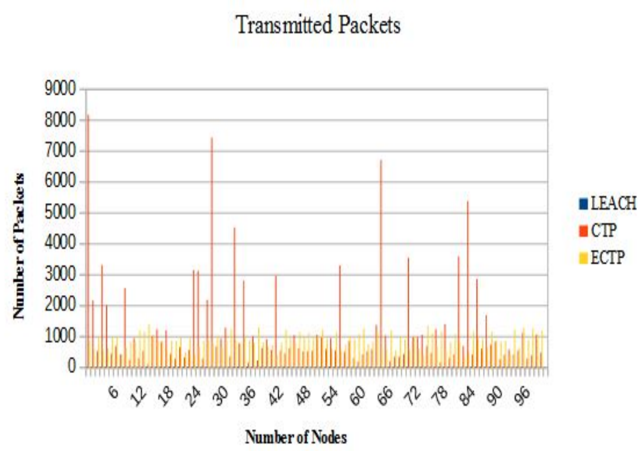

Fig. 5. Transmitted Packets of LEACH, CTP, and ECTP.

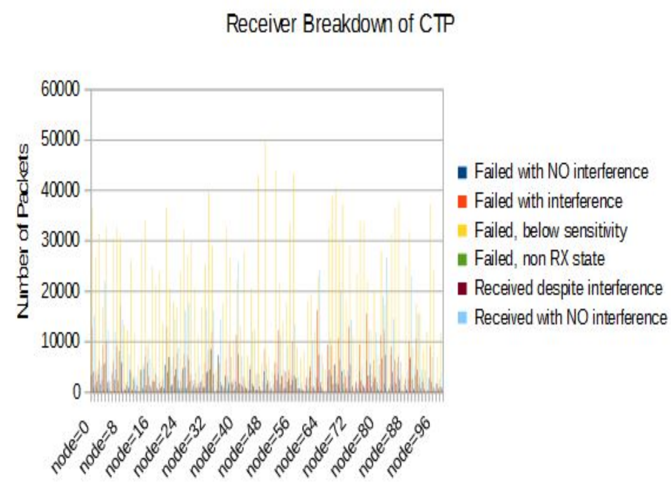

Fig. 7. Receiver packets breakdown of CTP

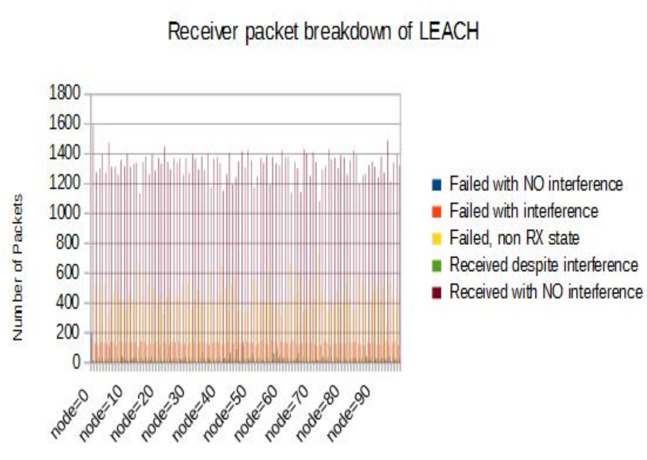

Fig. 6. Receiver packets breakdown of LEACH

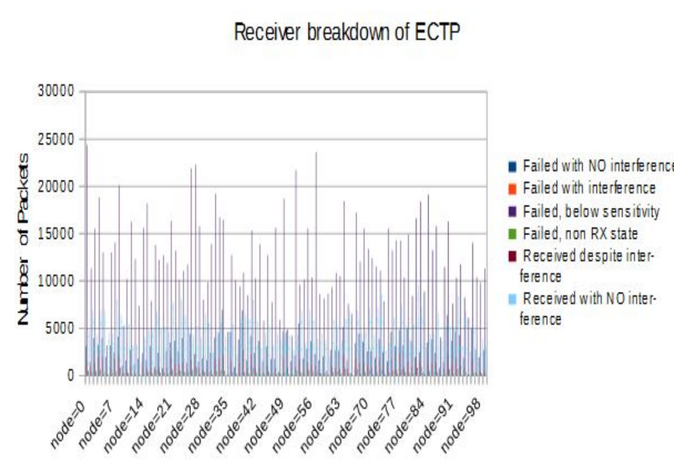

Fig. 8. Receiver packets breakdown of ECTP

IV. Analysis Of The Simulations Results

A. ***Consumed Energy:*** Energy consumed by node 0 is high for LEACH as it is initial cluster head (base station). Later energy consumed by each node becomes consistent as cluster head keeps changing depending on the energy levels of each node. For CTP and ECTP energy consumed by each node is nearly constant. Hence all nodes lifetime will be same but while discussing between CTP and ECTP .ECTP consumes less energy and the values are more constant .Figure 2 and 3 shows this comparison.

B. ***Application Level Latency:*** From Figure 4 we can see that most of the packets are received with under 400msecs latency, which means that they are transmitted in the first MAC frame after their creation .For LEACH latency will be nearly null after 20 bucket of packets.This is because LEACH assumes that all nodes are in same communication range i,e. From cluster head to sink, it's always one hop. It uses CDMA, so latency is less. CTP and ECTP is based on tree structure. As the number of levels are more in these protocols, delay is more For CTP, latency will be high for [200, inf) packets because packets receiver breakdown due to low signals is more .While with comparison to CTP ,ECTP has less latency.

C. ***Transmitted packets:*** The number of packets transmitted (includes both data and control packets) by CTP is high as compared to LEACH and ECTP. Hence CTP gives more control overhead than other two protocols. ECTP performs better than CTP as it considers power of the entire network and also in ECTP data collection is done only if the voltage of the node is above threshold. Thus it avoids unnecessary transmission of data .Figure 5 explains the comparison of this parameter for the protocols.

D. ***Receiver packet breakdown:*** For LEACH, the number of packets received without interference is more and hence packets that fail due interference, No interference and also for being in wrong state can been known. For CTP and ECTP number of packets failed due to low signals is more but number of packets received without interference is consistent for each nodes. Figure 6, 7, 8 explains the RX breakdown of LEACH, CTP and ECTP.

V. Conclusion And Future Work

This paper compares the three hierarchical routing protocols with respect to the concerned parameters. A collection protocol is an efficient, robust, and reliable in the presence of dynamic link topology. CTP and ECTP are robust to topology changes and failures. ECTP is energy efficient when compared to CTP. It places minimal expectations on the physical and link layer, allowing it to run on a wide range of platforms. LEACH is completely distributed and the nodes do not require information of the entire network in order to operate. Distributing the energy among the nodes in the network is effective in reducing energy consumption of the entire network thus enhancing system lifetime.

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