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Tree based routing protocol in WSNs: A comparative performance study of the routing protocols DEEC and RPL

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Abstract

Recently, energy optimization in WSNs have strained more and more attention. Enhancing the network lifetime in WSNs is based on minimizing messages exchanged by nodes. Various routing protocols have been proposed to improve the performance of WSNs. Among these protocols, tree-based routing protocols can increase the power efficiency of the network considerably. In this paper, we will evaluate two hierarchical protocols; RPL with the clustering routing protocols DEEC. To evaluate the performance capability of each protocol, comparison results based on the simulation tool Cooja applied in WSN operating system Contiki are presented in this paper.

1. Introduction

The current progresses of WSNs have made sensor nodes meet energy optimization problems and the difficulty to discover rapid route. A Sensor Node (SN) is composed of processor, sensor, transceiver, and power units. In addition to performing these functionalities, a sensor node must have also the capability of routing. Routing is the most energy consumption phase in WSNs. Thus, Most of the attention has been given to the routing protocols in low power consumption. To prolong the lifetime of the sensor nodes, designing efficient routing protocols is critical. In this context, several routing techniques have been proposed to report these issues. Clustering is one of the solutions adapted by several proposed routing protocols designed for WSNs and which demonstrates its effectiveness. The network is composed of sensor nodes, Cluster Heads (CH) and a Base Station (BS). A CH is placed in the head of each cluster and is responsible of a number of sensor nodes. Sensor nodes send data to CH that aggregates and send it to the Base Station. In addition to clustering algorithms, another type of hierarchical protocols was proposed which is the Routing Protocol for Low Power and Lossy Networks (RPL) [1]. This standard makes use of IPV6 and have as main goal to reduce energy consumption. RPL supports traffic in the ascendant direction and traffic flowing from a gateway node to all other network participants. In this paper, we present a comparison between two routing protocols. This comparison reveals the differences between the cluster-based routing protocol Distributed Energy Efficient Clustering (DEEC) [2] and the RPL protocol designed for wireless sensor networks. The rest of the paper is organized as follows: section II describes the functionality of DEEC and RPL routing protocols. The analysis and comparison of these protocols with respect to many metrics are discussed in Section III. In section IV, simulation results with Cooja in Contiki OS are presented. Finally, section V concludes the paper and presents possible future work.

2. Routing Protocol Overview

In WSNs, a sensor ensures sensing, data processing and communications. This last task of routing and finding a way to send a message from the source to the destination is the most energy consuming. Experiments show that transmission of data takes more energy compared with processing data. Energy cost of transmitting one separate bit of information equals to processing of thousands of functions in a sensor node. Therefore, a good energy management scheme should consider the communications task as a priority. Therefore, developing a low power routing algorithm of WSNs to minimize energy is today an important field of research. There are three main classes of routing protocols dedicated to WSNs, namely protocols using flat routing; hierarchical routing and location based routing. All of these classes have a set of representative protocols. Nevertheless, most of these protocols consume a lot of energy. The energy consumption is very interesting in different applications of WSNs to ensure the good evolution of the network. That is why most routing protocols developed for sensor networks focus on energy conservation. A typical example of the routing protocol we find RPL proposed by IETF ROLL, and DEEC based on cluster architecture in which a cluster was created and a head node was assigned to each cluster. In this section, a description of the function of DEEC and RPL protocols is presented.

2.1. DEEC protocol

DEEC is a routing protocol designed for heterogeneous wireless sensor networks. It is based on the clustering algorithm LEACH [3] but is an enhancement version. This protocol is composed of two phases: the setup phase and the steady state phase. In the setup phase, election of CH and formation of cluster are performed, while in steady state phase data is transmitted from sensor nodes to CHs. CHs then aggregate this data and transmit it to BS. CH selection in DEEC is based on the ratio between the residual energy of each node and the average energy of the system. Therefore, nodes that have the greater residual energy have more chance to become a CH [4]. Each node generates a random number between 0 and 1, if the number is less than the node's threshold, then this sensor node becomes a CH. After the election of CHs, each CH advertises its status using CSMA MAC protocol. The detailed flowchart of CH selection in DEEC protocol is described in the Figure 1 below.

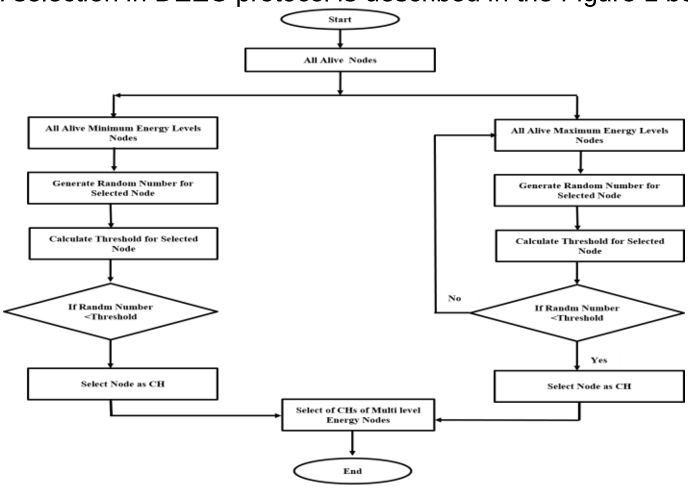

Figure1. Flow chart of CH Selection in DEEC protocol [5].

2.2. RPL protocol

The IETF ROLL working group developed an IPv6 routing protocol based on the distance vector named Routing Protocol for Low Power and Lossy network (RPL). It is designed for low power consumption. This protocol can be used for data collection networks that are based on three types of traffic: Point-to-Point, Point-to-Multipoint and Multipoint-to-Point [6]. RPL begins its function with the building of a Destination Oriented Directed Acyclic Graph DODAG from the source node. As mentioned in the figure 2 below, DODAG Information Object (DIO), DODAG Information Solicitation (DIS) and DODAG Destination Advertisement Object (DAO) are used as control messages to transfer DODAG information. DIO messages are used by RPL to form, maintain and discover the DODAG. The different parts of DIO message are the DODAG ID, RPL instance, DODAG version, the objective function (OF) and the rank of the node, which broadcasts the message. The rank is computed according to the OF. The receiver node can compute its position from it.

Figure 2. Control messages of RPL.

As initialization step, nodes start exchanging the information about the DODAG using DIO messages that contains information about the DODAG configuration and help the nodes to join the DODAG and select parents. Any node to explicitly solicit the DIO messages from the neighbor nodes uses the DIS. The node produces it in case when it could not receive a DIO after a predefined time interval. The DAO messages are used by RPL to propagate a node prefix to the ancestor nodes in support of downward traffic.

In order to route the traffic upward, RPL needs only the information in the DODAG. The DODAG tells who the preferred parent of the node is. So when a node wants to send a packet to the root , it simply sends the packet to its preferred parent in the tree, and the preferred parent then sends the packet to his preferred parent and so on until the packet reaches the root.

RPL uses DAO messages to maintain the routing table in support of downward traffic. Therefore, RPL forms a hierarchical network in terms of control messages flow. The DAOs can only be sent after the topology formation (or DODAG creation) by the exchange of DIOs control messages. The IP architecture proposed by IETF ROLL separates the forwarding task from routing. The task of the forwarder is to receive datagrams and forward it to the suitable interface based on the routing table. The router is responsible for populating and maintaining routing table. RPL enables nodes to store a list of candidate parents and siblings that can be used if the currently selected parent loses its routing ability. In the construction process of network topology, each node identifies a stable set of parents on a path towards the DODAG root, and associates itself to a preferred parent, which is selected based on the Objective Function.

The Objective Function defines how RPL nodes translate one or more metrics into ranks, and how to select and optimize routes in a DODAG. It is responsible for rank computation based on specific routing metrics (e.g. delay, link quality, connectivity, etc.) and specifying routing constraints and optimization objectives. The design of efficient Objective Functions is still an open research issue. A couple of drafts have been proposed. In [7], the draft proposes to use the Expected Number of Transmission (ETX) required to successfully transmit a packet on the link as the path selection criteria in RPL routing. The route from a particular node to the DODAG root represents the path that minimizes the sum of ETX from source to the DODAG root. In [8], the draft proposes Objective Function 0 (OF0), which is only based on the abstract information carried in an RPL packet, such as Rank. OF0 is agnostic to link layer metrics, such as ETX, and its goal is to foster connectivity among nodes in the network. The step of construction of DODAG in RPL is presented by the figure 3 below:

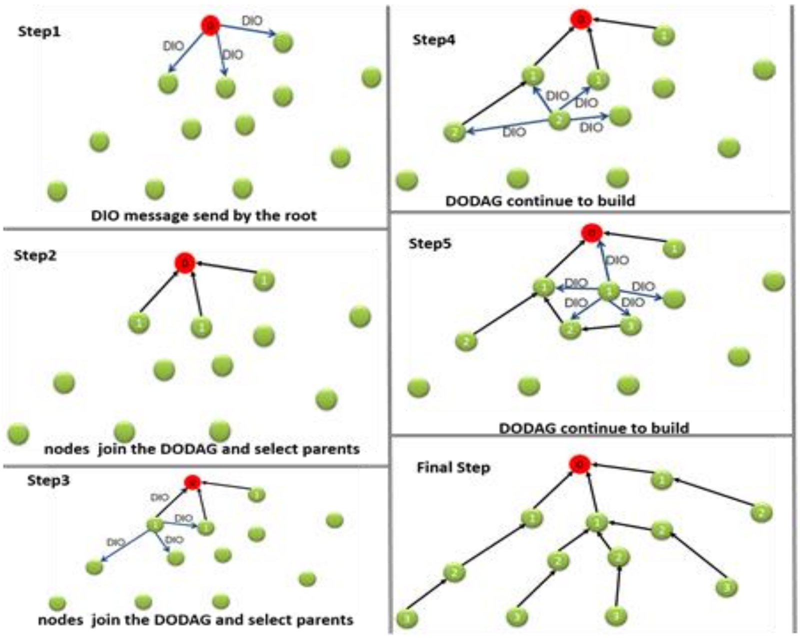

Figure 3. RPL DODAG construction steps

The construction of the topology starts at a root node that begins to send DIO messages. Each node that receives the message runs an algorithm to choose an appropriate parent. The choice is based on the used metric and constraints defined by the OF. Afterwards each of them computes its own Rank and in case a node is a router, it updates the Rank in DIO message and sends it to all neighboring peers. Those nodes repeat the same steps and the process terminates when a DIO message hits a leaf or when no more nodes are left in range. Therefore, there are three types of nodes in a RPL network. The first type are root nodes, which are commonly referred in literature as gateway nodes that provide connectivity to another network. The second type are router nodes. Such nodes may advertise topology information to their neighbors. The third type are leafs that do not send any DIO messages and have only the ability to join an existing DODAG.

	Routing topology	Hierarchical level	Scalability	Data aggregation	Low power consumption	Internet	Tree topology	Multihop
RPL	Proactive	multi	High	No	Yes	Yes	Yes	Yes
DEEC	Proactive	single	scalable	Yes	Yes	No	Yes	No

3. Analysis

RPL is a proactive routing protocols and start finding the routes as soon as the RPL network is initialized. DEEC, also, is a proactive routing protocol. The proactive routing protocols provide the route before it is actually needed by any data or node. Therefore, these protocols periodically exchanges control messages to find and propagate the routes in the network as soon as they start. Nodes send both local control messages to share local neighborhood information; and messages across the entire network for sharing the topology related information among all the nodes in the network. Data aggregation is not supported in RPL. However, DEEC is based on data aggregation to minimize energy consumption. Path selection is an important factor for RPL and DEEC. DEEC uses the ratio between the residual energy of each node and the average energy of the system. Nevertheless, RPL uses more factors while computing best paths for example routing metrics, objective functions and routing constraints. RPL uses TCP/IP for communication it to solve the problem of interoperability between devices from different vendors [9], [10]. It also facilitates the development of applications and integrations in terms of data collection and configuration [11]. In contrast, DEEC does not support TCP/IP. The architecture of a DODAG in RPL is similar to a cluster-tree topology in DEEC where all the traffic is collected in the root. However, the DODAG architecture differs from the cluster-tree in the sense that a node can be associated not only to one parent, but also to other sibling nodes. In table 1 below, we present a comparison between RPL and DEEC according to different metrics.

Table 1. Comparison between RPL and DEEC

From this table, we notice that RPL is better than DEEC in term of high scalability, multi hierarchical level, use of internet and support of multihop communication. According to this analysis study, we conclude that RPL outperforms DEEC. This decision will be confirmed with simulation results that will be presented in next section.

4. Performance Evaluation

4.1. Simulation Settings

In order to compare the performance of both RPL and DEEC in WSNs, an evaluation using the WSN operating system Contiki [12] and the Simulation tool Cooja [6] has been conducted. We choose Cooja simulator, as it is the most widely used and the only available simulator for the Contiki Operating System.
As the construction of clusters in DEEC and the establishment of the DODAG in RPL are repeated in each round, it increases the use of CPU resources. Then, it influences significantly the energy consumption. Therefore, CPU overhead is

considered as evaluation metric. The specific settings of the scenario studied are detailed in table 2 below.

Metrics	Number Of Nodes	Number Of Roots	Simulation Duration Time (Ticks)	Placement	Radio Environment	Area size
Values	20	1	700	Random	UDGM	100*100

Table2. Parameters

The nodes were placed randomly in the area of simulation. The simulation time and the number of nodes are similar for DEEC and RPL. The messages controlled in our simulation are only for the initialization of RPL and the construction of the DODAG. For DEEC, also, we simulate the setup phase that consists on the construction of cluster.

4.2. Simulation Results

We design a simple network in the Cooja simulator containing 20 client nodes and one server node acting as a root of the DODAG. The network scenario is shown in Figure 4. We use a Cooja plugin called Contiki Test Editor to measure the simulation time and stop the simulation after the specified time. This plugin also creates a log file for all the outputs from the simulation. In figure 4 below, we present an example of scenario that can be executed in simulation steps.

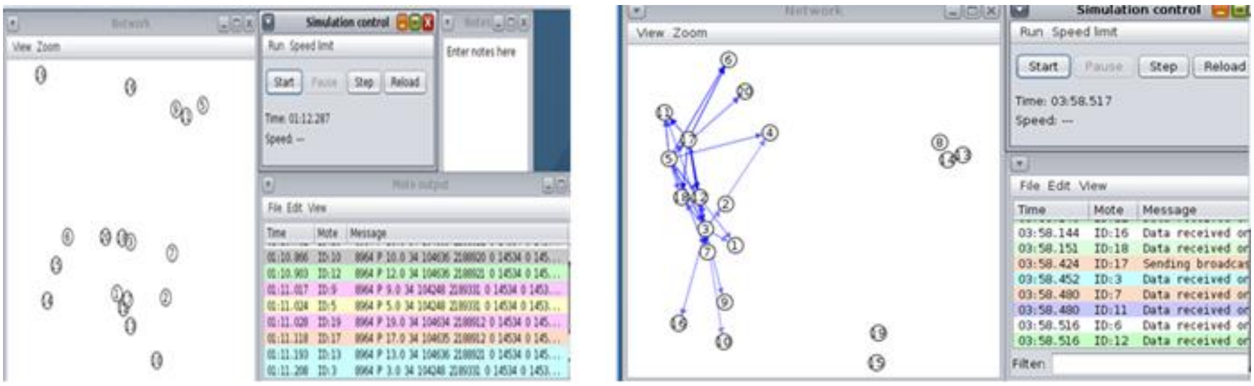

Figure. 4. The network scenario in Contiki (example)

We started the initialization of sending messages between sensors. After the specified duration, we stopped the simulation and we used the log files to create the curves below. In this curves, we present the use of CPU resources of DEEC and RPL in the first step of construction of cluster for DEEC and the construction of DAG for RPL.

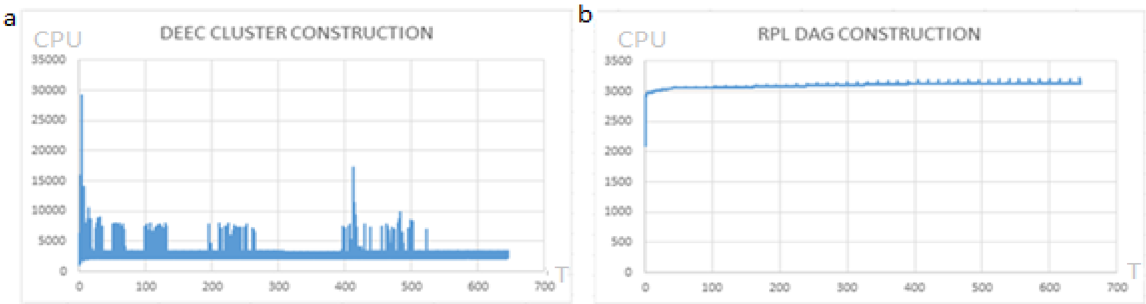

Figure. 5. (a) DEEC cluster construction; (b) RPL DAG construction.

From this curves, we notice that DEEC cluster construction can reach until 30000 CPU, but for RPL is not exceed 3500. Therefore, RPL consume less CPU resources than DEEC that help in maximum to minimize energy consumption. This result is confirmed also in figure 6 below. Consequently, from these results we conclude that RPL overcome the DEEC capacity as mentioned in previous section.

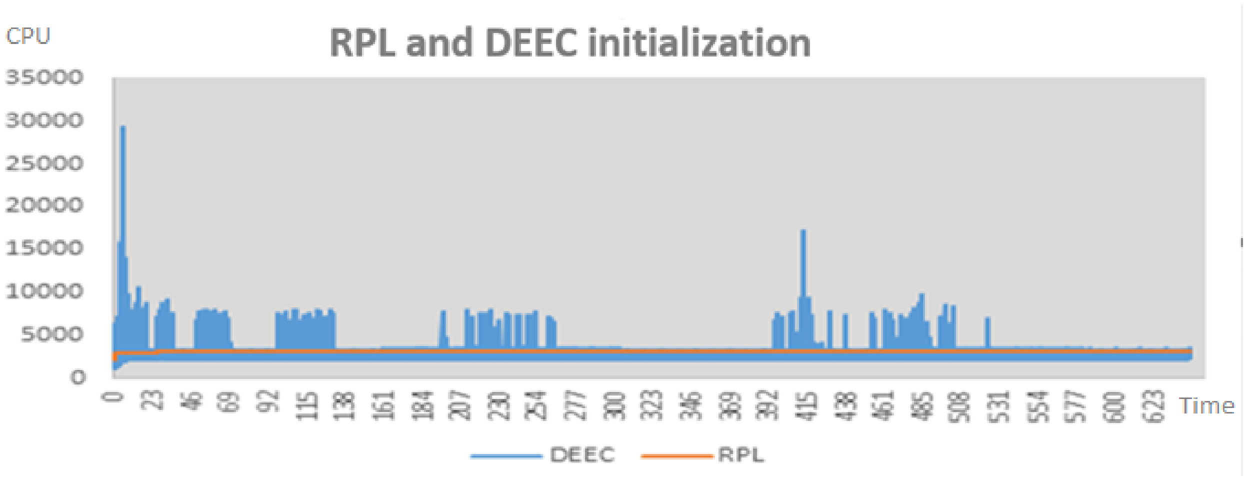

Figure. 6. DEEC and RPL initialization comparison

5. Conclusion

Energy efficiency is an essential issue for wireless sensors networks. Therefore, it is necessary to take into account in the performance evaluation of routing protocol. Choosing low power routing protocol to transfer information between nodes is among the typical solution used to minimize energy consumption. Thus, several studies are currently focusing on proposing routing protocol that help to maximize network lifetime in WSNs. In this paper, a comparison between two efficient routing protocols RPL and DEEC proposed in literature is detailed to find the best solution. RPL and DEEC represent two different alternatives for routing protocols in WSNs. RPL is optimized for specific topologies and traffic patterns with specific responsibilities for topology formation and maintenance. Thus, the strength of RPL is proactive construction of a collection tree for forwarding such traffic. DEEC represents a less optimized protocol. Observing that a large set of deployment application for sensor networks imply the need of minimizing energy consumption and maximize network lifetime. In this paper, we studied the performance of these two protocols. While both protocols are able to provide reasonably high and definitely comparable capacity from the analysis comparison. Nevertheless, simulation results show that RPL is more evident candidate routing protocol for WSNs especially in the application that applied large scale of sensors than is DEEC. As future work, we will use Powertrace tool of Contiki to estimate power consumption and enhance the results obtained in this paper.

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