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Evaluation of Cluster Formation Algorithm in Large Scale Wireless Sensor Networks

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***Abstract*—Large scale monitoring systems require reliable and efficient routing protocols used to overcome the limitations introduced by battery operated embedded devices, among which, energy consumption is considered the main concern. This topic has gained a lot of interest in the last decade. Due to numerous advantages, clustering is becoming more prevalent as a routing technology in WSN. This paper describes and evaluates a WSN clustering algorithm, with *a priori* elected cluster heads (CHs). Leveraging CONTIKI Cooja simulation environment, the proposed clustering mechanism is evaluated on several WSN static topologies. Stemming data, such as power consumption and number of iterations are analysed from a comparative standpoint.**

Keywords—wireless sensor network; clustering; energy efficient; routing

I. INTRODUCTION

The last decade has witnessed increased adoption of wireless sensor networks (WSNs) across numerous applications, due to scalability, ease of implementation, operation in different environments and robust technology with surprising computation capabilities. Moreover, under the rapid ongoing proliferation of IoT (Internet of Things), WSNs has become essential elements for making the most of this [1].

Large scale monitoring systems require reliable and efficient routing protocols used to overcome the limitations introduced by battery operated embedded devices. Complex WSNs comprising numerous randomly dissipated nodes have a high energy-consumption rate due to the burden on the communication channel. Data transmission bandwidth reliability and time synchronize are the major downside of WSNs alongside power management and data transfer problems.

Within the aforementioned context, it is mandatory to define data collection strategies that pursue the reduction of exchanged messages among the sensor nodes. It is suitable to limit the data exchange to local information exchange among cluster neighbours, and to perform local estimation of consensus value inside clustered sub-networks. A mobile data collector fitted with a sink node can be used to upload data from the clusters to a higher decision level. One possible strategy, suitable for large scale WSNs regard-less of terrain type, is to use an aerial mobile sensor node, as UAV's payload.

This paper introduces a WSN clustering mechanism suitable for randomly deployed WSN with uneven distribution described by well-connected graphs in some areas and less connected in other areas. The proposed clustering model for WSN organization assumes that cluster heads (CHs) are *a priori* elected thanks to the aerial mobile sink node support. The Aerial Supported Clustering Scheme (ASCS) assumes that the CHs are deterministically selected on the basis of an election process that implies an evaluation of the ground nodes located along the UAV's navigation path. The purpose of the evaluation is to determine the super nodes which best qualifies for the role of linking nodes or commonly referred to as CHs. Thus, CHs are mostly symmetrically deployed among the monitored area, which prevent clusters overlapping and guaranties the control of size and topology.

The outline of the paper is as follows. Section II provides a brief overview of clustering algorithms and further explores some well known methods for WSN organization. Section III details the proposed ASCS method, tailored for large scale hybrid UAV-WSN monitoring systems. In Section IV, simulation results are presented with focus on clustering time and energy consumption. Last section summarizes the paper and discusses future work.

II. CLUSTERING ALGORITHMS

Lately, routing protocols for WSN networks have become a hot research area, due to the rapid and active proliferation of WSN in monitoring applications. Clustering is a routing technology suitable for large scale monitoring systems, owing to a variety of advantages such as such as scalability, data convergence, less load, less energy consumption, robustness, etc. [2].

In literature, WNS routing is divided into two categories based on network structure: flat and hierarchically routing. The flat routing is described by the same functionalities and tasks performed by every node comprising the WSN. Thus, data transmission is performed hop-by-hop. Usually flat routing mechanism such as Flooding and Gossiping [3] or Trajectory Based Forwarding [4], are effective only for small scale networks. Hierarchically routing, on the other hand, is described by WSN comprising nodes performing different tasks, organized in sub networks, commonly referred to as clusters, based on some specific metrics. In a general structure, each cluster is represented by a main node, referred to as a CH and simple nodes.

Hierarchical routing technology is suitable for large scale networks. Some typical routing protocol include the well known Low-energy Adaptive Clustering Hierarchy (LEACH) [5] and the improved protocol Two-Level Hierarchy LEACH (TL-LEACH) [6], Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [7], Hybrid Energy-Efficient Distributed clustering (HEED) [8]. In general, this routing protocols aims at overcoming the main concern of large scale WSN – energy consumption.

III. PROPOSED ALGORITHM

We propose a new WSN clustering protocol suitable for large scale WSN, with uneven distribution resulting from the randomly nodes deployment. The ASCS protocol is tailored for a heterogeneous UAV-WSN monitoring system, where the ground nodes collect data and the UAV supports data uploading acting as a sink node, and also it supports the clusters allocation. ACSC protocol assumes that CHs are *a priori* elected using the UAV's support. The UAV performs an identification flight (Figure 1) following a predefined path, that is also used during normal monitoring, gathering information regarding nodes position, radio communication strength and battery level.

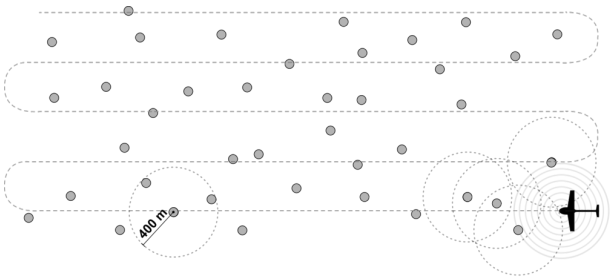

Figure 1: UAV navigation path

The navigation path is designed considering the radio communication range and aiming to cover the entire monitored area.

Based on these indicators and a scoring algorithm, CHs are further elected. The next step, which comprises the topic of this study, is the WSN clustering, more precisely the WSN organization in sub networks. Figure 2 illustrates a simplified cluster sequence. The convergence mechanism is based on RIME communication massages exchanged between neighbour nodes in a random manner, using broadcast and unicast messages.

The nodes broadcast a message comprising identification RIME address, current cluster membership, cluster role (CH or simple) and estimative number of cluster members. If a neighbor node receives a broadcast message, it checks the sender information and decide whether to join or not the neighbors cluster. This decision depends on number of hops to the CH, signal strength estimated through Received Signal Strength Indicator (RSSI) and other criteria.

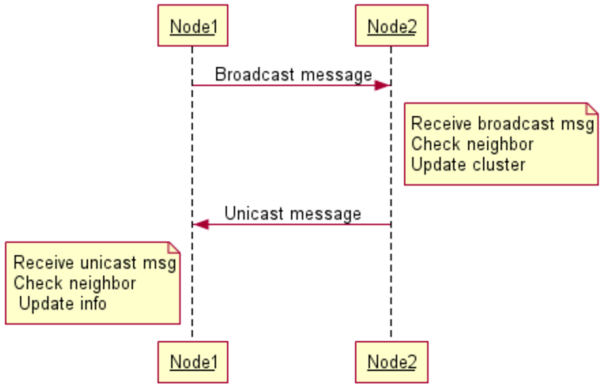

Figure 2: Clustering sequence

Once the node decides, it inform the sender if it joined the cluster membership, so that each can update the estimated number of cluster members. When the maximum number is reached, the node stops broadcasting process.

IV. SIMULATION AND RESULTS

To analyze the performance of the proposed ASCS algorithm we performed various experiments using several WSN test-beds. All the evaluated WSN are described by static topologies as undirected graphs, comprising a different number of nodes in a random deployment.

All the experiment are based on TelosB/Tmote Sky platforms compatible with Contiki OS. We took advantage of the new available virtual tools for WSN prototyping, the simulation environment Contiki COOJA.

Regarding the *a priori* selected CHs, we imagined a navigation path over the nodes diagram and we arbitrary chosen the CHs.

In this section we present the results for three WSNs, comprising 38, 80 and 100 nodes. Figure 3 illustrates the nodes deployment and a capture of data exchange during clustering mechanism. Simple nodes are filled with green and CHs are filled with different colours.

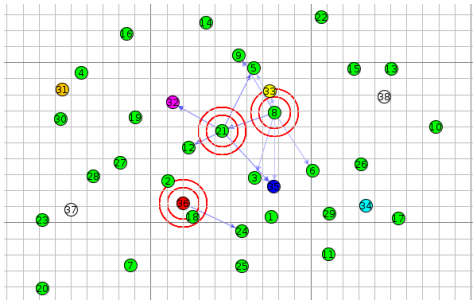

Figure 3: 38 nodes WSN simulation

Besides the time required for clustering formation we performed an online power consumption estimation for each node, using the available Contiki OS *powertrace* function that allows us to know the time spent in the

following states: CPU (active), LPM (Low Power Mode), Transmit and Listen. Knowing the current consumption of the node in this states we can perform a power consumption estimation.

Figure 4 illustrates the power consumption evolution during the clustering sequences for a randomly chosen node. As one can see RX (receive), TX (transmit) processes require most of the energy. TX and RX intersection can be explained by the clustering sequences described in the previous section. As the evolution illustrates, it took 45 seconds for the node to decide on the cluster membership.

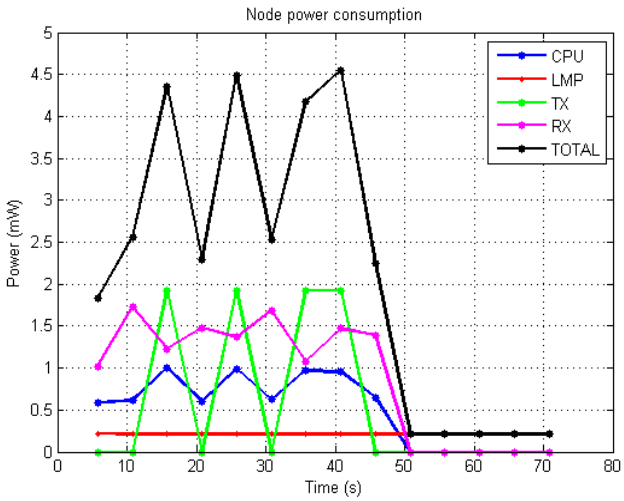

Figure 4: Node power consumption estimation

We further analyze the power consumption and time duration for the proposed three simulations. Results are available in figure 5, as histogram representations, power consumption on the left side and time duration, right side.

For the WSN comprising 38 nodes, a mean of 31.54 mW power consumption was estimated and the standard deviation is 12.241. In terms of time duration, the mean is 24.17 seconds and the standard deviation is 16.339.

Similar result are listed in table 1 for the other two WSNs.

WSN	Power (mW)		Time (s)	
	Mean	Std. dev.	Mean	Std. dev.
80 nodes	61.64	12.715	24.17	16.339
100 nodes	57.85	13.151	21.94	13.587

Table 1: Results

The standard deviation value reflects a large amount of variation for both power consumption and time duration. This is an expected result due to the random deployment and the uneven topology.

Another thing to mention is that although the density of the WSN is increased the time duration for the clustering mechanism is not affected.

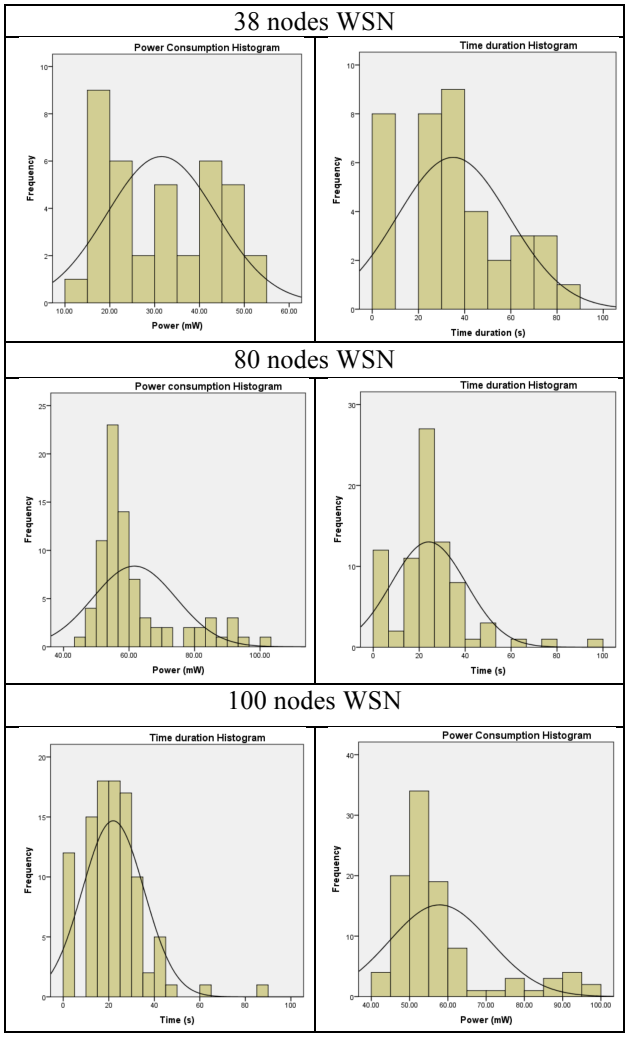

Figure 5: Power Consumption and Time Duration Histograms

V. CONCLUSION

The paper discussed a clustering mechanism, suitable for large area monitoring and tailored for hybrid UAV-WSN network. The proposed ASCS method assumes that the CHs are *a priori* elected thanks to the UAV support.

The cluster formation algorithm was evaluated on different WSN topologies, of various sizes.

Results have shown that the proposed solution is feasible and scalable.

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