Performance evaluation of clustering protocols using AODV routing protocols

S. Aouad, A. Maizate

Abstract— **Recent advances in wireless sensor networks have generated many new protocols for clustering specifically designed for sensor networks where energy consumption is an essential consideration. Variety of sensing capabilities results in profusion of application areas. However, Sensed data need to be delivered to the base station using multihop and must cope with the network unreliability problem and the energy consumption. In WSN, few routing and clustering protocols take into consideration of these problems. It is a major challenge of the clustering protocols to ensure network survivability through redundancy features. In this paper, we present a short literature review of the existing routing protocols for Wireless Sensor Network and we evaluate the performance of AEEPC, APC-T and APC using the routing protocols AODV.**

Index Terms—**Wireless sensor network, routing protocol, AODV, OSLR , clustering, energy-efficiency.**

I. Introduction

The past few years have seen increased interest in the potential use of wireless sensor networks (WSNs) in several application areas (industrial, cultural, environmental):

- Collection of information relating to the environment (temperature, light, carbon dioxide levels, the presence of toxic, radio activity, etc.).
- Monitoring structure of infrastructure,
- Optimizing treatment for patients, etc...

Sensors in these applications are expected to be remotely deployed in large numbers and to operate autonomously in unattended environments. Each sensor has an onboard radio that can be used to send the collected data to interested parties. Such technological development has encouraged practitioners to envision aggregating the limited capabilities of the individual sensors in a large scale network that can operate unattended [1–9]. To support scalability, nodes are often grouped into disjoint and mostly non-overlapping clusters. This method is called clustering.

Clustering is an important strategy to realize hierarchical topology, which becomes an effective scheme in increasing the scalability and lifetime of wireless sensor networks, and minimizing the consumption of energy.

In clustering networks, nodes are grouped into clusters. Each cluster is represented by a particular node called cluster-head. It is elected by a specific metric in active clustering protocols by a specific metric or combination of metrics. The cluster-head is responsible for coordination between the different members of the cluster. Each cluster member collects local data from the environment periodically and then sends the data to the cluster-head. When the data from all the cluster members is received, the cluster heads aggregate the data and send it to the base station (BS). Because CHs often receive and aggregate the data from their cluster members and transmit the aggregated data over longer distances, the energy consumption of cluster-heads is much larger than that of cluster members. So the network is re-clustered periodically in order to select the node with the highest energy as CH, thus distributing the load uniformly on all the nodes. Besides achieving energy efficiency, clustering reduces network contention and packet collisions, resulting in better network throughput under high load.

As cluster heads are charged with receiving and aggregating the data from their cluster members and transmitting the aggregated data from a long distance to BS, the energy consumption of cluster heads is more significant than members of cluster.

Due to the severe energy constraints of large number of densely deployed sensor nodes a large number of research activities have been carried out to implement various network control and management functions such as synchronization, node localization, and network security. The traditional routing protocols have many drawbacks when applied to WSNs, which are predominately due to the energy-constrained nature of such networks [10].

In this paper we are going to compare some clustering algorithms used in WSN. The rest of this paper is organized in the following manner: Section II will introduce the routing protocol AODV and the principles, advantages and objectives of self-organization protocols based clustering. Section III will present the energy model and the network. In Section IV, we compare the performance of self-organization protocols. Finally, Section V concludes this paper and proposes future research directions.

II. Related work

A. AODV [11]

The routing protocols are classified as reactive protocols and proactive protocols. In reactive routing protocols, the routes are discovered only when necessary i.e., on demand, from the source to the destination, and these routes are maintained as long as it is required. Ad hoc On Demand Vector (AODV) is the most popular reactive routing protocol.

AODV [11] is an approach of on-demand for detecting path. The path is set up as soon as the source node is prepared for the transmission of data packets. Routing table is maintained to store the next-hop address. Each intermediate node in the network forwards the Route Request (RREQ) message until it reaches the destination node. The destination

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node responds to the RREQ message by transmitting the Route Reply (RREP) message.

As the RREP flows through the network, it determines the route from source node to destination node. The sequence number is increased by each originating node and used to determine whether the received message is the most recent one. The older routing table entries are replaced by the newer ones. Active nodes in the networks are determined by broadcasting a "Hello" message periodically in the network. If a node fails to reply a link break is detected and a Route Error (RERR) message is transmitted which is used to invalidate the route as it flows through the network. A node also generates a RERR message if it gets message destined to a node for which a route is unavailable. Types of messages in AODV:

- *Route Request (RREQ) message*: It is used to form a route from one node to another node in a network.
- *Route Reply (RREP) message*: It is used to connect destination node to source node in a network.
- *Route Error (RERR) message*: It is used to indicate any route broken or node failure.
- *HELLO message*: It is used to determine the activeness of the network.

The transmission of data depends on route discovery and route maintenance in AODV. The route discovery depends on RREQ and RREP messages, if a node initiate's request of route it will form route after getting the RREP. The route will be maintained by sending HELLO messages to neighbour nodes, if any link failure it will indicate using RERR message.

AODV has greatly reduced the number of routing messages in the network. AODV only supports one route for each destination. This causes a node to reinitiate a route request query when it's only route breaks. But if mobility increases route requests also increases.

B. *Advanced Passive Clustering (APC)*

Advanced Passive Clustering (APC) [12] is a protocol based on the Passive Clustering (PC) that does not use any specific protocol control packets. It exploits the data packets to transmit neighbor's information. At startup, all nodes are in the initial state. A node changes its state only when it receives a packet from its neighbors. In APC the CH selects from its neighbors list a CH_Bakup, this is the node that has the highest energy among all its neighbors. Once the CH leaves the cluster, CH_Backup replaces the CH and chooses its CH_Backup from its neighbors list. So APC maintains the structure of the cluster even at the leasing of CH, increases the lifetime of the network and reduces energy consumption.

APC takes into account the energy level of nodes in operations and many decisions are made based on the energy level of nodes. So APC predicts changes in the topology of sensor networks in environments with high mobility.

The APC following principles: the designation of the clusterhead, the formation of clusters, election clusterhead_backup and maintenance of clusters formed. The following figure 1 describe APC algorithm.

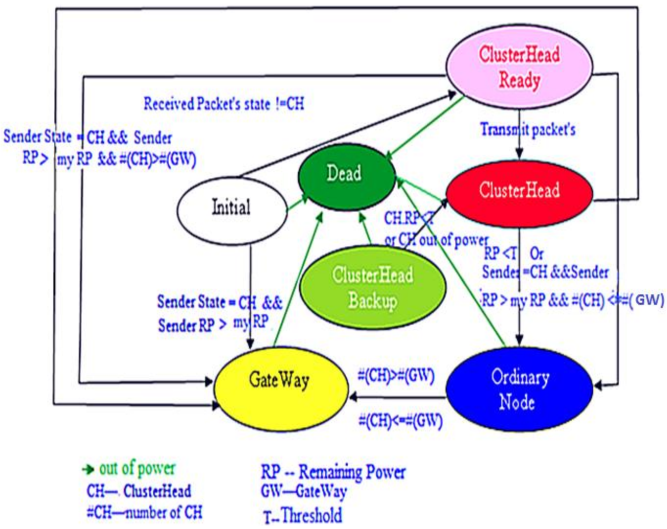

Figure-1: APC automate

C. *Advanced Passive Clustering-Threshold (APC-T)[13]*

Similarly, considering the APC algorithm, a valuable extension (that includes the concept of energy threshold) is proposed in [12]. (APC-T) where the information is included in the packet and the energy level of nodes is taken into account in the data transmission. Once the cluster is formed, the CH will select its CH_Backup from its neighbors list like APC algorithm; this is the node that has the highest energy among all its neighbors. In APCT, if the CH leaves the cluster, or its energy is below a given threshold T, CH_Backup replaces the CH and chooses its CH_Backup from its neighbors list. Figure 2 describe APC-T algorithm.

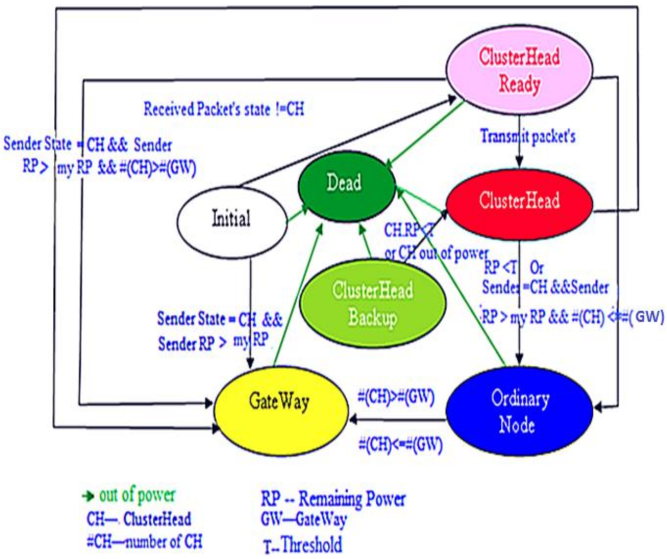

Figure-2: APC-T automate

APC-T [13] does not require an initialization phase of cluster before routing. Since the information is embedded in data packets, the traffic generated by the transmission of these packets is used to build the infrastructure of the Cluster regardless of the routing protocol. APCT also takes into account the energy level of nodes in operations and many decisions are made based on the energy level of nodes. So APC-T predicts changes in the topology of sensor networks in environments with high mobility.

By this way, APC-T maintains cluster longer than APC and allows balanced energy consumption between the nodes of network.

D. Advanced Energy Efficient Passive Clustering (AEEPC)

Advanced Energy Efficient Passive Clustering (AEEPC)[14] is a valuable extension to APC-T algorithm that includes additional Clusterhead-Backup election criteria and improves reliability of the network and uses balanced energy consumption among network nodes.

AEEPC is a protocol for cluster formation and election of clusterhead_Backup of the clusterheas. The principle of AEEPC as follow: There are six possible states: Dead, Initial, Ordinary, Clusterhead_ready, Custer-head, Gateway and Clusterhead-Backup. At cold start, all nodes are in the "initial" state, a node that joins the network, also starts with the initial state. This state does not change as long as a node does not receive a packet from another node. If the sender is not clusterhead, its status is cluster Head_Ready. The clusterhead-ready will be clusterhead, if it can transmit packets before receiving any packet of another cluster-head. If the packet comes from another clusterhead, the node records its id, the time of receipt and adds this node to the list of clusterhead and then it switches to Ordinary.

The node ClusterHead_ready switches to state gateway when the number of ClusterHeads is greater or equal to the number of Gateways. Otherwise, the node becomes an Ordinary Node or an alternate node. The clusterhead selects from its neighbors list a ClusterHead_Bakup, this is the node that has the highest coefficient K n among all its neighbors; with:

$K_n = \alpha_1 E_n + \alpha_2 D_n$
$E_n = E_{remaining}(n) \div E_{Initial}(n)$
D_n= (The average distance between the node n with all other nodes in the same cluster) ÷ (The maximum range of a node)
$\alpha_1 + \alpha_2 = 1$

Once the cluster-head leaves the cluster, or its energy is below a given threshold T, ClusterHead_Backup replaces the clusterhead and and launch the procedure to select a backup like in APC-T (see Fig 2).

The following figure describe AEEPC algorithm.

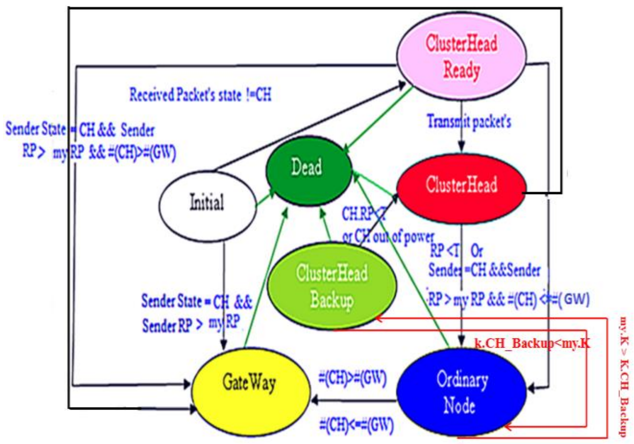

Figure-3: AEEPC automate

III. ENERGY AND NETWORK MODEL

In this section, we present the energy model for communication and the network model that will be used in the performance evaluations section.

A. Energy model

The energy model used is same with that in Ref. [20]. Equation (1) represents the amount of energy consumed for transmitting l bits of data to d distance. Equation (2) represents the amount of energy consumed for receiving l bits of data which is caused only by circuit loss.

$$E_{TX}(l,d) = \begin{cases} l * E_{elec} + l * \varepsilon_{fs} * d^2, d \prec d_0 \\ l * E_{elec} + l * \varepsilon_{mp} * d^4, d \geq d_0 \end{cases} \quad (1)$$

$$E_{RX}(l,d) = l * E_{elec} \quad (2)$$

where

- The energy consumption per bit in the transmitter and receiver circuitry;
- ε_{fs}: Free space model's amplifier energy consumption;
- ε_{amp}: Multiple attenuation model's amplifier energy consumption;
- d_0: a constant which relies on the application environment.

B. Network model

We consider a sensor field consisting of a set of sensors deployed randomly in a rectangular space. The algorithm assumes the following characteristics:

- Sensor nodes are mobile.
- Sensor nodes are densely deployed.
- Sensor nodes have similar capabilities for sensing, processing and communication.
- Sensor nodes transmit data to its immediate cluster head in the allotted time slots or to the backup.
- All nodes are energy constrained and perform similar task.

IV. SIMULATION AND PERFORMANCE EVALUATIONS

This section deals with the performance analysis of the proposed algorithms and its comparison using the routing protocol AODV. The implementation is done using C/C++ language-based event-driven simulator [16, 17] and the same simulation model as in [15] to implement different protocols. The network size taken into consideration is 1500mx1500m. Numbers of Nodes are increased from 10 to 50 in multiples of 10. The time for which the simulation is performed is 60 seconds. The node mobility model is set up as Random Waypoint Mobility. A total of 100 data packets are sent over the CBR traffic with an individual payload of 512 bytes.

The comparison of performance of the proposed algorithms with other algorithms is done using four performance metrics: Average end to end delay, Average throughput, average PDR (packet delivery ratio) and total number of packets received.

Others parameters considered in this simulation are given in Table-1.

Table-1. Parameter settings.

Parameter	Values
E_{elec}	50nJ/bit
E_0	0.5J
ϵ_{fs}	10pJ/bit/m2
ϵ_{mp}	0.0013pJ/bit/m4

A. THROUGHPUT

Throughput refers to how much data can be transferred from one location to another in a given amount of time. It is used to measure the performance of Internet and network connections. Throughput is usually measured in bits per second (bits/sec) [18]. High throughput is always desirable in a communication system. Here the graph shows that we have a better throughput in AEEPC in comparison to APC-T and APC.

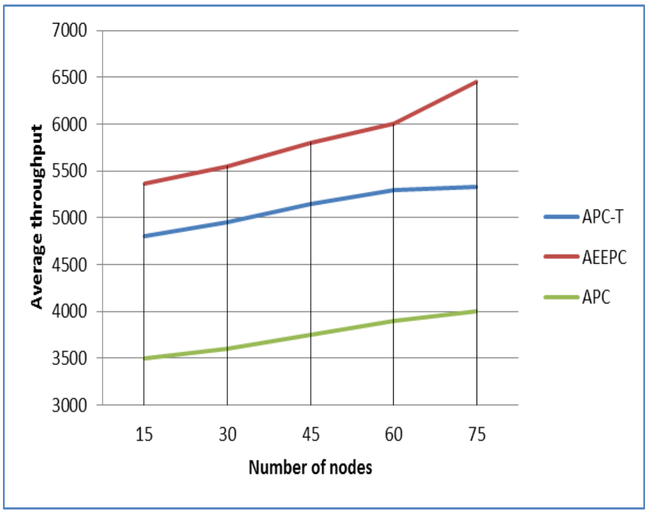

Figure-4. Average throughput.

The above figure (Figure 4) shows that throughput show that, the total number of data messages received in AEEPC is greater than APC-T and APC. Likewise, the throughput increases with the node density and is maximum in case of AEEPC due to the less of control overhead traffic.

B. END TO END DELAY

The end-to-end delay of a packet is defined as the time it takes to reach the destination after it is locally generated at the source. Usually a data packet may take few extra second to reach the client or the server's end, which happens due to congestion in the communication network in the situation of a queue or when different routing paths are chosen by the routing protocol. The expected end-to-end packet delay is obtained by averaging over all packets of the n traffic flows in the long term, and without incurring any ambiguity, it is called the packet delay for brevity. Notice that the end-to-end packet delay includes not only the packet delivery delay [19], but also the packet queuing delay at the source.

The graph below (Figure-5) shows the end to end delay is smaller in AEEPC as compared to the others which are very small. End-to-End delay increases with the increase in number of node. Because when number of node increases, more delay occurred because of node processing time, more queue management time. For better performance, it should be low.

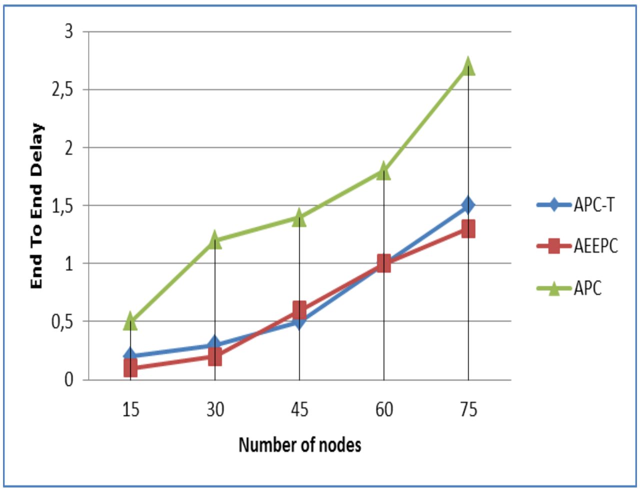

Figure-5. Average end to end delay.

C. PACKET DELIVERY RATIO

Packet delivery ratio is the number of delivered data packet to the destination and is calculated by dividing the number of packets received by the destination through the number of packets originated by the application layer of the source. The greater value of packet delivery ratio means the better performance of the protocol.

Graphs show the fraction of data packets that are successfully delivered during simulations time versus the number of nodes. Performance of the APC- T and APC are reducing regularly while the AEEPC is increasing. AEEPC is better among the three protocols.

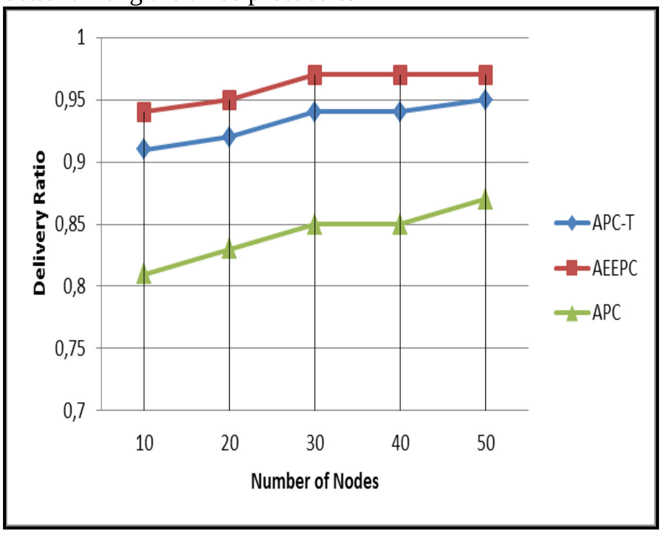

Figure-6. Average packet delivery ratio.

D. TOTAL NUMBER OF PACKETS RECEIVED

Total number of packets received at the destination. Its count tells us the total number of packets received out of total number of packets sent, in this case 100 data packets were sent. The graph(Figure 7) shows the best protocol to deliver the data packets to the destination are AEEPC in comparison to APC-T and APC.

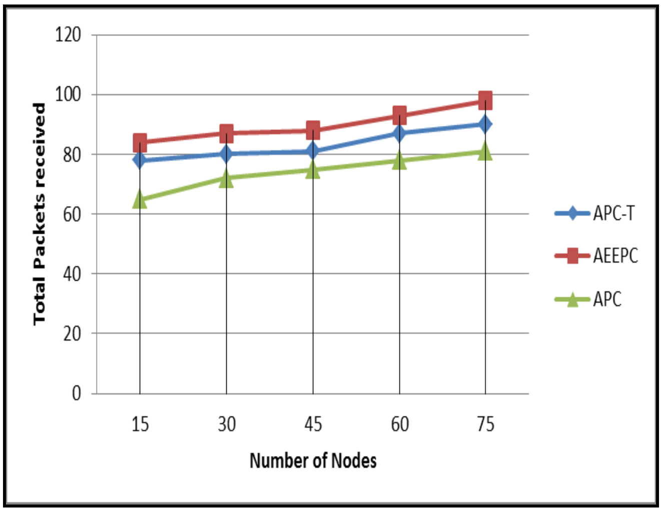

Figure-7. Total packets received.

V. Conclusion

In this paper we find out the performance of three algorithms of sel-organization based clustering like APC, APC-T and AEEPC by increasing numbers of nodes. Here, we find out the performance on the basis of throughput, delay and packet delivery ratio. By comparing these protocols on the basis of various performance metrics we have reached to a conclusion that AEEPC is better than APC and APC-T.

The overall conclusion is that AEEPC like self-organization protocol is best choice with AODV routing protocol to move towards a network with less energy consumption as it involves energy minimizing techniques like multihop communication, clustering, redundancy futures and data aggregation. We can still minimize the energy consumption and extend the network life time by improving the clustering technique. Significant research work has been done in these different clustering protocols in order to increase the life time and data delivery features. Certainly further energy improvement is possible in future work especially in optimal guaranteed cluster-heads selection.

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