Cluster Routing Protocol in Smart Agriculture

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***Abstract*—Smart agriculture is an IoT-based integrated approach that is related to Industry 4.0. As most of these fields are distant from urban areas, they have to be energy-efficient. In our project we are suggesting a Cluster based Routing Protocol, which can optimize energy usage of sensor nodes. Afterwards we compare our proposed routing protocol with the results other routing protocols achieve. Simulations shows that there is a slight difference in their performance, but overall it doesn't improve the energy-efficiency to a large extent.**

***Index Terms*—Industry 4.0, WSN, IoT, smart agriculture, AD-HOC AODV**

I. Introduction

Industry 4.0 is a revolution towards the automation and the communication of data within the manufacturing industries, which include the Internet of Things (IoT), Cloud computing, Artificial Intelligence (AI), etc. IoT describes the network consisting of sensors, software, and other technologies that can connect and exchange data with other software or system in the network to help with decision-making [1]. In our project, the use case is a smart agriculture, also known as precision agriculture which is IoT-assisted.

Smart agriculture is a scope of application within industry 4.0 that can provide automatic monitoring to the agricultural infrastructure, where sensors placed in the field can collect data such as soil temperature, moisture, potential of Hydrogen (pH), etc without human aid. The data will be transferred to a cluster head or base station to process and help the farmer make decisions. The usual network-type in this use-case is Wireless Sensors Networks (WSNs), which is composed of a large number of sensor nodes deployed in an area of interest.

The sensor nodes on the field don't move (static mobility) and are battery-powered since there is a lack of electrical infrastructure on acres. They are a crucial component of the system because they are responsible for gathering data. If one of these nodes fails, information about the farmland will be incomplete. Additionally, since the network needs to be maintained, changing the battery can cause problems [2]. Therefore, it is important to select an energy-efficient routing protocol that can increase the network's lifetime.

For this purpose, we choose the clustering routing protocol to reduce the need for long-distance transmission between nodes [3]. In clustering protocol, all the sensor nodes are divided into several clusters, and only Cluster Heads (CH) forward the data to the base station (BS) as long-distance transfer, the other nodes as Cluster Members (CMs) only need to transfer the data to CH which is the short-distance transmission. In this project, we choose Cluster based Routing Protocol (CRP) protocol as the major protocol to simulate the scenario. In order to notice energy-efficiency improvement, CRP is compared with other routing algorithms such as ad hoc on-demand Distance Vector (AODV).

The rest of the paper is structured as follows: Section III discusses the challenge and requirements of the protocol needed in this use case, and then the classification of known routing protocols related to this use case is in section IV. The simulation details are introduced in Section V, then in Section VI we describe and analyze the results of our simulation. At last, we summarized our work in Section VIII.

This paper aims to show that the energy efficiency in WSNs deployed on acre-sized network areas can be improved by employing cluster-based topologies in conjunction with according routing protocols.

II. Structure of a cluster head and cluster member

Each sensor node consists of the following four parts.

1) Sensing Unit It is an electro-chemical sensor, which measures data from the soil and air.
2) Processing Unit Each sensor node will have a microprocessor to compute data from the sensor.
3) Transceiver This part transmits and receives information from other sensor nodes.
4) Battery Source

As in our project we want to improve the energy efficiency through routing in our network, we are simulating energy consumption just for transceiver. Depending on transmission range and if a transceiver works as a receiver to transmit forward packets, we are comparing the power usage between configurations.

For the lifetime assumption of a single node it is worth mentioning the average power consumption of the other units in a sensor node and propose a battery size. As the sensor unit is controlled by micro-controller and runs only during its measuring cycle. Its power consumption is not taken into consideration. Therefore we assume, that controller is running non-stop and according to MaxBotix an average microprocessor used in similar purposes operates on 4 V with 3,4 mA current, what gives 0,0136 Wh [4]. As a battery source we can assume to choose a battery with 4 V and 30 000 mAh, which without considering the transceiver can run the micro-controller for around 368 days ((4 V * 30 Ah) / 0,0136 Wh / 24 hours).

Cluster heads don't use a sensor. All the received packets are straightly forwarded to base station. Therefore in our analysis we will consider it as just as a transceiver with same microprocessor as in cluster member.

III. Challenges and requirements related to the routing protocol

In our case, the sensor network is composed of three types of nodes as mentioned before. As shown in Fig**??**, the first type of node in the network, known as a Cluster Member (CM), is in charge of collecting data from the farm field. All the nodes are been grouped into clusters and have a Cluster Head (CH) in each cluster. A CH is responsible for the aggregation and fusion of all the data from the CMs that are covered by it and then transfers the processed data to the Base Station (BS), which is located far from the other sensor nodes. The decisions made by the farmer are according to the data in the base station. The challenges faced by the routing protocols used in this network are discussed in this section.

A. Imbalance power consumption

All CMs will transfer the data they have collected from the field to a CH, then to the BS. In contrast to directly transmitting data from CMs to BS, clustering mainly uses short-distance transmitting to reduce the power consumption of most nodes, only requiring clusters to transmit long-distance to the base station. However, the fact that CH must send such a large volume of data from all CMs in the cluster causes it to run out of power earlier than CMs. Furthermore, the distance between CHs and BS is different, ends to the imbalance of power consumption among CHs. In this case, setting the size and the number of CMs in each cluster to maximize the lifetime of the network is the challenge that needs to be faced when designing a protocol.

B. Limited bandwidth and storage

The bandwidth needs to be shared among all the sensor nodes in the network, and the sensor nodes have limited storage capability. The routing protocol should be able to maintain the network by reducing the bandwidth and storage requirements.

C. Scalability

The fields related to our use case are usually large and the sensor nodes placed in the field are random. Thus, the routing protocol needs to be able to handle the requirement of scalability.

IV. Classification of routing protocols

The clustering protocol excels at being highly scalable and effective. The hierarchical structure allows it to cover a wide area. It may be more efficient to fuse and aggregate the data in CH rather than simply transfer it from CH to BS. In this section, we introduce three clustering protocols: Cluster based Routing Protocol, AD-HOC AODV protocol and hybrid one between previously mentioned protocols. In all protocols nodes are randomly distributed.

Network area	400m x 200m
Communication range of nodes	75m
Number of nodes	50, 70, 90, 110, 130

TABLE I
NETWORK SETUP (NO CLUSTER)

A. Cluster based Routing Protocol (CRP)

In our scenario cluster heads are placed in transmission range of of every single node, therefore cluster members only sends their own packets and don't transmit data from other members. Packets comes to CH in a queue and are forwarded to base station.

B. Ad hoc On-Demand Distance Vector routing protocol (AODV)

AODV is essentially a combination of both Dynamic Source Routing (DSR) and Destination Sequenced Distance Vector (DSDV). It borrows the basic on-demand mechanism of Route Discovery and Route Maintenance from DSR, plus the use of hop-by-hop routing, sequence numbers, and periodic beacons from DSDV. AODV is loop-free due to the destination sequence numbers associated with routes. It creates routes only on-demand, which greatly reduces the periodic control message overhead associated with proactive routing protocols. Similar to DSR, poor scalability is a disadvantage of AODV.

C. Hybrid between CRP and AODV

In hybrid version, nodes are operating on quite short transmission range, and if they are placed with no cluster head in range, the packet is transmitted to the next node with usage of AODV.

V. Simulation

To simulate the network behaviour a simulation framework was chosen which can handle networks with the previously discussed properties. Omnet++ is an adequate solution which is public source and is publicly available since 1997 under the Academic Public License [5]. The software is an allrounder. From queuing network simulations to wireless and ad-hoc network simulations, from business process simulation to peer-to-peer network, optical switch, and storage area network simulations, OMNeT++ has been used in a variety of disciplines. Different simulation models and frameworks, such the Mobility Framework or the INET Framework, support particular application areas. These models follow their own release cycles and are entirely independent of OMNeT++ [5]. The network simulations mostly make use of components from the INET Framework.

Network area	400m x 200m
Communication range of CMs and BS	120m
Communication range of nodes	75m
Number of CMs	50, 70, 90, 110, 130
Number of cluster heads	8
Cluster members per cluster head	6-16

TABLE II
NETWORK SETUP (CLUSTER)

Network area	400m x 200m
Communication range of CMs and BS	120m
Communication range of nodes	75m
Number of CMs	50, 70, 90, 110, 130
Number of cluster heads	3, 4, 5, 6, 7
Cluster members per cluster head	16-18

TABLE III
NETWORK SETUP (CLUSTER HYBRID)

A. Setup

The simulations aim to compare the energy consumption of the different network setups shown in Table I, Table II and Table III.

For all the setups the Cluster Members (CM) run one application within OMNet++ called “UdpBasicApp” which tries to send a UDP packet with the message length of 512 bytes to port 5000 of a Base Station (BS). The BS is running one application called ”UdpSink” which is listening on port 5000. A packet is sent every 30 seconds for a total simulation time of 1 hour. The protocol responsible for routing the traffic to its destination is set to Ad-hoc On-demand Distance Vector (AODV).

For the no-cluster-setup from Table I the nodes are spread out over the network area randomly. Additionally, all nodes can forward packets to each other. In the cluster approach from Table II this behaviour is reserved for the Cluster Heads. The hybrid configuration from Table III allows both the Cluster Heads and the Cluster Members to forward packets. Using this approach, the network can work with less Cluster Heads over a larger network size. This stands in contrast to the pure cluster configuration where all Cluster Members of a Cluster Head must be inside its communication range of 120m. In that case the network area is limited by the number of Cluster Heads.

As shown in Table II, Table I and Table III the respective networks are each tested with 50, 70, 90, 110 and 130 transmitting nodes.

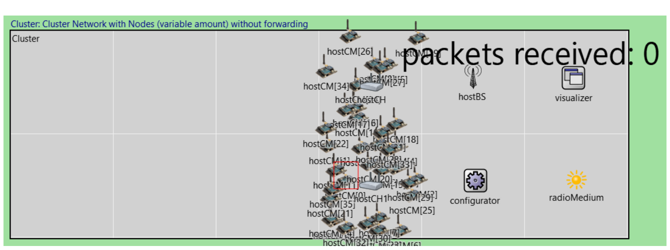

Fig. 1. Cluster network with 2 Cluster Heads (1 hop to CH)

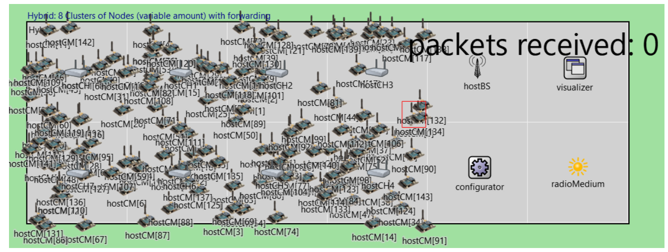

Fig. 2. Hybrid cluster network with 8 Cluster Heads (Hop count greater than 1 possible)

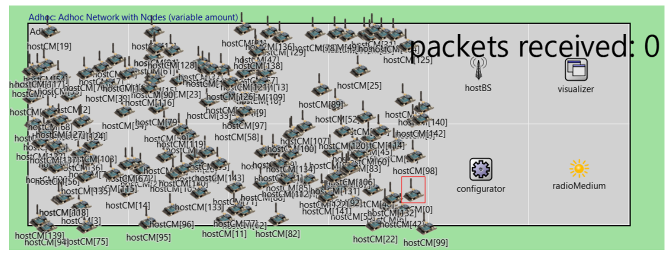

Fig. 3. Adhoc network without Cluster Heads and enabled forwarding

VI. RESULTS

Table IV - VI as well as Fig. 4 shows that, in any case, the total power consumption of the cluster based networks consumes less energy. This holds true for the 1-hop cluster and the hybrid cluster network. In fact the power consumption of these two configurations was the same. This is shown in Fig. 4 where the red line in the plot represents the 1-hop cluster and the hybrid cluster results.

Additionally it is clear that with a rising amount of transmitting nodes within the network, the cluster based networks power efficiency improves as the gap between the lines in the plot grows larger.

VII. DISCUSSION

As we were supposing in introduction, the cluster routing protocol is more power-efficient. Analyzing the Fig. 5 we can see, that by adding more nodes the angle of cluster’s curve is smaller than AODV curve angle, meaning that the power consumption is increasing with number of nodes faster for AODV, than for cluster using protocols. CRP is then more energy-efficient. On the contrary, when on a field are several

	Power consumption
Transmitting Node	7.9 J
Cluster Heads	8.8 J
Base Station	7.5 J

TABLE IV
ENERGY CONSUMPTION OF CLUSTER NETWORK

	Power consumption
Transmitting Node	8.5 J
Base Station	7.5 J

TABLE V
ENERGY CONSUMPTION OF NETWORK WITHOUT CLUSTERS

	Power consumption
Transmitting Node	7.9 J
Cluster Heads	8.8 J
Base Station	7.5 J

TABLE VI
ENERGY CONSUMPTION OF NETWORK WITH HYBRID-CLUSTERS

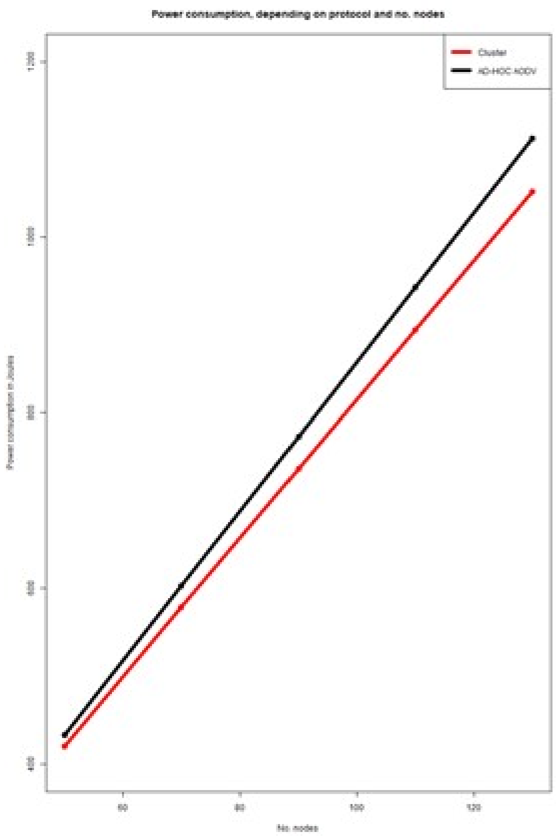

Fig. 4. Power consumption for cluster protocol and ad-hoc aodv

dozen nodes, ad-hoc protocol would be more energy-efficient than using cluster heads. Farmer would also save resources without need of clusters. In hybrid routing protocol, the values of power consumption are same as in CRP and it is caused by reducing the transmission range, which saves energy, but on the other hand some nodes will also transmit extra packets from nodes out of cluster range, which cause increasing power consumption, what gives in total same energy usage as for CRP with all nodes in range of CHs.

To show better the results, we can calculate how this difference between these two routing methods influence the average power consumption for a single node, with given in section III setup. In CRP the transceiver of an average node is consuming 7.9 Joules per hour, what converts to 0.0022 Wh. With adding the power consumption of micro-controller, they are using both 0.0156 Wh. A lifetime of the entire sensor unit changes then from 368 days to 316 days ((4 V * 30 Ah) / 0,0158 Wh / 24 hours). In ad-hoc AODV the average node is consuming 8.5 Joules per hour, what converts to 0.0024 Wh. In this scenario the lifetime of sensor unit amounts to 312 days ((4 V * 30 Ah) / 0,016 Wh / 24 hours). The difference in lifetime would be then only four days. On the other hand in CRP there are also clusters, which as well need to be energized.

VIII. Conclusion

Usually vast agriculture farms are localized aloof from urban areas where energy infrastructure is limited. Therefore it is import to make smart farms as energy-efficient as possible. Using Cluster based Routing Protocols as opposed to cluster-less Routing Protocols in WSNs we can reduce power consumption in sensor nodes and thus increase energy-efficiency.

In order to check our hypothesis we decided over three routing protocols, which are going to be simulated and compared. First one is designed by us Cluster based Protocol, where packets are transmitted straight to clusters without any hops to near nodes in between. The second protocol is ad-hoc AODV and third one is a hybrid between our protocol and AODV.

During the simulations we run each protocol on the same network-size, with the same amount of nodes and then compare results. Simulations show, that there is a reduction in power consumption of single nodes using CRP. With an increasing amount of nodes the difference is even more visible. The third tested protocol gives the same values as CRP, therefore is not further considered. When it comes to an actual difference in performance of a node, with the proposed configuration, the lifetime of a node, without changing battery, differs by four days, which in perspective of a year only makes a small difference. If we take the energy of the Cluster Heads into account, the energy consumption of the entire system would be similar for both methods. On the other hand, a farmer who is using this setup gets four more days for changing batteries, but he needs to take into consideration investing in cluster's units first.

As it results from our research, energy-efficiency is similar between above compared routing protocols. The parameter we managed to increase is lifetime of units. Further work can be carried on by optimizing our proposed cluster protocol or using more modern sensor units, which are less energy consuming.

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