Study of Cluster Formation Algorithm for Aquaculture WSN Based on Cross-Layer Design

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Abstract. Aquaculture WSN is composed of a large number of nodes with different monitoring function. In this paper, we present a cluster formation algorithm in Sensor MAC for event-driven Aquaculture WSN. The technique proposed is based on cross-layer design which is adopted to reduce the energy waste and guarantee the data transmissions. The event-driven Aquaculture WSN is simulated by OPNET and MATLAB. Simulation results show that the proposed protocol saves node energy, shortens average packet latency, and improves event detection reliability.

Keywords: Cluster Formation Algorithm, Cross-Layer Design, Event-Driven, Aquaculture WSN

1 Introduction

A large number of water quality monitoring nodes with low-power radio compose Wireless Sensor Network (WSN) for Aquaculture. In event-driven Aquaculture WSN, such as water quality changing, aquatic organisms tracking and water pollution detection, monitoring nodes only send little condition information to sink during usual time and send emergent information when event occurs.

Plenty of redundant information is sent by monitoring nodes deployed in Aquaculture WSN when specific event occurs. Topology features and data fusion must be considered in protocol design. Routing protocol is responsible for forwarding messages from source nodes to sink, which greatly influences the performance of data fusion, packets delay and node energy consumption. Meanwhile, Medium Access Control (MAC) layer directly controls the actions of wireless communication module which are regarded as the main part of energy dissipation [1]. Therefore, it is important that design of Sensor MAC (SMAC) protocol to the lifetime of network.

Low Energy Adaptive Clustering Hierarchy (LEACH) [2] applies TDMA within a cluster. There is a cluster head among each cluster. Instead of transmitting the data to the sink directly, the sensors send their data to the cluster-head. The cluster head relays the data to the sink node after data aggregation. LEACH assumes all nodes have data to transmit at all times, which did not consider the unique features of event, such as event severity level and occurrence position. EDC algorithm [3] and event driven data reporting algorithm [4] have been proposed for event-driven WSN. However, little consideration has been given to the features of regular status when sensor nodes only send little condition information to sink.

In schedule-based MAC protocol, TDMA is an important approach that is inherently collision free and avoids unnecessary idle listening. An intra-cluster communication bitmap-assisted (BMA) MAC protocol [5] is proposed for large-scale cluster-based WSN. Energy efficient TDMA [6] allows nodes with no data to transmit keep their radios off during their allocated time slots to reduce energy consumption. But when nodes have little information to transmit, it will achieve lower channel utility.

SMAC [7] is a contention-based MAC protocol especially designed for WSN. It forces sensor nodes to operate at low duty cycle by putting them into periodic sleep. It uses RTS/CTS/DATA/ACK to reduce collision and overhearing. However, packet collision problem will become severe when data traffic is heavy.

2 Details of Cluster Formation Algorithm

A cluster formation algorithm in Sensor MAC is presented in this paper for event-driven Aquaculture WSN, by which two network statuses: regular status and event status are defined. On regular status, no specific event happens and monitoring nodes only send normal detection information to report the usual state of Aquaculture WSN. Monitoring nodes energy consumption on regular status should be as low as possible. On event status, several monitoring nodes detect a specific event in the Aquaculture WSN, and the event must be transmitted to the sink node promptly. In order to reduce the energy waste, the techniques are adopted on regular status, in proposed event-driven cluster formation algorithm. In order to guarantee the event is efficiently transmitted to sink, on event status, an event-driven cluster formation algorithm is proposed according to the cross-layer theory.

When no water quality variation event happens, the approaches in SMAC protocol are adopted to reduce energy consumption. To save energy, monitor nodes go to sleep periodically with a low duty cycle. Using the mechanism of RTS/CTS/DATA/ACK, water quality monitor information of the normal network state is directly transmitted to sink, to reduce collision and overhearing.

When water quality variation event happens, all monitor nodes which have sensed the event are required to form into a cluster. Only one cluster head is elected according to the remaining energy level of the nodes in the cluster. All non-cluster head nodes transmit their water quality monitoring data to the cluster head using energy efficient TDMA approach. Using RTS/CTS/DATA/ACK technique, the cluster head node performs data fusion and transmits data to the remote sink. In the process of cluster formation, the proposed event-based cluster formation algorithm can guarantee that the event is efficiently transmitted to sink with low energy and delay.

Description of the event-driven cluster formation algorithm is:

In route layer, water quality monitor nodes calculate data arrival rate. If the data arrival rate is higher than threshold T_a, which indicates that a water quality variation event happens, monitor nodes will send cluster formation indication message to MAC layer to change the mechanism at MAC layer and perform cluster formation at route layer.

The operation of the event-driven cluster formation algorithm is divided into three phases: cluster set-up, data-transmission and cluster-dissolution. As shown in Fig.1., the data-transmission phase consists of several TDMA frames which include intra-cluster transmission and cluster head to sink transmission.

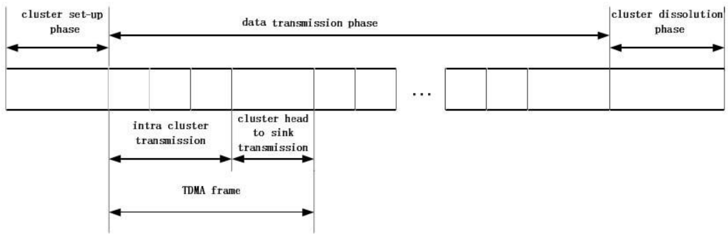


Fig. 1. Operation of event-driven cluster formation algorithm

Steps of cluster set-up phase are:

- Step 1: Monitor nodes that have sensed the water quality variation event broadcast a HELLO message when the next listen period comes. This message contains the node's ID and remaining energy. From now on, these nodes will not follow the sleep/wake-up schedule.
- Step 2: By comparing the remaining energy, the node with the minimum remaining energy will elect itself to be the cluster head. It must be sure that there is only one cluster head in this cluster.
- Step 3: The cluster head node broadcasts an advertisement message (ADV_CH) to let all the other nodes know that it has chosen this role.
- Step 4: Each non-cluster node informs the cluster head node with a join-request message (JOIN_REQ).
- Step 5: The cluster head node sets up a TDMA schedule and transmits it to the nodes in the cluster.
- Step 6: After the TDMA schedule is known by all nodes in the cluster, the cluster set-up phase ends.

When receiving any overhead packets in cluster set-up phase, the nodes that didn't detect the water quality variation event will set their NAV and go to sleep for an estimation time.

The data-transmission phase consists of several frames, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot, and also the radio components of each node are allowed to be turned off at all times except their own transmission duration to reduce the energy waste. Once the cluster head receives all the data, it performs data aggregation. In our analysis, we assume that all individual signals can be combined into a single representative signal. The resultant data are sent from the cluster head to the sink using RTS/CTS/DATA/ACK approach which will guarantee the transmission. As mentioned above, only one cluster was formed where the event happened in event-based cluster formation algorithm. Therefore, the approach of direct sequence spread spectrum (DSSS) in LEACH is not necessary to be used in our proposed protocol, which reduces the complexity of protocol.

We assume the event ends and the cluster should be dissolved, when the cluster head node receives no data in one frame. The cluster head broadcasts a cluster over message to dissolve the cluster. When the non-cluster nodes receive the OVER message, they return to their periodic sleep/wake-up schedule as on regular status.

3 Simulation and Analysis

The simulations are performed on OPNET and MATLAB, and 50 nodes are placed in a 100m×100m square region with no mobility. Each monitor node can communicate with sink directly. Three power consumption levels are set: 0.03 mW for sleep, 30 mW for receiving and idle listening, and 81 mW for transmitting. On regular status the packets interval time of CBR traffics is 10s. When the packets interval time is smaller than 1.432s, which is the time length of one sleep/wake-up period in SMAC protocol with 10% as its duty cycle, a water quality variation event is assumed to occur and the Aquaculture WSN turns into event status. In simulation, a water quality variation event is triggered in the middle of the topology at simulation time of 100s.

The simulation parameters of event-driven Aquaculture WAN are:

- Band-Width: 20Kbps
- Interval for Regular: 10s
- Interval for Event: 0.1s
- Tx Range: 250m
- Carrier Sensing Range: 550m
- Event Packets Number: 20
- Initial Energy: 100J

The metrics to evaluate the MAC protocols are: event get ratio, packets end to end delay, network energy consumption and network remaining energy. In event-driven cluster formation algorithm, Event get ratio (EGR) is defined as $(P_r \times D)/P_t$. In which P_r is the total received packets, P_t is the total transmitted packets when a water quality variation event occurs, D is the data aggregation degree, N_n is the number of nodes which sensed the event. We set D decreases with the increase of N_n. EGR is defined to indicate the delivery ratio of a water quality variation event in the Aquatic WSN. Packets end to end delay is the average delay experienced by a message from source node to sink, which indicates the real-time performance of the protocol. Network energy consumption is the total energy consumption among sensor nodes, which represents the network lifetime. Network remaining energy is the remaining energy of the network at different simulation time, which indicates the energy consumption rate.

The nodes number (N_n) represents the influential range of the specific event and it also indicates the sensing range of an individual sensor node. In our simulation, N_n is changed from 3 to 30.

As illustrated in Fig.2., a large number of packets collision and lost in SMAC for its contention mechanism, which means the event can not be successfully delivered to sink. By using TDMA approach, event-driven cluster formation algorithm gains a significant improvement of EGR. The results show that while the number of nodes, N_n, increases from 3 to 30, packets delay increases for both protocols in Fig.3. The event packets can be sent to sink promptly for event-driven cluster formation algorithm, which has resolved the long delay problem in SMAC.

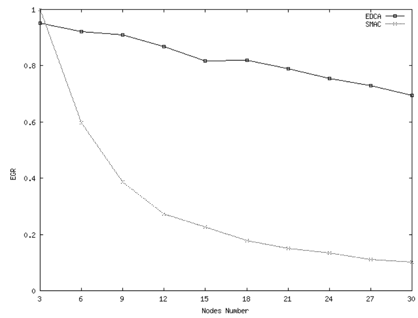


Fig. 2. EGR

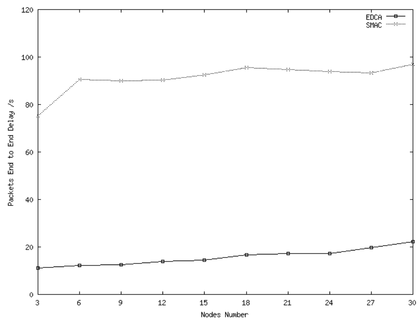
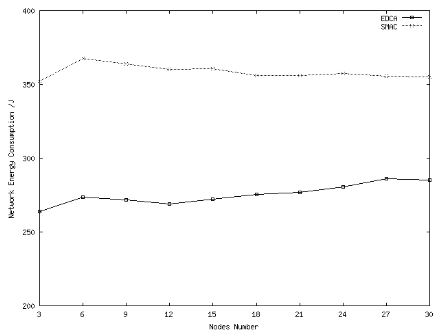


Fig. 3. Packets end to end delay

As illustrated in Fig.4., network energy consumption in SMAC protocol is the same with different number of nodes. It is mainly due to the fixed duty cycle in SMAC. It also can be seen that the larger of N_n, the more energy will be cost in event-driven cluster formation algorithm for more nodes will join in the cluster formation. Although there is cluster formation overhead in event-driven cluster formation algorithm, energy-TDMA approach is adopted which will reduce packet collisions and the energy consumption effectively.

Network remaining energy with simulation time after the event happens is shown in Fig.5. When an event occurs, event-driven cluster formation algorithm allows the nodes that have sensed the event to form into a cluster at once, therefore the energy is consumed faster. With the increasing of the nodes, the trend of rapid energy consumption becomes longer. When the cluster set-up phase ends, energy consumption becomes slower for the energy-efficient TDMA approach. Nodes always have data to transmit in each wake-up period in SMAC protocol after an event happened, therefore, the energy is consumed rapidly and the situation can not turn better.



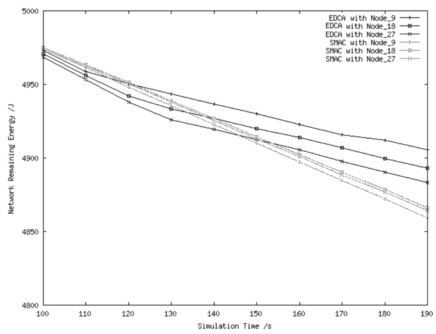


Fig. 4. Aquaculture WSN energy consumption

Fig. 5. Aquaculture WSN remaining energy

4 Conclusion

Event-driven Aquaculture WSN is an importance application of Aquaculture of Internet of things. Based on the features of event-driven Aquaculture WSN, a cross-layer designed cluster formation algorithm is proposed. The basic techniques in SMAC protocol are adopted for regular status, while new cluster formation algorithm is proposed for event status. The simulation experiments demonstrate event-driven static distributed Aquaculture WSN. The results show that the algorithm proposed achieves good performance on the water quality variation event detection reliability, average packets latency and monitor node energy consumption.

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