

The load size of each packet is 64 bytes. The experiment lasts for 600 seconds using CluFlow and each benchmark approach.

We count the number of cluster border nodes and the communication cost, i.e., the number of sent and forwarded IP packets in the border nodes. The results are shown in Fig. 11. Compared with the benchmark approaches, CluFlow utilizes the smallest number of border nodes and communication cost.

V. RELATED WORK

Most existing WSN structures utilize a distributed control system. They are facing the same difficulties as traditional wired networks. Existing WSN management does not provide high-level abstraction. Dynamically changing control policy in WSN becomes increasingly difficult as the scale of WSN increases [6]. The research in [15] provides a solution to utilize OpenFlow in wireless networks. It uses the OpenFlow centralized controller for routing data traffic. SDN-WISE [16] designs and implements a complete SDN system in a real multi-hop wireless network. Its SDN components consist of SDN controller, topology manager, protocol stacks, and wireless motes. It provides a stateful solution and reduces the amount of communication between nodes and SDN controllers. The research in [17] creates an SDN framework for IoT systems based on SDN-WISE and Open Network Operating System (ONOS) [18]. To connect IoT and SDN, it extends the functionality of ONOS as the controller in WSN, while the communication protocol relies on SDN-WISE. In these frameworks, the SDN controller must rely on distributed routing to setup control flow in the nodes that are several hops away. To update flow table entries, the nodes and the SDN controller have to exchange request and reply messages over multiple hops periodically. This process causes much communication delay and overhead in wireless networks.

Some researches focus on increasing the performance of WSN, such as energy efficiency, task scheduling, routing, etc., using SDN structure. SDN-ECCKN [19] proposes an SDN-based energy management system for WSN. The system reduces the total transmission time to increase the network lifetime. [20] minimizes energy consumption on sensors with guaranteed quality-of-sensing in multi-task software defined WSN. It utilizes a centralized SDN to formulate the minimum-energy sensor activation by jointly considering sensor activation and task mapping. The work in [21] presents an energy-efficient routing algorithm based on the framework of software defined WSN. To minimize the transmission distance and the energy consumption of sensor nodes, the algorithm partitions WSN into clusters and dynamically assigns tasks to the intra-cluster nodes by a cluster control node.

VI. CONCLUSION

We have presented a cluster-based SDN architecture CluFlow to manage communication flow in WSN, by controlling and monitoring the incoming and outgoing flow of cluster border nodes. CluFlow minimizes the number of border nodes and the communication overhead used for SDN control. Based on the simulations and the experiments in a real network, we have demonstrated that CluFlow significantly decreases the

number of nodes and communication load needed by the SDN controller to control and monitor cluster-level communication flow compared with benchmark solutions.

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