

EFFICIENT CROSS LAYER DESIGN ADAPTIVE PROTOCOL (ECLAP) FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

In case of wireless sensor network (WSNs) the importance of utilizing and saving energy has become very important and crucial. It is very much needed to fulfill the application objectives by making use of energy-efficient protocols with severe energy constraints. In this paper, we propose Efficient Cross Layer Design Adaptive Routing Protocol (ECLAP) which is designed to adopt cross-layer strategy that takes three layers such as network, MAC and physical layer together into consideration for Wireless Sensor Networks. Mechanism is adopted to save transmission power between the two nodes and maintain the nodes neighbor's tables interleaving to utilize the transmission energy efficiently. An optimal routing path is constructed by exploiting the transmission power available and neighbor tables of the physical layer to reduce the total energy dissipation. The node's sleep time is prolonged by determining the nodes duty cycle by MAC layer which make of use of the routing information from network layer. The simulations results show that ECLAP is efficient approach which yields good results and achieves significant improvement in terms of performance.

Key words: Cross Layer Design, energy efficiency, MAC protocol, Routing Protocol

1. INTRODUCTION

Wireless sensor networks (WSN) are event-based systems that exploit the collective effort of densely deployed micro sensor nodes which continuously observe certain physical phenomenon [1]. In general, the main objective of any WSN application is to reliably detect/estimate event features from the collective information provided by sensor nodes. Nevertheless, the main challenge for achieving this objective is mainly posed by the severe energy and processing constraints of low-end wireless sensor nodes. the collaborative sensing notion of the WSN achieved by the networked deployment of sensor nodes help to overcome the characteristic challenge of WSN, i.e., resource constraints. To this end, there has been significant amount of research effort that aims to develop networking protocols. in order to

achieve communication with maximum energy efficiency using efficient cross layer design.

In addition to the collaborative sensing and networking in WSN, spatial-temporal correlation is another significant characteristic of sensor networks. Dense deployment of sensor nodes makes the sensor observations highly correlated in the space domain with the degree of correlation increasing with inter node proximity. Similarly, some of WSN applications such as event tracking require sensor nodes to periodically sample and communicate the sensed event features, which yield temporal correlation between each consecutive observation of a sensor node [2]. The vast majority of the existing solutions are based on classical layered protocols approach. It is much more resource-efficient to have a unified scheme which melts common protocol layer functionalities into a cross-layer module for resource-constrained sensor nodes. It is very much needed to develop unified cross-layer communication protocol for efficient and reliable event communication which considers transport, routing, medium access functionalities with physical layer (wireless channel) effects for WSNs [3].

A unified cross-layer protocol is developed, which replaces the entire traditional layered protocol architecture that has been used so far in WSNs. The design principle is complete unified cross-layering such that both the information and the functionalities of traditional communication layers are combined in a single protocol. The objective of the proposed efficient cross layer protocol is highly reliable communication with minimal energy consumption, adaptive communication decisions and local congestion avoidance [4]. To this end, the protocol operation is governed by the new concept of initiative determination. Based on this concept, the cross-layer protocol performs received based contention, local congestion control, and distributed duty cycle operation in order to realize efficient and reliable communication in WSN [5]. Performance evaluation results show that the proposed cross-layer protocol significantly improves the communication efficiency and outperforms the traditional layered protocol architectures.

This research work investigates existing routing schemes and proposes new routing metrics for WSNs communications.

The main focus of the work is development of energy-efficient and dynamic routing protocols that can cope with severe energy-constraints, bandwidth constrained links and dynamic network topologies in WSNs. In this work, various existing routing protocols proposed in literature were investigated. Most of conventional routing algorithms are based on hop-count metric, which was found to be inefficient in terms of performance and energy consumption. Thus, a new routing metric is proposed with modification to Ad hoc On demand Distance Vector routing (AODV) algorithm to take into consideration, end-to-end delays and reliability of channel links. The new metric saves energy by reducing route-breakages, which in turn uses less routing control packets.

In this paper, a cross layer approach is used to design an energy efficient communication protocol for the wireless sensor networks. Each node in the WSNs shall maintain neighbor table and minimum transmission power between two nodes in physical layer is obtained. The neighbor table information is utilized by the network layer for finding a better routing path to transmit the data. The routing information is utilized to determine the nodes duty cycle in MAC layer and the sleep duration of the MAC layer can be increased. The extensive simulation study was conducted to evaluate the performance of the ECLAP on NS2 simulator and results show that the protocol is more efficient than the traditional methods. The remaining part of this paper is organized as follows. Our cross layer approach basics, overview and protocol descriptions are introduced in Section II. In Section III, Performance evaluation of ECLAP solutions and provide a comparative analysis. Finally, the paper is concluded in Section IV.

2. PROTOCOL DESCRIPTION

The traditional layered protocol architecture has been replaced with our cross layer protocol in WSNs. The design principle is complete unified cross-layering such that both the information and the functionalities of traditional communication layers are melted in a single protocol. The interactions among three layers are exploited and so that each layer could use the information of other layers. In the physical layer, ECLAP has mechanism to control transmission power dynamically and gets minimum transmission power between two nodes, and decides which nodes are near to main the tables. Each node in the network layer constructs its routing table by utilizing the neighbor table and minimum transmission power of the physical layer. At last ECLAP uses the routing information to determine the duty cycle of each node and also it take care of collision, hidden station and overhearing problems.

A. Transmission Power Control

The transmission power of a node is monitored and controlled in such a way that it uses transmission power as minimum as possible while transmitting the data. The study reveals that the transmission power between nodes is

affected by spatial and temporal factors. The relation between transmission power and received signal strength indication clearly depicts the impact on the spatial and temporal factors. The correlation between transmission power and received signal strength indication is approximately linear. Therefore there is a need to use an approach which controls the power transmission dynamically, so that each node can find minimum transmission power to communicate with its neighbor successfully. During this time, each node maintains a neighbor table to record this minimum transmission power and neighbor nodes number. The idea behind this approach is that each node maintains a neighbor table and nodes make use of a feedback closed loop for controlling transmission power. Each node assign a received data packets threshold.

B. Construction of Routing Information

We need to construct the routing table using the minimum transmission power between nodes and nodes of the neighboring tables. An algorithm based on Incremental Shortest path Tree Heuristic approach is used to update the routing information. This algorithm requires that different source nodes share the node of the routing path found as much as possible. The number of nodes in active less leads to more nodes are in sleep state. The energy efficient route to the destination node (sink node or base station) using some cost metric. $p(x, y)$ represents the amount of power transmission between node x and node y , where node y is the next-hop node of x on the path. When node x is active $p(x, y)$ is calculated using R_i and bandwidth B and nodal power consumption K . If the node x is inactive then the nodal power consumption K is not included because it has been counted in the existing routes.

The nodes routing table and neighbor table are constructed based on the heuristic algorithm. It calculates the power consumption with neighbor nodes by $p(x, y)$ and the energy efficient routing path to the base station provided by the algorithm. During this process, each node sets the neighbor node with the minimum power consumption to the sink as its next-hop node and constructs a table to record its routing information.

C. Duty Schedule of Sensor Node

The duty cycle scheduling based on the routing information is considered while routing the data from each source node in the WSN to another. Whenever there is a transmission of data from any source node transmits data to the sink, the nodes on the routing path are active and other nodes will be in sleep state. Major problems in WSN such as collision and overhearing are eliminated by adopting the RTS/CTS mechanism used in 802.11 MAC protocol. Let us explain the Duty-cycle scheduling scheme with the help of the following example. We assume that a routing path ($X \rightarrow Y \rightarrow Z \rightarrow \text{sink}$) has existed in WSN. Initially, all nodes keep sleep state, source node X start sending data to the sink at any time when triggered by an event of interest. Firstly node X listens to the

radio channel. If the channel is idle, node X knows the node Y is its next-hop node from the routing table, and wakes node Y up by sending a short wake-up tone to Y. then node X sends RTS packet to node Y. When node Y receives RTS packet sent by node X, it sends a short wake-up tone to the next-hop node Z. And node Y returns CTS packet to node X to imply that node X and Y occupy the channel. Node X begins to transmit data to node Y. Node Y returns an ACK packet to node X until node Y receives data successfully. After that, node Y starts to detect the channel and send RTS packets to node Z, and node Z receives RTS packet to wake up its next-hop, and continues to transmit data. After these nodes receive the ACK packet, they continue to listen to the channel, if there are data to send/receive, they keep awake, otherwise they switch sleep state.

3. PERFORMANCE ANALYSIS

A. Simulation Environment

In this section, the performance analysis of ECLAP is presented. The simulation experiments are carried out using NS2 [24] simulation, which is open free source of ISI. NS2 support simulations of S-MAC and other energy-efficient protocols which accurately model power consumed by the applications and also include detailed model of power consumption of NS2. In the simulation environment 500 nodes are deployed in 700 m x 700 m region. The source nodes are randomly chosen and sink node is far from the sensor region. Each simulation is carried out for 600 sec and results are average in 10 runs. Each source node sends a packet every 10 seconds and the number of source varies from 10 to 50. The performance analysis is carried out along with other MAC and routing protocols. We have chosen popular three MAC protocols and three routing protocols with the implemented ECLAP. The MAC protocol such as S-MAC [23], Z-MAC [25] and MAC-Cross protocol [26] and Routing Protocols AODV, DSR and DSDV are chosen for simulation study. Z-MAC is a hybrid MAC protocol which combines the features of TDMA and CSMA while offsetting their weakness. S-MAC is a contention-based channel access protocol, and it uses periodic sleep intervals to conserve energy. MAC-CROSS is an energy efficient cross-layer MAC protocol, and it utilizes the routing information in the network layer to coordinate the duty-cycle of node. In addition, S-MAC is coupled with a routing protocol—DSDV to transmit interesting data from source node to sink. MAC-CROSS uses the DSR routing protocol based on the greedy approach, where a next-hop node of each node is the nearest neighbor node to the sink node. In DSDV and MAC-CROSS, all communication links use the same transmission power. Z-MAC is coupled with AODV.

B. Simulation Parameters

There are various parameters that are available in Wireless Sensor Networks and they are also termed as performance metrics or design parameters. Every parameter has its own

importance. These parameters are listed below. These design parameters/performance metrics are used for the evaluation of routing protocols. These design parameters have a great impact on overall performance of a communication network. In this work, we have dealt with the first three performance metrics of a network i.e. Total Energy Consumption, Lifetime, and Packet Delivery Ratio (%). These three performance metrics are evaluated against duty cycle and number of sensing nodes with respect to routing protocols to see the performance.

1. Total Energy Consumption (in mJ)
2. Lifetime (in secs)
3. Packet Delivery Ratio (%)

C. Simulation Results and Analysis

In simulation parameters, we have considered four performance metrics out of the most important metric is energy consumption. For each protocol considered for simulation, we need to measure the total energy consumption that all source nodes successfully send the data packets to sink or destination. The performance of study of ECLAP is done through simulation using ns 2. The figure 1 shows that ECLAP consumes the least energy than the other MAC protocols. The ECLAP utilizes the cross layer information from MAC, Routing layers and try minimizing the exchange of information between the layers. As the number of nodes increases, all the protocols start losing their energy consistently. The different nodes share more middle nodes in the ECLAP, resulting in more nodes in sleep state and better energy efficient. Although S-MAC lets nodes will continue to keep asleep and they don't participate in the transmission activity and its routing paths contain fewer nodes.

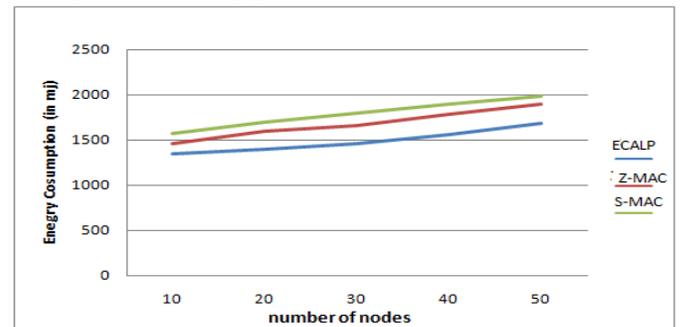


Figure 1. Energy Consumption vs. number of nodes

This makes more nodes keep asleep and it won't optimize the transmission energy so that all communication links use the same transmission power. S-MAC and Z-MAC consumes more energy than ECLAP. In S-MAC protocol, node has a fixed listen or sleep cycle, so a node must be waked up when its sleep period expires, even if the node hasn't any activity, resulting in unnecessary energy consumption. ECLAP effectively minimizes the total energy cost of the nodes.

In Figure 2, the energy consumption per packet is shown. In Figure 2, the values for Z-MAC and S-MAC at $\delta = 0.1$ are

not shown since no packets are received by the sink. It can be seen that ECLAP consumes significantly less energy per packet and hence is highly energy efficient when compared to the other layered protocol suites. This difference is mainly because of the periodic broadcast of beacon packets in Z-MAC and SYNC packets in S-MAC. Furthermore, the significant percentage of retransmission timeouts indicates significant energy wastage due to packets that cannot be transmitted to the sink. Since the network and MAC layers operate independently, the nodes chosen by the routing layer cannot be reached and significant energy consumption occurs. An interesting result is the significantly low energy efficiency of ECLAP. Although this configuration provides 100% reliability, the layered structure of the routing, transport and MAC functionalities results in a high penalty.

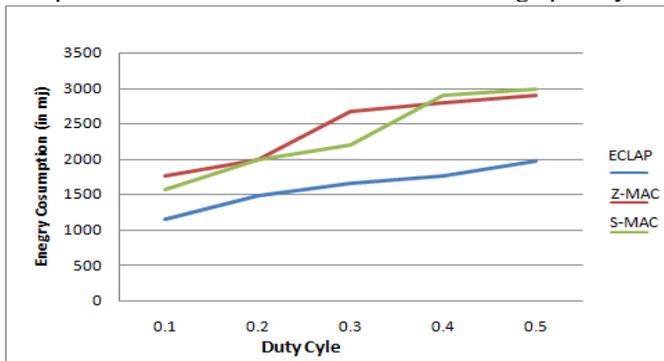


Figure 2. Energy Consumption vs. number of nodes

As explained before, the routing layer, i.e., directed diffusion, incurs significant amount of overhead in order to maintain end-to-end paths between sources and the destination. On the hand, ECLAP employs an adaptive routing technique that provides an energy efficient path in terms of both link quality and energy consumption distribution. Another important observation from Figure 2 is that the energy consumption per packet for ECLAP has a minimum at $\delta=0.1$ and 0.2 . Hence, we observe that the duty cycle value of $\delta=0.3$ provides the most energy efficient performance for the operation of ECLAP.

Another metric network lifetime is used as metric to evaluate the performance of ECLAP cross layer design. It is defined that the network lifetime is time taken for 40% of sensor nodes in the network to drain up their power. The change in the mobile rate to shows that performance of ECLAP is satisfactory.

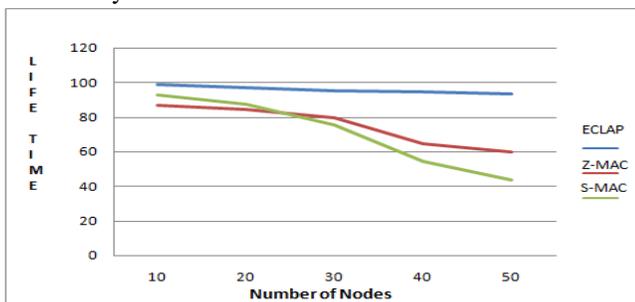


Figure 3. Lifetime vs. number of nodes

Figure 3 and Figure 4 shows the network lifetime with respect to number of nodes and duty cycle. As the mobile rate increases, the life time of S-MAC and Z-MAC changes, while ECLAP can alleviate this situation.

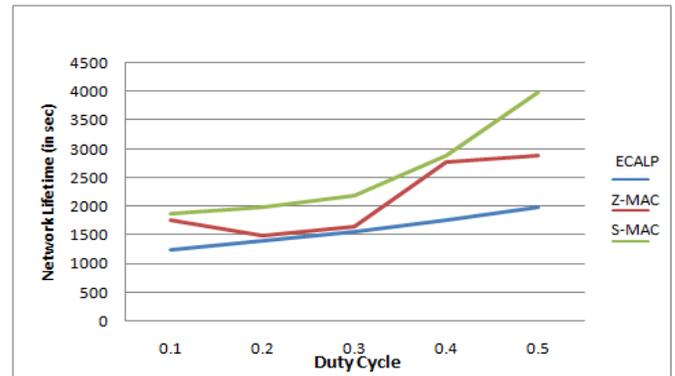


Figure 4. Lifetime vs. number of nodes

It shows that ECLAP significantly increases the lifetime of network. A network lifetime increased as much as 30 % of the lifetime of networks with other protocols in low mobility scenarios.

In case of S-MAC, it needs more time to set up the listen or sleep schedule with the neighbor. Small scale wireless sensor networks favor S-MAC to shorten the schedule synchronized process. The total numbers are varying from 10 to 50 which are randomly distributed in simulation area. The S-MAC is coupled with routing protocols and delivers the data from the sensor node to the sink. There is no need for S-MAC to use the initial phase to collect the information and for fair comparison. The energy consumption for the packet in ECLAP does include the energy used during the initial phase and compare ECLAP with S-MAC and Z-MAC.

In the figure 5 results shows that the energy based ECLAP is able to achieve higher delivery ration than contention based S-MAC and Z-MAC. This is possible only because of performance improvement of collision free guarantees during data transmission. The S-MAC is more susceptible to the contention or hidden terminal collisions. The total number of sensor nodes increases improvement becomes more significant. In a instance as shown in Figure 5, for 40 sensor nodes case the received of the ECLAP is consistent in the packet delivery ratio as compared S-MAC and Z-MAC out comes.

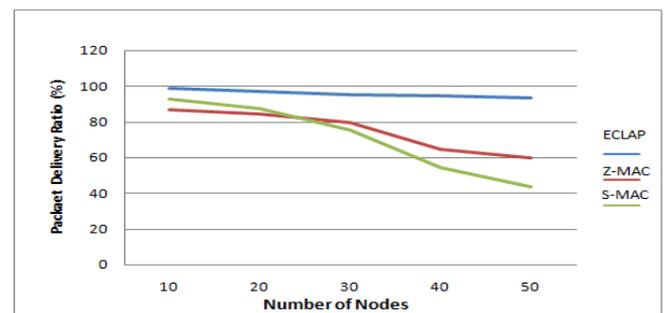


Figure 5. Packet Delivery Ratio vs. Number of Nodes

In another case, shown in figure 6 for 40 sensor nodes case the received ratio of the ECLAP as compared to S-MAC is 1.6 times and Z-MAC is 2 times under the duty cycle of 70% S-MAC and 2.8 times under the duty cycle of 40% S-MAC.

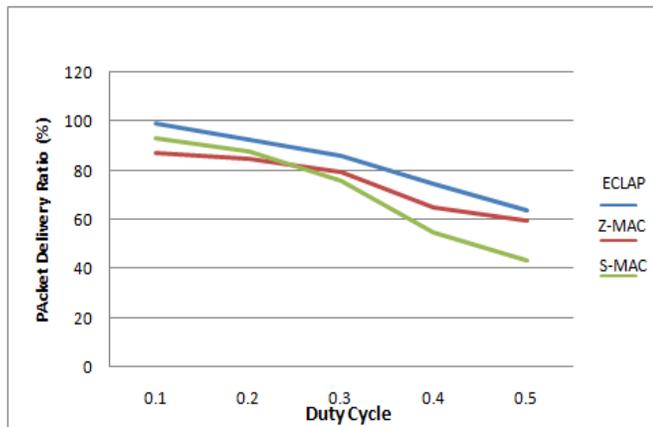


Figure 6. Packet Delivery Ratio vs. Duty Cycle

Moreover, it is clear that ECLAP is a schedule-based MAC, compared to S-MAC, it could also provide contention base MAC such as Z-MAC and S-MAC might suffer the contention collision a lot when the traffic becomes burst. ECLAP saves more energy than S-MAC and Z-MAC by considering the different characteristic of different cross layers trying to stable the each layer requirement.

4. CONCLUSION

In this paper, a cross layer approach is used to design a wireless sensor network. It is very much important to organize the upper layer such as the network layer or the transport layer to meet the application layer requirements. MAC layer schedule or access control information from lower layer is used to avoid collision and saves energy consumption. Thus it is very much required to design leads to a more energy-efficient design and provide better system performance. ECLAP is a cross layer communication approach for WSNs, which replaces the entire traditional layered protocol architecture used for WSNs. The concept of unified cross layer adds both information and functionalities of traditional communication layers are merged in to a single module. ECLAP performs received based contention, local congestion control, and distributed duty cycle operation in order to realize efficient and reliable communication in WSN. Cross Layering is the best approach to save energy in wireless sensor networks. Energy efficiency can be improved at various layers. The knowledge of physical MAC, network layer and transport layer should be shared with each other properly. The conventional layered approach has several drawbacks in the system design. In a cross-layer simulation platform, the state-of-the-art layered protocol configurations have been implemented along with ECLAP to provide a complete evaluation. Analytical performance evaluation and simulation experiment results show that ECLAP significantly

improves the communication performance and outperforms the traditional layered protocol architectures in terms of both network performance and implementation complexity. The results of analytical simulation experiment show that ECLAP conserves more energy and leads to the better system performance.

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