This full-text paper was peer-reviewed and accepted to be presented at the IEEE WiSPNET 2016 conference.

An Energy Efficient Routing and MAC protocol for Bridge Monitoring

P. Chakradhar Reddy
Department of Electronics and
Communication Engineering
National Institute of Technology
Warangal, Telangana 506004
chakra.pocha@gmail.com

Prof. N V S N Sarma
Department of Electronics and
Communication Engineering
National Institute of Technology
Warangal, Telangana 506004
sarma@nitw.ac.in

***Abstract*—Wireless sensor networks require protocols which are energy efficient to improve the network lifetime. This work mainly focuses on the cross-layer implementation that takes routing module and MAC module for the required application. At the routing layer unequal clustering is taken, which employe tunable range for cluster radius and eliminates the burden on nodes which are near to base station. At the MAC layer Timeout MAC is taken, which employe dynamic duty cycle that reduces the power consumption of node by making it to go to sleep state. This proposed model for the joint optimization system is tested by simulations in order to quantitatively evaluate the benefits of proposal. Castalia, which is based on OMNeT++ platform is used to evaluate the performance of the proposed protocol.**

***Index Terms*—WSN, Routing, MAC, Castalia and OMNeT++**

I. Introduction

Wireless Sensor Networks is the emerging field in Wireless Communication because of its capacities to sense, compute and communicate. They vary widely from the general computer networks because of limited power through the battery. The nodes cannot be recharged once they are installed. They need protocols which are energy efficient to minimize the power consumption. The infrastructure and deployment of nodes may vary depending on the scenario. They have wide range of applications like Military, Health Monitoring and Agriculture. This work presents the application of wireless sensor network in bridge monitoring. Bridges are the main transportation gateways in every city. Many existing bridges are quite old and the number of vehicles travelling along those bridges today has increased tremendously exceeding their, So it is necessary to monitor the bridge in order to analyse the condition of the bridge. Regular monitoring is necessary to ensure the safety of public. But monitoring the condition of the bridge has lots of problems with the previously used traditional approaches like visual inspection and even it is difficult to find the problem of cracking, leaching and vibrations. An alternative approach like diagnostic testing is also not a good approach in which it is exposed to different load conditions. Because of the diagnostic testing approach, there will be huge traffic jams and it is not cost effective. The ideal approach for this application is through wireless sensor networks. The specialized sensors which are placed at the critical points of bridge will monitor the vibrations of bridge and through the proposed routing protocol send it to the sink node. Proper sleep scheduling will ensure the minimization of the power consumption of nodes and thereby increasing the network lifetime.

II. Related work

In this section the previous work related to MAC and routing layer is discussed.

A. MAC Layer related work

There are different types of MAC protocols available in open literature. But they are not suitable for the Wireless Sensor Networks because of the limited energy source. The wastage of energy may be because of idle listening, collision, overhearing and overheads. This problem can be overcome with the proper protocol at MAC layer. The survey paper [1] on different type of MAC protocols for wireless sensor networks gives the brief idea of different protocols. This paper explains different types of MAC protocols which are used for Computer Networks, Wireless Sensor Networks and Satellite Communication. It also explains the control of medium to all nodes to access, define the frame format, acknowledgment and retransmission messages, how to prevent the loss of frames and error correction. But because of limited battery popular wireless MAC protocol like 802.11 cannot be used. Wei Ye et al., proposed [2] a new protocol for wireless sensor network which saves the energy almost 6 times than traditional MAC protocols. The popularly used SMAC protocol is explained in depth by Y. ming Liu [3]. In order to reduce the energy consumption and to increase the lifetime of node another protocol TMAC has been proposed [4]. The TMAC uses the dynamic duty cycle with the introduction of additional parameter and increases the lifetime of node. Tselishchev et al., [5] had mentioned different challenges while implementing MAC protocols with castalia simulator.

B. Routing Layer related work

The power consumption of node is not only in the sleep or awake state, but depends on how it sends the sensed data to base station. There are different types of routing

978-1-4673-9338-6/16/$31.00

algorithms that are proposed. The design of routing protocol is mainly influenced by many parameters like node deployment, Energy considerations, Data delivery model and many other. Research analysis reveals that flat routing is not that much efficient than that of hierarchical routing protocol. The paper [6] describes the first order radio model energy consumption for transmission and receiving state of each node and explains in detail the LEACH protocol. The total available nodes are divided into clusters with a cluster head. This still lacks in energy efficiency as the cluster head is selected based on random number not based on residual energy. There are other protocols which over come the problem of random selection of cluster heads. Shuo Shi et al., [7] proposed a modified LEACH protocol in which cluster head is selected based on residual energy. But there will be a burden on nodes near the base station because of additional effect to aggregate the data from all cluster heads. Chengfa Li et cl., had proposed [8] unequal clustering which improves the network lifetime. The efficient protocol for bridge monitoring has been explained by Shaladi [9]. User manual of castalia [10] explains how to write a new routing protocol for wireless sensor networks.

III. Proposed Method

For monitoring the condition of bridge using wireless Sensor Networks, the sensors are placed along its span at critical points of bridge. The total number of 200 sensor nodes are placed along the length of the bridge. The proposed method utilizes the optimization both at MAC and routing layers.

A. Proposed Routing layer Protocol

The proposed method uses unequal clustering with the radius of cluster given by following equation. This improves the network lifetime as the radius of cluster head is inversely proportional to distance from base station.

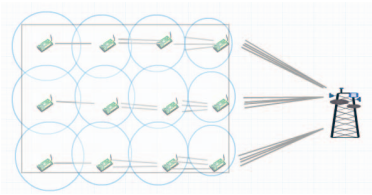

Fig. 1: Clusters with unequal radii

$$\mathrm{R}_i = \left(1 - c\frac{\mathrm{d}_{\max} - \mathrm{d}(\mathrm{s}_i, BS)}{\mathrm{d}_{\max} - \mathrm{d}_{\min}}\right)\mathrm{R}_i^o \qquad (1)$$

where,

- R_i is radius of cluster head.
- $\mathrm{d}_{\max}$ is the maximum distance from base station to node.
- $\mathrm{d}_{\min}$ is the minimum distance from base station to node.
- R_i^0 is the maximum radius.
- $\mathrm{d}(\mathrm{s}_i, BS)$ is the distance from particular node s_i to base station.
- c is the constant which varies from 0 to 1.

The proposed method utilizes the unequal clustering which reduces the burden on the nodes near the base station and the cluster head selection used in the algorithm is as shown.

Algorithm 1 Cluster Head Selection Algorithm

```
Select the Random Number between 0 and 1
if random number < threshold then
    be Tentative Head
end if
Send Compete Msg with node (ID, R_i and RE)
if d(s_i,s_j) < R_i then
    Add s_j to s_i.S_CH
end if
if s_i.RE > s_j.RE then
    s_i Send Final Cluster Head Msg(ID)
end if
On receiving a Final Cluster Head from s_i
    s_j Send Quit Cluster Head(ID)
    Remove s_j from s_i.S_CH
```

B. Proposed MAC layer Protocol

As the RF modules consume a lot of energy compared to other modules, proper MAC protocol should be taken to minimize the energy consumption. The MAC protocol has the direct influence over the Radio module. So, the energy efficient MAC protocol is chosen in WSN. In this work, the popularly used MAC layer protocol SMAC with TMAC which uses dynamic duty cycle is compared and found that there is better energy efficiency in Timeout MAC. The comparison table between SMAC and TMAC is given below. TMAC is the popular MAC layer protocol used in sensor networks as it minimizes the energy consumption with Listen and Sleep cycles. It adopts several mechanisms to minimize the energy consumption. It overcomes the problems like Idle listening, Collision, Overhearing and Overheads. The way they are overcome can be explained as follows.

- Periodic Listen and Sleep:
  TMAC protocol uses periodic listen and sleep to save the energy by turning of Radio during sleep state. One complete frame consists of one listen interval and one sleep interval. The ratio of the listen interval to total frame interval decides the duty cycle.

$$\mathrm{T}_{\mathrm{frame}} = \mathrm{T}_{\mathrm{listen}} + \mathrm{T}_{\mathrm{sleep}} \qquad (2)$$

  The frame format of TMAC protocol is as shown in figure 2. When compared to continuous listen MAC protocols, there will be 50% saving in energy with equal listen and sleep interval. The SYNC packet is used in the TMAC protocol in order to maintain synchronization among all the nodes in the network. Each node stores the table in order to transmit the information to the neighboring nodes. Every node exchanges SYNC packet with other nodes to main synchronization. The SYNC packet consists of address of the sender and time for the

next sleep interval. Each node maintains its own schedule, if it doesn't receive any information from neighboring nodes, then it broadcasts its schedule to every other node. If the node already has schedule and if it receives the schedule from another node it maintains both of them.

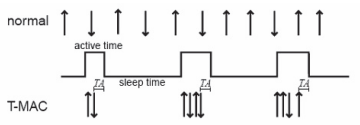

Fig. 2: Frame format of TMAC

Each node maintains its own schedule, if it doesn't receive any information from neighboring nodes, then it broadcasts its schedule to every other node. If the node already has schedule and if it receives the schedule from another node it maintains both of them.

- Collision and Overhearing Avoidance:
  In order to avoid collision and overhearing problems it uses same method as 802.11 MAC standard protocol. It uses RTS packet when a node is trying to transmit data and CTS packet when the node is trying to receive the data.
- Message passing:
  If the long message has been transmitted as it has been received, then if there exists any error in few bits, the total bits have to be transmitted once again. This consumes a lot of energy. Thus the message is divided into fragments to save the energy. We also need to overcome the problem of control overheads for small fragments. This can be done by reserving the medium for some amount of time. The receiver acknowledges each fragment with an ACK packet.

TABLE I: Comparison of different MAC protocols

	S Mac	T Mac
Activation Timeout	Not Required	15ms
Ack Packet size	11 bytes	11 bytes
Sync Packet size	11 bytes	11 bytes
CTS/RTS Packet size	13 bytes	13 bytes

IV. Result and Discussion

A. MAC Layer Results

The following sections explain the energy consumption with different MAC protocols for Bridge Monitoring application. For this the specifications to compare different MAC protocols are given in table below. The results obtained with different MAC protocols are given in figure 3.

TABLE II: Simulation Parameters for Bridge Monitoring using MAC protocols

Simulation Parameter	Value
Number of nodes	200
Simulation Area	2,000 x 15 meters
MAC Protocol	CSMA/SMAC/TMAC
RF transceiver	CC2420

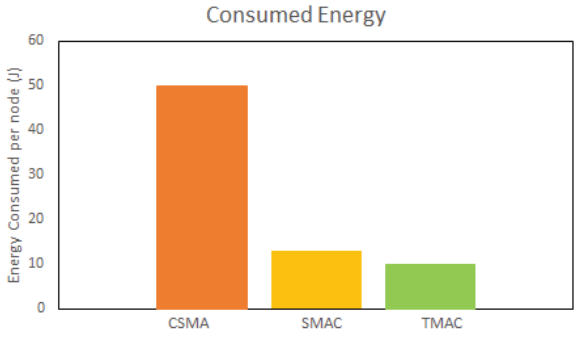

Fig. 3: Energy consumption per node

B. Routing Layer Results

For bridge monitoring application the specifications to compare different routing protocols are given in table below. The results obtained with proposed routing protocol is given in figure 5 and it is compared with leach protocol in figure 4. From the following figures it is observed that there will be even distribution of energy with unequal clustering.

TABLE III: Simulation Parameters for Bridge Monitoring using Routing protocols

Simulation Parameter	Value
Number of nodes	200
Simulation Area	2,000 x 15 meters
Routing Protocol	Leach/Unequal Custering
RF transceiver	CC2420

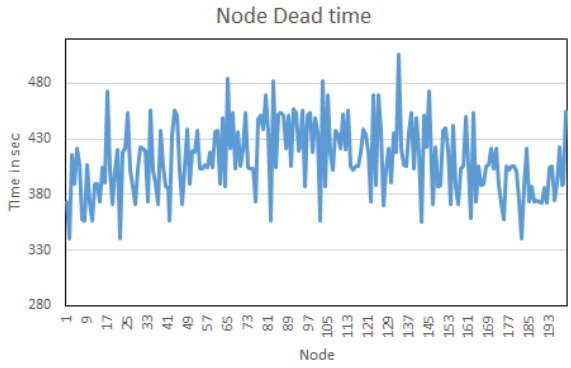

Fig. 4: Time taken by nodes to die in Leach

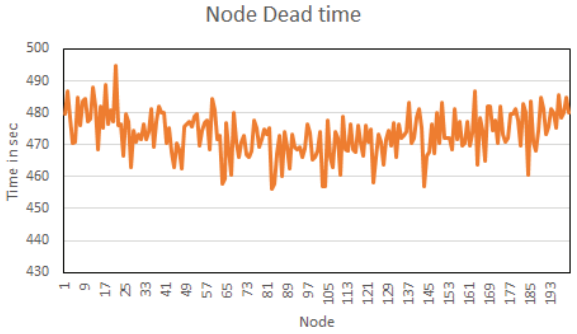

Fig. 5: Time taken by nodes to die in unequal clustering

The average energy consumption of node is given in figure 6. It is clear that because of proposed cluster head selection algorithm the energy consumed per node is decreased when compared to leach.

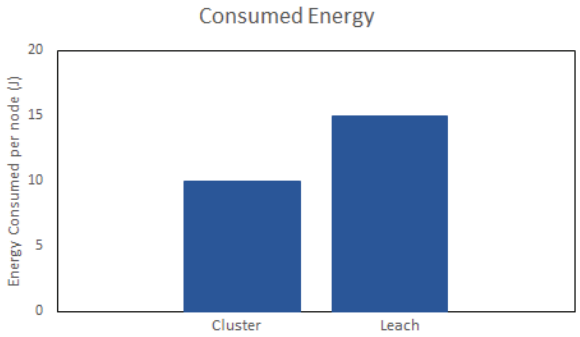

Fig. 6: Average energy consumption of node

V. Conclusion

In WSN, energy resource of a sensor node is the limiting factor while designing the communication protocols. The proposed routing protocol and MAC protocol are compared with existing protocols and it is found that proposed protocols are better energy efficient than existing protocols. The lifetime of WSN with proposed MAC and Routing protocols is simulated using Castlia which is based on Omnet++ simulation platform.

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