Abstract—Wireless sensor networks (WSNs) are ad hoc topologies with highly dynamic traffic rates offered. In this network, sensor nodes are often battery operated and the power consumption become more important issue. The medium access control (MAC) protocol designed for the network must be stable and consume less energy. The available non-persistent carrier sense multiple access (np-CSMA) based MAC protocol is not suitable for WSN because of higher possibility of frame collisions and consume more energy at variable traffic rates. To overcome this limitation, the carrier sense multiple access protocol with collision avoidance (CSMA/CA) called nanoMAC is used. The nanoMAC is more suitable for WSN to achieve high data and energy efficiency. In this paper Game theory based nanoMAC (G-nanoMAC) protocol and the performance is evaluated for the energy consumption and delay to maximize the lifetime of the multihop network. Simulation results shows that using game based nanoMAC protocol in WSN for multihop forwarding is more energy efficient.

Index Terms—WSN, nanoMAC, energy consumption, life time.

I. INTRODUCTION

Wireless sensor nodes are rapid deployment, self organization and fault tolerance characteristics of WSNs make a very promising sensing technique for various applications [1]. However, the power sources in sensor node limit lifetime of the whole system. Some researchers have proven that sensor node spends maximum energy for communication [2]. A sensor network is a distributed system made up of a large number of small sensors, equipments, low power transmitters-receivers, without a central processing unit. One of the major challenges in this network is to reducing energy consumption to maximize a network life time. The key sources of energy wastage are collisions, over-hearing, control-packet overhead and idle listening to the wireless medium. The huge number of collisions and retransmissions consume more power and also increasing an overall latency. Most common causes of collisions are false channel sensing and hidden terminals in a multihop communication environment [3], [4].

II. SYSTEM MODEL

Sensor nodes are formed as group known as cluster. Clustering scheme organizes the nodes of the sensor network into two domains, such as intra-cluster and inter-cluster domain. In the intra-cluster domain, the nodes within the cluster nodes sense the data and communicates with the cluster head directly [5].

In sensor network, the communication of data consumes much more energy than sensing and data processing. Therefore, highly localized and distributed solutions for different levels of communication protocols are required. MAC layer enables the successful operation of the sensor network and its protocol tries to avoid collisions by not allowing two interfering nodes to transmit at the same time [6], [7]. The simple linear multihop communications model is used with the exception that MAC modelling considers the multihop forwarding model in a network with a very large number of nodes and creates background traffic for the network. The modelling in this paper uses the term “linear path” which is illustrated in Fig. 1.

![Simple multihop linear model](image1)

NanoMAC protocol is of CSMA/CA type and is non-persistent, that is, with probability p, the protocol will act as non-persistent and with probability 1-p, the protocol will refrain from sending even before CS and schedule a new time to attempt for Carrier Sense (CS) [8]-[11]. Nodes contending for the channel do not constantly listen for the channel, contrary to normal binary exponential backoff mechanism, but sleep during the random contention window. When the backoff timer expires, the nodes wake up to sense the channel. The actual CS time for nanoMAC is short even though the backoff mechanism is binary exponential, and saves energy of the sensor node. In the RTS/CTS frames, nanoMAC does virtual carrier sensing in addition to informing overhearing nodes of the time they are required to

![Transmission periods of nanoMAC protocol](image2)
refrain from transmission. Virtual carrier sensing enables over hearing nodes to sleep during that period.

The MAC addresses as well as sleep information and the number of data frames to be transmitted is also communicated in the RTS and CTS frames. The data frames carry only temporary, short, random addresses to minimize the data frame overhead. With one RTS/CTS reservation, a maximum of 10 data frames can be transmitted using a frame train ideology as shown in Fig. 2.

The data frames are acknowledged by a single, common ACK frame that has a separate acknowledgement bit reserved for each data frame. The acknowledgement frame is an acknowledgement /negative acknowledgement (ACK/NACK) combination. In this way only corrupted frames need to be retransmitted and not the whole packet [12], [13].

III. NANOMAC PROTOCOL ANALYSIS

In conventional np-CSMA scheme, a node with a frame to transmit senses the channel using carrier sense. If the channel is detected busy, the node waits for a random time interval for transmission to avoid collision. When two users sense the channel idle at same time and transmit their frames, collision occurs. This results in high energy consumption of the sensor node. To minimize the energy consumption, nanoMAC protocol is suggested as a feasible solution for inter-cluster domain.

A. Energy Consumption

The nanoMAC is a powerful tool for medium access control. Nodes challenging for the channel do not constantly listen for the channel, but sleep until the contention window value is low. Now, the node wakes up to sense if the channel is busy for a short but high contention period before transmitting if the channel is detected vacant. This feature makes the carrier sensing time short, even though the backoff mechanism is binary exponential and saves energy. In the request-to-send (RTS) /Clear-to-send (CTS) frames, nanoMAC does virtual carrier sensing in addition to informing overhearing nodes of the time they are required to refrain from transmission. Fig. 3 illustrates the energy model for inter cluster.

This model describes the energy consumed during data transmission taking into account the average contention times, backoff times and frame collisions [14]-[16]. There are four different states: Arrive, Backoff, Attempt and Success state. Arrive state is an entry point to the system for a node to transmit new data. On every arrival to one of these states, energy is consumed. To reach the success state, all possible transitions starting from the arrival state and ending at the success state is calculated. On the arrival of data, when a device finds the channel busy, it refrains from its transmission, and reaches the backoff state.

When the channel is clear upon CS, the source CH transmits an RTS frame to the destination CH and it waits for a CTS frame and reaches the attempt state. On successful transmission of the RTS and reception of CTS, a transition to the success state is made. The success state represents a successful data exchange with the destination. When the RTS frame collides as shown in Fig. 3, the device returns to the backoff state and no new data transmissions are made during this failed period.

Let $E_{tx}$ be the average transmitter energy consumption by a node with new data at the arrive state until the node reaches success state, the point of receiving an acknowledgement frame and is given by

$$E_{tx} = P_1 E(A) + (1 - P_1) E(B)$$  \hspace{1cm} (1)

where $E_{cs}$ is the carrier sensing energy consumption when reaching the arrive state, $E(A)$ and $E(B)$ are the energy consumption on each visit by the node to attempt state and backoff state and is given by

$$E(A) = P_2 E_5 + (1 - P_2) E(B)$$ \hspace{1cm} (2)

and

$$E(B) = P_1 E(A) + (1 - P_1) E(B)$$ \hspace{1cm} (3)

![Fig. 3. Energy model for inter-cluster](image-url)
The average receiver energy consumption $E_{rx}$ listening for a transmission to detect and receive a packet for being the proper destination is given by

$$E_{rx} = E(I) = (\mu + P_{bb}\theta)(P_{rx}P_{mb})^{-1}$$

where $E(I)$ is the energy incurred in each visit of node to idle state, $\mu$ represents the energy model transitions from state idle, $\theta$ represents the energy model transitions from state reply, $P_{rx}$, and $P_{mb}$ are the probabilities of no collision during RTS or CTS transmission. The average packet delay $D$, from the cluster head to the base station is calculated and is given by

$$D = P_{bb}\left[T_{bb} + \frac{T_{p}}{2}\right]E(B) + (1 - P_{bb})(1 - P_{rr})\left[T_{bb} + \frac{T_{p}}{2} + E(B)\right] + (1 - P_{bb})P_{rr}[E(A)]$$

The game is played by having all the nodes to choose their individual strategies and the set of choices results in some strategy profile.

$$u_i(s) = u_i(t_1, t_2)$$

In every game, the node decides whether the sleeping time period based on the traffic level.

### IV. Simulation Results

The analysis of game based nanoMAC protocol is carried out using MATLAB 10. The parameters considered for the simulation is summarized in Table 1. The performance of the G-nanoMAC protocol is evaluated in terms of traffic load ($p$) in the network, energy consumption and delay.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>100</td>
</tr>
<tr>
<td>Area ($m^2$)</td>
<td>$100 \times 100$</td>
</tr>
<tr>
<td>Control frame size for nanoMAC (bytes)</td>
<td>18</td>
</tr>
<tr>
<td>Data frame size for nanoMAC (bytes)</td>
<td>41</td>
</tr>
<tr>
<td>Data frame payload of nanoMAC (bytes)</td>
<td>35</td>
</tr>
<tr>
<td>Device transmission distance (m)</td>
<td>100</td>
</tr>
</tbody>
</table>

The energy analysis of single hop and multihop network without using MAC is shown in Fig. 4. It is vivid from the graph that when the destination is within the characteristic distance range of 100 m, single hop transmission consumes less energy. Multihop communication is efficient when the characteristic distance is out of this characteristic distance range.

![Fig. 4. Energy consumption vs number of hops](image)

It can be seen from the Fig. 4, the game based nanoMAC consumes 1.2 times less energy than multihop within the transmission distance of about 100 m. When the hop distance is greater than 100 m (i.e. 10 hops), the energy consumption of single hop increases approximately by a factor of 0.5 than multihop because of path loss.

Hence when the transmission distance range is greater than characteristic distance range, multihop is more energy efficient. The energy consumption in inter-cluster communication is due to transmission of packets by cluster
head nodes to the sink. Fig. 5 illustrates the energy consumption in transmission of data as a function of traffic load for nanoMAC and G-nanoMAC.

Normalized delay characteristics of nanoMAC and G-nanoMAC protocols are shown in Fig. 6. Upon error or collision during this transmission period, the entire frame has to be retransmitted, hence the delay incurred in reception of frame gradually increases with traffic load. With G-nanoMAC protocol, a device sends 10 data frames of 41 bytes each, an ACK frame for the same transmission period and retransmits only the lost/collided frame under the consideration of traffic load, thus the delay offered in the network is 15 times less compared to nanoMAC.

![Fig. 5. Average energy consumption vs traffic load](image)

![Fig. 6. Normalized delay vs traffic load](image)

The transmission energy consumption of G-nanoMAC gives better performance compared to nanoMAC. This is because G-nanoMAC protocol does sleeping time variation depends the traffic load. G-nanoMAC performs up to the traffic load 0.75 and its energy consumption stays low by incorporating proper sleep schedules. Thus G-nanoMAC protocol when used for inter-cluster domain can achieve better energy efficiency.

V. CONCLUSION

The performance of the game based nanoMAC (G-nanoMAC) protocol in terms of energy and delay with offered traffic load has been explored for the cluster based wireless sensor network. From the simulation results it is evident that for the G-nanoMAC protocol provides better performance for inter-cluster communication and its energy expended for data transmission is almost 20% less than nanoMAC protocol. The delay of G-nanoMAC protocol is considerably reduced by 12% without any degradation in throughput when compared with nanoMAC scheme. This reduction in energy consumption and delay of the G-nanoMAC protocol can significantly prolong the lifetime of the sensor network.

REFERENCES


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