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Dynamic Clustering and Scheduling with Multipath Selection Cross Layer Protocol for Efficient Energy Management in Wireless Sensor Network

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Abstract: Wireless Sensor Network (WSN) is a collection of Sensor Nodes that work in the uncontrolled areas, structured into a cooperative network. It consists of a large number of sensor nodes which can keep an eye on the environment by gathering, processing as well as transmitting collected data to the remote sink node through direct or multi hop transmission. They are usually battery operated computing and sensing devices. The deployment of sensor nodes is performed in an Ad-hoc fashion without careful planning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. Energy management is an important issue in wireless sensor networks. In this paper, we describe DCSMCL Protocol for power management in wireless sensor networks. We assess the execution of the DCSMCL Protocol, over a sensor network with SMAC and ZMAC schemes, in terms of energy consumed, throughput, End to End Delay and Jitter for varying transmissions rates. DCSMCL demonstrates an exceptionally superior performance in terms of energy consumption, throughput, End to End Delay and Jitter contrasted with SMAC and ZMAC schemes.

Keywords: Energy Efficiency, Throughput, End to End Delay, Jitter, SMAC, ZMAC, MATLAB.

I. INTRODUCTION

Wireless sensor network (WSN) is widely considered as one of the most important technologies for the twenty-first century. In the past decades, it has received tremendous attention from both academia and industry all over the world. A WSN typically consists of a large number of low cost, low-power, and multifunctional wireless sensor nodes, with sensing, wireless communications and computation capabilities [1]. Wireless sensor networks present a promising technology for many applications, providing an intelligent and remote observation of a destination. Wireless sensor networks have attracted lots of attention in recent years due to their wide applications such as battlefield surveillance, smart home, healthcare, inventory, wildlife monitoring, etc. Each node has processing capability with a radio, sensors, memory and a battery. Since the sensor nodes are usually operated by limited battery power which may not be replaced once deployed, it is therefore vital that the sensor network is energy balanced in order to ensure an extended network lifetime and efficient data gathering.

In contrast to other sensing methods WSNs facilitate an aerial impression of the measured phenomenon and an in all very close to reality measurement. Due to the constrained resources of the sensor nodes, targeted approaches are required to meet the demands for long-running networks and low latency of data. As most of the energy consumption is originated by sensing, data processing and communication, these operations are the basis for identifying and exploiting energy saving potentials. Due to the limited power sources of the sensor nodes which are generally irreplaceable, the WSN research is focused on the energy-efficient network operation.

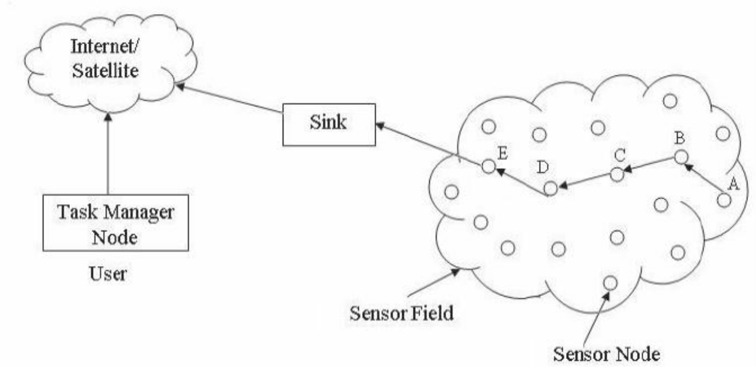

Figure 1 Structure of Wireless Sensor Networks

As the battery power of the nodes is limited, the main goal is to operate the network in an energy-efficient manner. From the communication point of view, this efficiency must be achieved in all layers of the network stack or if possible, to develop cross-layer protocols that achieves the same task with less energy consumption. Although there are various communication protocols proposed for sensor networks, there is no protocol accepted as a standard. One of the reasons behind this is the protocol choice will, in general, be application-dependent, which means that there will not be one standard protocol for sensor networks. Another reason is the lack of standardization at the physical layer and the sensor hardware. Unlike other wireless networks, it is generally hard (or impractical) to charge/replace exhausted batteries. That is why, the primary objective in wireless sensor networks design is maximizing node/network lifetime, leaving the other performance metrics as secondary objectives. Under these circumstances, the proposed MAC protocol must be energy-efficient by reducing the potential energy waste. The performance of the sensor network applications highly depends on the lifetime of the network [2].

II. DESIGN ISSUE OF MEDIUM ACCESS PROTOCOLS

The main source of energy utilization in WSNs is communication. The medium access Control protocols directly control the radio of the nodes in the network. The medium access Control protocols ought to be intended for controlling energy utilization, which thus expands the lifetime of the network.

The various design issues of the Medium Access Control (MAC) protocols suitable for sensor network environment are

- The MAC layer gives fine-grained control of the transceiver and permits on and off exchanging of the radio. The configuration of the MAC protocol should have this switching mechanism to choose when and how frequently the on and off mechanism should be done. This aids in saving energy.
- An Idle Listening is a vital factor as the nodes often hear the channel for possible gathering of the data which is not sent.
- Adaptability, Scalability and Decentralization are the other critical criteria in outlining a MAC protocol. The sensor network should adapt to the changes in the network size, node density and topology. Also some nodes may die overtime, some may join and some nodes may move to different locations. A decent MAC protocol ought to oblige these progressions to the network.
- When the sensor networks are deployed in critical applications the MAC protocol ought to have least latency and high throughput.
- A MAC protocol should avoid collisions from interfering nodes, over-emitting, overhearing, control packet overhead and idle listening. At the point when a receiver node receives more than one packet at the same time, these packets are referred as “Collided Packets”, which are to be sent again thereby increasing energy consumption. When a destination node is not ready to receive messages then it is said to be over-emitting. Overhearing occurs if a node grabs packets that were bound for some other node. The Sending and the receiving of less useful packets results in Control Overhead.

- Message Passing should be incorporated in MAC protocol, which means dividing a long message into small fragments and transmitting them in burst. Thus, a node having more data to send gets more opportunity to access the medium.
- Real-time requirements of the application should be satisfied by the MAC Protocols. MAC being the base of the communication stack, timely detection, processing and delivery of the information from the deployed environment is a necessary requirement in a WSN application.

III. Existing MAC Protocol for Wireless Sensor Network

MAC protocols can be classified from four perspectives such as contention-based, TDMA-based, hybrid, and cross layer MAC [3]. The following wide range of MAC protocols which are defined for sensor networks are described briefly by stating the essential behavior of the protocols wherever possible [4].

- Sensor-MAC (S-MAC) [4]
- Wise MAC [4]
- SIFT [4]
- Timeout-MAC (T-MAC) / Dynamic Sensor-MAC (DSMAC) [4]
- Traffic-Adaptive MAC Protocol (TRAMA) [4]
- IEEE 802.11 [5]
- Aloha with Preamble Sampling [5]
- Berkeley Medium Access Control (B-MAC) [5]
- PAMAS: Power Aware Multi-Access Signaling [5]
- Optimized MAC [5]
- Data Gathering MAC (D-MAC) [5]
- Self Organizing Medium Access Control for Sensor Networks (SMACS) [5]
- Energy Aware TDMA Based MAC [5]

IV. Related Work

Ye et al. [6] have proposed SMAC which is one of the well-known energy efficient protocols for wireless sensor networks. It is a contention based random access protocol with a preset listen/ sleeps cycle and uses a synchronized sleep mechanism. A time frame in SMAC is separated into two parts: one for a listen period and the other for a sleep period. For the purpose of announcement and synchronization for the subsequent data transmission, SYN and RTS/CTS control packets are broadcasted during the listen period based on the CSMA/CA mechanism. Any two nodes exchanging RTS/CTS packets in the listen period require to be in the active state and to enter the data transmission without entering the sleep mode. To avoid the energy wastage due to idle listening, all the other nodes enter the sleep mode. The duration of a listen period is always fixed in SMAC. This results in redundant energy wastage.

Rhee et al. [7] proposed a new hybrid MAC scheme (ZMAC), which is used for sensor networks to merge the strengths of TDMA and CSMA. Its adaptability to the level of contention in the network is the major aspect of ZMAC. Under low contention, it acts like CSMA and under high contention like TDMA. It is robust to energetic topology changes and time synchronization failures regularly occurring in wireless sensor networks.

Polastre et al. [8] have proposed the Berkeley Media Access Control (BMAC) which is a contention based MAC protocol for WSNs. B-MAC is similar to Aloha with Preamble Sampling [9], which duty cycles the radio transceiver i.e. the sensor node turns ON/OFF repeatedly without missing the data packets. However in B-MAC, the preamble length is provided as parameter to the upper layer. This provides optimal trade-off between energy savings and latency or throughput. The experimental results show B-MAC has better performance in terms of latency, throughput and often energy consumption as compared to S-MAC.

Dam et al. [10] have proposed TMAC which is an extension of the SMAC protocol which adaptively adjusts the sleep and wake periods based on estimated traffic flow to increase the power savings and reduce delay. TMAC also reduces the inactive time of the sensors compared to S-MAC. Hence, it is more energy efficient than S-MAC. This protocol has proposed to enhance the poor results of S-MAC protocol under variable traffic load that listen period ends when no activation event has occurred for a time threshold. It reduce idle listening by transmitting all messages in bursts of variable length and sleeping between bursts and the end of advantage this type of MAC is times out on hearing nothing. It can be said that T-MAC gives better result under variable load and suffers from early sleeping problem, node goes to sleep when a neighbor still has messages for it.

Yadav et al. [11] have proposed Optimized MAC protocol in which the sensors duty cycle is changed based on the network load. The duty cycle will be more for higher traffic conditions and it will be less for smaller traffic conditions. The network load is identified based on the number of messages in the queue pending at a particular sensor. The control packet overhead is minimized by reducing the number and size of the control packets as compared to those used in the S-MAC protocol. This protocol may be suited for applications in which apart from energy efficiency there is need for low latency.

Campelli et al. [12] have proposed μ-MAC to obtain high sleep ratios while preserving the message latency and reliability at an acceptable level. The μ-MAC assumes a single time slotted channel. The protocol operation alternates between a contention and a contention-free period. The contention period is used to build a network topology and to initialize transmission sub channels. The μ-MAC differentiates between two classes of sub-channels: general traffic and sensor reports. In μ-MAC protocol, the contention period incurs large overhead and has to take place frequently.

Gang Lu et al. [13] have proposed Data-gathering MAC (DMAC), an energy efficient and low latency MAC that is designed and optimized for data gathering trees in wireless sensor networks. DMAC solves the interruption problem by giving the active/sleep schedule of a node an offset that depends upon its depth on the tree. They further proposed a data prediction mechanism and the use of more to send (MTS) packets in order to alleviate problems pertaining to channel contention and collisions.

V. DCSMCL PROTOCOL

A DCSMCL (Dynamic Clustering and Scheduling with Multipath Selection Cross Layer) protocol is proposed for optimizing energy efficiency in Wireless Sensor Network. This protocol is using the duty cycling approach for energy efficiency along with clustering and cross layer interaction among the various layers of WSN. A network system has been proposed to execute the fundamental idea in an actual situation wherein cluster heads are selected on the basis of residual energy and distance for transmitting the data from the node where the event occurs to the base station.

The protocol maintains the details of the locations of all the nodes and a table which contains mapping of distance between nodes. The network field is divided into clusters and numbers of nodes inside each cluster are identified. The node with the maximum energy at given time is elected as the cluster head. During route discovery process cluster head selects the nearest node and forms the path till destination by looking up the distance table. This way complete path is identified from source to destination and process is repeated to find all possible paths and the best path will be chosen for the transmission.

The schedule synchronization phase makes the nodes to coordinate their schedules. And create a schedule table of each of its neighboring nodes. The nodes wait for a particular time period, if a node receives a schedule within the threshold it accepts and adopts that as its own schedule. In case the node does not get any schedule from its neighboring nodes it will create its own schedule and communicate it to the other nodes during the synchronization period. In an exceptional scenario the node first checks if its schedule has been accepted and adopted by any other node. If no, it drops its own schedule and accepts incoming one otherwise it will check the spread of both the schedules. The schedule with lower spread is dropped and other is retained. The cluster head is the source and the base station is the destination.

VI. SIMULATION SCENARIO

The simulation of the DCSMCL Protocol is done using the Matlab 7.10.0 (R2010a) simulator. For realistic depiction of a wireless sensor network scenario the simulator tool was given network area, number of nodes and number of cluster heads as input and all other node properties were set through configurations.

VII. RESULTS AND DISCUSSION

We consider sensor nodes deployed in a sensing field. The following properties are assumed to simplify the network model. All sensor nodes have limited batteries and recharging is not possible. We are assuming all the nodes to be homogeneous so, all nodes have equal capabilities with respect to data processing, wireless communication and battery power. The simulation network consists of many sensor nodes distributed in a grid pattern of 400x400 m2. All nodes have a transmitting energy of 0.35 mJ, a receiver power of 0.15 mJ, sleep time energy consumption of 0.10 mJ and high power transmitter energy of 0.50 mJ. Initial energy for the first set of simulations is taken as 100 mili Joules. We have compared the DCSMCL scheme with the SMAC and ZMAC schemes, in terms of Energy Consumption, Throughput, End to End Delay and Jitter against varying Transmission rate. The Transmission rate is varied from 100 Kb/s to 1000 Kb/s.

Figure 2 shows the Energy utilization for the 3 schemes with respect to the Transmission rate. When there is rise in the transmission rate, taking into account the fact that a sizeable number of packets are transmitted per unit of time, the Energy consumption decreases for all the 3 schemes. Simulation results demonstrates that ZMAC has larger Energy utilization as compared to DCSMCL protocol on increasing transmission rates because nodes have a tendency to wake up extensively for transmission due to their large back off window extents and synchronization packets also add to their wake up periods. SMAC scheme also shows higher Energy utilization as it is static in nature. DCSMCL scheme displays least Energy consumption when compared to the other 2 schemes and as the Transmission rate increases the Energy consumption further decreases. This is due to the best route followed for data transmission of packets in this scheme and also because the nodes need not be mandatorily awake except those are intended next hop nodes, at the expiry of the packet length, as indicated in the RTS/CTS packet.

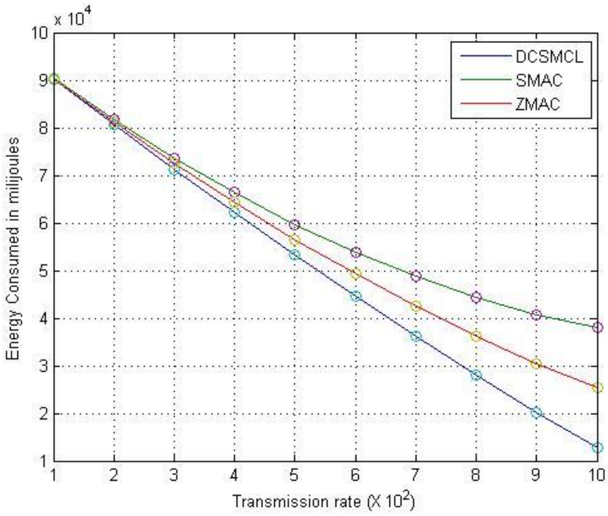

Figure 2: Variation of energy Consumed with Transmission Rate

Figure 3 shows the changes in Throughput for a variation in the Transmission rate. When there is increase in the Transmission rate the Throughput level rises for all the 3 schemes. However better incline is proved after simulation for DCSMCL and ZMAC protocols. SMAC schemes exhibits lower throughput when compared to ZMAC due to the factors like sporadic sleep/wake operations, the schedule adoption, coordination and synchronization, adaptive listening, RTS/CTS message trade after the medium sensing by utilizing CSMA supporting it to avoid packet losses due to collisions or other factor. In any case, when more messages get transmitted from the source, it fails to display the better results as ZMAC plan consolidates the qualities of CSMA and TDMA. To start with, when the level of contention in the system is low ZMAC acts like normal CSMA and later when Transmission rate and level of contention in the network is increased, to accomplish a higher execution it starts to act like TDMA. The DSSMCL scheme shows the best results.

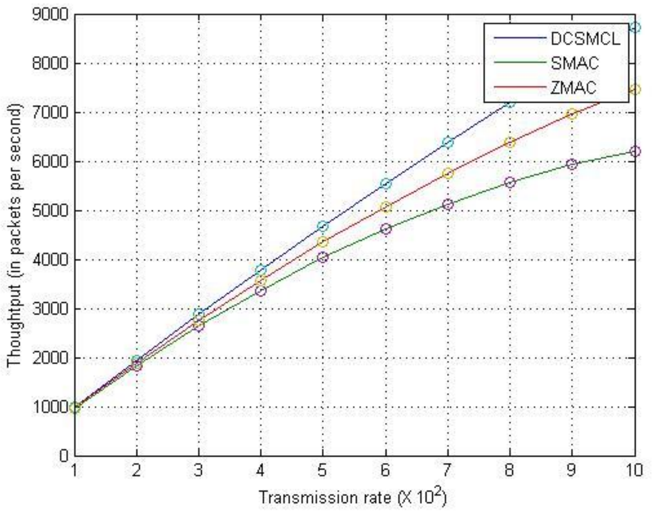

Figure 3: Variation of Throughput with Transmission Rate (Cumulative Study)

When there is increase in Transmission rate, the end to end delay caused for the packets in the network also tends to increase. Figure 4 demonstrates the change in end to end delay for the 3 schemes with respect to the change in the Transmission rate. SMAC scheme shows the most noteworthy end to end delay. This is on account of the increase in latency in SMAC scheme because of its static nature. End to End delay is quite less in DCSMCL and ZMAC schemes as these are not static in nature. Healthier performance in terms of End to End delay is shown by ZMAC scheme since it combines the traits of TDMA and CSMA schemes as indicated by the level of contention in the system. Be that as it may, the end to end delay for DCSMCL scheme is slightly better when contrasted with the ZMAC, in light of the fact that it approaches to the best performance as showed by the ZMAC plan. In DCSMCL protocol, however the end to end delay is less when contrasted with SMAC and ZMAC yet the littlest of end to end delay showed is because of sleep/wake system and best path selection which is a dynamic procedure.

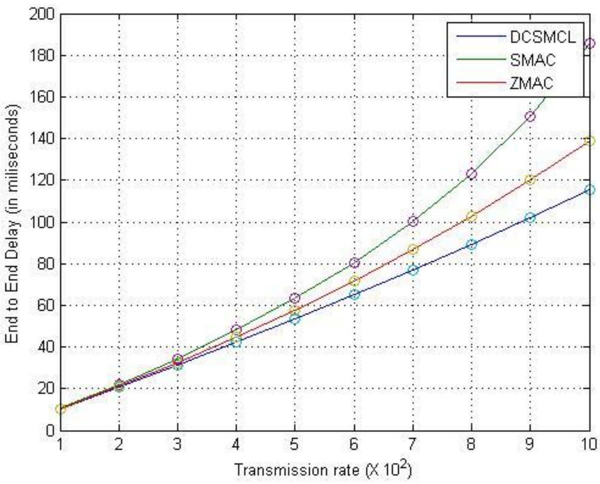

Figure 4: Variation of End To End Delay with Rounds of Transmission

When there is increase in the transmission rate the Jitter in the network increases for the reason that more amounts of data are getting transmitted per second and more data traverses through the nodes which increase the variance in the delay of the packet transmission thereby increasing the jitter. Figure 5 shows the variation in jitter for the 3 schemes with respect to the Transmission rate. SMAC scheme shows the highest level of jitter because the latency in SMAC increases due to the periodic sleep of each node. And in addition to this the strict schedule is followed by the nodes and the static nature of the SMAC protocol also increase the latency and jitter in the system whereas this is lesser in DCSMCL and ZMAC schemes. Better performance in terms of Jitter is exhibited by ZMAC scheme since it combines the features of TDMA and CSMA schemes as indicated by the level of contention in the system. But the jitter in DCSMCL scheme is still better when contrasted with the ZMAC, taking into consideration the fact that it approaches to the best performance as showed by the ZMAC plan. In DCSMCL scheme, however the jitter is less when contrasted with SMAC and ZMAC yet the littlest of jitter showed is because of sleep/wake system and best path selection which is a dynamic procedure.

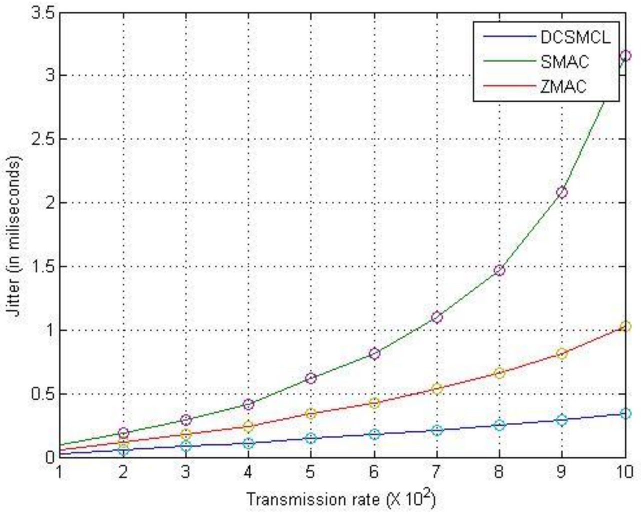

Figure 5: Variation of Jitter with Rounds of Transmission

VIII. CONCLUSIONS

In this paper, the validation of the (Dynamic clustering and scheduling with multipath selection cross layer protocol) DCSMCL Protocol is done. Performance evaluation was conducted for various performance metrics which critically affect the performance of any MAC protocol in a wireless sensor network. The DCSMCL protocol was compared with SMAC and ZMAC protocols.

Simulation results prove that, the proposed scheme DCSMCL exhibits a much superior performance compared to the existing schemes SMAC and ZMAC, in terms of all the performance metrics used for evaluation. DCSMCL scheme gives a lower Energy consumption, End to End Delay and Jitter and a higher Throughput against the varying transmissions rates.

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