IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2016

A Clustering based Cross Layer Protocol for optimizing Energy Efficiency in Wireless Sensor Network using Duty Cycling Approach

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Abstract: WSNs are a special type of wireless networks where the nodes are static, have limited computation and battery capacities and have limited transmission ranges. They are battery operated computing and sensing devices. The sensor nodes will be planted in an ad hoc fashion with individual nodes staying inactive for large periods of time but suddenly becoming active on detecting an event. Energy management is a noteworthy 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 rounds of transmissions. 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.

I. INTRODUCTION

The recent advances in micro-electro-mechanical systems (MEMS), low power and highly integrated digital electronics have led to the development of micro sensors [1], [2]. So the ongoing miniaturization of electro mechanical parts and the permanent decrease of costs, lead to a growing number of applications for Wireless Sensor Networks (WSNs). Wireless sensor networks (WSNs) present a promising technology for many applications, providing an intelligent and remote observation of a destination. Among the various potential applications, there are health monitoring, disaster monitoring, habitat monitoring, precision agriculture and surveillance systems.

Improvements in hardware technology have resulted in low-cost sensor nodes which are composed of a single chip with embedded memory, processor and transceiver. Low power capacities lead to limited coverage and communication range for sensor nodes compared to other mobile devices. With the ongoing research both on new sensor types and on the hardware for improved computation, communication and power capacities, the emergence of novel application areas are expected.

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.

Because of the battery constraints, the primary objective 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. Since the communication of sensor nodes will be more energy consuming than their computation, it is a primary concern to minimize communication while achieving the desired network operation.

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 [3].

 DOI 10.17148/IJARCCE.2016.5780

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II. REASONS OF ENERGY WASTE IN WIRELESS SENSOR NETWORKS

There are various challenges in wireless sensor networks, the larger part of which leads to energy waste [4]. The main reasons of energy waste in wireless sensor nodes communication are the following:

- Idle listening: It occurs when nodes wake up and pay attention for incoming data packets even when there is no transmission. This reduces the life span of wireless sensor networks.
- Collision: It happens when two or more close stations wish to broadcast packets at the same time. When this happens, all packets involved in the collision have to be abandoned and retransmitted which outcome in energy waste.
- Over-hearing: when a node in the wireless sensor network transmits a message, various nodes around the sender may possibly overhear the packet transmission even when they are not the planned recipients of these transmissions. Overhearing needless traffic can outcome in energy loss.
- Control packet overhead: control packets spend a lot of energy in sending, receiving and listening, As a result it is appropriate that a lesser number of control packets should be employed for data transmission with the intention to reduce the overhead.

III.PROPERTIES OF A WELL-DEFINED MAC PROTOCOL

To outline a decent MAC protocol for wireless sensor networks, the accompanying traits must be considered [5]. The principal quality is energy efficiency. We need to characterize energy-efficient protocols in order to increase the network life span. Other critical characteristics are scalability and adaptability to changes. Changes in network size, node density and topology ought to be taken care of quickly and viably for a fruitful adjustment. A portion of the purposes for these system property changes are constrained node life span, addition of new nodes to the network and fluctuating interference which may modify the connectivity and hence the network topology. A decent MAC protocol should gracefully oblige such network changes. Other generally imperative qualities such as latency, throughput and bandwidth utilization may be secondary in sensor networks. In opposition to different wireless networks, fairness among sensor nodes is not usually a design objective, since all sensor nodes share a common task.

IV. EXISTING MAC PROTOCOLS FOR WIRELESS SENSOR NETWORKS

MAC protocols can be classified from four perspectives such as contention-based, TDMA-based, hybrid, and cross layer MAC [4]. 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 [6].

- Sensor-MAC (S-MAC) [6]
- Wise MAC [6]
- SIFT [6]
- Timeout-MAC (T-MAC) / Dynamic Sensor-MAC (DSMAC) [6]
- Traffic-Adaptive MAC Protocol (TRAMA) [6]
- IEEE 802.11 [7]
- Aloha with Preamble Sampling [7]
- Berkeley MAC (B-MAC) [7]
- PAMAS: Power Aware Multi-Access Signaling [7]
- Optimized MAC [7]
- Data Gathering MAC (D-MAC) [7]
- Self Organizing Medium Access Control for Sensor Networks (SMACS) [7]
- Energy Aware TDMA Based MAC [7]

V. RELATED WORK

Ye et al. [5] 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.

Dam et al. [8] 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.

Rajendran et al. [9] have proposed TRAMA which is a TDMA-based algorithm and used to increase the utilization of classical TDMA in an energy-efficient manner. It is similar to Node Activation Multiple Access (NAMA) [10], where for each time slot a distributed election algorithm is used to select one transmitter within each two-hop neighborhood. This kind of election

IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

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eliminates the hidden terminal problem and hence ensures that all nodes in the one-hop neighborhood of the transmitter will receive data without any collision. However, NAMA is not energy-efficient and incurs overhearing

Campelli et al. [11] 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.

Sohrabi et al. [12] have presented SMACS which is a schedule based medium access control protocol for the wireless sensor network. This MAC protocol uses a combination of TDMA and FDMA or CDMA for accessing the channel. In this protocol the time slots are wasted if the sensor node does not have data to be sent to the intended receivers. This is one of the drawbacks of this MAC scheme.

Polastre et al. [13] 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 [14], 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.

Gang Lu et al. [15] 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.

VI. BASIC 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.

VII. 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.

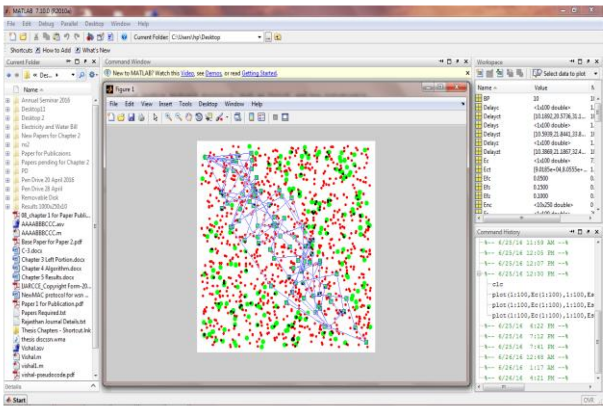

Fig.1. User Interface of Matlab Simulator

VIII. 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. 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

DOI 10.17148/IJARCCE.2016.5780

grid pattern of 400 x 400 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 are assuming all the nodes to be homogeneous. We have compared the DCSMCL scheme with the SMAC and ZMAC schemes, in terms of Energy Consumption, Throughput, End to End Delay and Jitter with respect to the rounds of transmissions.

Fig. 2. presents the Energy consumption graph of DCSMCL, SMAC and ZMAC schemes with respect to the rounds of transmissions. Since each round of transmission consumes a part of energy of all the nodes involved in the route of transmission, so in general when the number of rounds of transmission increases the total energy consumption also increases. When compared to ZMAC and DCSMCL schemes, the SMAC has a higher Energy consumption for a low number of rounds of transmissions. When the number of rounds of transmissions is increased the energy consumption increases for all the three schemes due to large number of communications but DCSMCL scheme shows better output in terms of performance than the other two schemes since the sleep/wake mechanism and path of transmission used by DCSMCL protocol is more energy efficient. Therefore at the end of large number of rounds of transmission the total energy consumed by DCSMCL protocol is comparatively very low despite of SMAC scheme also does schedule selection, sleep/listen operations, schedule synchronization, adaptive listening and CSMA and RTS/CTS methods for access control like the DCSMCL scheme.

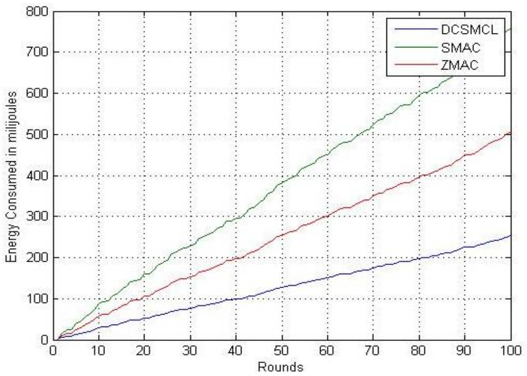

Fig. 2. Variation of Energy Consumption with Rounds of Transmission

Fig. 3 demonstrates the Throughput level of the network with respect to rounds of transmission. In general for wireless sensor networks Throughput decreases with increases in number of rounds performed for transmission. On simulation it was found that the Throughput is at a low value for SMAC protocol when compared to ZMAC and DCSMCL protocol. Throughput for ZMAC scheme does not show level of poor execution for large number of rounds because SMAC uses only the active frame for communication. DCSMCL protocol gives best execution contrasted with SMAC and ZMAC schemes on the grounds that DCSMCL protocol considers residual energy and shortest distance to perform the routing. As the nodes with maximum residual energy are chosen as cluster head and least distant cluster heads are involved in routing process.

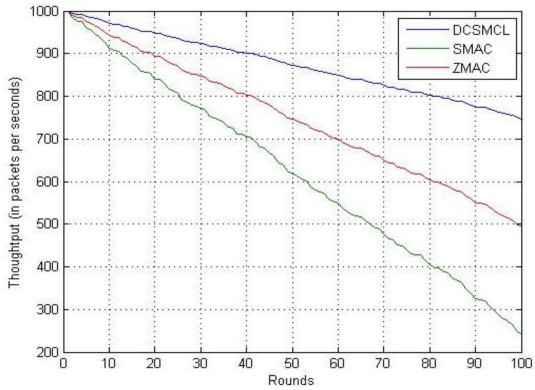

Fig. 3. Variation of Throughput with Rounds of Transmission

Fig. 4 presents the End to End Delay level with respect to the rounds of transmission for the three schemes. On simulation it was found that the End to End Delay level is lower for DCSMCL scheme compared to SMAC and ZMAC schemes. SMAC exhibits higher End to End Delay because the nodes in this scheme follow strict schedules as this protocol works on fixed duty cycle. Moreover, queuing of data packets increases if an event occurs during sleep time of the node and have to wait till start of its next wakeup cycle. ZMAC scheme shows lesser End to End Delay following the qualities of CSMA and TDMA are combined in this scheme. The DCSMCL protocol proves better results in terms of End to End Delay for higher number of rounds of transmission. This is because DCSMCL protocol does schedules synchronization and also because the routing is done majorly through cluster heads which are elected on the basis of residual energy. Overall SMAC scheme shows greatest delay and DCSMCL protocol least delay when simulated for high number of rounds of transmission.

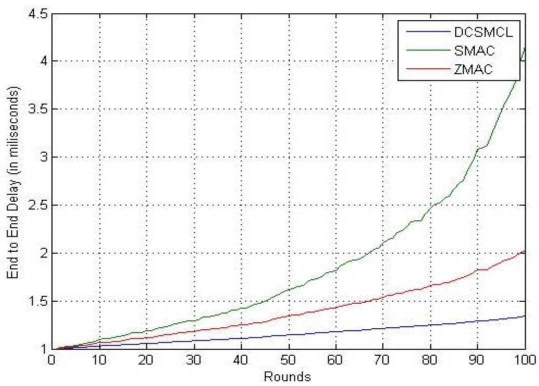

Fig. 4. Variation of End To End Delay with Rounds of Transmission

IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2016

Jitter is characterized as a variation in the delay of received packets. The sender transmits the packets in a consistent stream and introduces an even space between them. As a result of network congestion, errors and dishonorable queuing, the delay between the packets can vary as opposed to staying constant. Fig. 5 presents the Jitter level with respect to the rounds of transmission for the three schemes.

The Jitter level is much lesser for DCSMCL scheme compared to SMAC and ZMAC schemes. ZMAC scheme exhibits a lesser jitter since the strengths of CSMA and TDMA are merged in this scheme and higher in SMAC because it follows strict sleep/wakeup schedule. The DCSMCL protocol proves better results in terms of jitter for higher number of rounds of transmission. This is because DCSMCL protocol does schedules synchronization and also because the routing is done majorly through cluster heads which are elected on the basis of residual energy and the tentative paths are discovered in the initial phase itself. Overall SMAC scheme shows greatest jitter and DCSMCL scheme shows least jitter when simulated for high number of rounds of transmission.

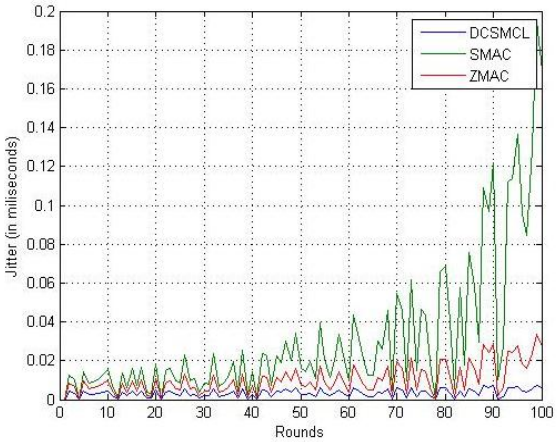

Fig. 5. Variation of Jitter with Rounds of Transmission

XI. 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 with respect to rounds of transmissions.

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