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A TRANSMISSION POWER LEVEL AWARE APPROACH TO MAXIMIZE THE LIFETIME OF WIRELESS SENSOR NETWORK

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ABSTRACT

In recent times the lifetime of Wireless Sensor Networks (WSN) has attracted many researchers. As a result, many power aware algorithms have been designed with different strategies. These strategies are based on time scheduling techniques, Delay bound constraints, Data adoption techniques, Data aggregation, Mobile sinks, Query based approach, and Management of spare nodes depending on the levels of their residual energies. All the mentioned approaches are implemented simulators. Results obtained in terms of life extensions with simulators and practical deployments have shown major deviations. Lifetime extensions obtained with practical deployments is far less than that obtained with simulations, using the same strategies. Investigations have shown that a lower lifetime with practical deployment is due to premature exhaustion of the sensor node's battery. The three important reasons for the early death of the battery is found to be an improper selection of sampling interval, the effect of the environment of sensor field, and transmitting the sensed data with improper transmission power level. In this paper, a practical approach is adopted to understand the impact of different transmission power levels on the lifetime of the sensor node and hence the wireless sensor network. In the process, an optimum value of the transmission power level of data packets is found out. With the optimized transmission power level, a 22.72% improvement in the lifetime of the sensor node has been achieved. However, when the sensor node is operated at optimum sampling interval and optimum transmission power level, the achieved lifetime improvement is 35.14%.

KEYWORDS: Lifetime, Transmission power level, Rate capacity, Optimum sampling interval.

INTRODUCTION

The chief constraint of a sensor node in WSN is its limited energy supply. When the sensor nodes are deployed in hazardous environments and impenetrable terrains, it is not possible to replace the exhausted batteries. Thus the lifetime of the sensor node depends on the lifetime of the battery. Therefore it is important to develop techniques to prolong the lifetime of the battery. The electrochemistry of the battery plays a major role in its lifetime. Apart from that, the sensor field environment also plays an important role in its longevity. Rate capacity and Recovery effect of the battery are studied with respect to the load. These two factors are related to sampling interval and transmission power level of the sensor node. When the current is drawn from the battery, the positive ions are consumed at electrolyte anode interface. And further, positive ions are supplied to the anode of the battery. If the current drawn is low to moderate, the inactive regions are uniformly distributed throughout the cathode. However, when the current drawn is higher, then the cathode outer surface gets covered with inactive sites. This results in unavailability of internal active sites. As a consequence, the battery gets drained out of most of its energy unused. Hence, an arbitrary selection of transmission power level of data packets may result in premature exhaustion of the battery. Therefore, there is a need to find an optimum transmission power level for the data transmitted so that the Rate capacity effect can be mitigated. The typical architecture of the WSN is as shown in the Fig. 1.

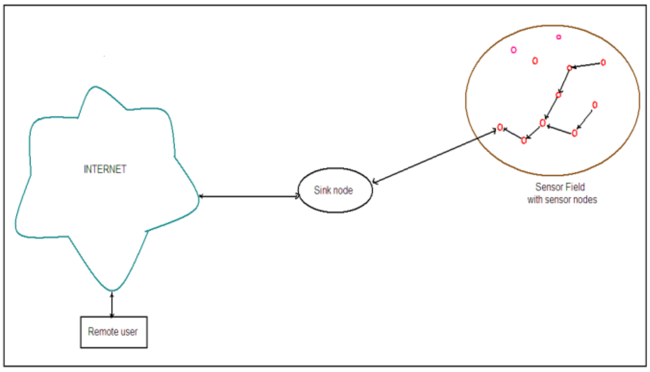

Fig. 2: A typical Wireless sensor network.

The block diagram of the WSN is shown in the Fig. 2. Of the three units shown in the figure, communication unit consumes the major part of the energy budget.

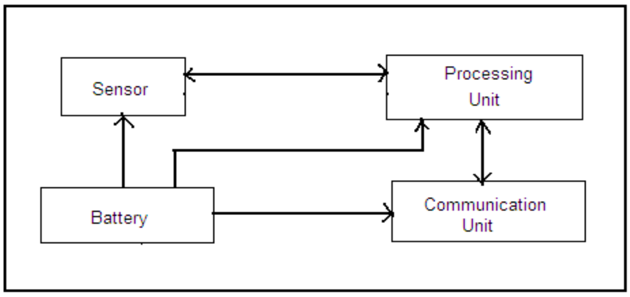

Fig. 1: Schematic of a typical sensor node.

Existing Methodologies for Extending the Lifetime of Wsn

Recent research showed that good levels of energy savings can be achieved by time scheduling of the sensor nodes.[1] In this direction, research has been carried out where the sensors can be partitioned into different sets of sensors that can satisfy the coverage requirement and activate the sets in round robin fashion. This has resulted in network operating time which is equal to the lifetime of the individual sensor node multiplied by the number of sets.

Yang Yu et al[2] have demonstrated energy minimization with Rate adaptation technique. The basis of their work was that the transmission energy can be significantly reduced by lowering transmission power and increasing the duration of the transmission.

A set of distributed algorithms has been reported in the literature[4] with which a lifetime improvement of 10% to 20% have been expected.

Prolonging the lifetime of the wireless sensor network up to 6 times by the controlled sink movements have been reported in the literature.[5] In this work, it was identified that the sensor nodes that can directly communicate with the sink's neighbours tend to deplete their energy faster than other nodes. Not only have they consumed energy to communicate their own data to the sink, but also for relaying to it the data from any other node. This problem leads to premature disconnection of the network. The sink gets isolated from the rest of the network due to the death of its neighbours while most of the sensor nodes are still fully operational. This problem was mitigated by exploiting the mobility of some of the network components.

Data aggregation coupled with optimal routing has resulted in maximizing the lifetime of the sensor network.[6]

An approach has been reported in[7] for analysing energy hole problem based on corona model. In this sink organizes the sensors around it into dynamic infrastructure and position the disk into disjoint concentric sets termed as coronas. The authors in this work assumed each sink is equipped with a steady energy supply. And an improved corona model with a new transmission range assignment strategy was adopted to maximize the lifetime of wireless networks.

Wireless sensor networks have opened new domains to distributed data acquisition. Such networks are prone to premature failure because some nodes deplete their batteries more rapidly than others due to workload variations, non-uniform communication and heterogeneous hardware. Many-to-one traffic patterns further increase node power consumption. To mitigate this problem a novel battery allocation formulation has been reported in.[8] This formulation is based on cost-constrained heterogeneous battery allocation.

A life time of wireless sensor network can also be improved if each node does not need to send the data immediately. Instead, the node can store the data temporarily and transmit the same when the mobile sink node is at the most favourable location. Investigations in this direction have been reported in.[10] where a frame work that maximizes the lifetime of the WSN subject to the delay bound constraints was formulated and simulation results have exhibited a better lifetime than the existing models.

In impenetrable terrains and hostile zones, the best possible way to get the information about the various physical quantities is to deploy a large number of sensors. In such a scenario the lifetime extension becomes pivotal. To maximize the network life time in such conditions, two energy efficient approaches were investigated.[11] In this work, a two tiered wireless sensor network where nodes are divided into clusters and nodes forward data to base stations through cluster heads is considered.

A query based wireless sensor system has been reported in the literature.[12] In query-based wireless sensor systems, a user would issue a query and expect a response to be returned within the deadline. While the use of fault tolerance mechanisms through redundancy improves query reliability in the presence of unreliable wireless communication and sensor faults, it could cause the energy of the system to be quickly depleted. Therefore, there is an inherent tradeoff between query reliability versus energy consumption in the query- based wireless systems. In this paper, an adaptive fault tolerant quality of service control algorithms based on hop-by-hop data delivery utilizing ‘source' and ‘path' redundancy, with the goal to satisfy the quality of service requirements while prolonging the life time of the sensor system was presented. Here path redundancy refers to using multiple disjoint paths to connect a source cluster to the processing centre instead of using a single path. And source redundancy refers to using multiple sensor nodes to return readings to cope with data transmission and or sensor faults.

Research on maximizing the lifetime of heterogeneous wireless sensor networks happened at a slower pace. Inspired by ants, pheromone and heuristic information a new approach has been reported in the literature.[13] Based on pheromone and heuristic information, the ants seek an optional path on the construction graph to maximize the number of connected covers. The pheromone serves as the metaphor for the search experiences in building connected covers. The heuristic information is used to reflect the desirability of device assignments. This approach resulted in the maximization of the life time of heterogeneous WSNs.

A remarkable improvement in the lifetime of wireless sensor network was reported by replacing the single mobile sink node with multiple mobile sinks.[14] Many wireless sensor networks use a tree rooted at the sink as the underlying routing structure. The problem of maximizing the lifetime of wireless sensor network can be related to the routing structure. Delay is an important element in time critical applications, and it is imperative to find the shortest path tree with the long lifetime.

A mathematical model based on this model has been reported in the literature[15] which has resulted in improvement in the lifetime of the network with dense node environment.

One important reason for the decrease in the lifetime of the wireless sensor network is an unbalanced distribution of the data among the sensor node. Mitigating this problem has resulted in an improvement in the lifetime of the wireless sensor network, which has been reported in the literature.[16] In this work, the authors introduced special nodes called mobile agent. They have designed an energy prediction strategy which enabled mobile agents to know about the remaining energy of all sensors in their clusters. Based on this strategy they have proposed a solution for energy dissipation problem.

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In non-time-critical applications of wireless sensor network applications with a mobile sink can reduce the energy consumption resulting in prolonging the network lifetime of wireless sensor network.[18]

A sensor network cannot carry out its task after the nodes energy is exhausted. Thus a sensor's lifetime is the duration of the time when it begins to generate the first data packet to the time when it generates the last data packet that is deliverable to the sink. When one sensor is out of operation or a few sensors are partitioned from the sink, the rest of the network can still work, as long as useful data generated by other sensors can reach the sink. Therefore the lifetime of a sensor network includes the lifetime of all sensors that produce useful data. Research in this direction has been reported in the literature.[19] Authors in this work coined the phrase ‘lifetime vector' which was defined as the vector of all sensors lifetimes sorted in ascending order. Their work was based on the fact that instead of just maximizing the time before the first sensor is out of operation, lifetime vector must be maximized. A fully distributed algorithm that runs iteratively was proposed by them and every iteration produces a lifetime vector that is better than the vector produced by the previous iteration.

A novel approach called Intra-route and Inter-route coordination to prolong the sensor network lifetime under the end-to end delivery delay constraints has been reported in the literature.[20] Their work focused on two important aspects. First, the Intra-route coordination module that allows the nodes on the same route to balance their nodal lifetimes through adjusting the MAC-Medium access control behaviours collaboratively. Second, the Inter-route coordination module that balances the nodal lifetimes across different routes via adjusting the communication routes.

Satyanarayana Chanagala and Zafar Jawed Khan have designed a method[25] to achieve optimum performance of WSN at optimum sampling interval. Optimum sampling interval has improved the lifetime by 18%. They [26] have also investigated the environmental effects on the lifetime of the WSN. As one of the strategies, data compression is used at the colder temperature, which has increased the lifetime by 8%. Further, they [27, 28] have observed an increase in the lifetime by 16.68% by employing optimum sampling interval and data compression at the lower temperature of 15^{o}C.

Limitations of the Above Methods

As observed in most of the existing methodologies, it is clear that they are based on the various strategies primarily focusing on minimizing the energy usage of the battery. Most of the works are simulation centric. However, the limitations in the simulators are electrochemistry based characteristics of the battery are not taken into effect. As a result of this, it is assumed that the battery behaves in the same manner irrespective of transmission power level of data packets. Also, the behaviour of the battery is unchanged irrespective of the volume of the data transmitted and sampling interval. Furthermore, most importantly, the environmental conditions are not at all considered. As a consequence, the achieved lifetimes certainly would be less as compared to the calculated lifetimes with the practical deployment of the nodes in the real time conditions.

Also, the study of existing methodologies emphasizes the fact that there were not enough efforts that quantitatively analyse the effects of the environmental conditions, and electrochemistry dependent characteristics of the battery which could play a decisive role in the life time of WSNs. These studies are definitely going to open new avenues whereby there could be a paradigm shift in the research related to the lifetime improvement of the wireless sensor networks.

Proposed Approach

In the present approach, Rate Capacity and Recovery effects, which are the important battery discharge characteristics of the battery, are considered. Rate Capacity and Recovery effects are responsible for premature exhaustion of the battery which results in reduced lifetime of the battery. Therefore, these two characteristics of the battery could be properly exploited to improve the discharging efficiency and hence its capacity as well as lifetime.

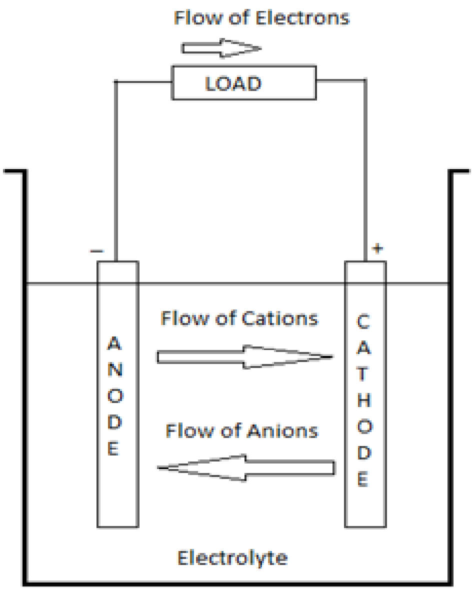

Fig. 3: Typical Electrochemical cell.

This paper deals with exploiting these two parameters to maximize the lifetime of the battery. Authors,[25] have designed an algorithm to find optimum sampling interval to mitigate the Recovery effects. The optimum sampling interval is found to be 0.62 seconds. The present work in this paper focuses on finding an optimum transmission power level that could mitigate the detrimental effects of Rate Capacity effect. Finally, the enhancement in the lifetime of the sensor node is recorded with optimum sampling interval and optimum transmission power level.

Experimental Setup

The sensor node is designed and fabricated with three sensors viz., temperature sensor, accelerometer and light sensor. These sensors are interfaced to the microcontroller. Further, the sensed signals of sensors are conditioned by LM324. The microcontroller used in the present work is PIC18F252 made by Microchip. It is a 28 pin controller. Further, it is high-performance equipped with enhanced flash memory and a 10 bit analogue to digital converter. Sensed physical quantity by the sensors, which is in the analogue form, is converted into digital by the microcontroller. In the present work, the resolution of analogue information is set to 4.88mv. USART of the microcontroller is set at 9600 baud rate while transmitting the data to the receiver node or sink node. Timer ‘1' of the microcontroller is used for measuring the sampling time. A 20MHz crystal oscillator is used for the microcontroller. Sink node or receiving node acts as the master node, with which the sampling time of the slave node or sensor node is controlled. Each sensed physical quantity is converted into two-byte digital data. Since there are three sensors, there will be six bytes of the sensed information. Along with these, two data bytes are used for providing the information regarding the power consumed by the microcontroller and the sensors followed by one byte for start bit and another for the stop bit. Thus total numbers of ten bytes are transmitted nine times during each sampling interval to make the communication between sensor or slave node and the master node or receiver node to improve the quality of service. Further an additional nine bytes are used to provide the guard band. In total ninety-nine, bytes are transmitted by the sensor or slave node to the receiver node or the sink node.

Three lithium-ion batteries with specifications of 2200mAh, 3.7V each are used to energize the sensor node. The microcontroller is energized with regulated five volts using IC 7805 regulator which is further given to IC 2941 to improve the supply efficiency of IC 7805 and this output is finally given to the microcontroller.

CC2500 Transceiver from Texas Instruments is used to provide the wireless communication between the sensor node and the receiver node. The CC2500 is a low-cost 2.4 GHz transceiver designed for very low-power wireless applications. The circuit is intended for the 2400-2483.5 MHz ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency band. The RF transceiver is integrated with a highly configurable baseband modem. The modem supports various modulation formats and has a configurable data rate up to 500 baud. CC2500 provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and wake-on-radio. It is energized with +3.3 volts supply.

Receiver node also consists of CC2500 to receive the data bytes from the sensor node and it is so configured to change the sampling interval of the sensor node as required by the experiment. The output of the receiver node is connected to the computer through USB port to record the results of the experiment.

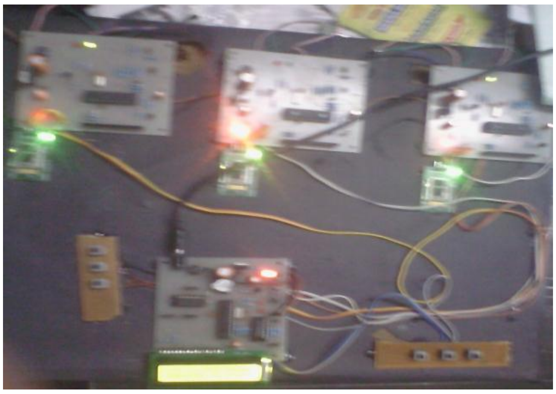

Fig. 5: Experimental setup.

RESULTS AND DISCUSSIONS

Command word of Communication module CC2500 is set to fix the transmission power level of data packets. A lifetime of the sensor node is observed at different transmission power levels. In this experiment, fifteen different transmission power levels have been considered. In the first set of experiments, an arbitrary sampling interval of 0.2seconds has been selected. In the second set of experiments, an optimum sampling interval of 0.62 seconds has been considered.

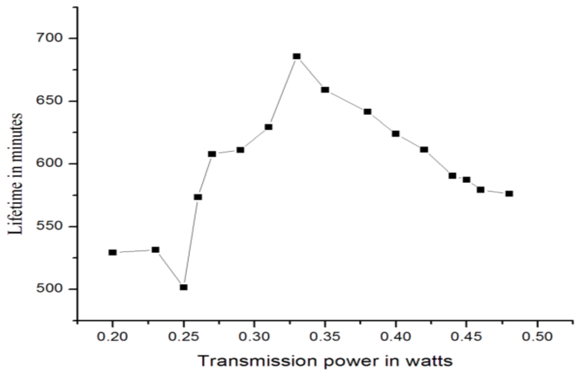

Fig. 6: Transmission power level versus Lifetime at arbitrary sampling interval of 0.2s.

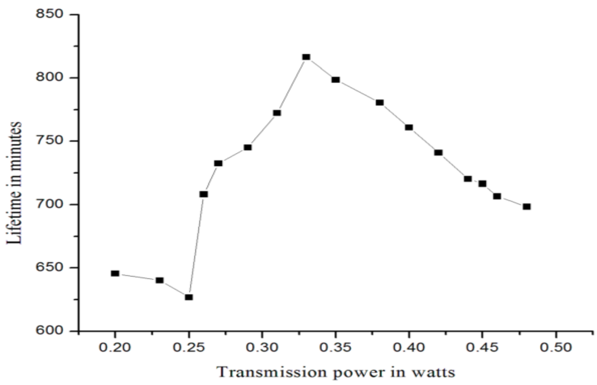

Fig. 7: Transmission power level versus Lifetime at optimum sampling interval of 0.62s.

As observed from Fig.6, the lifetime of the sensor node is 529.34 minutes when the transmission power level is 0.2watts. At 0.23watts, the recorded lifetime is 531.45 minutes. At 0.25watts, it is 501.44 minutes. An increasing trend in the lifetime is observed from 0.26watts. The lifetimes recorded are 573.64 minutes, 607.8 minutes, 610.9 minutes, 629.34 minutes, and 685.77 minutes at transmission power levels of 0.26watts, 0.27watts, 0.29watts, 0.31watts, and 0.33watts respectively. From 0.35watts onwards, a decreasing trend in the lifetime is observed. However, the maximum lifetime of the sensor node is observed when the transmission power level is 0.33watts. All the above findings are observed when the sampling interval is the arbitrary value of 0.2 seconds.

The lower lifetime of the sensor node at lower transmission power levels is due to the fact that at lower transmission power levels, the time taken for the transmission of the data packets is more. Further, the framing time of the data bits is higher; as a result, the battery is stressed more at lower transmission power levels. Therefore, the lifetime of the battery is reduced, resulting in the reduced lifetime of the sensor node.

When the transmission power level is 0.33watts, the lifetime of the sensor node is maximum, which is 685.77 minutes. At this transmission power level, there is minimum Rate Capacity effect, which increases the capacity of the battery and its lifetime. Hence, this power level is termed as optimum transmission power level.

For transmission power levels beyond optimum value, the lifetime of the sensor node is decreasing due to pronounce Rate Capacity effect.

Thus, the improvement in the lifetime from lowest transmission power level to the optimum transmission power level is 22.81%.

At same transmission power levels, but with the optimum sampling interval of 0.62seconds, the observed lifetimes are relatively higher than the results observed when the sampling interval is 0.2 seconds. Results are shown in the Fig.7.

With optimum transmission power level of 0.33watts and the optimum sampling interval of 0.62 seconds, the observed lifetime is 816.2 minutes. This increase in lifetime of the sensor node is due to cumulative effects of operating the sensor node at optimum transmission power level, which mitigates Rate Capacity effect and at optimum sampling interval, which mitigates the Recovery effects of the battery.

The net improvement in the lifetime of the battery with optimum transmission power level and optimum sampling interval is 35.14%.

Fig.8 shows the comparative graphs of lifetime versus transmission power levels with arbitrary sampling interval and optimum sampling interval.

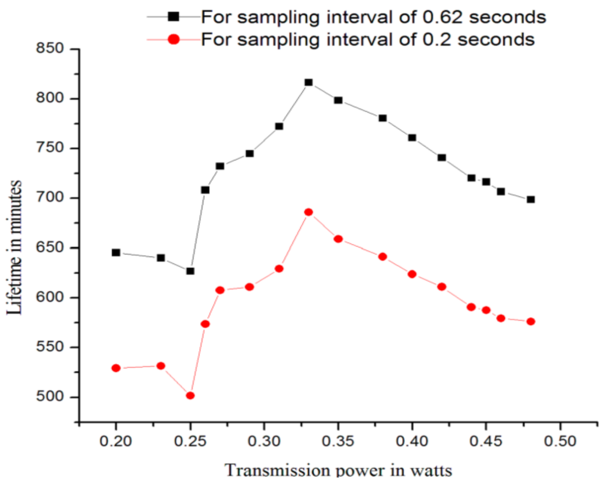

Fig. 8: Comparative graph of Transmission power levels versus Lifetime of sensor node.

Performance enhancement with suggested technique is shown in Table 1.

Lifetime of the sensor node in minutes at arbitrary transmission power level of 0.2watts and arbitrary sampling interval of 0.2 seconds	A lifetime of the sensor node in minutes at optimum transmission power level of 0.33watts and the arbitrary sampling interval of 0.2 seconds.	Lifetime of the sensor node in minutes at optimum transmission power level of 0.33watts and optimum sampling interval of 0.62seconds	% improvement with only optimum transmission power level	% improvement with optimum transmission power level+Optimum sampling interval
529.34	685	816.2	22.72%	35.14%

CONCLUSION

The work in this paper substantiates the fact that the electrochemical based discharge characteristics of the battery viz. Rate Capacity and Recovery effect have the impact on the lifetime of the battery and if not properly exploited, they may result in premature exhaustion of the battery. Transmission power level used for the data packets, if it is lower, result in reduced lifetime of the battery due to the fact that at lower transmission power levels, time taken for the transmission of data packets will be longer and also frame time of the bits will be higher that eventually put more stress on the battery. Therefore, the lifetime of the battery and hence the lifetime of the sensor node is lower. At higher transmission power levels, the Rate capacity effect of the battery results in premature exhaustion of the battery. Hence, in the present work, an optimum value for the transmission power level is found at which the lifetime improvement is 22.72%. However, when the sensor node is operated at optimum transmission sampling interval to mitigate the Recovery effect along with optimum transmission power level, the improvement in the lifetime is found to be 35.14%.

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