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Low Power Wireless Sensor Networks with Improved Lifetime using Adaptive Duty Cycle

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Abstract: Now a day, power consumption of WSN is a very critical issue which is under research. Because of the limited availability of power resources, the fundamental challenge in WSN is to enhance the lifetime of network. Most of the energy is consumed by the nodes which are in bottleneck zone that leads to decrease in lifetime of the network. In this paper, a new technique called Adaptive Duty Cycle has been introduced that works on the basis of queue length under the variable traffic rates. This reduces the energy consumption in bottleneck zone which leads to increased lifetime of WSN. The input parameters are duty cycle and no. of active neighbour nodes. Simulation has been performed on MATLAB software and achieved expected results.

Keywords: Adaptive, Duty cycle, Energy consumption, Network lifetime, Wireless sensor networks (WSN).

INTRODUCTION

The vast development in wireless communication and in semiconductor based technologies such as Micro-Electro-Mechanical Systems (MEMS), Very Large Scale Integration (VLSI) allows us to develop the low cost, low power, small size and multifunctional smart sensors [30]. The main functions of sensor are sensing, compressing and processing the information from the surrounding environment. Wireless Sensor Networks (WSN) is a collection of large number of independent sensor nodes that are deployed inside the phenomena or nearby it either in Ad-hoc or pre-planned manner. Each sensor node has few main hardware components [1] such as embedded processor, transceiver, memory and power supply. Each sensor node has limited power supply. Since the lifetime of network is totally dependent on power supply associated with each node, it must be used very carefully so that it can be saved. To reduce the energy consumption is very necessary because sometimes recharging of the battery is not possible in unmanned area. The more energy consumption by nodes means less network lifetime. There are several methods used to increase the lifetime of network by reducing the energy consumption. But now days, one method is very popular known as Adaptive duty cycle that enhanced the lifetime of WSN effectively and it is discussed deeply later.

WIRELESS SENSOR NETWORKS (WSN)

WSN is wireless network that consists hundreds or thousands of nodes that are capable of sensing and processing the data. WSNs are of two types: Unstructured and structured WSN. In unstructured WSN, deployment of nodes is Ad-hoc in nature means not pre-planned, all the nodes have equal status on network and nodes are infrastructure less. In structured WSN, nodes are deployed in pre-planned manner. In it, network maintenance is easy because of few and scarcely distributed nodes. In WSN, topology is very common term that plays an important role in minimizing the various constraints such as limited energy, latency etc. Actually, the energy consumption depends on number of packets transmitted, received and also upon the distance between sender and receiver nodes. This energy consumption can be reduced by using the energy efficient routing protocols. Some of them are discussed below:

A. LEACH

It is first and most popular hierarchical clustering algorithm that was introduced to minimize the energy consumption. LEACH stands for Low Energy Adaptive Clustering Hierarchy. It is simple in structure and also efficient [20]. Under this protocol, the Base Station (sink) is fixed and sensor nodes are homogeneous. The whole network is divided into several clusters and run time is further partitioned into many rounds. In each round a Cluster Head (CH) is selected among the nodes on the basis of predefined criterion. After it, all nodes send its data to CH which aggregate and compress the data and send it to Base Station (BS). All the nodes have same probability to become CH due to which nodes consume energy in a balanced way so as to enhance the lifetime of network.

B. GAF

It is a part of location based routing protocols where the sensor nodes are addressed using their locations [20]. GAF stands for Geographic Adaptive Fidelity that is used to reduce the energy consumption in transmission and reception of the data packets as well as in idle mode. In idle mode the transceiver is on but not sending and receiving any data, only sensor nodes are sensing the data. Using GAF, unused nodes are turned off and sensor field is divided into grid squares. The information is provided to sensor by GPS or any other location systems. In sleeping mode, the sensor node turned off its radio to reduce the energy consumption. In discovery mode, a node exchanges its discovery message to know the status of other node that is also in same grid. In active mode, a node transfers its discovery message at regular intervals. In this way, GAF protocol reduces the energy consumption which leads to increased lifetime of network.

C. Directed Diffusion

This protocol comes under Data-centric protocols where sensor nodes send its data to receiver through intermediate nodes using data aggregation mechanism [20]. Direct diffusion has high energy efficiency, provides scalability and robustness features also. The data is transferred according to the data rate. Nodes having the higher data send its data to sink after performing reinforcement process.

D. SPIN

It is also a part of Data-centric protocols [20]. SPIN means Sensor Protocols for Information via Negotiation. It is designed to remove the implosion and overlap problems and to enhance the flooding protocols. Under it, nodes estimates the energy consumption required to send or receive the data. SPIN has two main mechanisms i.e. negotiation and resource adaption. In negotiation, nodes communicate with each other before transferring the data to sink to avoid redundancy because it reduces the energy consumption. In resource adaption, Each and every node is conscious of its resource consumption.

PAST RESEARCH IN WSN

In the past few years various techniques were studied to reduce the energy consumption for the enhancement of network lifetime of WSN. The research work on WSN has been started from the year 2002. Researchers were taken more interest to improve the various parameters of WSN from the year 2009.

Qinghua Wang et.al, (2009) [4] analysed the effect of bottleneck zone (area near sink) on the performance of network and the performance bound in terms of network lifetime has been estimated. They also identified the bottleneck zone in an energy constrained WSN. A main disadvantage of WSN is energy constraint. The nodes sometimes fail to work because of exhausted energy. Nodes near the sink have high energy consumption than those further away due to which nodes near the sink fail earlier which degrades the performance of network.

Giuseppe Anastasi et.al, (2009) [5] proposed an Adaptive Staggered Sleep Protocol (ASLEEP). It is an independent sleep/wakeup protocol working above MAC layer. It needs a continuous co-ordination among nodes for maintaining the network wide sleep schedule. Adaptive schemes are complex than non-adaptive schemes. Under ASLLEP protocol, a sleep schedule is defined by communication period and talk interval of each individual parent node. Parameters which they considered are message latency, average latency and average delivery ratio. Simulation results had shown that ASLEEP protocol reduced the energy consumption which leads to increased lifetime. It had also reduced the message latency and increased the delivery ratio.

Yun Li et.al, (2011) [7] presented one of the best clustering-based Low Energy Adaptive Clustering Hierarchy (LEACH) routing protocol. Clustering-based routing used the information aggregation mechanism. LEACH is simple in structure and also efficient. Under this protocol, whole network is divided into several clusters and run time is further partitioned into many rounds. In each round a Cluster Head (CH) is selected among the nodes on the basis of predefined criterion. After it all nodes send its data to CH which aggregate and compress the data and send it to Base Station (BS). All the nodes have same probability to become CH due to which nodes consume energy in a balanced way so as to enhance the lifetime. Parameters used in this paper are number of cluster heads and number of frames.

Peng Guo et.al, (2012) [8] focused on critical event monitoring. For the reduction in delay of alarm broadcasting from any sensor node, a novel sleep scheduling method was introduced. It follows the level-by-level offset based wake-up pattern. The main aim is to minimize the broadcasting delay and energy consumption. The delay was reduced by minimizing the time consumed in waiting during broadcasting. Under this method, broadcasting of a message had done in two phases: one is uplink and second is downlink. Parameters which they considered are transmission delay, broadcasting delay.

Jenq-Shiou Leu et.al, (2013) [11] introduced Regional Energy-Aware Clustering with Isolated Nodes method (REAC-IN). The process of selecting the CH was improved by REAC-IN which also helped in solving the problem of node isolation. CH's are selected on the basis of weight. Weight is calculated by the residual energy and regional average energy of all sensors in each cluster. These two energies are calculated to determine whether the isolated node is sending the data to CH in previous round or to sink. They had shown the increased lifetime with more stability in their results.

An Energy- Balanced Routing Method based on Forward-Aware-Factor (FAF-EBRM) had been introduced in Deg Zhang et.al, (2014) [12]. On the basis of link weight and forward energy density the next-hop node is selected. Comparison was also done between FAF-EBRM and LEACH. Under this method, transmission power of nodes varies according to distance to receiver. The parameters they considered are Energy Balanced Facto (EBF), number of last surviving nodes, Function Lifetime (FL) and Packet Reception Ratio (PRR). Simulation results had shown that FAF-EBRM has better performance in terms of energy consumption and lifetime as compared to LEACH.

COMPARISON OF VARIOUS METHODS USED TO ENHANCE THE NETWORK LIFETIME

For the purpose of lifetime enhancement various methods are there which are shown in Table 1. In this table different methods for the network lifetime enhancement and parameters which are used in various methods are listed.

Table 1: Comparison of various methods

AUTHORS	YEAR	METHOD	PARAMETERS	COMMENTS
Qinghua Wang[4]	2009	Bottleneck zone analysis	Energy consumption	Nodes near sink consumes more energy
Guiseppe Anastasi[5]	2009	Adaptive sleep	Message latency	Less energy consumption
Yun Li[7]	2011	LEACH protocol	No. of cluster heads and no. of frames	Balanced Energy
Peng Guo[8]	2012	Sleep scheduling	Transmission delay	Less delay
Jenq-Shiou Leu [11]	2013	REAC-IN	No. of nodes, no. of packets	Enhanced lifetime with more reliability
Deg Zhang[12]	2014	FAF-EBRM	EBF, FL, PRR	FAF-EBRM has better performance over LEACH

WSN POWER CONSUMPTION

In WSN, each sensor node has a limited battery or energy. This energy is consumed in sensing, processing, transmitting and receiving the data. But most of the energy is consumed in transmission of data packets. Since power supply is limited and recharging of battery is not possible generally in unmanned area and sometimes solar energy is not trustworthy so it will be used properly without any wastage of it. If node will not use its available limited energy effectively then node depletes its energy very quickly known as Energy Hole problem which leads to depreciation in network lifetime. The fundamental challenge in WSN is to enhance the lifetime of network. Energy consumption can be reduced by using the efficient routing protocols. Energy can also be saved by duty cycle method in which node goes ON and OFF periodically. Duty cycle saves the energy which is consumed in idle state. It is that state when transceiver is ON but not sending and receiving any data. There are some techniques used to reduce the power or energy consumption as shown below:

A. Dynamic Power Management

This technique [13] reduces the energy consumption without deteriorating the performance of network. The components are made in such a way so that they consume the low power. Under this technique, the events that had already missed are not considered in the sleeping state of node. Nodes are ON only when required otherwise they are in OFF state to save the energy. When the node will be OFF or ON, it's totally depends on the present and past activity of the node itself.

B. Dynamic Voltage Scaling and Dynamic Frequency Scaling

In it energy consumption is reduced by varying the voltage and frequency [13]. The nodes having heavy load will have the first priority to get ON and it will work faster and the nodes having less load will work slowly. Hence energy consumption is reduced.

C. Duty Cycle Control

Duty cycle is defined as the ratio of time spent by node in active state to the total time of active and sleep state. Under it [14], energy consumed in idle state is saved by turning off the transceiver if communication is not needed.

WSN LIFETIME USING ADAPTIVE DUTY CYCLE

The network lifetime is defined as the duration of data transfer from the deployment to the first breakdown of nodes. The Enhancement of network lifetime is very important because of the limited availability of power resources. In an energy constraint WSN, the enhancement of the lifetime of network is a very difficult task. In WSN, all the traffic reaches at the sink. There is heavy load on the nodes which are nearer to the sink due to the continuous transmission and reception of data packets. The area near the sink is called bottleneck zone [15]. The nodes that are in bottleneck zone deplete their energy very quickly. This result in wastage of available energy leads to reduction in lifetime of network. From the literature survey, it has been observed that there are several methods that prolong the network lifetime. In some techniques which were used earlier, even energy has been also consumed in idle state. Idle state is that state in which radio module is ON but it is not sending or receiving the data. Sometimes idle state consumes as much energy as reception sate. So, to save energy in idle state, the concept of duty cycle was introduced where transceiver is OFF if nodes do not have any information to send. The energy is saved by switching between active and sleep states periodically. The duty cycle is defined as the ratio of the time in which sensor node is in active state to the total time of active plus sleep states. The duty cycled WSN are of two types: Random duty cycled WSN and Co-ordinate duty cycled WSN [15]. In random duty cycle, nodes work independently and are turned OFF and ON in a random order. But in co-ordinate, nodes communicate with each other before transferring the information and it requires additional control message. In [15] random duty cycle based WSN is used. Under it, nodes are turned ON even if there is no incoming data or sensed data that leads to wastage of energy which further degrades the network lifetime.

Hence, to enhance the lifetime of network we proposed a new technique called **Adaptive Duty Cycle**. The idea comes from [15] [19]. The proposed technique reduces the energy consumption by controlling the duty cycle on the basis of the queue length to obtain high-performance under variable traffic rates. A feedback controller will be designed to minimize the delay and to achieve the high energy efficiency. The sleep time is set according to the traffic that is changing dynamically by constraining the queue length at a predetermined threshold value. The trajectories of the queue (the queue length and its varying trends) are used as an implicit indicator of network status, such as traffic load and route depth. On the basis of the queue length and its variations, a dynamic duty cycle control scheme has been designed to meet time-varying traffic loads by constraining the queue length at a predetermined threshold value [19]. The controller will automatically adjust the sleep time so that the queue length at the steady state is equal to the predetermined queue threshold. The sleep interval time increases as the value of the queue length becomes smaller than the threshold value. But the sleep interval time decreases as the forward difference of queue length becomes larger than zero because the increased forward difference of queue length induces a longer latency. The queue threshold is set according to the application requirements. When the queue threshold is set at low value, delay decreases because sleep time decreases. If the queue threshold is set at very high value, the delay increases because sleep time increases. At this condition, more time is required to buffer the packets until the queue length becomes equal to or greater than queue threshold value.

In bottleneck zone, the total energy consumption is mainly due to three reasons: (a) to relay the bits those are received from outside of the bottleneck zone (E_{01D}), (b) to sense the data bits inside the bottleneck zone (E_{02D}), (c) to relay the data bits those are generated inside the bottleneck zone (E_{03D}) [15]. The total energy consumption inside the bottleneck zone in time t for a p duty cycle can be calculated as:

$$E_D = E_{01D} + E_{02D} + E_{03D} + (1-p)tN\frac{B}{A}E_{sleep} \tag{1}$$

$$E_D = \left[\frac{m+1}{2}\right]Npr_st\frac{A-B}{A}\left(\alpha_1\frac{n}{n-1}\frac{D}{d_m}\right) + Np\frac{B}{A}r_ste_s + p\frac{N}{A}r_ste_s + p\frac{N}{A}r_st\iint_B\left(\alpha_1\frac{n}{n-1}\frac{x}{d_m}-\alpha_{12}\right)dS + (1-p)N\frac{B}{A}E_{sleep} \tag{2}$$

where ‘N’ is the total number of nodes in monitoring area , ‘A’ is the total area, ‘B’ is the area of bottleneck zone, ‘m’ is the number of active neighbours inside bottleneck zone to the node which is outside of the bottleneck zone and transferring the redundant bits, ‘D’ is a bottleneck zone radius, ‘d_m’ is optimal hop length, ‘p’ is duty cycle, ‘r_s’ is the average sensing rate of each sensor node, ‘e_s’ is the energy consumed by a node to sense a bit and its value is taken very small, ‘E_{sleep}’ is the energy consumed by a sensor node per second in the sleep state, ‘α_{12}’ is energy consumption of a node during receiving a bit, ‘α_2’ is the energy consumption per bit in transmit op-amp, ‘n’ is path loss exponent, ‘H’ is the number of bits transferred. The lifetime of a WSN depends on the energy consumed at the node level. Let E_b is the initial battery energy of each sensor node. For N number of nodes, the total energy in the beginning available is ($N\times E_b$).

$$E_D \leq \frac{NB}{A} E_b \Rightarrow t \leq \frac{d_m B E_b}{Q_x} = T_U D \quad (3)$$

Where $T_u D$ is the lifetime of WSN with duty cycle (p) and Q_x is given by:

$$Q_x = p\alpha_1 \frac{n}{n-1} r_s \left[D(A-B)\left[\frac{m+1}{2}\right] + \iint_B xdS \right] + Bd_m \left[pr_s (e_s - \alpha_{12}) + (1-p) E_{sleep} \right] \quad (4)$$

The maximum amount of energy is consumed at p=1 which means that all the nodes are in active state and lifetime obtained for p=1 is minimum. The bottleneck zone area is defined by πD^2. The value of r_s is H/((A-B) *N/A) and $\iint_B xdS = \left(\frac{2}{3}\right)\pi D^3$. All the equations defined above and the Table 2 which is shown below is taken from [15] directly.

We will implement the proposed technique by using same equations and same parameters with the same values as was used in [15]. The value of duty cycle has been taken from 1% to 10%. As the duty cycle p increases, the network lifetime decreases because high value of duty cycle suggest that more number of nodes will be in active state due to which more energy consumption will occur. A low duty cycle is preferred in WSN because it results in less energy consumption. The increase in the value of m means that more energy is consumed for the transmission of the redundant bits in bottleneck zone.

Table 2: Settings of Parameter

PARAMETER	TYPE	VALUES
Number of nodes(N)	General	1000
Area(A)	General	200×200
Path loss exponent(n)	General	2
α_{11}	General	0.937 µJ per bit
α_{12}	General	0.787 µJ per bit
α_2	General	0.0172 µJ per bit
E_{sleep}	General	30 µJ per bit
E_b	General	25 KJ
α_1	General	0.33 µJ per bit
Data bits(H)	General	960 bits
D	General	60 meters
d_m	General	2
No. of packets(k)	General	2
Active neighbour nodes (m)	Input	1,3,5,7, 9
Duty cycle(p)	Input	0.01 to 0.1
Lifetime in seconds	Output	--------

SIMULATION RESULTS

The simulation work has been performed on MATLAB tool. The input parameters used in this paper are duty cycle p and number of active neighbours inside bottleneck zone i.e. m. Any node during transmission have [1, m] number of active neighbours inside the bottleneck zone. The output parameter is lifetime that is measured in seconds. The flow chart of proposed algorithm is shown in Fig.1. The results are obtained using equation (3) and the values of all the parameters are set according to Table 2. The results using randomly duty cycle based WSN from [15] is shown in Fig.2. The simulated results using proposed technique (Adaptive duty cycle) are shown in Fig. 3. The graph is plotted between network lifetime at Y-axis and duty cycle at X-axis for different values of m. It is observed that as the value of m and p increases, the network lifetime decreases. The value of p is taken from 0.01 to 0.1 and the value of threshold is taken constant.

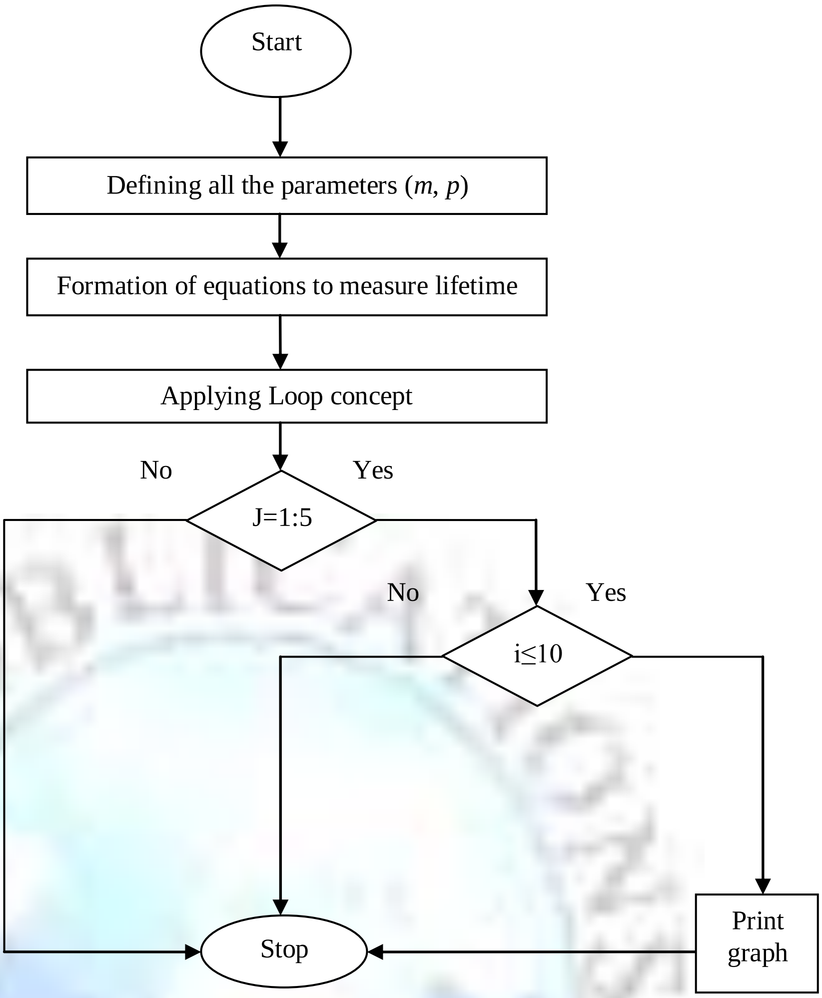

Fig.1: Flow chart of proposed algorithm

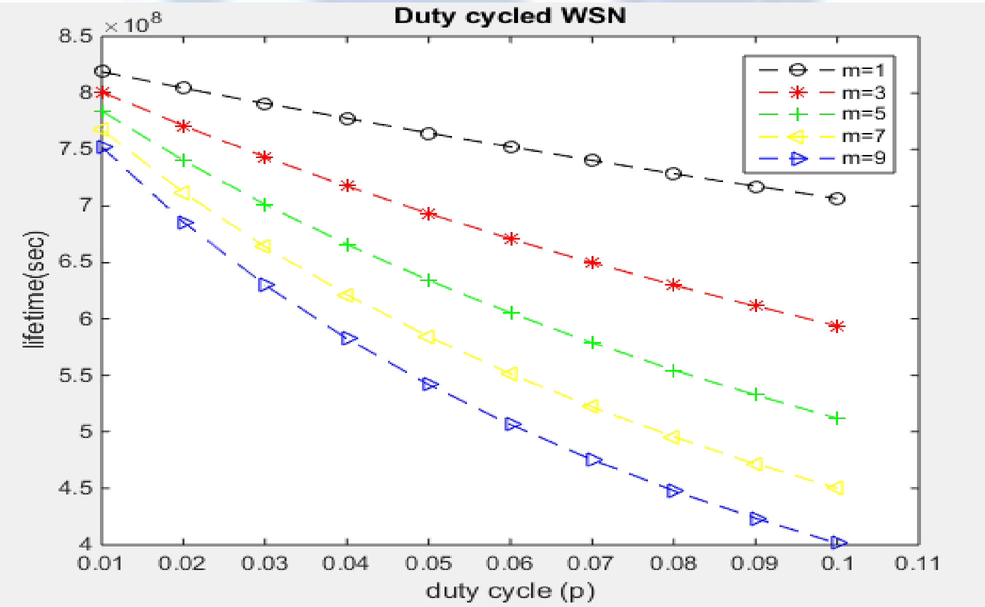

Fig. 2 : Network lifetime using random duty cycle

For m=1, the lifetime obtained is 8.1864×10^{8} seconds at p=0.01 and 7.0653×10^{8} seconds at p=0.1.
For m=9, the lifetime obtained is 7.5239×10^{8} seconds at p=0.01 and 4.0144×10^{8} seconds at p=0.1.

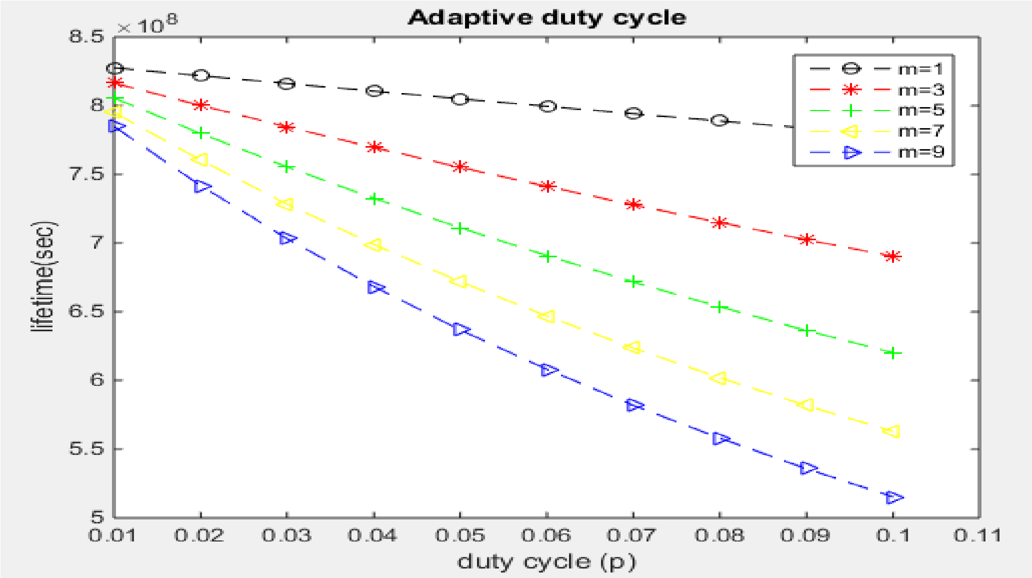

Fig.3: Network lifetime using Adaptive duty cycle

For m=1, the lifetime obtained is $8.2750*10^8$ seconds at p=0.01 and$7.7847*10^8$ seconds at p=0.1.
For m=9, the lifetime obtained is $7.8489*10^8$ seconds at p=0.01 and $5.1527*10^8$ seconds at p=0.1.

CONCLUSION AND FUTURE SCOPE

In WSN, the maximum flow of traffic is in bottleneck zone. The lifetime of whole network is totally depends on lifetime of bottleneck zone. So, to save energy a new technique has been proposed known as Adaptive duty cycle that operates on queue management process under variable traffic rates. From the obtained results it has been observed that this proposed technique reduced the energy consumption in bottleneck zone which in-turn improves the lifetime of wireless sensor networks. Simulation results show that by using the proposed technique network lifetime has been enhanced by 10.942%. (Average value) Adaptive duty cycled WSN is better than randomly duty cycle based WSN and the proposed technique has better energy efficiency. Further existing or current work can be extended by adding the concept of network coding in adaptive duty cycle.

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