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PROTOCOLS FOR INCREASING THE LIFETIME OF NODES OF AD HOC WIRELESS NETWORKS

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Abstract

Power consumption of nodes in ad hoc networks is a critical issue as they predominantly operate on batteries. In order to improve the lifetime of an ad hoc network, all the nodes must be utilized evenly and the power required for connections must be minimized. Energy management deals with the process of managing energy resources by means of controlling the battery discharge, adjusting the transmission power and scheduling of power sources so as to increase the lifetime of the nodes of an ad hoc wireless network. In this paper, two protocols are proposed to improve the lifetime of the nodes. The first protocol assumes smart battery packages with L cells and uses dynamic programming (DP) to optimally select the set of cells used to satisfy a request for power. The second one proposes a MAC layer protocol denoted as Power Aware medium Access Control(PAMAC) protocol which enables the network layer to select a route with minimum total power requirement among the possible routes between a source and a destination provided all nodes in the routes have battery capacity above a threshold. The life time of the nodes using the DP based scheduling policy is found through simulation and compared with that obtained using the techniques reported in the literature. It is found that DP based policy increases the lifetime of the mobile nodes by a factor of 1.15 to 1.8. The life expectancy, the average power consumption and throughput of the network using PAMAC protocol are computed through simulation and compared with that of the other MAC layer protocols 802.11, MACA, and CSMA. Besides this, the life expectancy and average power consumption of the network for different values of threshold are also compared. From the simulation results, it is observed that PAMAC consumes the least power and provides the longest lifetime among the various MAC Layer protocols. Moreover, using PAMAC as the MAC layer protocol, the performance obtained using different routing layer protocols are studied. It is observed that AODV consumes the least power and provides the longest lifetime.

Keywords:
Lifetime, Battery, Mac layer protocols, AODV, Adhoc network, Power consumption, Dynamic programming.

1. INTRODUCTION

The nodes in an adhoc network are constrained by limited battery power for their operation. The use of multi-hop relaying requires a sufficient number of relaying nodes to maintain the network connectivity. Hence, battery power which is a precious resource must be used efficiently in order to avoid early termination of any nodes [1]. Efficient battery management, transmission power management and system power management are the three major means of increasing the lifetime of a node [1].

Battery management is concerned with problems that lie in the selection of battery technologies, finding the optimal capacity of the battery, and scheduling of batteries. Transmission power management techniques attempt to find an optimum power level for the nodes in an adhoc wireless network. System power management deals with minimizing the power required by hardware peripherals of a node and incorporating low power strategies into the protocols used in various layers of the protocol stack[1].

Battery–driven systems are those systems which are designed taking into consideration mainly the battery and its internal characteristics. They try to maximize the amount of energy provided by the power source by exploiting the inherent property of the batteries to recover their charge when kept idle. It is shown that by varying the manner in which energy is drawn from the batteries, significant improvement can be obtained in the total amount of energy supplied by them [1].

Each node in an ad hoc network communicates directly with nodes within its transmission range. To send a packet to a destination, a node forwards the packet to its neighbor, which in turn forwards it to its neighbor, and so on, until the packet reaches the destination. The topology of the Ad hoc network depends on the transmission power of the nodes and the location of the mobile nodes, which may change with time. There are several MAC layer protocols such as CSMA, MACA and IEEE 802.11. In CSMA protocol, a station wishing to transmit, first listens to the medium in order to determine if another transmission is in progress. If the transmission medium is busy, the station waits, otherwise it may transmit. But CSMA protocol has the limitations of hidden and exposed terminals. The MACA and the 802.11 protocols use the RTS/CTS dialogue for collision avoidance on the shared channel. MACA does not make use of carrier sensing for channel access. It uses two additional signaling packets: the request–to-send (RTS) packet and the clear-to-send (CTS) packet. When a node wants to transmit a data packet, it first transmits an RTS packet. On receiving the RTS packet, the receiver node transmits a CTS packet if it is ready to receive the data packet. The reception of the CTS packet at the transmitting node acknowledges that the RTS/CTS dialogue has been successful and the node starts the transmission of the actual data packet. The IEEE 802.11 requires an Acknowledgement (ACK) from the receiver after the successful reception of packets. So the RTS/CTS dialogue in MACA provides some degree of improvement over the CSMA schemes.

But the binary exponential backoff algorithm used in MACA completely blocks the data flow from a specific node over a period of time. To overcome these limitations, a MAC layer protocol denoted as Power Aware medium Access Control (PAMAC) protocol is proposed in this paper. It is coded on lines similar to MACA in the sense that it too uses the concept of RTS/CTS dialogue. Additionally, it incorporates the feature of checking the battery capacity of the nodes in the network.

The rest of the paper is organized as follows. Section 2 provides an overview of battery characteristics and describes the existing work in this area. Section 3 presents the proposed scheduling policy and the implementation details. Section 4 presents the proposed MAC layer protocol PAMAC and the implementation details. Section 5 analyses the results of two protocols and finally section 6 summarizes the results.

2. OVERVIEW OF BATTERY CHARACTERISTICS

A battery consists of an array of one or more electro chemical cells. It can be characterized either by its voltages or by its initial and remaining capacities. The behavior of the batteries is governed by the following major chemical effects [2].

2.1 RATE AND RECOVERY CAPACITY EFFECTS

As the intensity of the discharge current increases, an insoluble component develops between the inner and outer surfaces of the cathode of the batteries. The inner surface becomes inaccessible as a result of this phenomenon, rendering the cell unusable even while a sizable amount of active materials still exists. This effect termed as rate capacity effect depends on the actual capacity of the cell and the discharge current. Recovery capacity effect is concerned with the recovery of charges under idle conditions. Due to this effect, on increasing the idle time of the batteries, one may be able to completely utilize the theoretical capacity of the batteries [2].

2.2 BATTERY CAPACITIES

The amount of active materials contained in the battery refers to its theoretical capacity *(T)* and hence total number of such discharges cannot exceed the battery's theoretical capacity. Whenever the battery discharges, the theoretical capacity of battery decreases. Nominal capacity *(N)* corresponds to the capacity actually available when the battery is discharged at a specific constant current. Whenever the battery discharges, nominal capacity decreases and it increases probabilistically as the battery remains idle which is also called as recovery state of the battery. This is due to the recovery capacity effect. The energy delivered under a given load is said to be the actual capacity of the battery. In this paper, the lifetime of a node is defined as the duration over which the battery delivers the energy corresponding to its actual capacity. A battery may exceed the actual capacity but not the theoretical capacity. This is due to rate capacity effect. By increasing the idle time, one may be able to utilize the maximum capacity of the battery [2].

2.3 REVIEW OF THE PREVIOUS WORK ON BATTERY MANAGEMENT TECHNIQUES

Battery models depict the characteristics of the batteries used in real life. The following models namely analytical model, stochastic models, and electro-chemical models are discussed in [3]. It summarizes the pros and cons of each of the models. C.F. Chiasserini and R.R. Rao[4] showed that the pulsed discharge current applied for bursty stochastic transmissions improves the battery life time better than that using constant discharge. Different battery management techniques are presented and compared analytically by C.F. Chiasserini and R.R. Rao[5]. It is also shown by simulation that the lifetime of the battery can be maximized under simple traffic management schemes. When energy needs to be drained from the battery, one of the several cells of the battery is chosen to provide the energy, while the rest of the cells may potentially recover part of their charge. Thus efficient battery discharge strategies can increase the battery lifetime, if they take advantage of this recovery mechanism. Each node is assumed to contain a battery package with L cells and three battery scheduling policies are proposed. Further, the battery behavior under two different modes of pulse discharge is studied. In a battery of L cells, a subset of cells can be scheduled for transmitting a given packet leaving other cells to recover their charge. The following approaches are applied to select the subset of cells namely delay free approaches and no delay free approaches [5].

No delay free approach considers a battery management technique that involves coordination among the cells of the array and drains current from the cells according to their state of charge. Because of the availability of smart battery packages, it is possible to track the discharged capacity of the cells. The goal is to monitor the cell's status and make them recover as much as they need to obtain the maximum available capacity from the discharge process.

A number of suboptimal policies are proposed and the performances using them are evaluated through simulation and the results are compared in the paper [6].

A framework has been developed to compute the optimal discharge policy that maximizes the battery lifetime by Saswati Sarkar and Maria Adamou [7]. But this strategy requires significant time and memory for computation. Hence, a strategy known as Maximum Charge scheduling policy which aims to efficiently choose the cell to be discharged, so as to approximate the optimal is proposed in the same paper.

The size of the packet is specified in terms of number of charge units to be discharged from a battery. The size of the packets corresponding to each traffic burst is assumed to be poisson distributed [6]. The poisson process is the oldest process that has been used to model interarrival times of traffic streams. With poisson traffic, clustering occur in short term but smoothes out over the long term. A queue may build up in the short run but over a long period, the buffers are cleared out. Hence, only modest sized buffers are needed. This model can describe short length dependence traffic accurately. But it is not adequate to describe the phenomenon of real traffic because of long range dependence in network traffic. In view of this, alternate traffic models such as self similar model have been proposed in the literature [8].

In this paper, the burst size is assumed to be uniformly distributed in the interval (0,N) where N is a variable. Using dynamic programming (DP), the battery recovery capacity is optimized and the number of packets successfully transmitted during the lifetime of a node is compared with two scheduling policies namely Round Robin scheme with delay free approach and Round Robin scheme with no delay free approach.

2.4. REVIEW OF THE PREVIOUS WORK ON NETWORK LEVEL TECHNIQUES

A major issue in the energy constrained ad hoc networks is to find ways that increase their lifetime. The use of multihop radio relaying requires a sufficient number of relaying nodes to maintain network connectivity. Hence, battery power is a precious resource that must be used efficiently in order to avoid early termination of any node. Advances in battery technologies have been slower as compared to the recent advances in the field of mobile communication [2]. However, users' desire to extract more functionality from the mobile device continues. In view of these, low power design and energy saving techniques have become the focus of recent research. A number of works have been reported in the literature with these objectives.

Minimum Total Transmission Power Routing (MTPR) algorithm is proposed by M.Woo et al., [9]. This uses the fact that minimum transmission power is dependent on interference noise, distance between nodes, and desired BER. To obtain the route with minimum total power, the transmission powers between nodes are used as a metric. Since transmission power depends on distance, this algorithm selects routes with more hops than other routing algorithms. Minimum Battery Cost Routing (MBCR) algorithm is proposed by S.Singh and C.S.Ragavendra [10].In this protocol, the remaining battery capacity is used as a metric to prevent hosts from being overused and thereby increases the lifetime of hosts till the network is partitioned. However, this algorithm has the disadvantage that a route containing nodes with little remaining battery capacity may still be selected, since the sum of battery cost functions is considered. This limitation is overcome in the Min _Max Battery Cost Routing algorithm (MMBCR) proposed by Woo et al. MMBCR defined the battery cost function in such a way that this metric always tries to avoid the route with nodes having the least battery capacity among all nodes in all possible routes. Here, the battery of each host is used more fairly than other protocols. Initially it seems that the lifetime of all nodes will be elongated. However, on closer examination, it reveals that there is no guarantee that minimum total transmission power paths will be selected under all circumstances. It may consume more power to transmit the user traffic from source to destination and may actually reduce the lifetime of all nodes.

It may be noted that the maximization of the lifetime of each node and fair utilization of the battery power cannot be achieved simultaneously by applying MTPR or MMBCR schemes. MMBCR can only fulfill both of them sometimes. To overcome this problem, Power Efficient Battery Capacity Routing (PEBCR) algorithm is proposed in the literature [11]. In order to select a route between a source and destination, it considers only those routes between the source and the destination in which all the nodes in each of the routes have battery capacity above a threshold. Among the various possible routes satisfying the above criteria, the one requiring the minimum total transmission power is chosen. Since the total power required to forward packets is reduced for each connection, the power spent to relay the packets by most of the nodes will be reduced and their lifetime will be extended. When the battery capacity of a node goes below a predefined capacity, routes going through this node are avoided. Such nodes can only act as either source or destination node.

It is assumed that all nodes transmit packets with a fixed power level. In this case, the path selected by MTPR is identical to the shortest hop path, and MTPR has no power-saving effect compared to other shortest hop path algorithms, such as AODV. In fact, if the MAC layer of each mobile node uses CSMA/CA to broadcast a RREQ packet, energy consumed by MTBR is equivalent to that consumed when using the shortest hop algorithm. Hence, a new MAC and network layer algorithms for energy efficient routing is proposed in the paper [12]. But this algorithm requires the cross-layer design between the MAC layer and network layer.

3. PROPOSED SCHEDULING POLICY

With the advent of Smart Battery Packages (such as Linuxsbs), it is possible to find the state of each cell (i.e.) the nominal and theoretical capacities of each cell. In round robin delay free approach, the state information is ignored for scheduling. In round robin no delay free approach, the state of the battery package is compared against a threshold for scheduling. In any case, the search for optimality must also be balanced against the need to accurately model the batteries and to keep the overall system as simple as possible. Every discharge policy tries to take advantage of recovery capacity effect which can be stated as the ability of a cell to recover probabilistically one charge unit in one time slot when it is idle. The scheduling policy proposed in this paper, tries to take advantage of the inherent pattern present in cells that are recovering a unit of charge: the recovery of one charge unit in a time slot by each cell is mutually independent of charge recovery by any other cell.

Let us assume that there are L cells each numbered from 0..L-1, the probability of recovery of cell i whose state is defined by the two tuple set (N_i,T_i) is given by S. Jayashree et al.,[2].

$$P(r_i) = \exp(-g_c (N-N_i)-\varphi(T_i)) \text{ if } 0< N_i < N \text{ and } 0< T_i < T$$
$$P(r_i) = 0 \text{ otherwise} \qquad (1)$$

where

g_c is a device dependent parameter which gives the internal resistance or conductance of the cell.

N – the rated nominal capacity of the cell under fully charged condition.

N_i - the available nominal capacity of the cell

T – the maximum capacity of the cell (a direct function of the amount of active materials initially present)

T_i – the available maximum capacity (a direct function of the amount of active materials present at that instant)

The sum of the probability of recoveries is given by

$$P(R) = \sum_{i=0}^{L-1} P(r_i) \qquad (2)$$

Assuming each cell to have a pulsed discharged profile and a generalized pulsed discharge model for the battery, we propose that each request can be optimally satisfied if P(R) is maximized. For expressing the result mathematically, we assume a request of size K arrives (i.e the next burst to be transmitted requires K charge units). For a cell i, its state is given by the 2-tuple set (N_i, T_i),

Let a_i be the amount of charge units supplied by the i^{th} cell.

P(R) must be maximized subject to the constraint

$$\sum_{i=0}^{L-1} a_i = K \qquad (3)$$

and

$P(r_i) = \exp(-g_c\,(N-(N_i-a_i))-\varphi(T_i-a_i))$ for all i=0,1,…..L-1.

Since we assume a pulse discharge profile, each cell discharges the required amount of charge units for a fraction of the time slot.

3.1 A SCHEDULING THE DISCHARGING OF THE CELLS USING DYNAMIC PROGRAMMING

With a battery package with L cells, there are O (2^L) ways by which a request of size K can be satisfied. Hence, implementing the above mentioned idea in an efficient and optimized manner presents a big challenge. Fortunately, the problem of satisfying optimally the request of size K contains an optimal substructure and hence is solvable by the strategy of dynamic programming (DP) as proposed by Richard Ernest Bellman [13],[14].

Dynamic Programming is typically applied to optimization problems. In such problems, there can be many possible solutions. Each solution has a value and we wish to find a solution with the optimum value. The development of the DP algorithm can be broken into a sequence of four steps.

1. Characterize the structure of the optimal solution
2. Recursively define the value of an optimal solution
3. Compute the value of the optimal solution in a bottom-up fashion.
4. Construct an optimal solution from computed information.

Basically the DP protocol works as follows: It computes in a bottom up manner, the optimal power requirements for each burst size up to the maximum burst. In that sense, the protocol is burst size independent.

For a random access MAC protocol, for transmitting any burst, the transmitter has to wait for a time equal to at least the minimum contention window (the wait could be longer as the size of the contention window increases due to collisions). If the execution of the DP protocol is pipelined with the contention window period of the previous burst, the overhead in executing the algorithm can be effectively absorbed. So we neglect the delay caused by it in our simulation. This is a valid assumption because the size of the contention window is almost equal to the time required for executing the DP algorithm.

Following step 1, the sub problems are nothing but the optimal ways to satisfy the request of size j ($0 \leq j < K$).

Now the recurrence relation connecting the various sub problems can be given as follows

$$\begin{aligned} P[i] = \max\{&P[i-k] - \exp(-g_c(N-N_i + set[i-k][j])- \\ &\varphi(T_i - set[i-k][j])) + \exp(-g_c(N-N_i + set[i-k][j]+ k)- \\ &\varphi(T_i - set[i-k][j] - k))\} \text{ if } i>0 \end{aligned} \qquad (4)$$

For j = 0….L-1, k = 1….min(Nj,Tj),

set[i-k][j] defines the amount of charge units taken from the cell j for satisfying the request of size (i-k).

4. PROPOSED POWER AWARE MAC PROTOCOL (PAMAC)

The proposed Power Aware MAC protocol(PAMAC) uses the basic ideas of PEBCR and it incorporates these features into the MAC layer as it is essential to minimize the total transmission power consumption. The important features of PAMAC are the following:

- A node, on receipt of RTS first checks to see if its battery capacity is above the threshold. This condition has to be satisfied for the node to send a CTS message to the node that sent the RTS message.
- As and when a node keeps transmitting data packets, its battery capacity parameter is appropriately subtracted according to the size of the packet being transmitted and the destination to which it is transmitting the packet.
- If the battery capacity of a certain node reaches the threshold limit, it sends a request message to all the other nodes seeking for a position exchange with one of the exterior nodes.
- On receipt of such a request message for exchange, the nodes compare their battery capacity with a certain threshold which is higher than the above mentioned threshold so that the exchange is profitable. They also compare the number of messages that they process to check if it is below a certain minimum. If both the criteria are met then the node sends a positive response to the node that initiated the request.
- Thereby PAMAC enables the network layer to select a route with nodes requiring minimum total transmission power

5. SIMULATION RESULTS

5.1 COMPARISON OF DP PROTOCOL WITH ROUND ROBIN

The no. of packets successfully transmitted during the life time of a node using both DP protocol and the ROUND ROBIN protocol are computed through simulations and are compared. For the simulation, ‘C’ program is developed and is executed in Windows XP environment. Two assumptions are made about the characteristics of the nodes. In the first case, the nodes are assumed to have cells with very high internal resistance (high value of g_c parameter) and it corresponds to delay free protocol. In the second case, the cells are assumed to have very low internal resistance and it corresponds to no delay free protocol. In this case, the performance metric also includes the average packet delay.

Assumptions made for the simulation:

N=10 (nominal capacity is assumed to be 10 charge units)
T=15 (theoritical capacity is assumed to be 15 charge units)
g_c=2 (device discharge parameter g).

Traffic bursts assumed:

1) Variable traffic burst (with maximum burst size fixed).

2) Constant traffic burst size, assuming that in each time slot the burst of constant size is transmitted.

The results of the simulation for variable traffic burst and constant traffic burst corresponding to delay free assumption are given in Table 1 and 2 respectively

Table 1. Probabilistic distribution of traffic bursts with maximum burst size fixed.

Maximum size of the burst	No. of packets successfully transmitted during the lifetime of a node	
	Using DP	Using round-robin
8	30	17
6	34	23
5	38	30
4	51	32
2	93	64

Table 2. Constant size burst mode traffic

Maximum size of the burst	No. of packets successfully transmitted during the lifetime of a node	
	Using DP	Using round-robin
8	13	10
6	18	10
5	22	19
4	29	20
2	69	52

From Table 1 and 2, we find that the DP protocol results in the increase in the number of packets transmitted during the life time of the node by a factor of 1.15 to 1.8.

The second case involves the device with very low resistance that is low $g_{c.}$

Hence, the recovery capacity of the device is very high. In this case, both the protocols use NO-DELAY FREE approach. That is, traffic shaping techniques are employed wherein a burst is not transmitted immediately if the cell does not have sufficient power to transmit it. Rather it is forced to wait till the cell recovers sufficient charge to transmit it. Thus, a new concept of packet delay is introduced.

Assumptions made for the simulation:

N=10 (nominal capacity is assumed to be 10 charge units)
T=15 (theoritical capacity is assumed to be 15 charge units)
$\mathbf{g_c}$=0.5 (device discharge parameter g)
Frame Size = 10 ms.
Here variable traffic burst (with maximum burst size fixed) is assumed.
power and transmitter power are assumed to be 1000mw and 32mw respectively.

The results of the simulation corresponding to variable traffic burst corresponding to no delay free are assumption is given in Table 3.

Table 3. Lifetimes with Low Internal Resistances

Maximum size of the burst	No. of packets successfully transmitted during the lifetime of a node	
	Using DP	Using round-robin
7	128	45
6	141	58
5	178	81
4	202	144

Let Ti be the fraction time for which the cell supplies charge. Since in our DP protocol, the probability that the cell supplies charge or not for the current request depends on the state of the cell which in turn depends on the distribution of the traffic burst, it is fair to assume that on an average L/2 cells are used to satisfy a request. Thus the time taken in case of our DP protocol is (L/2)* Ti. Typical values of Ti are 500 microseconds [4]. So, in this case, the average packet delay is 2.5 ms. for L=10. The average packet delay for various traffic bursts in case of round-robin with no delay free protocol is given in Table 4.Here; the values of average packet delay are measured in seconds. Thus we find that PAMAC offers a significantly better performance as compared to round robin with no-delay free in case of a device with very low internal resistance.

Table 4. Average packet delay for round-robin approach with no delay free protocol

Maximum size of the burst	Average packet delay in sec
7	0.131556
6	0.126379
5	0.038395
4	0.117153

5.2 PERFORMANCE ANALYSIS AND SIMULATION RESULTS WITH PAMAC PROTOCOL

The proposed PAMAC protocol is simulated using GloMoSim [15] by considering thirty nodes randomly distributed in an area of 2000 x 2000 m. Within the network, the communications between any two wireless terminals is achieved through Direct Link. The network size is determined based on the magnitude of transmission power. In the simulation, the transmission power is fixed for all wireless terminals. It is assumed that two terminals can hear each other if their distance is in the transmission range. The transmission range is set to 30m. All nodes are assumed to have the same amount of battery capacity at the beginning of simulation process. Here initial battery

5.2.1 Average Power Consumption Analysis:

Fig.1. shows that the average power consumption of the nodes of the network as a function of battery threshold when Bellman-Ford algorithm is used as a routing layer protocol. It shows that it decreases as the minimum battery threshold is increased. This behavior can be attributed to the fact that the proposed PAMAC protocol enables the routing layer to select a route with minimum total transmission power among the possible routes between a source and a destination, provided all nodes in the routes have battery capacity above a threshold. When the battery capacity goes below a predefined threshold, routes going through these nodes will be avoided and these nodes will act only as source and destination. Thus higher the battery threshold, lower is the power consumption of the overall network.

Fig.2 compares the average power consumed by the nodes in the network for the different MAC Layer protocols when Bellman-Ford algorithm is used as a routing layer protocol. The PAMAC consumes the least power while MACA comes a close second with CSMA third. 802.11 has a very high power consumption level that is out of this scale. Thus this figure clearly illustrates that PAMAC helps in reducing the average power consumed by the network when compared with any other protocol in the MAC Layer.

Fig.3 compares the average power consumption of the network nodes for different Routing Layer protocols with PAMAC as the MAC layer protocol. This graph shows that AODV with PAMAC consumes the least power while Bellman Ford consumes the most. This can be attributed to the fact that AODV focuses on minimizing unwanted broadcasts. Thus when coupled with a power Aware algorithm (PAMAC) in the MAC layer, it consumes the least power.

5.2.2 Lifetime Analysis:

Fig.4 plots the lifetime of the nodes in the network for different values of battery threshold. PAMAC and Bellman-Ford protocols are used at the MAC layer and routing layer respectively. This graph shows that the lifetime of the node increases as the battery threshold is increased.

Fig.5 compares the lifetime of the nodes of the network for different routing layer protocols with PAMAC as the MAC layer protocol. The above graph shows that nodes have the highest lifetime when AODV is used and the least when Bellman Ford is used.

Fig.6 compares the lifetime of the nodes for various MAC layer protocols for Bellman-Ford routing algorithm. From this figure, it can be inferred that PAMAC gives 5-10 times higher lifetime for the nodes compared to other MAC layer protocols. MACA and CDMA have nearly the same lifetime while 802.11 have a relatively longer lifetime.

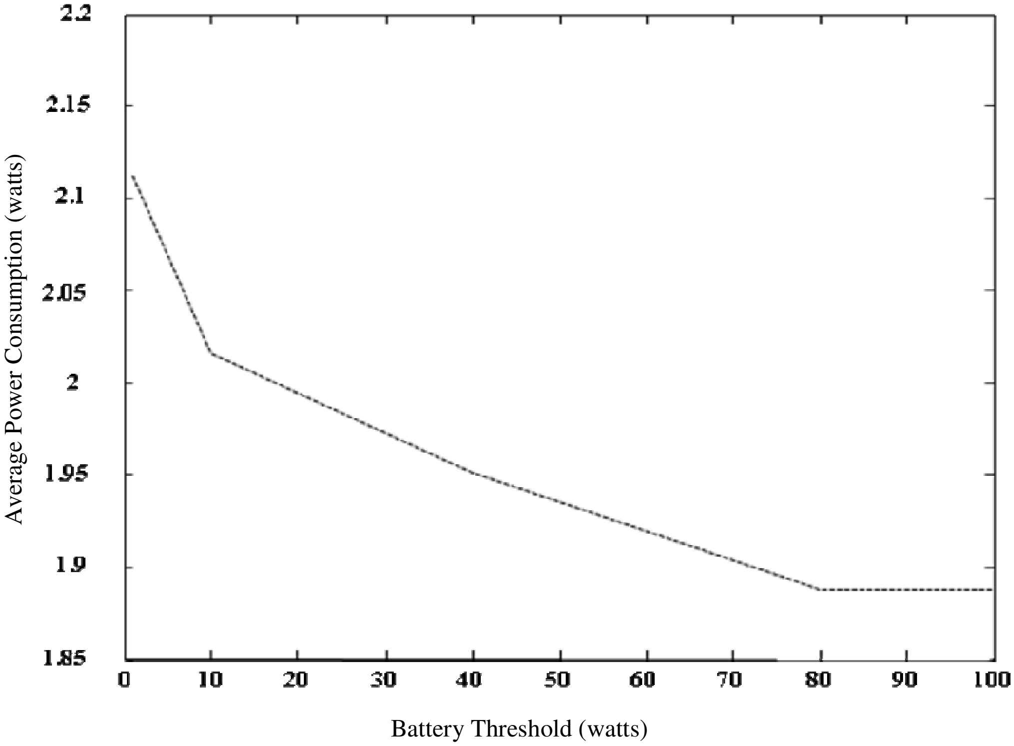

Fig.1. Average Power Consumption vs. Battery Threshold

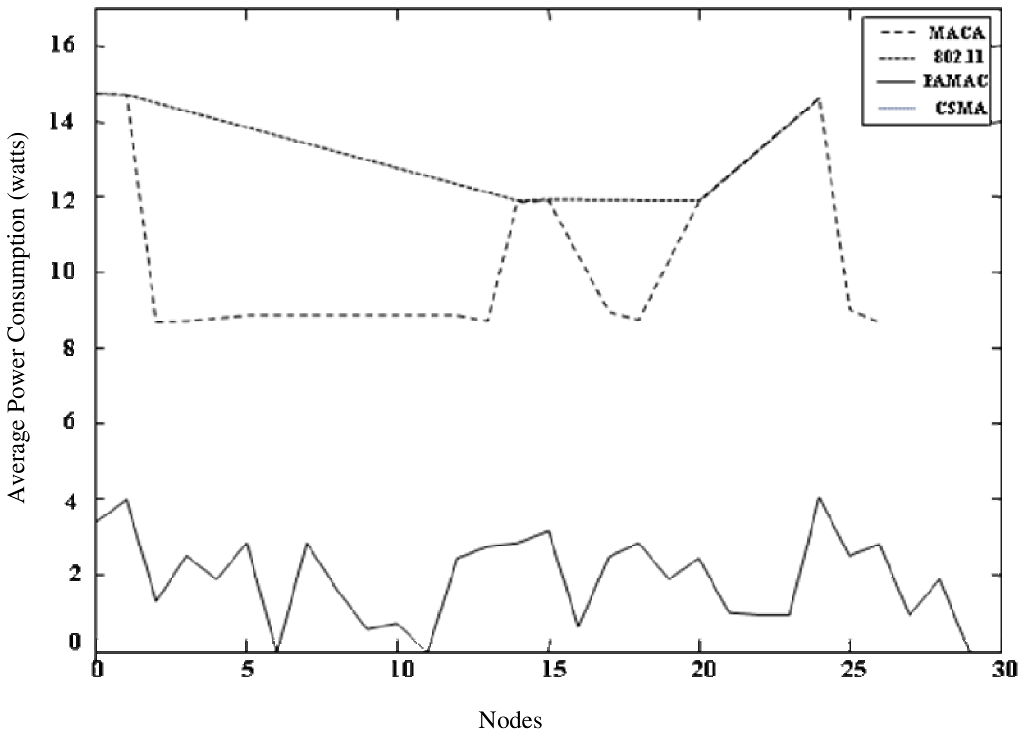

Fig.2. Average Power Consumed vs. Nodes for different MAC protocols

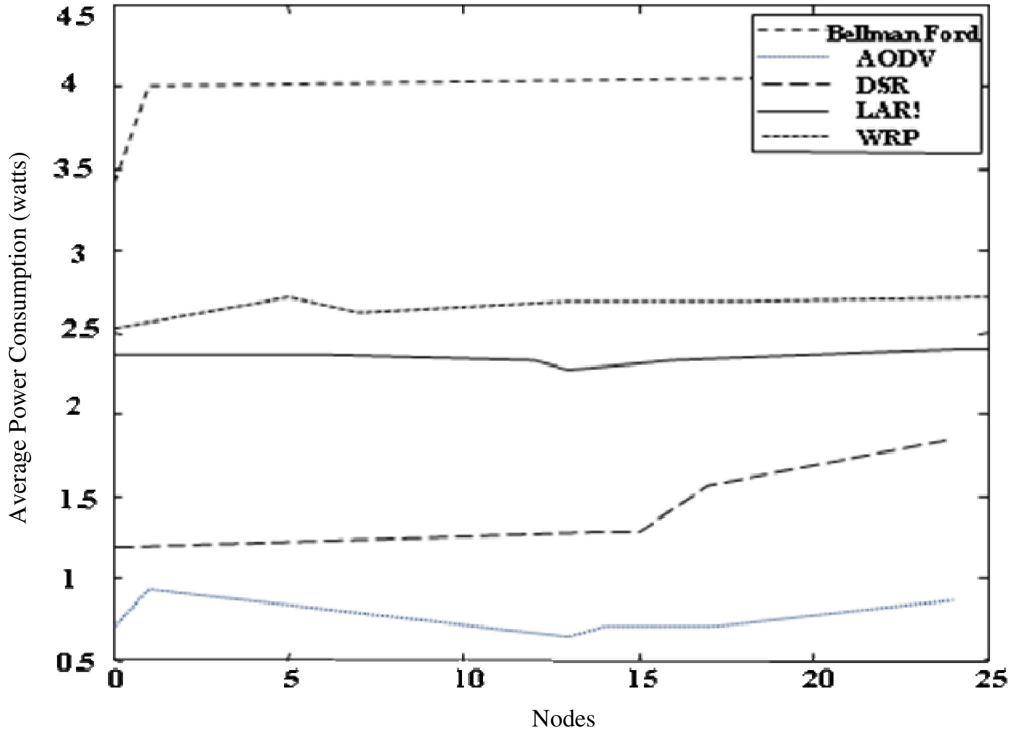

Fig.3. Average Power Consumed vs. Nodes for different routing layer with PAMAC as the MAC layer protocol

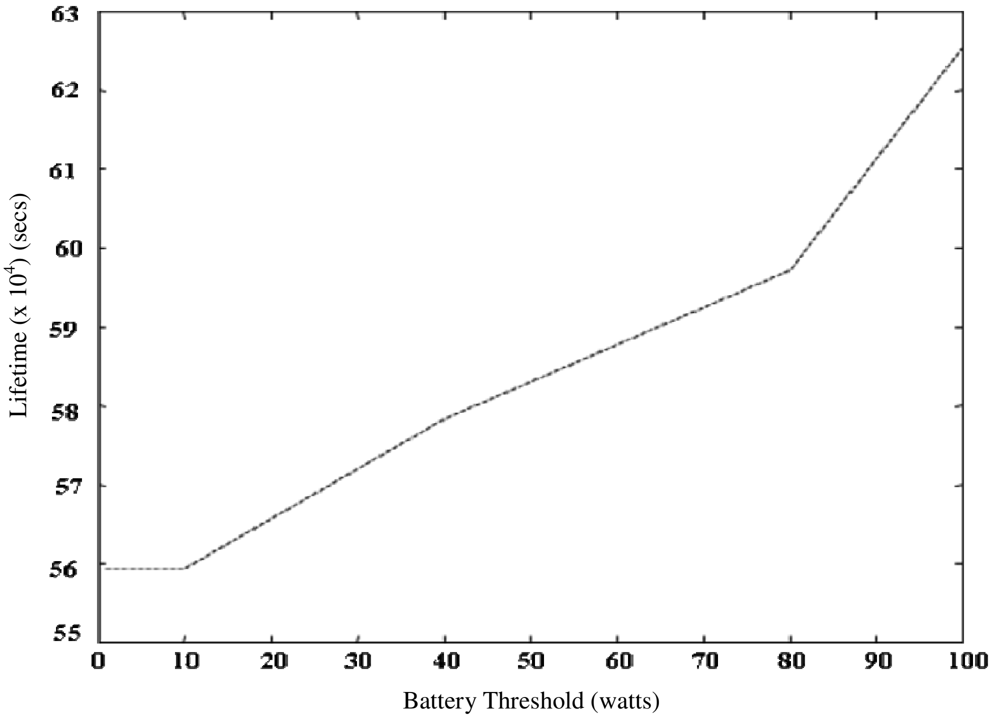

Fig.4. Lifetime vs. Battery Threshold with Bellman-Ford routing algorithm and PAMAC protocol

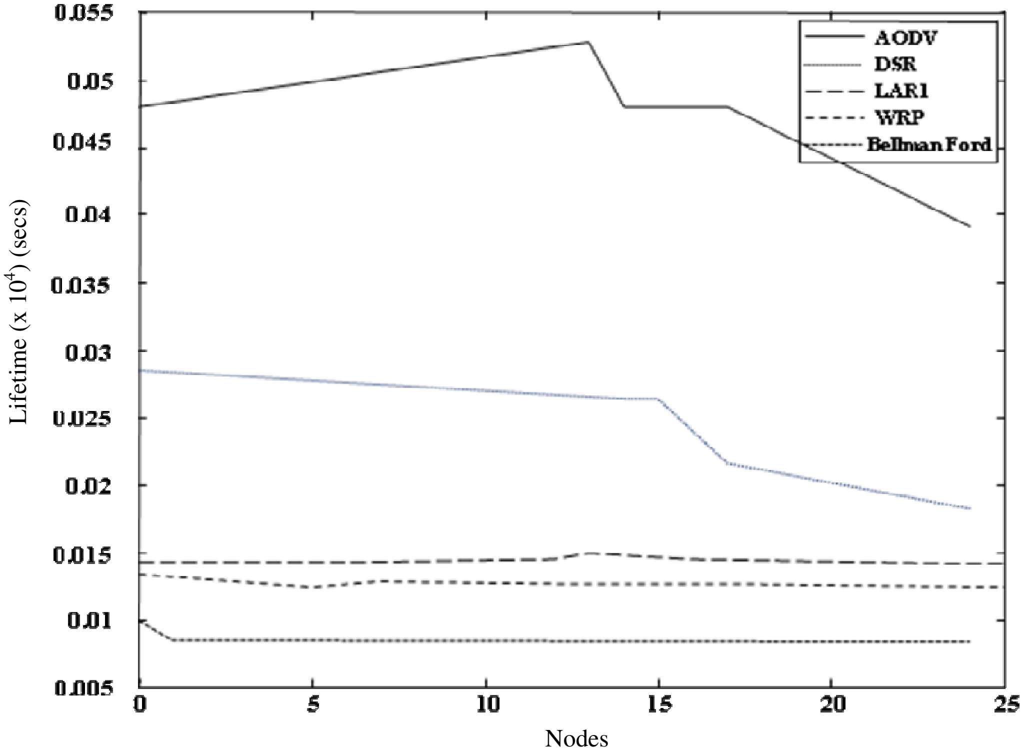

Fig.5. Lifetime vs. Nodes for different Routing Protocols with PAMAC as the MAC layer protocol.

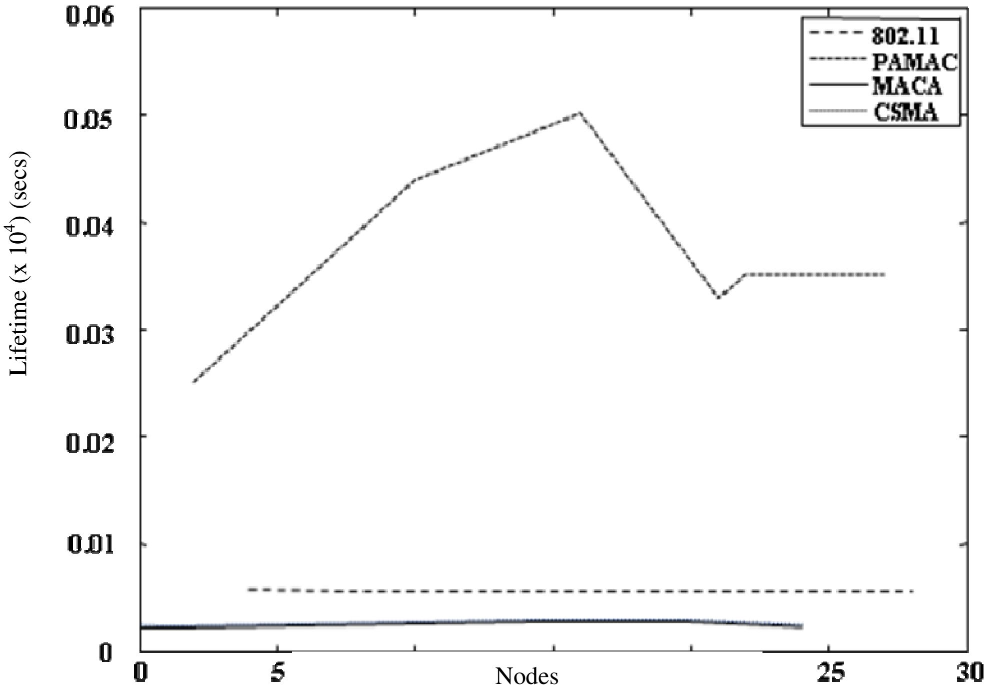

Fig.6. Lifetime vs. Nodes for different MAC Layer Protocol for Bellman Ford routing algorithm

6. CONCLUSIONS

In this paper, a new battery power scheduling policy based on dynamic programming is proposed for mobile devices. Through simulations, it is shown that the proposed DP protocol increases the lifetime of nodes of an ad hoc network compared to two of the existing protocols using round robin scheme. The average packet delay obtained using the proposed DP approach is found to be smaller than that obtained using round robin protocol with no delay free approach. A novel algorithm called as Power Aware MAC protocol (PAMAC) is also proposed in this paper for an ad hoc network. The performance of PAMAC and other MAC Layer protocols are studied through simulation and compared. It is observed that PAMAC consumes the least power and provides the longest lifetime. With PAMAC as the MAC layer protocol, the performance of the ad hoc network using different routing layer protocols are studied and compared. It is observed that AODV consumes the least power and provides the longest lifetime.

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