International journal on applications of graph theory in wireless ad hoc networks and sensor networks
(GRAPH-HOC) Vol.2, No.3, September 2010

A BATTERY POWER SCHEDULING POLICY WITH HARDWARE SUPPORT IN MOBILE DEVICES

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ABSTRACT

- *. A major issue in the ad hoc networks with energy constraints is to find ways that increase their lifetime. The use of multihop radio relaying requires a sufficient number of relaying nodes to maintainnetwork connectivity. Hence, battery power is a precious resource that must be used efficiently in order to avoid early termination of any node. In this paper, a new battery power scheduling policy based on dynamic programming is proposed for mobile devices.This policy makes use of the state information of each cell provided by the smart battery package and uses the strategy of dynamic programming to optimally satisfy a request for power. Using extensive simulation it is proved that dynamic programming based schedulingpolicyimproves the lifetime of the mobile nodes.Also a hardware support is proposed to succeeds in distinguishing between real-time and non-real-time traffic and provides the appropriate grade of service, to meet the time constraints associated with real time traffic.*

Keywords

lifetime; battery; dynamic programming;mobile nodes; Scheduling;hardware unit

1.INTRODUCTION

The nodes of an ad hoc wireless network, a group of uncoordinated heterogeneous nodes that self organise themselves to form a network have constrained battery resources. Advaces in battery technologies have been negligible as compared to the recent advances in the field of mobile computing and communication. The increasing gap between power consumption requirements and energy density(energy stored per unit weight of a battery) tends to increase the size of the batteries and hence increases the need for energy management. The lifetime of the ad hoc networks can be defined as the time between the start of the network to the death of the first node. The death of even a single node may lead to partitioning of the network and hence may terminate many of the on going transmissions. In view of this, the strategies to increase the lifetime of ad hoc networks become important. Towards this purpose, a new battery power scheduling policy based on dynamic programming is proposed in this paper.

The rest of the paper is organised as follows. Section 2 provides an overview of battery characteristics. Section 3 describes the existing work in this area.In section 4, the description of the proposed scheduling policy is described and Section 5 presents the implementation andsection 6 explains the simulation results. Section 7 describes the hardware support proposed and section 8 ends with the conclusions.

DOI :10.5121/jgraphoc.2010.2307

2. OVERVIEW OF BATTERY CHARACTERISTICS

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

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.

Battery capacities: The amount of active materials (the materials that react chemically to produce electrical energy when battery is discharged and restored when battery is charged) 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 the 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 increases probabilistically as the battery remains idle and 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. A battery may exceed the actual capacity but not the theoretical capacity. This is due to the rate capacity effect. By increasing the idle time, one may be able to utilize the maximum capacity of the battery. The lifetime of a node is the same as the actual capacity of the battery.

3.RELATED WORK

Battery models depict the characteristics of the batteries used in real life. The following models are discussed in [1]. It summarizes the pros and cons of each of the models, namely analytical model, stochastic models, electric current models and electro-chemical models. The authors of [2] have shown that the pulsed dicharged current applied for bursty stochastic transmissions improves the battery life time better than that using constant discharge. In [3], different battery mangement techniques are presented and compared analytically. 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. The authors of [3] have assumed each node to contain a battery package with L cells and have proposed three battery scheduling policies for scheduling them. Further, the battery behaviour under two different modes of pulse discharge are 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 [3].

No delay free approaches consider 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 [3].

In [4], a framework has been developed to compute the optimal dicharge policy that maximizes the battery lifetime. 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 [4]. Here, the total energy delivered is computed using the theory of stochastic Dynamic programming. In [5], a number of suboptimal policies are proposed and the performance using them is evaluated through simulation and the results are compared. The performance ratio of various policies for different values of cell , nominal and theoretical capacities are plotted as a function of average packet size.

The size of the packet is specified in terms of number of charge units to be discharged from a battery[4]. In [4], the size of the packets corresponding to each traffic burst is assumed to be poisson distributed. 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 [6].

In view of this, alternate traffic models such as self similar model has been proposed in the literature[6]. 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 lifetimes obtained are compared with two scheduling policies both using Round Robin scheme one using delay free approach with high internal resistance of the cell and another using no delay approach with low internal resistance .

4. PROPOSED SCHEME

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 theoritical capacities of each cell. In round robin delay free approach, for scheduling the state information is ignored. In round robin no delay free approach the state of the battery package is compared against a threshold for scheduling. as. 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. Our scheduling policy tries to take advantage of the inherent mathematical pattern that is present in cells that are recovering a unit of charge i.e, the recovery of one charge unit in that time slot by each cell is mutually independent of charge recovery by any other cell.

Assume 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 [7]

$P(r_i) = \exp(-g_c * (N-N_i)-\varphi(T_i))$ if $0< N_i < N$ && $0< T_i < T$

$P(r_i) = 0$ otherwise (1)

Where

g_c – 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 has 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. Expressing the result mathematically, we assume a request of size K arrives(i.e the next burst to be transmitted has K packets). 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 ith 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.

5. IMPLEMENTATION USING DYNAMIC PROGRAMMING

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 in [4] and [5].
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 [8] and [9]. The development of a DP algorithm can be broken into a sequence of 4 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. So in that sense the protocol is burst size independent.
We know that for any random access MAC protocol, for transmitting any burst, the transmitter has to wait for a duration of 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). So if we could pipeline the execution of the DP protocol with the contention window period of the previous burst, we could effectively absorb the overhead in executing the algorithm. So we neglect the delay caused by it in our simulation. This is a valid assumption because the size of the contention window is similar to the running time of 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
$P[i] = \max\{P[i-k] - \exp(-g_c*(N-N_i + set[i-k][j]) - \varphi(T_i - set[i-k][j])) + \exp(-g_c*(N-N_i + set[i-k][j] + k) - \varphi(T_i - set[i-k][j] - k)\}$

if i>0 (4)

For j=0….L-1

$k=1\ldots\min(Nj,Tj)$

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

6.SIMULATION RESULTS

First we assume a device which has very high internal resistance (high value of g_c parameter) and then we show that DP protocol gives a much better performance measured in terms of battery lifetime than the existing ROUND ROBIN protocol by way of extensive simulations through ‘C’ language in Windows XP environment and present our results through tabulations and graphs.

Next we assume that the device has very low internal resistance and so we have assumed the existing protocol to be NO-DELAY FREE protocol. Since the round-robin protocol is no-delay free our performance metric also includes the average packet delay, apart from the usual lifetime of the battery, again we present our extensive simulation results through tabulations and graphs.

Assumptions made during the simulation:

N=10 (nominal capacity is assumed to be10 charge units)
T=15 (theoritical capacity is assumed to be 15 charge units)
g_c=2 (device dependent parameter which gives the internal resistance of the cell)
.

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 these two simulations are presented in a tabular form.

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

Maximum size of the burst	Lifetime (DP)	Lifetime (round-robin)
8	30	17
6	34	23
5	38	30
4	51	32
2	93	64

Table 2. constant size burst mode traffic

Burst size	Lifetime (DP)	Lifetime (round-robin)
8	13	10
6	18	10
5	22	19
4	29	20
2	69	52

Since $g_c = 2$, the device has very high internal resistance. Hence the recovery capacity effect is considered to be negligible. So we assume the lifetime of the battery to be defined as the

number of requests successfully satisfied (number of traffic bursts transmitted successfully). With this assumption we calculate and tabulate the lifetimes of the battery assuming various bursts as in tables 1 and 2.
Thus we find that our DP protocol performs significantly better under highly constrained circumstances (such as devices with very high internal resistance) as indicated by tables 1 and 2.

Now 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 such cases the existing protocols use a 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 during the simulation:

N=10 (nominal capacity is assumed to be 10 charge units)
T=50 (theoritical capacity is assumed to be 15 charge units)
g_c=0.5 (device dependent parameter which gives the internal resistance of the cell)
FRAME SIZE = 10 ms.

Here variable traffic burst(with maximum burst size fixed) is assumed.
Now we present a table 3 comparing the lifetimes of our DP protocol with no-delay free round-robin protocol for probabilistic distribution of traffic bursts with maximum burst size fixed..
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[2] . So in this case, the average packet delay is 2.5 ms.
Now we present a table 4 showing the average packet delay for the various traffic bursts

Table 3. lifetimes with low internal resistances

Maximum size of the burst	Lifetime (DP)	Lifetime (round robin with no-delay free)
7	128	45
6	141	58
5	178	81
4	202	144

Table 4. average packet delay for the various traffic burst

Maximum size of the burst	Average packet delay(s)
7	0.131556
6	0.126379
5	0.038395
4	0.117153

Thus we find that our protocol offers a significantly better performance as compared to round robin with no-delay free in case of a device with very low internal resistance.

In most of the communication protocols the maximum burst size is known apriori and so we fix the maximum value of ‘k’ and since ‘L’ is a device parameter it is a constant and so is N.

This algorithm need not deal with variablevariable sized objects and so the need for recompiling and relinking doesn’t exist. So for faster execution we may use an on-chip programming cache containing the binaries of this algorithm along with the on-chip data cache containing the states of the various cells (which is maintained by the smart battery package).

So this algorithm is further optimized and its execution takes typically negligible overhead. If an ARM core is used this algorithm can be used as a fast interrupt.

7.HARDWARE SUPPORT

The dynamic programming algorithm splits the request to be distributed among ‘L’ cells (some cells may satisfy trivial requests for 0 charge units meaning that they are in recovery state).So any efficient mechanism is requires the pulses drawn from each of the ‘L’ cells into a single cell so that it may be used to power the burst to be transmitted.

Also this dynamic programming algorithm and hardware mechanism is typically an overkill for non-burst mode transmission, i.e., those transmissions which require acknowledgements for every packet, so we have a mechanism to bypass this hardware unit for burstmode transmission (typically a two way switch)

Two way Switch:
The CPU is able to detect that what follows is a burst mode or non-burst mode traffic and it sends a signal S2 to the switch depending on S2 ; level switch is positioned
If S2 = 1 (means real time traffic) the switch connects C to B
Else (means non real time traffic) the switch connects C to A
Current summing circuit:
This is used in case of real time traffic; since the pulse comes out discrete instants of time, we need a mechanism to sum the pulses up with as little overhead as possible. So we use the hardware block of current summing circuit. Typical implementations use a capacitor (with very large time constant) for charging up on occurrence of the pulse.In order to protect against its discharge between successivecharging instants we use a capacitor with very large time constant. At the end of the L^{th} charging instant a signal is sent which switches on the transistor through which the capacitor discharges.

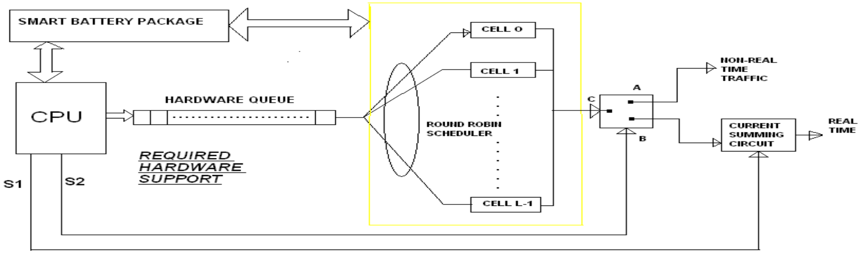

Figure.1Two way Switch

8.CONCLUSIONS

A new battery power scheduling policy based on dynamic programming is proposed for mobile devices. Through extensive simulations, it is shown that the proposed DP protocol increases the lifetime of nodes 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.In addition to the simulation,on chip programming cache is proposed for faster execution so as to have a negligible overhead. A hardware mechanism with two way switch is proposed for bursty and non bursty transmission.

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