Introduction:

Battery Operated Portable systems demand tight constraints on energy consumption. System level dynamic power management algorithms are designed to increase the battery lifetime by selectively placing idle components into lower power states.

The power manager makes state transition decisions according to the power management policy. The choice of the policy that minimizes power under performance constraints (or maximizes performance under power constraints) is a constrained policy optimization problem. Most of the systems use the timeout policy (most common in case of hard disks) but it wastes too much of power in waiting for the timeout period to expire. Also this might not be an optimal policy as it might miss small enough breaks which should have been taken but are not due to improperly programmed timeout values. Also these timeout values are not dynamic in real sense. The timeout mechanism, strangely enough, finds its place as the power management policy in the IEEE 802.11 standard. It only implements the timeout at the MAC and the physical layers. If the wireless card was turned off much larger power savings can be obtained.

Most of the policies discussed in the literature are not globally optimal. But all these heuristic policies do not give globally optimal results. An approach based on the Discrete time Markov decision process model. This assumes that the state transitions follow geometric distribution which is not observed in practice. Also here the decision is evaluated periodically thus wasting power. But this re-evaluation helps in adapting to situations where the requests do not have true geometric distribution.

Another variant is using the Continuous time Markov decision process. But here the assumption is that the active state and the idle state arrivals are exponential in nature. This research shows that the arrivals in idle state can be modeled better by using Pareto distribution.

System Model:

The research here considers three typical components which are found in general: Hard disk, Wireless LAN card and a SMARTBADGE (wearable computer). The system was modeled with a user who sends request which are queued in a limited capacity queue and the queue, the component and the users request performance is managed dynamically by the power manager under certain performance constraints.

The request arrivals in the idle and active states were experimentally measured and curves were fit to get better approximations. It was observed that the user request arrivals in the active state could be modeled effectively with the exponential distribution function. When the same requests arrival rates were measured with the hard disk and the WLAN card in the idle state it was found that the exponential distribution could effectively model only arrivals only within a small interval. Longer idle times could be nearly exactly modeled by the use of Pareto distribution. The service time distribution generated for the hard disk indicated that the requests are service following an...
exponential distribution. The transition time required for effective the transition between
states was also studied experimentally. It was shown that the uniform distribution would
model this better than the exponential distribution.

A similar study with the WLAN card running the www and the telnet application
indicates that the interarrival times in the idle state can be correctly fit with the Pareto
distribution in contrast with the exponential distribution.

The queue was modeled using the estimates of the number of requests and the
acceptable performance limits. Also as the service time of the WLAN card and the
Smartbadge being very low the queue of 10 jobs was assumed to be sufficient.

While generating the optimal policy the following were the conditions imposed :
1. Only the PM can make the decision whether to leave the device idle or turn it off
2. If the PM turns the device off or places it into sleep state the system starts
   transition between idle and off state.
3. If during the transition time a request arrives from the user the device starts the
   transition to active state as soon as transition to off state is completed.

The goal is to minimize the performance penalty under energy consumption constraint.
A semi-Markov Decision process optimization problem is formulated and the time
indexing is introduced to add the memory dependency. Under the given state and state
transition probability the optimization problem is of minimizing the cost of performance.
This can be solved in polynomial time using the Linear programming formulation with
performance constraints. The assumption here that at most one of the underlying
processes is not exponential in nature. The transitions where the processes are not
exponential in nature the time indexed Markov chain decision process formulation is to
be used to preserve history information. It can be shown that the probabilities of going to
sleep once in the idle state are monotonically increasing thus ensuring the transition. This
filters out the shorter idle times and there is an increasing probability that the system goes
to sleep.

This is done by generating a pseudo random number at each evaluation that dictates the
probability of the occurrence of the state transition. The device returns back to the active
state as soon as the first request arrives in its queue.

Simulation:

The simulation is performed and the results are characterized with the power
consumption, the performance penalty, the transition time probability density and the
probability of transition. Performance penalty is defined as the percent of time the system
stays in the sleep state with a non-empty queue.
From the simulation results it can be seen that the performance penalty could be reduced
by as much as 85%. Also about 50% power can be saved if the system makes a transition
from the idle state to the sleep state.
The comparison results with the hard disk in comparison with the other policies which
use the exponential distribution shows that the exponential model pays a higher
performance penalty if the idle times are too short.
Also if the decision is to stay awake upon entry to the idle state then the large idle time
such as lunch breaks are missed. The results show that as much as 2.4 times power saving
can be obtained using the Time indexed semi Markov Decision process model. Also the complexity of the TISMDP is justified in comparison with the SMDP model. The event driven (or the pseudo event driven nature actually) saves considerable power while in sleep state as it does not require any evaluation before another request arrives. Similar simulations are performed on the WLAN card using trace based methodology. The simulations are done with different performance penalty TISMDP variants. The delay penalty, the number of shutdowns and the number of wrong shutdowns were also measured in this case. The number of shutdowns indicates the eagerness of the policy and the wrong shutdowns indicate the accuracy of the policy in question. It was observed that the TISMDP performs much better than the timeout policy. The measurements were done with the www trace and telnet application for a couple of hours. The telnet application allows much more power savings over the www application as the amount of data exchanged is very small in comparison.

**Conclusion:**

In conclusion it can be said that the event driven policy TISMDP is the best performer as compared to the CTMDP, DTMDP and timeout policies. The measurements with the hard disk indicate a power saving upto 1.7 times lower as compared to the default windows policy. The TISMDP policy when employed for the WLAN card shows that on an average 3 times lower power consumption can be achieved. This seems an elegant formulation where the event driven nature of the TISMDP formulation eliminates any requirement of power for making transition decisions. So power is only spent in serving requests not making decision as to whether or to make transitions.

**Future work:**

The future work could be focused in implementing this policy in situations where not only the single user but some other agencies collaborate to generate requests. This is the case with the Ad-hoc networks where an intermediate router has to decide whether or not it has the sufficient power to carry the packets across the network. This packet request in IP would be overlaid on the TISMDP policy to make decisions of transitions. Similar is the scenario with sensor networks where not all nodes need to respond to all requests. Here too the decisions are to be made on the availability of not only the power of the node in question but also the power availability of the adjacent nodes. Here too the decisions of changing the state of the WLAN card, are to be made based on the overall network state rather only the local queue length. This in conjunction with the TISMDP could significantly increase the available power with the nodes here. Another application could be its implementation in the cellular network where the communication is done in the idle state using the beacon signals. Here too the power is constrained and for larger idle times significant power savings could be obtained when TISMDP is used. A variation of TISMDP could be thought of which spends minimum power in the idle state (for the beacon signals) and then returns to the sleep state. The above applications of the TISMDP could be an interesting research.