An Energy-Aware Simulation Model and Transaction Protocol for Dynamic Workload Distribution in Mobile Ad Hoc Networks

Farhad Ghasemi, Peng Rong and Massoud Pedram

Dept. of EE Systems
University of Southern California

Oct. 15, 2003

Outline

- Introduction
- MANET Simulation Model
- Energy-aware Network Transaction Protocol
- Experiment Results
- Conclusion

Introduction

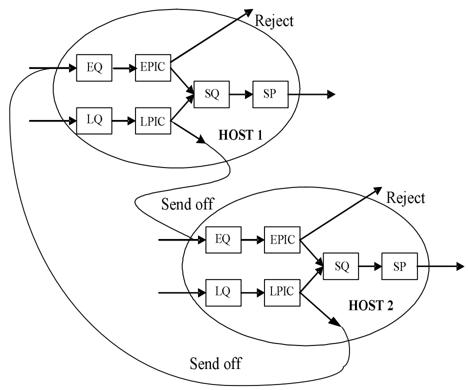
- Mobile ad-hoc network (MANET)
  - Consist of battery-powered wireless mobile hosts
  - Required to achieve a certain level of performance while remain operational for a desired period of time
  - Extending network lifetime is a key design issue for MANET
- Previous work on power management of MANET
  - Economics and game theory based workload allocation approaches [Shang, 02]
  - Energy-aware routing protocols [Singh, 98; Maleki, 03]
  - Energy-aware cooperative signal processing for wireless sensor network [Pradhan, 02; Krishna 03]

Discussion

- The problem of evaluating power management policies in MANETs is often modeled with a network of queues. The non-Markovian stochastic nature of the problem, even in a simplified aspect of practical models, limits the use of analytical approaches
- We presents a simulation model to evaluating power management policies for a MANET functioning in a real world environment
- We study the effects of redistributing energy on the two network performances:
  - The *network lifetime* (*end-to-end throughput*) characterized by the total number of service requests executed throughout the network life time,
  - The *latency* in processing service requests as measured by the average waiting time for a request to receive service from some host in the network.

MANET Simulation Model

- A schematic view of the MANET model
- Model of mobile host
  - Service provider (SP)
  - Two service-request (SR) dispatcher
    - EPIC for external SR
    - LPIC for local SR
  - Service queues for SP, EPIC and LPIC



MANET Simulation Model

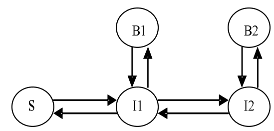
- Host mobility model
  - Two-dimensional movement
    - Mobility rate projected on each axis is represented as a random variable, adhering to a given probability density function
- Host energy model
  - Computation energy: power consumption of SP, EPIC, LPIC
  - Communication energy: power consumption for SR transmission and reception
    - Data transmission energy is proportional to the square of distance $D(t)$ between two mobile hosts

$$engy(xmit) = \sum_{t=1}^{n} g(D(t)^2)$$

Components of Simulation Model

- SP model
  - Multiple function/power states
  - State transition occurs based on specific policies and requires a certain amount of energy to complete
  - Energy consumption calculation

An SP example with 5 states: busy1, busy2, idle1, idle2 and sleep



$$engy(SP) = \sum_{s_j \in SSP} pow(s_j) \int_0^{Ts} \delta(s_j)dt + \sum_{(s_j, s_k) \in TSP} swengy(s_j, s_k) \int_0^{Ts} \delta(s_j, s_k, t)dt$$

Components of Simulation Model

- LPIC and EPIC model
  - Similar to SP model, but only two power states: busy and idle
- SQ, EQ and LQ model
  - Combination of FIFO disciplined and priority queues
  - Finite space
    - When a Queue is full, new coming service requests are dropped
- SR model
  - A random request generation rate with a given probability density function.

Policy Evaluation

- This Model can work with a wide range of workload distribution policies
  - Rejection policy for the external requests
  - Send off policy for the local requests
- Policies can be evaluated for multiple simulation conditions:
  - Different capacities of service queues.
  - Different statistical distributions for request generation rates
  - Different service rate distributions
  - Different initial energies, initial locations and mobility rates for each mobile host.

Energy-Aware Network Transaction Protocol

- A mobile host maintains a cache table
  - contains the latest two records of the remaining energy and corresponding time of its adjacent hosts
- The protocol procedure
  - When a host receives a local request:
    - It evaluates the remaining energy of its neighbors using linear extrapolation

$$remengy = remengy_2 + \frac{remengy_2 - remengy_1}{t_2 - t_1}(t - t_2)$$

    - If there is another host with higher remaining energy, it sends off the request to that host for remote processing. In addition, it sends along a message with its current level of remaining energy.
    - Otherwise, it processes the request locally.

Energy-Aware Network Transaction Protocol

- The protocol procedure (Cont'd)
  - When a host receives an external request,
    - It records the attached remaining energy level of the sending host in its cache table
    - Compares it with its own current remaining energy. If it has higher level of remaining energy than the sending host, then it accepts the external request
    - Otherwise, it rejects the request by sending it back with information about its own residual energy.

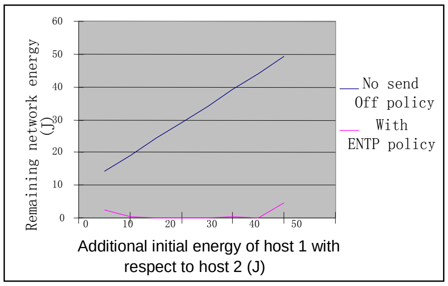
Experimental Results

- Experimental setup of a two-host network

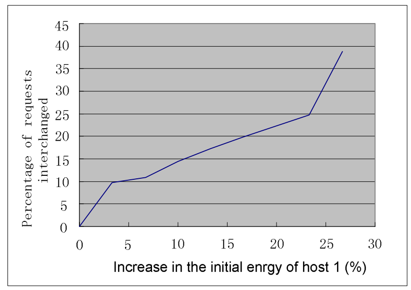
Local & external request generators for the two hosts	Poisson with requests average arrival rate of 1/60 ms
Local & external PIC service times for the two hosts	Exponential with average service time of 4 ms
Service time of the service provider, in the high/low speed state, host 1 / host 2	Exponential with average service time of 7 ms / 12 ms
The distance between to hosts	Initially at 200ft, changed based on the Normal distribution with the speed of 10 ft per second
Initial battery energy, host 1 / host 2	155,000 mJ /150,000 mJ
PIC power dissipation, host 1 / host 2	Local 0.10 W / 0.11 W, external 0.09 W / 0.10 W
SP power dissipation, host 1 / host 2	*busy1*: 0.125 W / 0.100 W, *busy2*: 0.500 W / 0.400 W, *idle*: 0.125 W / 0.125 W, *sleep*: 0.066 mW /0.066 mW
SP switching energy, in the two hosts	*busy1* to *idle1*, vice versa: 0 *busy2* to *idle2*, vice versa: 0 *idle1* to *idle2*, vice versa: 0.05 mJ *idle1* to *sleep*, vice versa: 0.20 mJ
Maximum SQ length, in the two hosts	8 requests

Experimental Results

- Experimental results of a two-host network



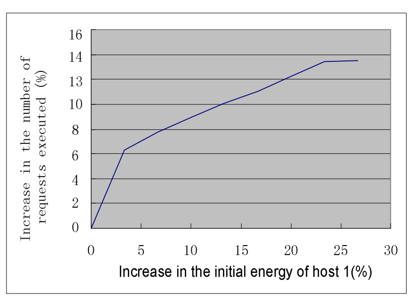
Network energy utilization



Percentage of requests interchanged between the two hosts

Experimental Results

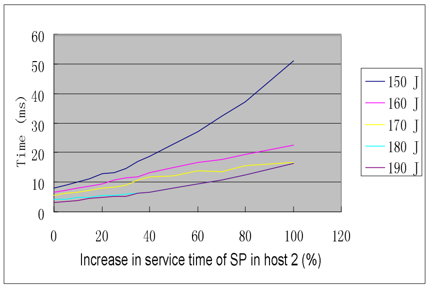
- Experimental results of a two-host network (Cont'd)



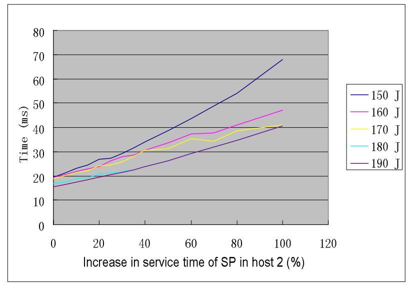
Throughput increase of the two-host network

Experimental Results

- Experimental results of a two-host network (Cont'd)



Average waiting time in SQ of host2 (all requests)



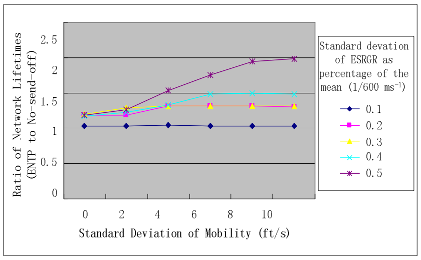
Average waiting time in SQ of host2 (queued requests)

Experimental Results

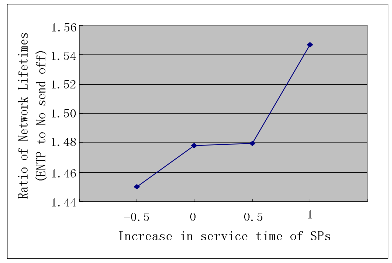
- Experimental setup of a multi-host network
  - 10 hosts, restricted in a 2000-by-2000 square foot area
  - Mobility rates of the hosts are assumed a Normal distribution with mean 0
  - Other parameters are the same as host 1 in the two-host network

Experimental Results

- Experimental results of a multi-host network



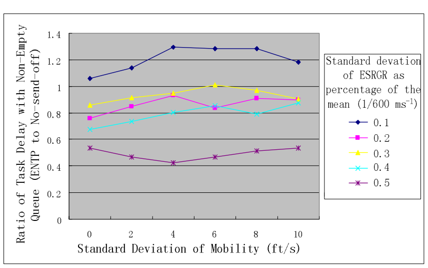
Increase in network lifetime when using ENTP



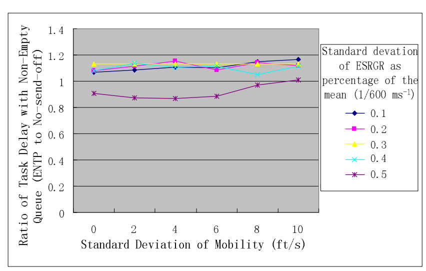
Network lifetime increase vs. SP service time

Experimental Results

- Experimental results of a multi-host network (Cont'd)



ENTP: Average waiting time of the worst host (all requests)



ENTP: Average waiting time of the worst host (queued requests)

Conclusion

- We developed a network simulation model for evaluating power management policies for a MANET functioning in a real world environment
- We developed an energy-aware network transaction protocol that dynamically redistributes computational workloads among the cooperative hosts within a MANET to achieve a better network lifetime
- Using two measures of the network performances, the network lifetime and the average execution latency for requests, we evaluated the performance of the proposed protocol under a wide range of network conditions
- Finally, by using ENS, empirical rules for redistribution of workloads and battery energy among the hosts in the network were derived and presented.