MobiCom Poster Abstract: Leveraging a power save protocol to improve performance in ad hoc networks *

Laura Marie Feeney[a,b]
lmfeeney@sics.se

Christian Rohner[b]
Christian.Rohner@it.uu.se

Bengt Ahlgren[a]
bengta@sics.se

[a]Swedish Inst. of Computer Science, Kista, Sweden; [b]Uppsala Univ., Uppsala, Sweden

I. Introduction

Power save protocols reduce energy consumption in ad hoc and sensor networks by allowing nodes to put their network interface into a low power consumption sleep state. The power save protocol must allow neighboring nodes to establish intervals during which they are mutually awake and available to exchange traffic. Many such protocols are based on a coordinated election of a covering set that is responsible for buffering traffic for sleeping nodes, but uncoordinated (i.e. asynchronous) protocols have also proven an attractive option.

Most uncoordinated power save protocols are based on a well-known, periodic wakeup schedule. Each node follows the schedule independently of its neighbors, resulting in an arbitrary phase offset between their wakeup schedules. The schedule is defined such that there is deterministic overlap between the awake intervals of each pair of nodes, regardless of the timing offset between them (e.g. quorum scheduling [1]). Nodes use these overlapping awake intervals to rendezvous and exchange traffic with their neighbors.

These timing relationships between the nodes' wakeup schedules result in uncoordinated, periodic patterns of link availability and utilization, as neighbors can only exchange traffic when they are both awake. We call these patterns "wakeup patterns".

A natural question is whether some wakeup patterns obtain better network performance than others. For example, consider the problem of contention along a multihop flow ([2]). A "good" wakeup pattern would ensure that conflicting transmissions were separated in time. For a CSMA/CA MAC, this would reduce risk of collision, as well as the time wasted in contention and backoff.

The preferred wakeup pattern is obvious in such a simple example, but it is not clear whether there are wakeup patterns that would achieve overall advantage in realistic networks. Such networks exhibit complex effects of contention and interference between transmissions associated with multiple disjoint flows. (The complexity of these interactions is suggested by variants of the multi-hop TDMA assignment problem that are both computationally and practically hard.)

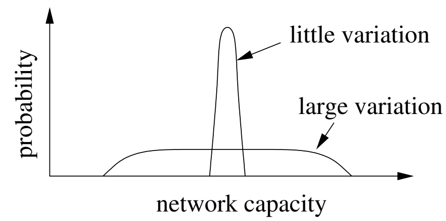

Figure 1: Hypothetical distributions: If the wakeup pattern has little impact, flow capacity measurements will lie in a narrow range. If the wakeup pattern is significant, there will be a large variation in capacity. The goal of our experiment is to distinguish between these cases.

We therefore investigated how the network performance depends on the wakeup patten. In our experiment, we measure the flow capacity of a fixed topology and traffic scenario for each a large number of randomly generated wakeup patterns. The probability distribution of the flow capacity measurements demonstrates the impact of the wakeup pattern on network performance (Figure 1). We chose flow capacity as an easily computed metric that reflects the combined performance of all communication layers.

The probability distributions observed in our simulation results exhibit a narrow central distribution with long tails, suggesting that there do exist a small proportion of wakeup patterns with considerably better and worse performance than the median.

This abstract describes our experiment and its results in detail. We also discuss the implications of the results for the feasibility of leveraging operation of an uncoordinated power save protocol to improve performance in multihop wireless networks.

II. Experiment

We use a periodic wakeup schedule in which each node is awake for slightly more than half of each period, guaranteeing some overlap between awake intervals for each pair of neighbors. We chose to model this schedule because of its simplicity and because its

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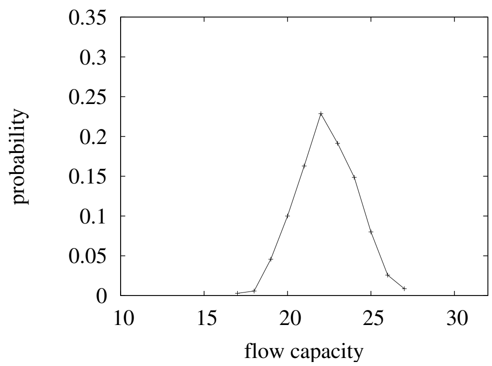

Figure 2: Simulation data: Flow capacity distribution for a representative 100-node topology (350 wakeup patterns).

high duty cycle makes it unlikely to be the limiting factor in the capacity.

For each experiment, we fix a topology and offered load. The offered load consists of CBR flows between randomly chosen source-destination pairs with fixed minimum hop-count routing. The number of flows in the offered load is such that the network is slightly under-dimensioned: most, but not all, flows are admissible. The admissibility of each flow in the offered load is evaluated in turn: the flow capacity is the total number of admitted flows.

To evaluate flow admissibility, we use a simple model of network operation. We consider only the "steady state" operation of a static network to avoid the overhead of modeling time varying behavior. This simplification requires that the periodicity of the wakeup schedule and the periodicity of the CBR flows are compatible, allowing us to model only a single "representative" period. We therefore assume an ideal MAC that operates without error and without large variation in channel access times. Transient traffic such as routing and admission control is also ignored.

The model allows us to efficiently simulate statistically many wakeup patterns for each of many topologies, making it suitable for rapid qualitative exploration of the performance space: in effect, to distinguish between the hypothetical curves in Figure 1.

For each fixed topology and offered load, we generate a large number of wakeup patterns and determine the flow capacity of each wakeup pattern. The observed flow capacities for a representative topology are shown in Figure 2.

The simulation results show that the flow capacity is roughly normally distributed. In general, half of all wakeup patterns account for a variation of only $\pm 5\%$ about the median flow capacity - a negligible difference given the simple network model. The extremes, however, vary $\pm$ 20-25% about the median, suggesting that the best wakeup patterns provide a significant performance advantage. These results hold over a wide range (800 scenarios) of network size and nodes densities.

We also note that the simulation results show that total number of transmissions varies as much as the flow capacity. This confirms that the variation in flow capacity is the result of variation in the wakeup schedule and not just an artifact of selection of longer or shorter flows from the offered load.

III. Conclusion

The simulation results demonstrate that the network flow capacity is sensitive to the effects of the wakeup pattern, with the best patterns accommodating 20-25% more flows than the median. They also suggest that performance can be improved by adjusting the timing offsets between nodes' wakeup schedules.

Making a local change to a node's wakeup schedule is trivial, because the power save protocol is intended for uncoordinated operation and therefore allows any wakeup pattern. The challenging problem is to find a way manage such local changes to obtain better overall performance. The current results suggest that simple randomization is not likely to be effective, due to the apparent rarity of good wakeup patterns. We believe that a local adaptive strategy is promising, although care must be taken to avoid problematic feedback loops. Work is continuing in this area.

We further speculate that future cross-layer architectures may leverage the structure imposed by the operation of the power save protocol. The periodic patterns of link availability defined by the relationship between the nodes' wakeup schedules create coarse-grained, variable-length "slots", which might be used support QoS resource allocation, TCP bandwidth estimation, and similar functionality. This approach could obtain some of the benefits of TDMA MAC's, which support sophisticated resource allocation schemes, but have proven challenging to implement in the multihop wireless environment.

References

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[2] Sanzgiri, K., Chakeres, I. D., and Belding-Royer, E. M. Determining intra-flow contention along multihop paths in wireless networks. In *BROADNETS* (2004), pp. 611–620.