Power Saving in Wireless Ad hoc Networks Without Synchronization

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Abstract

Power saving strategies generally attempt to maximize the time that nodes spend in a low power consumption sleep state. Such strategies often require the sender to notify the receiver about pending traffic using some form of traffic announcement. Although asynchronous traffic announcement mechanisms are particularly suitable for the ad hoc environment, they also provide relatively limited power savings. This paper proposes a mechanism that improves the efficiency of asynchronous traffic announcement mechanisms by reducing the proportion of time that nodes need to spend awake, while still maintaining good connectivity properties. The mechanism is based on allowing traffic announcements to be rebroadcast by neighbouring nodes.

1 Introduction

Power saving is an important and challenging issue in wireless networks, in particular for battery operated nodes such as mobile devices and sensor nodes. A popular approach to save energy is to periodically switch off a node or a few of its components for a certain time interval. In wireless ad hoc networks, switching off network nodes might not only have impact on the reachability of a single node but also on the connectivity of the whole network. Several approaches therefore propose to introduce synchronization mechanisms among the ad hoc network nodes. Nodes may wake up in a synchronized way, exchange data, and fall into sleep again after data exchange. Synchronization however is not easy to achieve and introduces also some overhead. We therefore propose a mechanism that avoids synchronization and try to take advantage of intermediate nodes that can relay traffic indication map messages between a sender and a receiver node.

After discussing related work in Section 2, we motivate and present our mechanism in Section 3 for a single-hop mobile ad hoc network scenario. Section 4 extends the concept for a multi-hop scenario. Section 5 concludes the paper.

2 Related Work

IEEE 802.11 introduces ad hoc traffic indication map (ATIM) messages that can be used in an IBSS (Independent Basic Service Set) ad hoc network to indicate that a node has data for a certain destination node. The ATIM messages are broadcast at the beginning of a beacon interval during the so-called ATIM window. All nodes must wake up at the beginning of the beacon interval and remain awake during the ATIM window. A node goes back to sleep at the end of the ATIM window if it does not hear an ATIM for itself in the ATIM window. The mechanism therefore requires synchronization. Scalability issues of distributed beacon generation in the IEEE 802.11 timing synchronization function (TSF) are studied in [1] .

In [2] quorum based systems have been proposed to reduce the wake period of a node. The authors propose that each node divides its beacon intervals into groups of n consecutive intervals. MTIM (Multi-hop TIM) messages are sent by the nodes at the beginning of an interval. Each group of n intervals is organized in $\sqrt{n}$ * $\sqrt{n}$ arrays with $\sqrt{n}$ columns and $\sqrt{n}$ rows. Each node selects a column and a row and will be wake during the selected $2\sqrt{n} - 1$ intervals. This mechanism ensures that even if two hosts are not synchronized (i.e. they select the starting point of an interval in an asynchronous way), a node will receive a MTIM message not later than after n intervals. However, the number of n may be quite large and may result in a very high delay. Moreover, the wake ratio of $(2\sqrt{n} - 1)/n$ is rather high in this scheme. For n = 25 a node needs to be active for 9/25 of the time, i.e. 36 %. Even for n = 100, the wake ratio is 19 %. This also means that we need many, but very small intervals to reach very low wake ratios. This increases the overhead of the approach, since the MTIM messages must be sent many times then.

Another approach [3] proposes that nodes are active $(0.5 + \varepsilon)$ I, with I as an interval time. This ensures that wake periods of any two nodes overlap by at least ε, providing a predictable traffic announcement.

3 Power Saving for Single Hop Mobile Ad hoc Networks

3.1 ATIM Forwarding with Synchronized Wake Periods

Our power saving mechanism is inspired by quorum systems, but we try to reduce the wake ratio further by making use of the nodes' forwarding capabilities. In contrast to [2], where connectivity is achieved by ensuring that two communicating nodes will both be wake during some time interval, we try to achieve connectivity by relaying nodes, that share a common wake period with both the sender and the destination node.

Before presenting our mechanism in subsection 3.2 we describe a mechanism for the case that the wake periods of all nodes are synchronized. In this case, all wake periods have the same length and begin at discrete points of time. Figure 1 describes when the different nodes are active. In total we have 2K = 10 periods grouped into two groups A and B of K = 5 periods each. The periods of group B alternate with the periods of group A. Each of the nodes selects one period out of group A and one out of group B. For example, node X is wake during the first period of group A (A1) and in the third period of group B (B3).

If a node X wants to communicate with node Z, it broadcasts an ATIM message. This ATIM message is received by various other nodes that forward the ATIM message once during their next wake period. The ATIM message may then reach the desired node Y via such an intermediate node. In our example depicted in Figure 1 this ATIM message may be relayed via a node Y to node Z. By carrying information about the wake periods of X in the ATIM message Z can contact X and coordinate the data transfer.

In our example, each node is only active during one out of K periods. In Figure 1 with K=5 this results in a wake ratio of 20 %. By ensuring that there is one node in each of the K^2 array fields we could guarantee full connectivity between arbitrary nodes.

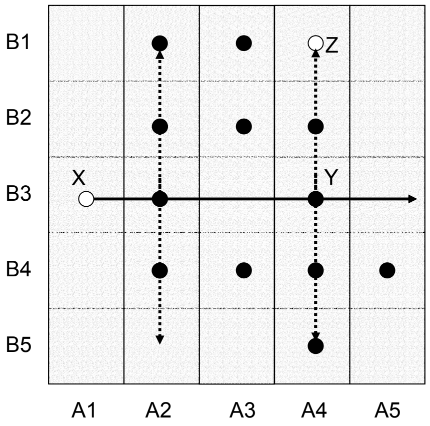

Figure 1: ATIM Forwarding

3.2 ATIM Forwarding Without Synchronization

Full synchronization as required for the mechanism proposed in subsection 3.1 is hard to achieve and we aim to avoid it. The power saving mechanism introduced in the following, therefore, avoids any synchronization among nodes.

As depicted in Figure 2 nodes select a certain basic interval length and wake up twice during that interval for a fixed period (wake periods). During the other part of the interval the nodes are sleeping (sleep period). We distinguish between primary and secondary wake periods. A node strictly alternates between a primary (A) and secondary (B) wake period. For a primary wake period, a node wakes up always at the same point of time relative to the start of the interval. In a secondary wake period a node wakes up randomly, but avoiding overlaps of primary and secondary wake periods.

We do not assume that two communicating nodes have intervals that are synchronized with each other or with a relaying node, but the intervals and wake periods are expected to be similar at all nodes. Due to low drifts in clocks this should be easily achievable in practice. Small differences as they might happen due to clock drifts do not matter.

Figure 2 illustrates the operation of our mechanism. Node X sends two ATIM messages, one in the primary wake period and another in its secondary wake period. We send two ATIMs in order to increase the probability to reach a node. Each node receiving an ATIM message forwards it during its next wake period. Forwarding of ATIM messages is limited to one intermediate node, because we have to limit uncontrolled flooding of those messages. This can easily be done using a time-to-live bit in the ATIM message set to 1 by the origin.

In our example, the first of the two ATIM messages sent by X is received by node Y and forwarded to node Z. However, it might happen that an ATIM message does not reach its target destination node, if two nodes X and Z do not have overlapping wake periods and if there is also no intermediate node Y that overlaps with wake periods of both X and Z. This problem can be solved by ATIM retransmissions during other wake periods and by changing the wake periods of the intermediate nodes.

This also motivates our choice for a fixed primary wake period pattern and the random secondary wake period pattern. The fixed primary wake period pattern simplifies to contact a node if its periodically occurring primary wake period pattern is known. The random selection of the secondary wake period ensures that ATIM messages are retransmitted with different delays after the start of the interval. It makes also sure that not always the same set of intermediate nodes forward retransmitted ATIM messages.

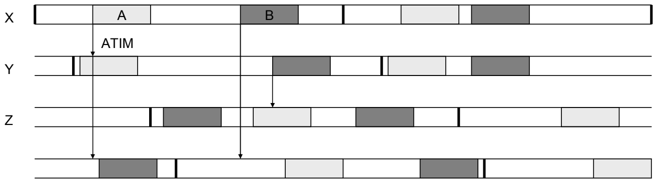

Figure 2: Operation of Power Saving Mechanism

3.3 Analytical Evaluation

First, we assume a wireless ad hoc scenario in which each node can be reached by any other node. If p is the wake ratio (= length of wake period / interval length) of a node, q = 1 – p, and N = total number of nodes that can reach other, we can calculate the failure probability that the sender does not reach the destination by two ATIM messages neither directly nor via intermediate nodes. The number of nodes M that receive the first TIM message of the sender node is given by

$$M = p\,(N-1)$$

The sender node transmits an ATIM message twice in its interval, once in the primary and once in the secondary wake period. An intermediate node can forward each of the two messages only once. P’ is then the probability that a single ATIM message does not reach the destination either directly from the source or indirectly via one of the M intermediate nodes. It can be calculated by

$$P' = q\,q^{M}.$$

Both ATIM message transmissions are independent. So, P'' is the probability that both ATIM messages sent by a sender do not reach the destination.

$$P'' = (P')^2 = q^{2(M+1)} = q^{2((p(N-1)+1)} = (1-p)^{2(p(N-1)+1)} \qquad (1)$$

This failure probability decreases for large wake periods, but also decreases for a large number of nodes in a given area. While we need a wake ratio of 50 % for 10 nodes to achieve a failure probability below 5 %, this can be achieved with a wake ratio of 20 % for 50 nodes and 10 % for 100 nodes. Figure 3 shows the results of equation (1). Each line represents the failure probability for a single wake ratio value.

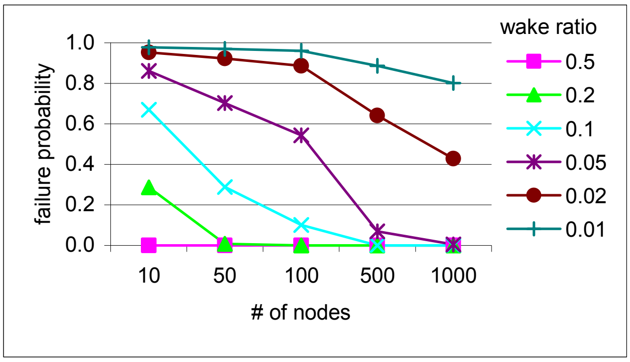

Figure 3: Analysis of failure probability

3.4 Simulation

In order to prove our analysis and to investigate the behaviour in a network under load we performed simulations using Omnet++. The diagram in Figure 4 shows the simulated failure probability dependent on number of nodes and wake ratio. As simulation parameters, we have chosen a 50 % loaded 10 Mbps network, data packet size of 1000 bits and ATIM message sizes of 100 bits. Potential collisions among ATIM messages and data have been simulated. The basic interval length was set to 2 s. The simulation results nicely confirm the result given by the equation (1) above.

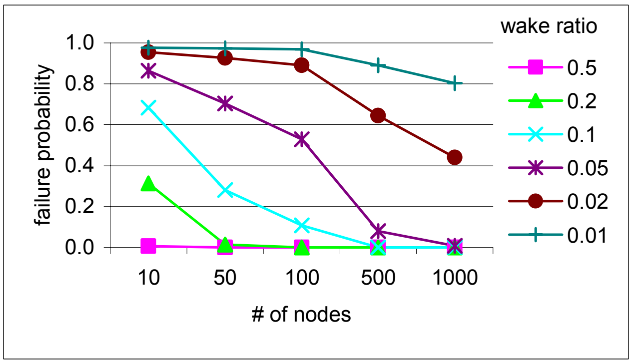

Figure 4: Simulation of failure probability

As already mentioned our mechanism does not guarantee that an ATIM message does arrive at a destination. In case of a failure, which can be detected by missing acknowledgements, the sender of an ATIM message shall retransmit ATIM transmissions until receiving an acknowledgement. In order to evaluate the efficiency of this mechanism we performed simulations with the same parameters as above. We repeated ATIM transmissions until the sender has received an acknowledgement from the destination.

In our evaluation we used wake periods with durations that depend on the number of nodes. Intuitively, wake periods should be shorter for high node densitites and longer for lower node densities.

As mentioned in subsection 3.1 a full reachability can be achieved, if there is at least one node in each of the K^2 array fields representing the fully synchronized scenario depicted in Figure 1, i.e.

$$N \geq K^2.$$

With p = 1/K this results in

$$N \geq \frac{1}{p^2} \Leftrightarrow p \geq \frac{1}{\sqrt{N}}.$$

As a first approach, we select

$$p = \frac{\alpha}{\sqrt{N}}, \alpha \geq 1$$

Figure 5 shows the results of an experiment, in which we repeat ATIM pairs in scenarios with different numbers of nodes and wake periods. We set $\alpha = 2$ for all simulations. For all scenarios we have between one and two additional ATIM pair transmissions in average. Note that we achieve full reachability in that case.

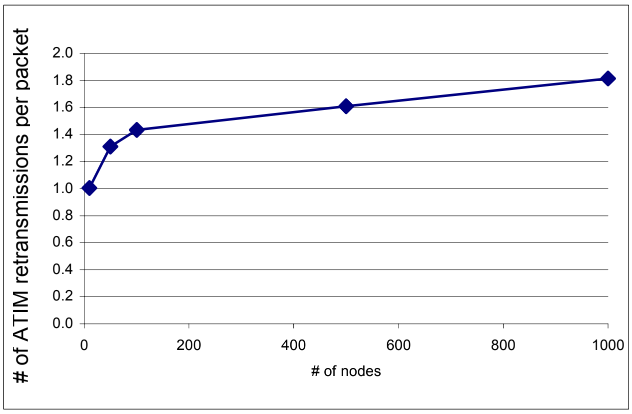

Figure 5: Retransmissions of ATIM pairs per packet

3.5 Estimating the Number of Nodes

Based on our results, we propose adapting the wake period dependent on the number of nodes: For larger number of nodes, shorter wake periods should be chosen, while a node should be wake for a longer time if there are fewer nodes in its environment. The number of redundantly received ATIM messages can serve as an indication whether a node should reduce or increase its wake period.

Shortening the wake periods has another advantageous side effect, because for high node densities the number of duplicated ATIM messages becomes lower. If the wake periods were not shortened, the number of duplicated ATIM messages would increase for large node densities and become a problem if they consume a significant fraction of the network capacity. Therefore, it would be beneficial if the length of the wake periods could be controlled dependent on the number of nodes.

We propose to use the number of received ATIM duplicates as a parameter to estimate the node number of nodes and to control the wake period. Assume that a sender generates ATIM messages during the primary and the secondary wake period. We further assume that all nodes have wake ratios of p. The two ATIM messages are then duplicated by p N nodes. This results in 2 p N ATIM copies in addition to the 2 ATIM messages generated by the sender. In total 2 + 2 p N ATIM copies are generated. If the receiver has a wake ratio of p, it will receive p (2 + 2 p N) ATIM messages in average. Let us now assume that a node has received M copies of a single ATIM message. Then we have

$$M = p\,(2 + 2\,p\,N) = 2\,p + 2\,p^2\,N$$

$$N = (M - 2\,p) / (2\,p^2) \qquad (2)$$

This result means that if all nodes have the same wake ratio and this ratio is known to all nodes, each node can estimate the number of nodes in the single hop ad hoc network based on the received copies of ATIM messages.

In our simulation scenario described in Section 3.4 we have tried to estimate the given numbers of nodes based on the received ATIM copies according to equation (2). Figure 6 shows the results. We have averaged all estimated values of all involved nodes in the simulation. The results suggest a nice match between estimation and real number of nodes.

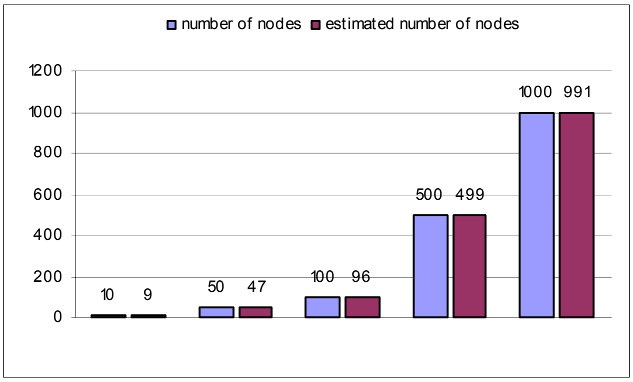

Figure 6: Estimation of node numbers

It is important to note that the estimation requires equal wake ratios at all nodes. This can only be achieved by some control mechanism. For example, a dedicated node could estimate the node number, calculate the resulting wake ratio and broadcast that value to its environment.

Another possibility is that nodes choose individual wake ratios dependent on the number of received ATIM duplicates. A node might increase its wake ratio if the number of received ATIM duplicates falls below a certain threshold, and decrease the wake ratio if the number of received ATIM duplicates exceeds another threshold. Such an algorithm has the risk of oscillations and need to be carefully designed and evaluated in future work.

4 Power Saving for Multi Hop Mobile Ad hoc Networks

The concept of forwarding ATIM messages can also be applied in a scenario, where not all nodes are directly connected to each other. We propose to adapt our mechanism to reactive mobile ad hoc network routing protocols. Route request messages are triggered by the source node and forwarded via intermediate nodes that receive the route request during their wake period. Each node forwards a received route request only once during the next wake period.

We simulated a scenario of 1000 x 1000 m with 200 nodes and 100 m transmission range. Route requests have been randomly generated between random pairs of nodes. We increased the wake ratio from 0.1 to 1. Beyond a wake ratio of 0.2 all route requests reached the target destinations, while 1 % of the route requests did not reach the destination for a wake ratio of 0.1. Smaller wake ratio values result in a larger number of hops, because due to the sleep periods of some nodes the optimal path may not be found. Figure 7 shows that the average number of discovered routes decreases from 6 to below 4 for increasing the wake ratio from 0.1 to 1.

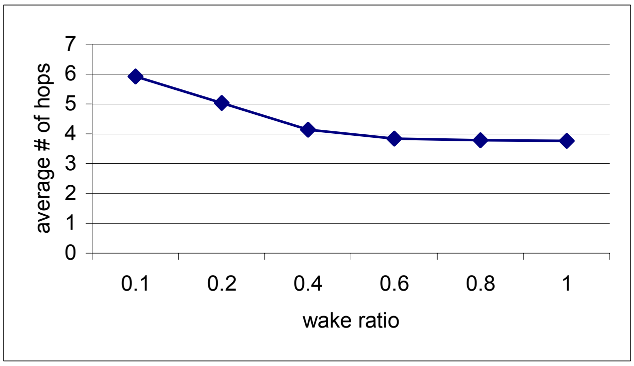

Figure 7: Length of established routes

5 Conclusions and Outlook

In this paper, we have proposed a mechanism for ATIM message exchange supported by intermediate nodes that share wake periods with both the sender and the destination of an ATIM message. Our analysis and simulations ina single hop scenario showed that the proposed mechanism works if there is a sufficiently large node number and the wake ratios are appropriately chosen.

The mechanism can also be adapted for multi-hop scenarios. Initial simulation results show that routes across a multi-hop network can be established for very low wake ratios, but the chosen routes may then not be optimal in terms of hop counts. Future work will focus on the improvement and detailed evaluation of the multi-hop scenario.

6 References

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