The effect of beaconing on the battery lifetime

Lucia Tudose
P:O. Box 407, 0045
NOKIA GROUP
lucia.tudose@nokia.com

Abstract

The ad hoc wireless devices may relay completely or partially on batteries. The technology for battery lifetime improvement is slower then the processor speed and memory capacity. Therefore power conservation becomes one of the design requirements for ad hoc wireless network protocols. Several protocols use beaconing messages for route updating. An experiment implementing Associativity Based Routing ABR protocol analyses the effect of beaconing interval on battery lifetime. Also the time for power down is observed in diverse configurations: beaconig standalone and beaconing with neighbors. The experiment demonstrates that high frequency beaconing consumes more battery lifetime then low frequency beaconing. The power consumption in the presence of the neighbor mobile hosts as a result of receiving beacons does not contribute much to the overall power degradation when the beaconing interval is small. That is because the receiving beacons consume less then to transmit beacons.

1 Introduction

Many of the ad hoc wireless applications require autonomous functionality and thus longer battery lifetime. Power conservation-based applications are:

- Sensor networks
- Rescue applications
- Rooftop networks
- Personal area networks

The technology for improvement of battery lifetime is developing slower then memory and processor technology. That is a driving factor for the power conservation aware software.

Several link-state or distance vector protocols uses periodic transmissions of Hello messages to propagate route updates through network. Beaconing is used to announce the presence of a node to the neighboring nodes. That is why is important to find the effect of beaconing on battery lifetime and to find the optimal values of beaconing interval for communication performance.

2 Ad-hoc wireless networks

A mobile ad hoc network is defined as an autonomous system of mobile routers and hosts connected by wireless links. The routers are free to move randomly and organize themselves arbitrarily; therefore the network's wireless topology may change rapidly and unpredictably. The network may operate in a standalone mode, or may be connected to the Internet.

The basic characteristics of ad hoc wireless networks are defined in Routing protocol performance issues and evaluation consideration [2] as:

- Dynamic topologies
- Bandwidth constrained
- Energy constrained
- Physical security threats prone

Mobile computers act as router and packet forwarders in a wireless environment with no base station.

2.1 Power management issues

There are two directions in power management for computers and computers networks:

- device capabilities in terms of power conservation
- communications design with regard to power conservation

The former covers the hardware associated with a standalone mobile computer and the overall power management of LCD displays, hard and floppy disk drivers, LCD displays, CD/DVD ROMS. The latter addresses the power consuming by the network layers actions as beaconing, or routes update. There is an effort toward energy aware and energy efficient software [6].

The power management in existing mobile computers includes Advanced Power Management APM [4] that is BIOS-based system power management, Operating System Power Management OSPM and Advanced Configuration Power Interface ACPI [3].
For example APM control the power usage of a system on the basis of the system's activity. The power is reduced gradually when the resources are unused.

ACPI evolves the existing power management solutions as APM, into an operating system OS-based power management solution. It allows OS-directed power management. ACPI interface gathers power management information from users, applications and hardware and supports elaborate power management policies.

2.2 Smart batteries

The smart battery highlights are:

- Prevent unexpected loss of power and shutdowns
- Enable longer battery runtimes of up to 30%.
- Enable precise indication of state of charge, minutes of runtime remaining, time to full charge, etc.
- Provide a warning system by monitoring state of battery health due to effects of environment, age, and wear.
- Assure safe, battery controlled smart charging to get a full charge every time and minimize battery abuse due to overcharging. Improve cycle life.
- Enable effective power management systems that take advantage of accurate information supplied by the battery.

A smart battery contains smart electronic components and software that enable measurements, calculations and communications through a standard interface to take place.

The power management ACPI can read the remaining power of battery and put the system in a sleep mode when the power level drops bellow a threshold or is convenient for an application.

A high-performance battery is characterized by:

- low self-discharge rate,
- long cycle life,
- a wide operating temperature range
- High energy density.

The main battery technologies used in mobile computers today are nickel cadmium NiCad, nickel metal hybrid NiMH, and lithium ion Li-ion. The energy density of Li-based batteries is more then two times NiCad and therefore most commonly used nowadays.

3 Associativity based routing

Associativity based routing protocol ABR is a *source-initiated on-demand routing protocol*. It is free from loops, deadlock and packet duplicates.

ABR does not maintain routing information in every node. ABR introduces a new metric for ad-hoc mobile networks known as *degree of association stability.* The associativity stability defines the connection stability of a mobile node with regard to another node over space and time.

Each mobile host periodically broadcasts beacons to identify itself (like Hello message). When the neighboring mobile host receives a beacon, it will update the associative table. For each beacon received the associative tick (count) of the current node with respect of beaconing node is incremented. Low associativity ticks with its neighbors means that mobile host has high state of mobility. If there is high associativity ticks then the mobile hosts are in a stable state and therefore are chosen to perform ad hoc routing.
The associativity threshold is defined as the value where associativity transitions take place. It is a function of beaconing interval, mobile host's migration speed and the size of wireless cell.

Associativity ticks are reset when the neighbor of a node or the node itself moves out of the proximity. ABR associativity ticks are not reset if a node fails to receive a beacon from a neighboring node. If the beacon in not received after 'N' times the beaconing interval then the decision is taken to delete the associatvity ticks.

ABR protocol has three mode of operation:

1-route discovery phase
2-route reconstruction phase
3-route deletion phase

3.1 ABR Route Discovery Phase

The route discovery phase uses *broadcast query* BQ messages and an *await replay* BQ_REPLY messages. Each BQ message has a uniquely identifier. A source node desiring a route to destination broadcasts the network with BQ messages. An intermediate node that receives the query first checks if they have processed the packet: if yes query packet will be discarded, otherwise check if the node is the destination. If not the intermediate nodes appends the following information before broadcasting the BQ message:

- its address
- the associativity ticks with its neighbors
- the route relaying load,
- the link propagation delay
- the hop counts information.

The next intermediate node will then erase its upstream neighbor's associativity ticks and retain only those concerns with itself and its upstream neighbor. In this manner, the query packet reaching the destination will only contain:
-the intermediate mobile hosts address
-mobile host's associativity ticks
-mobile host's relaying loads
-route forwarding delay
-hop count.

After receiving first BQ packet the destination node will choose the best route based on stability and quality-of-service QoS. Given a set of possible routes from source to destination node, if a route consists of mobile hosts having high associativity ticks then that route will be chosen by the destination in favor of other existing shorter-hop routes. The selected route is likely to be long-lived due to the propriety of associativity.

The destination node responds by sending a BQ_REPLY message back to source node via the route selected.
Intermediate nodes that receive the BQ_REPLY message validate their routes. Other routes are marked as inactive. This mechanism prevents duplication of messages.

3.2 Route reconstruction phase

When one of the source, destination or intermediate nodes moves the route reconstruction operation start.

Route reconstruction phase includes

- Partial route discovery
- Invalid route deletion
- Valid route updates
- New route discovery

Intermediate nodes moves

When an intermediate node along an existing route moves out of range, the immediate downstream node sends a *route notification* RN message toward the destination. Nodes along the path to destination that receive a route notification message RN delete this route entry. The immediate upstream node initiates a *local-query* LQ to discover a new, partial route as is shown in figure 1.

LQ messages are similar to BQ messages but use a hope count field to limit their range of action.

Once the destination receives several LQ messages it chooses the best route based on stability and QoS and responds by sending an LQ_REPLAY. If the upstream node does not receive an LQ_REPLY after a certain amount of time LQ_TIMEOUT, it responds by sending its own RN message to its immediate upstream node. The new upstream node removes the invalid route and initiates anew LQ messages process.

The LQ process continues till it reaches halfway point to the source node then is aborted and a new BQ message is initiated.

Source node moves

When source node moves, it will cause a route reconstruction similar with route initialization that is BQ and BQ-REPLAY messages.
Concurrent node movements may generate route reconstruction conflicts. ABR resolves the multiple route reconstruction messages by assuring that only one ultimately succeeds. Each LQ process is tagged with a sequence number so that earlier LQ process is terminated when a new one is invoked. For example if a node processing LQ messages hears a new BQ for the same connection then the LQ process is terminated.

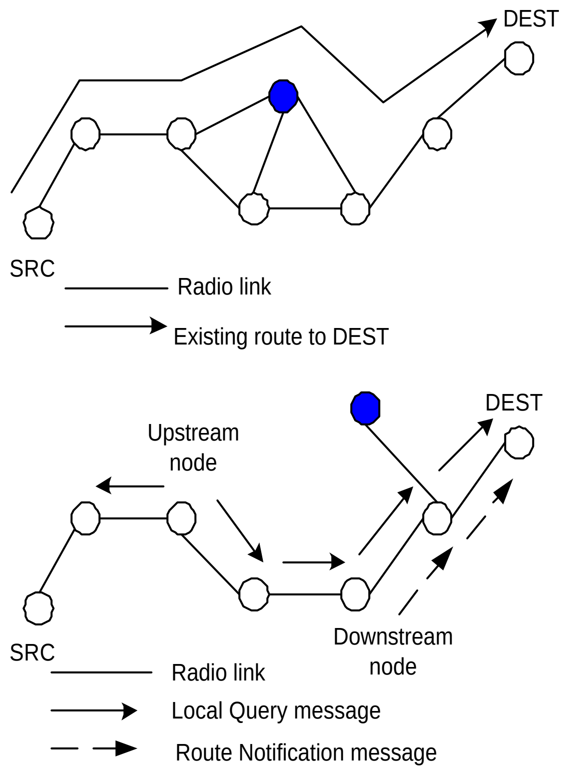

Figure 1: Route maintenance when intermediate nodes move

Destination node moves

When the destination node moves, its immediate upstream node (known as the pivoting node) will erase his route. It then sends a localized query LQ[H] messages to localize the destination node. H is the hop count from the upstream node to the destination node. If the destination node receives LQs messages it will select the best route and send a LQ_REPLAY. If LQ_TIMEOUT period is reached and the destination node hasn't received LQ, the next upstream will became the pivoting node. The backtrack process continues until the new pivoting node will be half away from the destination. If no partial route is found the pivoting route will send a route notification RN back to the source. The source will initiate a new route discovery process BQ that is the worst situation.

3.3 ABR Route deletion phase

Route deletion phase is used when a source no longer requires a route and it consists of a route delete RD broadcast from source node to all intermediate nodes. The full broadcast is used because the source may be not aware about new routes after many reconstruction phases.

4 Effects of beaconing on battery life

4.1 Experimental hardware and software

The experimental tesbed consist from seven laptop computers IBM and Compaq notebooks. Each of the laptop runs the Linux operating system version 2.0.3 which has a copy of TCP/IP/Ethernet protocol suite enhanced with the ABR protocol ad hoc implementation software.

The mobile computer is IBM ThinkPad 600 with Intel Mobile Pentium processor with built-in 64-Mb memory, 5 GB hard disc drive and an active color display with 1024 by-768 resolution.

The laptop has also standard I/O interfaces serial, parallel, USB, diskette, keyboard/ mouse, audio I/O, and an internal 56k modem. It has three power –saving modes controlled by the BIOS: standby, suspend and hibernation. The laptop uses a Li-ion battery with nominal voltage and capacity of 3.2 AH.

The wireless adapter is the 2.4GHz WaveLan PCMCIA card. The card has three operating modes, each having different consummation level: sleep, receive and transmit mode. Table 1 values shows that while the card is in sleeping mode consumes only 10% of the transmit or receive power.

Table 1: Classes and values

Power consumption	2.4 Hz
Sleep mode	0.175 W
Receive mode	1.575 W
Transmit mode	1.825 W

WaveLan does not support the power management in ad hoc configurations because it requires dedicated support from Wave Point access points and thus is not utilized during experiments.

Propagation characteristics of the experiment: the nodes are situated 10m of each others with no obstacles.

Experimental software

The operating system chosen is Linux, and the ABR protocol is implemented within TCP/IP layers. Beaconing functions are implemented in the ABR layer.

The ABR protocol is implemented within IP protocol layer as shown in figure 2. The beacon striker is shown in figure 3. which illustrates the ABR base header with the Type field defined as BEACON encapsulated by the data link header. The ABR beacon is a network control message generated at the ABR layer and broadcast to the network.

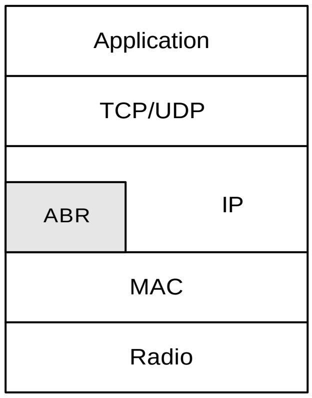

Figure 2: ABR implementation within TCP/IP

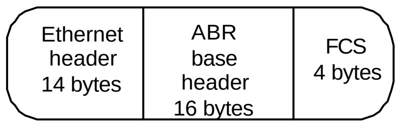

Figure 3: the beacon structure

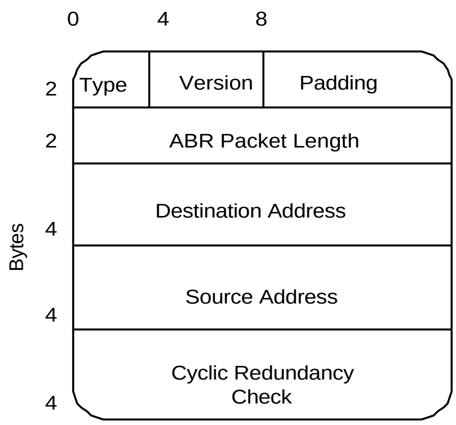

Figure 4: the ABR base header

5 The experiment implementation

The goal of the experiment is measuring the percentage of battery life remaining over time after each beaconing period. Also the time when computer shuts down is observed
The following scenarios were implemented for a complete testing of the beaconing effects:

- Standalone beaconing at high frequencies
- Standalone beaconing at low frequencies
- Beaconing in the presence of neighboring nodes at low and high frequencies

5.1 Standalone beaconing at high frequencies

A single computer was set up to beacon at millisecond intervals. At the beginning of the experiment the battery was fully charged. The computer had X Window, `xload` and `netstat` applications running. The Advanced Power Management daemon in the OS and the BIOS APM ware disabled.
The range of the experimental time is from zero to the time of power down that is about 230 minutes for non beaconing computer.
The beaconing intervals chosen are 10-ms, 50-ms, 100-ms and 500-ms.
The interval for measuring the battery life is 20 minutes.
The results are that for 10-ms beaconing interval the battery life degrades at the fastest rate, while the others have relatively similar power characteristics.
Also at 10-ms beaconing interval the computer has a shorter lifetime about 40 minutes compared to other beaconing intervals.
At 10-ms beacon interval the CPU load is high and the computer seems to be slow in forking new applications and responding to commands.
The battery capacity suddenly decreases at 20 minutes before the computer shuts down operation.

5.2 Standalone beaconing at low frequencies

In the second experiment the beaconing intervals are 1-sec, 5-sec, 10-sec and 15 seconds. The system set up was the same as in previous experiment. For up to first 40 minutes the difference in power degradation for different beaconing intervals is not significant. After a period of 180 minutes is passed, the difference in remaining battery life between 1 second and 15 seconds is about 15%.
For 1-sec and 5-sec beaconing intervals the remaining power life drops at 180 minutes. For the 10-second and 15-second beaconing intervals this significant decrease happens 20 minutes later at 200 minutes. This is the action taken by BIOS and OS actions for power down preparation and is similar to the phenomena observed in the previous experiment.

These experiment shows that with low-frequency beaconing interval the system will operate longer.

Comparison of high-frequency and low-frequency beaconing for standalone configuration
Comparing the results for 10-ms and 15 seconds of beaconing interval the difference in battery lifetime is about 60 minutes. This implies a carefully selection of an appropriate beaconing interval.

5.3 Beaconing with neighboring nodes at high frequencies

The real scenario for ad hoc networks is the presence of the neighboring nodes. This experiment aims to observe the influence of receiving and transmitting beacons on battery lifetime.
-There are the same high frequency beaconing intervals as in standalone testbed 10 ms, 50 ms 100 ms and 500 ms.
-the results are that at 10-ms the battery life decreases at the fastest rate.
-the lifetime of computer beaconing at 10-ms is about 40 minutes shorter then those beaconing at 50, 100 and 500-ms.
Comparing power degradation with and without neighbors at high frequency beaconing results: the difference in battery lifetime is about 7% for 50-ms beaconing interval on a range of experimental time from 20 to 180 minutes.

5.4 Beaconing with neighboring nodes at low frequencies

The low frequency intervals are the same as in standalone experiment.
-There is small differences in the remaining battery lifetime at 1, 5, 10, and 15 seconds during the first minutes of experiment.
-Compared to the high frequency with neighbor presence experiment the computer has a longer lifetime, about 50 minutes more, for 10-ms and 1 sec beaconing intervals.
-The differences in remaining battery lifetime for standalone and neighbors testbed are insignificant except for the 10 and 15 seconds beaconing intervals.

5.5 The experiment main conclusions are:

- Beaconing at high frequency i.e. 10 ms interval can reduce significantly the battery lifetime and also affect the application speed.
- Only small differences are observed if a standalone ad hoc mobile host beacons at 50 ms, 100 ms, 500 ms and 1-sec intervals.
- The power degradations of standalone ad hoc mobile computer do not differ greatly from one that has a periodic beaconing interval of 5, 10 or 15 sec.
- With the presence of the neighbor the power consumption as a result of receiving beacons from neighbors does not contribute much to the overall power degradation when the beaconing interval is small. That is because the receiving beacons consume less then to transmit beacons.
- For both low frequency and high frequency beaconing more power is drawn when the OS and BIOS take actions in preparation of system power down.

6 Conclusion

In this paper an Associativity Based Algorithm ABR implementation shows the impact of beaconing on battery lifetime.
The results are in favor of accurate selecting of a beaconing interval for a mobile host power conservation. The experiment has pointed out also that the actions for shutdown preparations have significant effect on battery life.
Future work with regard the further development of ABR protocol includes implementing the ABR protocol into existing WLANs [5].
There are nowadays many efforts for power conservation software design. Another approach for extending battery lifetime is controlled entering in "sleep" mode of mobile hosts. One example is Span protocol. Span is an energy-efficient protocol for topology maintenance and it improves the system lifetime besides communication latency, and capacity. [8].

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