IEEE 802.11
Wireless Access Method and Physical Specification

Title: **The importance of Power Management provisions in the MAC.**

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Abstract: This paper discusses the importance and required characteristics of Power Management provisions in the MAC. The subject is very relevant for a Wireless MAC, because its primary application will be in mobile usually battery powered handheld devices.

Summary:

Power (consumption) Management will be extremely important to provide wireless connectivity for mobile users that typically need to operate from batteries. A few different cases have been addressed from applications that need only moderate Power Management provisions, up to devices that need extreme low power operation. The power reduction can only be achieved by allowing stations to power-down their receivers for most of their time. It is an important requirement that this can be supported without any knowledge about the application. Since the higher layer protocols can not deal with this, the MAC should provide for temporary buffering functions to assure that packets are only send to the destination receivers when they are "Awake".
This has effect on the services that can be provided as function of the required power reduction requirements. To allow the use of LLC-2 services, restrictions for the allowable sleep intervals will apply.
Extreme low power devices, which can on average turn on their receivers only once per several tens off seconds will only be able to use the LLC-1 services without Broadcast capability.

The MAC should provide specific Power Management functionality like temporary buffering and transmitter and receiver synchronization, to allow stations to go into sleep without loss of service.

1. Introduction:

Wireless Networks can be used to increase flexibility in many different applications. In many environments the location of stations may change frequently, which would normally require re-wiring that can be very costly and sometimes time consuming causing loss of service.

The most important users of wireless communications will be mobile devices. This will typically be handheld devices that operate from battery power. There will be the users from Notebook computer that want the same connectivity as provided for their desktops today. Other applications that need wireless connectivity will be the PDA users or some messaging devices that typically would run from a few AA cells or less.

Size, weight and battery life are the most important characteristics of these devices. They all will need some sort of wireless connectivity with very diverse needs in throughput and response times. They all will need an infrastructure that allows for continuous connectivity within its operating environment. It is very desirable that a single infrastructure can serve all these diverse applications.

Today's wired LANs are designed such that receivers need to be continuously active to assure that traffic destined to that station does not get lost. This will be a very big burden on the batteries that power these devices, even when a very low power receiver design can be accomplished.

To really conserve power it is needed that transceivers can be turned off most of the time. This means that it becomes an important requirement that the LAN system must be able to deal with devices that have their receivers turned off most of the time.

2. What are the applications for wireless communication.

The following different applications classes can be distinguished, which are different in terms of required battery life and traffic service requirements.

* Mobile computing
  - Support Low Power operation for battery operated high speed data transfer devices like Notebooks, and Notepads.
  - These devices will need similar connectivity provisions as the desktop devices.
  - The main traffic that needs to be handled will be file transfer, Data-Base access, and Email.
  - They need to support the major Network Operating Systems in use today.

* Messaging/Transaction Systems
  - Support Extreme Low Power devices like PDA's, scanning devices and a sort of personal communicator that can accept and return short voice messages and mail.
  - These devices may not need all Network services, but use the network infrastructure to provide the necessary connectivity.
  - Devices are very small and need to run on a few penlight batteries that provide battery life from days to months.

* Current (wired) LAN applications
  - Support Wireless Network for flexibility.
  - These devices are usually stationary and not battery powered.
  - The main traffic that needs to be handled will be file transfer, Data-Base access, and Email.
  - They need to support the major Network Operating Systems in use today.

The traffic requirements of the first two mobile classes may differ a lot. However it should be understood that all of them are idle most of the time. So not the power consumption needed for the actual data communication, but the idle time power consumption will be the most determining factor for the average power consumption.

3. How much Power Consumption must be conserved.

The amount of power that can be used for communication will depend on the battery capacity of the device in which the transceiver is installed, and typical useful battery life for the particular application.

3.1. Mobile Computing applications:

For today's Notebook computers the useful battery life ranges from 2-4 Hrs, with the unit typically consuming an average between 500-1500 mAh. The communication device that go in this equipment should not affect the useful battery life with more then 10-20%.

While performance of Notebooks will improve, the battery life will need to improve also, to assure that no recharge would be needed during one business day.

The 10-20% factor would today result in an allowable consumption for the connectivity device of below 100 mAh, which should be reduced in the near future to below 50 mAh.

3.2. Messaging/Transaction systems:

The small handheld, palmtop or pocket devices that use rechargeable batteries would need an effective battery life in the order of days.
When non-rechargeable batteries are being used the device should have a battery life time in the order of multiple weeks to months. The power consumption of the device itself depends on the use duty cycle, which can be very low. The power consumption of the communication device would be allowed to have a similar impact of 10-20% of the battery life for applications like exchange of information between a pair of devices like that. The connectivity may only be needed when the device is actually being used.

However for messaging and transaction devices, continuous connectivity will be the dominant requirement. The actual use duty cycle of the device can be very low, but continuous connectivity with adequate response time is required. The power consumption of the connectivity function itself will then be the most determining factor for the battery life, and may perhaps cost more then 50% of the power budget.

Rechargeable AA size batteries have a capacity of 500-650 mAh, while high capacity Alkaline AA-size batteries have a capacity of approx. 2000 mAh. AAA-size alkalines have a capacity of approx. 250 mAh.

3.3. Extreme low power example:

Now lets assume that the connectivity function of a device like that is allowed to use 50% of the available battery capacity, while it needs to last for approx. 2 months on AAA-size alkaline batteries. Assuming 8 hours operation per day, 5 days a week for 8 weeks is approx. 320 hours. This allows for an average current drain of 125/320=.39 mAh.

4. Transmit power requirements.

The power consumption during actual transmission of a packet depends on the range that need to be covered, which will determine the actual Transmit Power level, which will range between 10 mW to 1Watt. However the transmission duty cycle for stations will generally be very low for the asynchronous data applications.
Even when we consider a Notebook that needs to transfer a large files of 1 MByte every 15 minutes, then the duty cycle is still well below 1%. Assuming 1W Tx-Power at 25% efficiency would require 800 mA for roughly 5 seconds (@ 2 Mbps), which translates to approx. 1 mAh of battery capacity. This is about 1 % of the battery capacity set aside for the connectivity function for these devices.

It is clear that the actual power needed for the transmission of the packets is insignificant compared to the capacity set aside for the connectivity function. Transmit Power Control is therefore not important to conserve battery power. Its main purpose would be to increase the medium re-use efficiency (reference Doc IEEE 802.11-92/76). While the transmit power consumption is not important from a battery capacity point of view, its peak current requirements can be important. The battery must be able to provide a high instantaneous current while a packet is being transmitted.

It should be understood that the above is considered for a Station transmitter. In an Access Point the transmitter duty cycle may be much different. This is because an AP will probably need to handle most traffic within a BSA, where the dominant traffic direction will likely be from the AP to the Stations.

5. Receive power requirements.

Unlike the transmit power requirements where the required current during the actual packet transmission is roughly related to the power level transmitted, it is much harder to predict the power requirements of the receiver.
The actual power requirement will depend on:

- Baseband and RF linearity requirements
- Baseband Bandwidth (Gain + AD-Converters)
- Complexity (amount of signal processing required)
- Receiver activity level

There will be a difference in power consumption level depending on the presence of a modulated signal, and the operational state of the receiver. It could for instance be that the PHY is active receiving a frame, while the MAC is still inactive.
The most important factor in terms of power consumption in a bursty traffic data environment will be the idle situation. This is because the average traffic load of most networks will in practice be very low. However the idle receiver state does not necessarily mean that its power consumption can be very low in this stage.

In practice the receiver will be continuously in a process to check for modulated input signals. To achieve short response times it is probably required that most of the RF and Baseband analog frontend functions are active and consuming close to their normal power levels. Also part of the modem processing function that is needed to detect incoming signals will be continuously active. Given the fact that most current will be drawn by the Baseband and RF analog processing circuits, it is expected that the power consumption of the receiver in the idle state is not much lower than when the receiver is actually receiving a packet.
Practical implementations today show that receive currents of approx. 150 mA are feasible. So let us assume an idle current level of 150 mA for further analyses.

5.1. Impact of bitrate on Power consumption

Power consumption in devices using different bitrates are not linear to the bitrates used. The base band bandwidth will relate somehow to the bitrate, and higher bitrates/bandwidths will translate into higher power consumption. However the power consumption of the IF and RF will be more or less independent of the bitrate. Given a certain traffic load, the amount of time needed to transmit and receive will reduce inversely with the bitrate. Therefore it may be advantageous from a power consumption point of view to use a high bitrate.
So even systems that need a low throughput (like the messaging devices) can benefit from a high bitrate, because of power consumption advantages and the fact that infrastructure can be shared with other systems that do require LAN speeds.

6. Power Management methodology.

It should be clear from the above considerations, that meeting the power consumption budget requirements can only be achieved by putting the transceiver into a low power sleep mode with a duty cycle depending on the overall power requirements of the station. It is assumed that the power consumption in the sleep mode is reduced to a minimum. In this "Doze state" at least a timing function would be needed to wake-up the device after a predetermined time.

However the protocols in use today do assume that the receiver is continuously aware for incoming traffic. Therefore additional functionality will be needed in the MAC to allow receivers to go into sleep mode, without loss of traffic.
The most important requirement is however that any solution should be independent from any knowledge about the application.

7. Resulting duty cycle requirements.

To summarize, the following requirements for the two different environments were derived above as an example, which result in the following receiver duty cycle requirements.
Assumptions:

- Continuous receive power in the idle state of approx. 150 mAh.

- Notebook application assumptions.
  - Required battery life is about 4 Hrs per day
  - Assume a connectivity power budget of 50 mAh

  The receiver can only be active for 50/150=33% of the time maximum. This would not allow for any transmission budget, so the actual duty cycle of the receiver should be lower.

- Extreme Low Power messaging application assumptions.
  - Requires a battery life of 8 weeks (320 Hrs).
  - 50% of power capacity set aside for connectivity function.
  - This results in .39 mAh of average power consumption.

  Now the receiver can only be active for .39/150=.26% of the time maximum, not counting the transmission budget. This is 2.6 msec/sec.
  The "Doze" state power consumption could dominate in this situation, which would further reduce the active receive time limit. It is clear that for these applications very low sleep currents should be used. A .2 mA sleep current would for instance reduce the active receive time limit by an other factor of 2.

Another factor that is to be taken into account is the time needed for the receiver to wake-up from its Doze state. This time is needed to stabilize different sections of the receiver before reliable packet reception is possible. The time required for this depends on the implementation, but is expected to range from .5-5 msec.

Applying the 5 msec number to the above example, makes clear that the transceiver can only be activated once per several seconds to tens of seconds.

The above provides some insight in the extremes, and the factors that dominate the power consumption.

7.1. Power Consumption Conclusion:

To meet power consumption requirements of the mobile users that depend on battery power it is required that the transceiver is regularly put into sleep mode, in which no packet reception is possible.
To meet the needs of Notebook computing devices, moderate sleep intervals in the order of 10-20% duty cycle are needed.
To meet the needs for the extreme low power devices that need to run from non-rechargeable batteries that need a battery life of months, it should be possible to use sleep intervals of tens of seconds. This requires duty cycles of less then 1%.

8. MAC Functionality required to support Sleep modes.

The higher layer protocols used on current networks do assume that the communication channel is continuous available, and they can not really deal with stations that do not continuously listen. If a guaranteed service is being used, then the LLC protocol stack will retry a failing transfer a couple of times before it causes a disconnection. When no further provisions are included in the MAC, then this is very likely to happen especially with long sleep intervals. For the LLC-1 "Datagram" service no recovery is available at all. The probability that the packet is not delivered is extremely high, so this service would become useless.

As already stated, the solution should be made independent of any higher layer protocol, while still meeting the power saving requirements.
Therefore the conclusion is that specific MAC functionality is needed to allow stations to go into sleep mode, while maintaining the LLC service. To accomplish this, at least a buffer function is needed to temporarily store the packets until the station is "Awake". Further a transmitter needs to know somehow when the remote receiver is "Awake" to receive the packet.
On the other hand a station does also need to know when the transmitter is likely to transmit relevant information to that station, so that it can turn on its receiver in time. To meet the power consumption requirements of extreme low power devices, which can only tolerate an on-time of a few ms per second, it becomes clear that a station should be able to predict pretty accurately when a relevant packet can come in. This calls for accurate synchronization within a BSS.

9. Services required by the different device classes.

When the "temporary buffer" functionality is available in the MAC, then different service levels should still be distinguished as a function of the sleep requirements of the station. When assuming the LLC-2 guaranteed delivery service, then this service can only be used when the sleep intervals are limited. The LLC-2 timer defaults are typically such that when no response is available within approx. 400 msec, then the packet is considered lost and will be retransmitted. This will put a limit on the duration that a packet can be buffered, because after that time the packet has lost its function and will be retransmitted anyway.

This means that stations that need much longer sleep intervals can not use the LLC-2 services. In practice the sleep interval should be limited to something like 100-200 msec to prevent that the LLC-2 timers are expiring while the packet is not lost, but still buffered. Please note that the LLC protocols are end-to-end, which can represent multiple wireless and Distribution system segments.

This also means that those devices that need longer sleep intervals to meet their Power consumption requirements can not use the LLC-2 services. Only the LLC-1 "Datagram" service would be available. The application that run on those devices need to implement their own provisions to assure proper delivery of the application data.
There will be a similar implication for the "Broadcast" service for those devices.

9.1. Supported Services Summary:

Low Power Devices:	Full LLC-1 and LLC-2 service available
Extreme Low Power Devices:	Only LLC-1 service available, possibly without Broadcast

10. Network Operating system characteristics

An other factor for Power Management is the characteristics of the Network Operating System (NOS) that are in use today. This especially relate to the "Stay alive" procedure that is used by such systems to keep the communication session open. When a station does not respond within a particular time, then the system will close all open sessions for that station, and will disconnect. The frequency with which this is done and the sensitivity for communication interruption differ a lot from one NOS to the other.
For instance Novell Netware 2.15 allows stations to be disconnected for more then 10-15 minutes, while LanManager seems to be much more sensitive which may start to cause problems when a station is not available for more then 30 seconds.

This characteristic is especially problematic when applications are still active when a connection gets temporarily disrupted.

11. Conclusions:

In this paper we arrived to the following conclusions.

1- Power (consumption) Management is a crucial function for the 802.11 MAC.
2- Transmit power consumption has a very insignificant effect on battery life. Therefore Transmit Power Control is not done for power conservation, but its function is to optimize medium re-use.
3- The idle traffic situation is the most dominant factor for power consumption.
4- Different Power Management levels are needed to support a large range of applications.
5- Stations must be able to turn off their receivers for most of the time to meet the power requirements of most power critical devices.
6- Power Management scheme should be independent of any application knowledge.
7- Provisions in the MAC are needed to support sleeping stations without loss of service.
  - Temporary buffering of packets for sleeping stations.
  - Synchronization between transmitter and receiver.
8- Different Power Management levels have impact on the MAC services supported.
9- Extreme Low Power Devices can only use LLC-1 services, without Broadcast.
10- Network Operating Systems show different sensitivity for service interruptions.