# A Review of Power Control MAC Protocols for Mobile Ad Hoc Networks

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## Abstract

A mobile ad-hoc network is a collection of mobile nodes forming an ad-hoc network without the assistance of any centralized structure. Since the devices used in an ad hoc network are mostly battery powered, power conservation is a major issue of such networks. Power control is not related to any particular layer, since we can apply power conservation methods in all layers. But most of the power control mechanisms are working in MAC layer. This paper presents an insight into the existing work on the power control at the media access level. Various objectives of the power control, distinct approaches, and the issues related to power control are discussed.



Keywords: Ad Hoc networks; Power Conservation: Media Access; Review.

## 1. Introduction

An Ad Hoc network is a decentralized type of network. It does not rely on a preexisting infrastructure, such as routers in wired networks or access points in managed (Infrastructure) wireless networks. Instead, each node participates in routing by forwarding data for other nodes, so the\determination of which nodes forward data is made dynamically on the basis of network connectivity. An ad-hoc network is a self-configuring network of wireless links connecting mobile nodes. These nodes may be routers and/or hosts. The mobile nodes communicate directly with each other and without the aid of access points, and therefore have no fixed infrastructure. They form an arbitrary topology, where the routers are free to move randomly and arrange themselves as required.

Each node or mobile device is equipped with a transmitter and receiver. They are said to be purpose-specific, autonomous and dynamic. This compares greatly with fixed wireless networks, as there is no master slave relationship that exists in a mobile ad-hoc network. Nodes rely on each other to established communication, thus each node acts as a router. Therefore, in a mobile ad-hoc network, a packet can travel from a source to a destination either directly, or through some set of intermediate packet forwarding nodes.

In a wireless world, dominated by Wi-Fi, architectures which mix mesh networking and ad-hoc connections are the beginning of a technology revolution based on their simplicity.

Ad hoc networks date back to the Seventies. They were developed by the Defense Forces, to comply with a military framework. The aim was to rapidly deploy a robust, mobile and reactive network, under any circumstances. These networks then proved useful in commercial and industrial fields, first aid operations and exploration missions. Power control problem in wireless ad hoc networks is that of choosing the transmit power for each packet in a distributed fashion at each node. The problem is complex since the choice of the power level fundamentally affects many aspects of the operation of the network.

- The transmit power level determines the quality of the signal received at the receiver.
- It determines the range of a transmission.
- It determines the magnitude of the interference it creates for the other receivers
- Power control affects the physical layer.
- It affects the network layer since the transmission range affects routing.
- It affects the transport layer because interference causes congestion.
- Power control has a multidimensional effect on the performance of the whole system.
- The power levels determine the performance of medium access control since the contention for the medium depends on the number of other nodes within range.
- The choices of power levels affect the connectivity of the network and consequently, the ability to deliver a packet to its destination.
- The power level affects the throughput capacity of the network.
- Power control affects the contention for the medium, as well as the number of hops and, thus, the end-to-end delay.



Therefore, power control is important in wireless ad hoc networks for at least two reasons:
**(i)** It can impact battery life.
**(ii)** It can impact on the traffic carrying capacity of the network.

Hence various efforts have been made to control the power by incorporating different power control MAC layer protocols.

## 1.1 Sources of power waste

The major sources of power waste in mobile computing devices include:

- Radio Communication
- Data Processing

### Radio Communication

The energy expenditure in radio communication includes the power consumed by transmitting and receiving devices of all nodes along the path from source to destination, together with their neighbors that can overhear the transmission. In mobile ad hoc networks, communication related energy consumption includes the power consumed by the radios at the sender, receiver and intermediate nodes in the route from the source to the destination. Actually, at any time a mobile node in MANETs must be in one of the following four modes: transmit, receive, idle listening, and sleep. When a node is in transmit or receive mode, it is transmitting or receiving a packet. Idle listening mode means the node is neither transmitting nor receiving a packet, but is doing channel monitoring. This mode consumes power because the node has to listen to the wireless medium continuously in order to detect the arrival of the packet that it should receive, so that the node can switch to receive mode. When in the sleep mode, nodes do not communicate at all. Receive and idle mode consume similar amount of power, while transmit mode requires slightly larger amount. Nodes in sleep mode consume extremely low power.



### Data Processing

Data processing involves the usage of CPU, memory, hard drive, etc. Its energy consumption is relatively negligible compared with that of the radios. Data compression techniques are introduced in to reduce packet length and therefore achieve energy saving in radio communication, but the cost of computation is increased.

## 2. Low-power MAC design guidelines

The major energy waste comes from idle listening, retransmission, overhearing and protocol overhead. Thus there is no wonder why all power-aware MAC protocols try hard to reduce energy waste from one or all of the above sources. To make MAC protocol energy efficient, at least one of the following design guidelines must be obeyed.

### Minimize random access collision and the consequent retransmission

Collisions should be avoided as far as possible since otherwise the followed retransmission will lead to unnecessary energy consumption and longer time delay. Actually one of the fundamental tasks of any MAC protocol is to avoid collisions so that two interfering nodes do not transmit at the same time. The simplest ways for collision avoidance in a general network include code division multiple access (CDMA), time division multiple access (TDMA), and frequency division multiple access (FDMA). However, for mobile ad hoc networks there exist many special issues that need to be addressed for a MAC protocol design. For example, because of the non existence of fixed base stations in MANETs, mechanisms to avoid collision among mobile nodes must be distributed. Since collision avoidance may result in substantial overhead, which will burn more energy, tradeoffs must be explored to achieve reasonable solution. Such schemes are designed to increase the channel utility and at the same time to avoid collisions.

### Minimize idle listening

In typical MANET systems, receivers have to be powered on all the time. This results in serious energy waste. Since the power consumed in idle listening is significant, we should pay attention to the energy conservation in nodes other than the source and destination. Ideally the radio should be powered on only when it needs to transmit or receive packets, thus remove the unnecessary monitoring of the media. Recently, energy-aware MAC protocols that require nodes be in sleep mode periodically for energy conservation has been proposed. When in sleep mode, nodes neither transmit nor receive packets; but they must be woken up to idle mode first for attending traffic relay. Sleep mode requires more than an order of magnitude less power than idle mode. Hence, intelligently switching to sleep mode whenever possible will generally lead to significant energy saving.

### Minimize overhearing

Wireless nodes consume power unnecessarily due to overhearing the transmissions of their neighbors. This is often the case in a typical broadcast environment. For example, as the IEEE 802.11 wireless protocol defines, receivers remain on and monitor the common channel all the time. Thus the mobile nodes receive all packets that hit their receiver antennae. Such scheme results in significant power consumption because only a small number of the received packets are destined to the receiver or needed to be forwarded by the receiver. One solution to this problem is the introduction of a control channel for the transmission of control signals that will wake up the nodes only when needed. Another solution for overhearing avoidance is to power interfering nodes after they hear an RTS or CTS packet proposes to broadcast a schedule that contains the data transmission starting times for each mobile node.

### Minimize control overhead

Protocol overhead should be reduced as much as possible, especially for transmitting short packets. Due to the large channel acquisition overhead, small packets have disproportionately high energy costs. Header compression can be used to reduce packet length, thus achieving energy savings. Since significant energy is consumed by the mobile radio when switching between transmit and receive modes, packet aggregation for header overhead reduction will be useful. When mobile nodes request multiple transmissions lots with a single reservation packet, the control overhead for reservation can be reduced.

### Explore the tradeoff between bandwidth utilization and energy consumption

Energy consumption and bandwidth utilization are substantively different metrics. But they are strongly related to each other. To conserve power, its radio must be turned off if the node does not participate in the traffic dissemination, as the energy spent in receiving and discarding packets (this happens when overhearing and idle listening) is significant. Further, to shun the energy consumption resulted from packet retransmission, a node need to be powered off if the media is busy. This greatly decreases the channel utilization, thus decreases network through-put. Therefore, the tradeoff between the bandwidth utilization and energy consumption must be exploited for throughput improvement. Scheduling the channel efficiently among neighboring nodes is a challenging problem. To design a good MAC protocol for MANETs, designers must take into account energy, bandwidth, delay, channel quality, etc. Other factors that play important roles in power-aware MAC protocol design include network wide traffic pattern (broadcast versus point to point traffic, short packet vs. long packet, etc) and per node operation mode (promiscuous mode vs. non-promiscuous mode). Different tradeoffs must be explored based on application requirement (operation time, availability of infinite power supply, etc.) such that multiple factors can be considered together. We can simplify the design goal of power-controlled MAC protocols as follows: to increase the overall network throughput while maintain low energy consumption for packet processing and radio communication. We will discuss different mechanisms for power-controlled MAC protocols in detail in the following sections. All of them are trying to achieve the above goal.

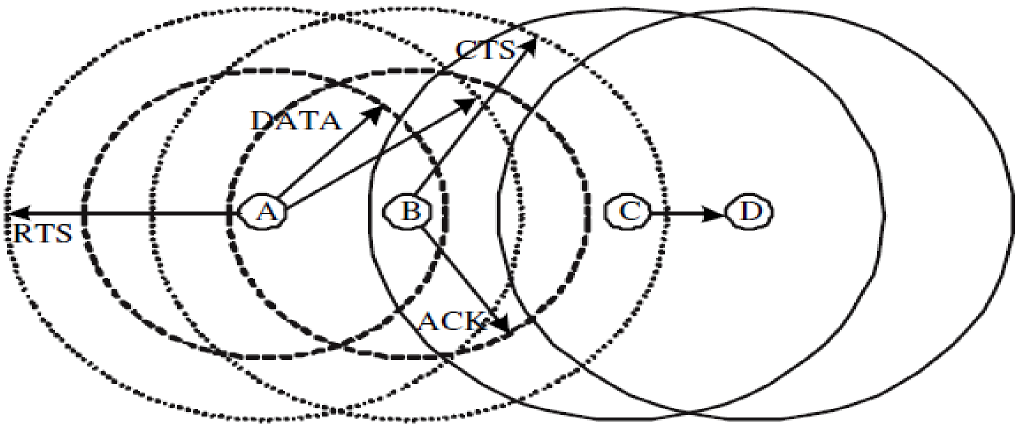


## 3. Power Control Schemes

### a) Power Control MAC (PCM) protocol

A Power Control MAC (PCM) protocol allows per-packet selection of transmit power. In PCM, RTS/CTS packets are transmitted with a max power level, Pmax. But for data packets, they are transmitted with a lower power level. In order to avoid a potential collision caused by the reduced carrier sensing zone, during the DATA packet transmission. PCM periodically increases the transmission power to pmax. ACK packets are transmitted with the minimum required power to reach the source node.

**Figure shows the power level used in PCM:**






By periodically increasing the power level for data transmission, PCM effectively reduces the amount of possible collisions. This way, retransmission is avoided as much as possible, and correspondingly, the goal of energy savings is achieved. Results show that PCM can achieve a throughput comparable to the IEEE 802.11 but with less energy consumption. However, PCM requires a frequent increase and decrease in transmission power levels; hence the implementation is not easy.

## b) Power Controlled Multiple Access

The Power Controlled Multiple Access (PCMA) Protocol proposes a flexible variable bounded power collision suppression model and allows variable transmit power levels on a per-packet basis. Similar with IEEE802.11, PCMA uses RPTS/APTS handshake to determine the minimal transmission power required for successful packet reception. The difference lies in that PCMA introduces a second channel, the busy tone channel, to implement the noise tolerance advertisement. During data transmission periods, each active receiver will periodically send a busy tone to advertise the maximum additional noise power it can tolerate. Any potential transmitter must first sense the channel for busy tones to determine the upper bound of its transmit power for a minimum time period (determined by the frequency with which the busy tones are transmitted). Actually, PCMA uses the signal strength of a received busy tone message to bound the transmission power of neighboring nodes. This way, power control mechanism is realized and spatial reuse is achieved. PCMA works effectively in energy conservation since it allows more con-current data transmission compared with IEEE 802.11 standard by adapting the transmission ranges to be the minimum value required for successful reception on the receiver side. Results show that PCMA can improve the throughput performance by more than a factor of 2 compared to the IEEE802.11 for highly dense networks. The throughput gain over 802.11 will continue to increase as the connectivity range is reduced. What's more, the power controlled transmission in PCMA helps increase channel efficiency at the same time preserving the collision avoidance property of multiple access protocols.

### c) Dynamic Channel Assignment with Power Control (DCA-PC)

A Dynamic Channel Assignment with Power Control (DCA-PC) uses one control channel to transmit all the control packets (RTS, CTS, RES etc). The difference is that multiple data channels are assigned on demand. In DCA-PC, the pair of source and destination nodes uses a RTS/CTS dialogue to decide which channel to grab and which power level to use for data transmission. A RES message is used to reserve the data channel. Then data packets and ACKs are transmitted on the reserved data channel using the assigned power level. In DCA-PC, all the control packets are transmitted with a maximal power level in order to warn the neighboring nodes of the communication. The data packets are transmitted with proper power levels for channel reuse.
Results show DCA-PC can achieve a higher throughput with the same energy consumption compared to DCA protocol, which includes no power control mechanisms.
DCA-PC is the first protocol to realize the mechanisms of power control and multi-channel medium access together in MAC protocols of MANETs.
By using multiple channels, it is easier to increase the throughput, reduce normalized propagation delay per channel, and support quality of service.



### d) Power Controlled Dual Channel (PCDC)

The Power Controlled Dual Channel (PCDC) Medium Access Protocol also uses two channels like PCMA, one control channel and one data channel. However, PCDC is the first to utilize the inter-layer dependence between the MAC and network layers to provide an efficient and comprehensive power control scheme. The idea is based on the observation that the transmission power has direct impact not only on the oor reserved for the next transmission but also on the selection of the next hop node. Hence, the interaction between the MAC and network layers can help for an effective power control scheme. In order to select the lowest possible power level while maintaining the network connectivity and proper MAC function, PCDC uses a distributed algorithm to compute a minimal connectivity set(CS) for each node. By controlling the transmission power of a route request (RREQ) packet, PCDC broadcasts the RREQ packets to the connectivity set only, hence the MAC can effectively control the set of candidate next-hop nodes. Since RREQ packets are only transmitted to the nodes in the connectivity set, it is easy to control the potential contention. Hence, the process to find the destination in PCDC has low overhead, less contention and less power consumption. Compared with

IEEE 802.11, PCDC achieves improvements of up to 240% in channel utilization and over 60% in throughput, and a reduction of over 50% in energy consumption. However, the adaptive computing of the connectivity set may impose a lot of computing workload for each node.

## e) Power-aware Multi-access Protocol with Signaling (PAMAS)

The Power-aware Multi-access Protocol with Signaling (PAMAS) is proposed to conserve battery power by powering o® nodes that are not transmitting or receiving. This is a combination of the original MACA protocol and the use of a separate signal channel - the busy tone “channel.

By using busy tone, the terminals are enabled to determine when and how long they should power or the radio. The determination must obey the following rules: If a host has no packets to transmit, then it should power the radio or if one of its neighboring nodes begins transmitting. Similarly, if at least one neighboring node is transmitting and another is receiving, the host should also power itself or because it cannot transmit or receive packets (even if its transmit queue is nonempty).
In the proposed protocol, each host makes the decision whether and when to power or the radio independently. As proposed in, a host knows whether a neighboring node is transmitting because it can hear the transmission over the channel. Similarly, a host (with a nonempty transmit queue) knows if one or more of its neighbors is receiving because the receivers should transmit a busy tone when they begin to receive packets (and in response to the RTS transmissions). Thus, a host can easily decide when to switch to the sleep mode. And, PAMAS also gives several factors to determine the length of time for which nodes can be in sleep mode: empty transmit queue and t probe control packet.
The results show that PAMAS works effectively in power conservation. It achieves power saving from 10% (when the network is sparsely connected) to almost 70% (in fully connected networks) without affecting the delay and throughput behavior of the basic protocol.

## f) Pico Node's Multi-Channel MAC

A low power distributed MAC is proposed in UC Berkeley's Pico Node project. A power saving mode based on waking up radio without synchronization is used in this MAC protocol. With a separate wake up radio, the normal data radio can be powered down when it is in idle listening state.

Multiple channels and CSMA/CA are combined in the MAC for efficient energy usage. The multi-channel spread spectrum helps reduce collisions and retransmissions. It also helps reduce delay and increase throughput. The exploit of random access results in the avoidance of synchronization since it does not require any topology knowledge.

Therefore there is no overhead in exchanging schedules and reservation information. All these measures help in energy consumption reduction. Simulation results show the proposed protocol can reduce the power consumption by 10-100times compared with existing MAC protocols with traditional radio. As defined by the MAC protocol, each terminal in the network is either in \mobile mode", or static mode". Mobile nodes periodically broadcast a beacon through the wake-up channel to keep the neighboring nodes awake, thus maintaining a dynamic active zone within two hops. Channel assignment is conducted as the problem of two hop coloring in graph theory. Static hosts in the active zone remain awake. They go back to sleep mode again when no beacon has been received for a pre defined period. Under two instances a node can be waken up: it has packets to send out, or it will receive packets from a neighbor. A node can be woken up by itself, or by a beacon from a neighboring node through the wake-up radio channel.



## g) Multi Channel Mechanism

The main function of MAC layer protocols is to control and coordinate the multiple accesses of wireless terminals to share the communication medium, while at the same time maintain high network utilization.

Most MAC protocols assume that there is only one channel shared among different mobile nodes in ad hoc networks. Thus the essential design goal is to increase the channel utilization while avoid hidden terminal and exposed terminal problems. Hidden terminals and exposed terminals cause collisions if no measures are taken. This problem is more serious if transmission delay is longer. In MAC layer, unnecessary collisions should be avoided, since retransmissions cause additional power consumption and further increase packet delay. MAC protocols based on RTS/CTS, such as have been proposed to alleviate these problems. However, as the number of mobile terminals increase, more energy will be consumed for channel contention and the network performance will degrade quickly. On the other hand, as explained in the following, RTS/CTS-based protocols do not completely solve the hidden terminal and exposed terminal problems.

Exposed terminals are allowed to send their RTS packets. However, they could not receive any CTS replies if another node is transmitting on the same channel. Similar scenario happens on the hidden terminals: they are forbidden to access the channel because they cannot reply to RTS packets. Since the in-band transmission of RTS/CTS packets inhibits the data transmission of the exposed terminals and the data reception of the hidden terminals, the introduction of an additional control channel may be a proper solution to relieve the hidden terminal and exposed terminal problems. Motivated by this observation, multi channel mechanism has been proposed. With an additional control channel, the hidden exposed problem is avoided. Therefore the corresponding unnecessary energy consumption is conserved.

## h) Dynamic Channel Assignment (DCA)

Dynamic Channel Assignment protocol, that assigns channels dynamically in an on demand style. This protocol exploits one control channel to resolve contentions on data channels and assigns data channels to mobile hosts. Multiple data channels are available for data transmission.

In this protocol, all data channels are equivalent with the same bandwidth. Each host has two half-duplex transceivers, thus it can listen on the control channel and its data channel simultaneously. This protocol is sketched below. For a mobile node A to communicate with B, A sends a RTS to B carrying its free channel list (FCL). Such list includes all information about the data channel condition around A. Then B matches this FCL with its channel usage list(CUL) to select a data channel (if any) for subsequent communication and replies A with a CTS. After receiving B's CTS, A sends a RES (reservation) packet to inhibit its neighborhood from using the same channel. Similarly, the CTS inhibit B's neighbors from using that channel. These entire messages are transmitted on the control channel. After this handshake protocol is done, DATA packets and their ACK messages are exchanged on the selected data channel. Channels are assigned on demand in this protocol. There is no need for clock synchronization. Thus channels are used with little control message overhead. Results show that DCA ensures less collision and corruption com-pared with a simple 802.11-like multi channel protocol. The introduction of the control channel and multi data channel helps to reduce unwanted power consumption.



## i) Dual Busy Tone Multiple Access protocol (DBTMA)

In Dual Busy Tone Multiple Access protocol (DBTMA), two busy tones, namely transmit busy tone and receive busy tone, are place don’t he available spectrum at different frequencies with enough separation.
Receive busy tone provides two functions:

- Acknowledge the sender that the channel has been successfully acquired.
- Notify its neighboring nodes of the following transmission and provides continuous protection for the on-going traffic.

Transmit busy tone is used to protect the RTS packets. With these two busy tones, exposed terminals can establish their own transmission, since there is no need for them to monitor the channels to receive the acknowledgment from their intended receivers. Instead, the acknowledgment of the successful channel request will be sent by means of the receive busy tone. Furthermore, the hidden terminals can reply to the RTS requests by simply setting up its receive busy tone. Power control techniques also exploited in DBTMA. Simulation results show that DBTMA protocol is superior to RTS/CTS-based protocols, such as MACA [35], MACAW, and FAMA-NCS protocols, which works on a single channel. DBTM Achieves the performance gain as high as 140% over MACA and FAMA-NCS, 20% over RI-BTMA. It also reduces the number of possible collisions and corruptions. However, this scheme requires hardware support. Additional busy tone transmitters and sensing circuits need to be incorporated into each wireless terminal.

## j) Directional MAC

Directional antennas are applied to the IEEE 802.11a MAC protocol.RTS, data and ACK packets are sent directionally and a better performance is achieved than current MAC protocols since it allows simultaneous transmissions that are not allowed by the current MAC protocols.

**The Directional MAC protocol works under the following assumptions:**



All the terminals in a region share a wireless channel and communicate on the shared channel. Each node is equipped with multiple directional antennas. Transmissions from two different nodes will interfere at some node X, even if at X, different directional antennas are used to receive the two transmissions. Simultaneous transmissions to different directions are not allowed at any node. Under these assumptions, several possible cases are considered and two different schemes are proposed in [37]: Directional MAC scheme1 for using only directional RTS (DRTS) packets, and Directional MAC scheme 2 for using both DRTS and Omni-directional RTS (ORTS) packets. The use of ORTS and CTS packets allows the corresponding recipients to determine the direction of the transmitters. These directions are then used for directional transmission and reception of the data packets.  also discussed an optimization using directional Wait-to-Send (DWTS) packets to prevent unnecessary retransmissions of RTS packets. However, it relies on an accurate tracking and locating technology, such as GPS or periodic location beaconing, which may be impossible in some cases.

## k) DMACP

A new directional antenna based MAC protocol with power control (DMACP) is proposed which uses directional antennas along with power control technique. DMACP focuses on the adaptation of IEEE 802.11 so as to find practical solutions for:

- Finding the directions of transmission reception at mobile nodes.

- Designing appropriate transmission and reception strategies for the MAC control packets to minimize interference amongst distinct pairs of communicating hosts.
- Implementing the power control strategy for data transmission to reduce power consumption. In addition, discuss how to take advantage of directional antennas and present some practical schemes for implementing directional RTS and CTS transmissions.

Results show that the use of directional antennas offers many benefits, such as significant power savings, network throughput improvement, and much less interference. However, all these benefits do not come for free. Different from the omni-directional antennas based scheme, the antennas of transmitters/receivers have to be aimed at each other before the communication starts. The implementation is complex, and the hidden terminals, deafness problems may also exist.

## l) DPC with smart antenna

A distributed power control (DPC) protocol is proposed for ad hoc network stations with smart antennas. In the proposed protocol, the receivers gather local interference information and send it back to the transmitters. Then the transmitter can use this feedback to estimate the power reduction factors for each activated link. The feedback information consists of the corresponding minimum SINR (signal to interference plus noise) during RTS, CTS, DATA and ACK transmission. Here DATA and ACK transmissions are in (beam formed) array-mode since smart antennas are used at both ends of the link.



In DPC protocol, the interference information is collected during both omni-directional RTS/CTS transmission and the beam formed DATA/ACK transmission. RTS /CTS packets are always transmitted with full power in omni-directional mode, and the power level of DATA/ACK transmission is determined by a power reduction factor which is determined by the maximum interference. According to the simulation results, significant performance improvement has been achieved compared with a system using conventional IEEE 802.11 protocol. And the results indicate that the DPC protocol enables the network to dynamically achieve capacities close to the optimal levels which is achieved by a system where the power control has been statically optimized.

## 4. Conclusion

As the dynamic, fast deployable ad hoc networks have many promising applications such as e-conference, emergency services, home networking, etc. More and more attention is focused on ad hoc network research, especially on energy-aware mechanisms. It is important to study how to reduce the power consumption while at the same time fully-utilize the bandwidth re-source. Moreover, third generation wireless networks are supposed to carry diverse multimedia traffic that will consume more power than a normal data device. Thus energy-aware mechanisms will play important role in future wireless networks. In this paper, we study the low-power MAC layer mechanisms. We not only analyze the design motivation of each mechanism but also study multiple example protocols in each category.

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