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Power Control in Ad Hoc Networks

Muhammad Mazhar Abbas and Hasan Mahmood
Quaid-i-Azam University
Pakistan

1. Introduction

In this chapter, we present the power control techniques used in ad hoc networks. Traditionally, the power control has been implemented and used effectively in cellular networks. While the use of transmission power control in infrastructure based networks has proven to work well and improve performance, the application of power control techniques to ad hoc networks has many challenges and implementation complexities (Chauh & Zhang, 2006) (Basagni et al., 2004). The power control is of great significance in ad hoc networks because of their organizational structure and lack of central management. With the implementation of effective power control techniques, the ad hoc network can improve their vital parameters, such as power consumption, interference distribution, throughput, routing, connectivity, clustering, backbone management, and organization (Basagni et al., 2004).

We discuss several power control algorithms commonly used in ad hoc networks to get insight of power control techniques and their effectiveness. Most of the algorithms are adapted from cellular networks, modified accordingly, and proposed for ad hoc networks. Moreover, we argue the enhancement in performance of ad hoc networks with the use of these power control algorithms.

The power control requirements vary depending on the physical and network layer implementation of ad hoc networks (Stüber, 2002). We show the application of the prevailing power control algorithms to different physical layer models and discuss their performance. The application to CDMA based networks is emphasized as these types of networks have strict power control requirements and the performance is severely degraded without appropriate power control. In cellular networks, the power control requirements are stringent, especially in multiple access technologies. The appropriate allocation of power to the transmitters facilitates interference control and saves energy.

The near-far effect starts to dominate as the transmission power levels are not properly managed. The advantage of cellular networks over ad hoc networks is the presence of central management, and as a consequence, the uplink power control can be achieved. This is in contrast to ad hoc networks, which lack central management and most of the nodes are in peer to peer configuration (Blogh & Hanzo, 2002).

In addition, transmit power control is a cross layer design problem affecting all layers of the OSI model from physical layer to transport layer (Jia et al., 2005). In general, power conservative protocols are divided into two main categories: transmitter power control protocols and power management algorithms. Second class can be further divided into MAC layer protocols and network layer protocols (Ilyas, 2003).

At the end of the chapter, we discuss the concept of joint power control and routing in ad hoc networks. Power can be controlled in ad hoc networks by choosing optimal routes. The existing routing protocols may be classified as, uniform, non-uniform, proactive, reactive, hybrid, source, and non-source routing protocols (**?**Chaudhuri & Johnson, 2002). To further explain joint power control and routing techniques, we discuss a Minimum Average Transmission Power Routing (MATPR) technique (Cai et al., 2002), which implements a power control routing protocol using the concept of blind multi-user detection to achieve the task of minimum power consumption. The Power Aware Routing Optimization (PARO) technique (Gomez et al., 2003), a protocol for the minimization of transmission power in ad hoc networks, is based on the concept of node to node power conservation using intermediate nodes, usually called redirectors. PARO is efficient in both static and dynamic environments and is based on three main operations: overhearing, redirecting, and route maintenance.

2. Cellular networks

The wireless cellular networks require a fixed and well defined infrastructure. This type of network infrastructure is suitable to efficiently manage the network operations. Generally the network can be managed and operated by a central operations point. In the field, the the physical parameters, such as transmission frequency, resource allocation, and power control parameters are monitored and controlled by base station which have fixed location. We focus on power control for these types of configurations in order to study and analyze implementation to ad hoc networks.

Power control is a necessary feature in cellular communication networks with multiple access technologies. Power control has many management features such as interference control, energy saving, and connectivity (Almgren et al., 2009). In power control mechanism each user transmits and receives at an appropriate energy level, i.e., the transmission powers are controlled in such a way that the interference is minimized, while achieving sufficient quality of service (Lee, 1991).

In the absence of power control, the near-far effect is introduced as all the mobile users transmit at same power level or at a level which is not suitable at receivers in the network. In other words, the transmitters close to the base station create interference to neighboring users which are in the vicinity. In the absence of power control, the system capacity degrades as compared to other wireless systems (Hanly & Tse, 1999). The power control also increases the battery life by using a minimum required transmission power and is equally important in both uplink and downlink transmissions. In uplink transmission, the near-far effect problem is created as the signals of mobile propagate through different channels before reaching their corresponding base station (Moradi et al., 2006). The purpose of power control is to allow all mobile signals to be received with same power at the base station. Uplink power control enhances capacity of networks (Gilhousen et al., 1991). On the other hand, in downlink transmission, the near-far effect problem is not as important, because signals from the base station reach the mobile station while propagating through same channel (Lee et al., 1995). Uplink power control algorithms achieve their functions through open loop and closed loop power control, which can be further divided into closed outer loop power control and closed inner loop power control. In open loop power control, the mobile user adjusts its transmission power based on the received signaling power from the base station (Chockalingam & Milstein, 1998). In closed-loop power control, based on the measurement of the link quality, the base

station sends a power control command instructing the mobile to increase or decrease its transmission power level and sets the target signal-to-interference ratio (SIR) to such a level that sufficient quality of service is guaranteed (Rintamäki, 2002).
Power can be controlled in a centralized or distributed fashion. In centralized form a controller manages the information of all the established connections and channel gains, and controls the transmission power level (Grandh et al., 1993). While in the distributed form a controller controls only one transmitter of a single connection. It controls transmission power based on local information such as the signal to interference ratio and channel gains of the specific connection. Distributed form of power control is easy to use in common practice because it does not require extensive computational work (Zender, 1993).
Although we aim to discuss power control techniques for wireless ad hoc networks, it is important to get insight for the similar techniques used in cellular networks. These techniques were initially applied to cellular networks, and with the advent of ad hoc network were adapted and modified to meet new requirements. Some of the basic power control algorithms are presented below which are related to wireless cellular networks and their implementations.

2.1 Power control as eigen value problem

In the era of 1980s the concept of Signal to Interference Ratio (SIR) balancing in power control algorithms for cellular networks based on Code Division Multiple Access (CDMA) and other technologies were used by researchers (Nettleton, 1980) (Nettleton & Alavi, 1983) (Alavi & Nettleton, 1982). Initially, the power control problem was focused and treated as an eigen value problem with a non negative matrix G and corresponding balance power vectors p_u and p_d which satisfy the eigen value problem as

$$Gp_u = [(1 + \gamma_u)/\gamma_u]p_u \tag{1}$$

and

$$G^T p_d = [(1 + \gamma_d)/\gamma_d]p_d \tag{2}$$

where γ_u and γ_d are desired uplink and downlink $SIRs$. By taking $\lambda(G)$ as eigen value of G a solution to the above problem is given as

$$[(1 + \gamma_u)/\gamma_u] = [(1 + \gamma_d)/\gamma_d] \in \lambda(G) \tag{3}$$

Another solution to SIR balancing problem is given as

$$\gamma_u = \gamma_d = 1/(\rho - 1) \tag{4}$$

where spectral radius ρ is such that $\rho > 1$.
Iterative methods are very effective in solving these type of problems. One approach (Foschini & Miljanic, 1993) to solve the above eigen value problem iteratively is by solving liner algebraic equations, represented as $AP = b$, where $P = [p_1, p_2, ...p_N]^T$, and

$$P(k+1) = (1 - A)P(k) + b \tag{5}$$

This algorithm converges and the method use derivative named as surrogate derivative and concludes that their algorithm is converging synchronously.

A generalized frame work for convergence is given in (Yates, 1995). By using proper power control, the interference is eliminated and we get iteration as

$$p_i(k+1) = \gamma_i^{tar}(k) p_i(k) / \gamma_i(k) \tag{6}$$

where p_i is the power of i^{th} user and γ_i^{tar} is the target SIR

2.2 Distributed power control techniques

The Distributed Power Control (DPC) algorithm is applied at individual nodes in the network and the objective is to converge system power allocations to a suitable level (Grandhi et al., 1994). This can be accomplished by using feedback power control (Ariyavisitakul, 1994). In this method the power is adjusted in steps which may have fixed or variable size. It is seen that the performance of a power control algorithm with fixed step size and variable step size is almost the same. In addition, the higher power control rate can accommodate the effect of fast fading.

With the implementation of distributed power control, the SIR of the system can be controlled and managed to some extent. As a result, the outage probability of an individual link or a set of links can be reduced or entirely eliminated. The implementation of this type of method requires a distributed power control algorithm which reduces the outage probability to zero by keeping SIR above threshold value (Zander, 1992).

In another approach, a smaller balancing systems can be constructed by turning the transmitter of cells off so the outage probability is minimized. In some scenarios, if the value of SIR for a mobile is less than threshold value then outage probability is reduced and mobile is dropped from network (Wu, 1999). This improves the remaining network SIR.

An optimal SIR based distributed power control technique can be used by unconstrained and constrained optimization (Qian & Gajic, 2003). The theme of this algorithm is to establish a proportionality between transmission power and the error between the actual SIR and the desired SIR. Difference of transmission power from time step k to $k+1$ is given as

$$\Delta P_i(k+1) = P_i(k+1) - P_i(k) \tag{7}$$

The error between desired SIR and actual SIR is given as

$$e_i(k) = \gamma_i^{des} - \gamma_i \tag{8}$$

Then the proposed algorithm is described as

$$\Delta P_i(k+1) = \alpha_i(k) e_i(k) \tag{9}$$

where $\alpha_i(k)$ is the gain. Thus power allocation is given as

$$P_i(k+1) = P_i(k) + \alpha_i(k)(\gamma_i^{des} - \gamma_i) \tag{10}$$

2.3 Discrete time dynamic optimal power control

In this method, the reverse link system information is used for power control. A cost function, consisting of weighted sum of powers and some additional parameters is defined. An optimal power control law is presented based on a cost function comprising of weighted sum of power, power update information, and SIR error. It is also assumed that there is no significant change in SIR from one step to the next. For this purpose, a technique named as discrete time dynamic optical control is implemented (Koskie & Gajic, 2003). The general cost function and sufficient conditions for optimality are defined as

$$J[N] = g(x[N]) + \sum_{K=0}^{N-1} L(x[k], u[k], k) \tag{11}$$

and

$$\begin{pmatrix} H_{xx} & H_{xu} \\ H_{xu}^T & H_{uu} \end{pmatrix} > 0, H_{uu} > 0 \tag{12}$$

where J is the controller, L is the cost function and H is the hamiltonian. Some of the different optimal controllers for three cost functions are

$$J_I = (1/2) \sum_{k=0}^{K} (qe^2[k] + su^2[k]) \text{ for cheap power cost} \tag{13}$$

$$J_{II} = (1/2) \sum_{k=0}^{K} (qe^2[k] + 2rp[k] + su^2[k]) \text{ for linear power cost} \tag{14}$$

$$J_{III} = (1/2) \sum_{k=0}^{K} (qe^2[k] + rp^2[k] + su^2[k]) \text{ for quadratic power cost} \tag{15}$$

This method considerably saves power and improve quality of service.

2.4 Linear and bilinear power control techniques

The optimization of power conservation results in improved SIR distribution for the entire network. Although these optimizations are based on some estimates, as a consequence, errors are introduced in the actual results (Gajic et al., 2004).

The power control techniques named as linear and additive power updates algorithm and bilinear control algorithm are based on optimization of SIR error. It can be seen that mobile power is updated by using a distributive linear control law, given as

$$P_i(k+1) = P_i(k) + U_i(k) \tag{16}$$

where $i = 1, 2, ...n$. By minimizing SIR error and after other calculations the optimized power updates can be obtained as

$$P_i^*(k+1) = P_i^*(k) + U_i^*(k) \tag{17}$$

$$P_i^*(k) = \gamma_i^{tar} I_i[P\_i^*(k)]/g_{ii} \tag{18}$$

Where P_i^* is the optimized power. In the second algorithm, bilinear control law is used for update of power as

$$P_i(k+1) = P_i(k) U_i(k) \tag{19}$$

where $i = 1, 2, ...n$, and corresponding optimized power is same as in above case.

2.5 Power control technique based on relaxation method

This method is particularly useful in networks with multiple access technology, such as CDMA. A relaxation method can be used in solving iterative power control techniques. Two common techniques for iterative solution of power control problems can be used effectively with relaxation method. Application to Jacobi iteration method and Gauss Siddel iteration method for solution of power control problem, by introducing a relaxation parameter in these techniques, is presented as a modified Jacobi iteration

$$P_i(k+1) = [1 - \beta + \beta \frac{\gamma_i^{tar}}{\gamma_i(k)}] P_i(k) \tag{20}$$

and modified Gauss Siddle iteration

$$P_i(k+1) = [1 - \beta + \beta \frac{\gamma_i^{tar}}{\gamma_i(k,k+1)}] P_i(k) \tag{21}$$

The Gauss Siddle iteration with relaxation parameter β is more efficient than Jacobi iteration technique for solution of power control problem. The algorithms implemented by relaxation method converge faster than simple distributed power control algorithm (Siddiqua et al., 2007).

2.6 Distance based power control technique

The distance between transmitters and receivers can be estimated in a wireless networks. The attenuation of the signals is proportional to the distance which they travel. Therefore, if the information about the distances is know in real time or a prior, the power can be adjusted efficiently (Nuaymi et al., 2001). If a base station is present, the transmit power of each mobile station can be controlled by using distance information between base station and mobile stations. This algorithm computes the transmitted power P_m of a mobile node m as

$$P_m = k x_{a_m m}^n \tag{22}$$

where

$$x_{a_m m} = \begin{pmatrix} \frac{d_{a_m m}}{rR}, & \text{if} \quad \mathrm{d_{a_m m} > d_{min}} \\ \frac{d_{min}}{R}, & \text{if} \quad \mathrm{d_{a_m m} \leq d_{min}} \end{pmatrix} \tag{23}$$

where R is the base to mobile maximum distance and $d_{a_m m}$ is the distance between mobile and assigned base station.

2.7 Kalman filter based power control technique

In an uplink closed loop power control algorithm based on Kalman filter technique, the controller or a base station estimates SIR in a closed loop system (Rohi et al., 2007). The SIR can be estimated by any suitable method. The outage probability calculated by this method is smaller as compared to others. According to algorithm details, the base station estimates the SIR for a user and provide as input to Kalman predictor. Its output is compared with the desired SIR and the difference is quantized by a PCM. The transmitted power of user is then updated and SIR estimation is given as

$$SIR_{n+1}^* = SIR_n^* + \alpha \Delta SIR_n^* + \omega_n \tag{24}$$

and

$$\Delta SIR_n^* = SIR_n^* - SIR_{n-1}^* \tag{25}$$

The outage probability is given as $P_0 = P_r(SIR_r < SIR_0)$. Where SIR_r is measured at base station and SIR_0 is the minimum value of SIR for achieving desired BER.

2.8 Power control technique based on linear quadratic control theory

The state-space formulation and linear quadratic control technique can be used to solve the problem of power control by considering each mobile to base station link as an independent subsystem described as

$$S_i(n+1) = S_i(n) + V_i(n) \tag{26}$$

where

$$S_i(n) = P_i(n)/I_i(n) \tag{27}$$

and

$$V_i(n) = U_i(n)/I_i(n) \tag{28}$$

and

$$I_i(n) = \sum_{j \neq i}^{Q} P_i W_{ij} + n_i/G_{ki} \tag{29}$$

The input to each subsystem $U_i(n)$ depends on the total interference produced by other users plus the noise in the system and each $S_i(n)$ track is made equal to the threshold value of SIR (Osery & Abdallah, 2000). For the discrete case the new state is given by

$$\varsigma_i(n+1) = \varsigma_i(n) + e_i(n) \tag{30}$$

where error $e_i(n) = S_i(n) - \gamma^*$. Each subsystem can now be expressed as a second-order linear state-space system as

$$X_i(n+1) = \begin{pmatrix} e_i(n+1) \\ s_i(n+1) \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix} X_i(n) + \begin{pmatrix} 0 \\ 1 \end{pmatrix} V_i(n) \tag{31}$$

The feedback controller $V_i(n) = -[k_\varsigma k_s]x_i(n) + k_s\gamma^*$, where $[k_\varsigma k_s]$ is the gain matrix which are found by solving the Riccati equation. If the right feedback gains $[k_\varsigma k_s]$ is chosen, the steady-state $S_i(n)$ will go to the threshold SIR. To find the optimum feedback control for the state-space representation given above, the Linear Quadratic Control theory is used. After the gain matrix $[k_\varsigma k_s]$ is found, the power control can be expressed as

$$P_i(n+1) = min[P_i, S_i(n+1)I_i(n)] \tag{32}$$

The method assures that the maximum transmission power of the mobile i will not be exceeded. This method reaches a zero outage probability with less iterations than other distributed power control methods. This approach was also found to be more effective in handling a large number of mobile stations in the system.

2.9 Power control technique based on utility and pricing

The power control algorithm can be implemented in a distributed fashion based on utility and pricing concepts (Shah et al., 1998). The efficiency of this protocol can be improved in low BER and high SIR conditions. The formula of SIR of user j at base station k is given as

$$\gamma = \frac{W}{R} \frac{h_{jk} p_j}{\sum_{\forall i \neq j} h_{ik} p_i + \sigma_k^2} \tag{33}$$

In this method, by introducing a pricing factor the utility is maximized and as a result helps in power control problem. A general utility function which is a monotonically increasing function of SIR is given as

$$u_j = \frac{E}{p_j} R f(\gamma) \tag{34}$$

Where $f(\gamma)$ is a measure of efficiency of protocol. The power control problem is considered as a cooperative power control game. The user maximizes its utility at equilibrium point with maximum SIR value as $Max \quad u_i(p_1, p_2, ...p_N), \forall i = 1, 2, ...N$, and $f(\gamma^*) = \gamma^* f\prime(\gamma^*)$. We can also consider a monotonically increasing pricing function, $F = \beta p_j$, which is assumed to depend upon a cost function, given as,

$$c_{ij} = -\frac{\partial u_i}{\partial p_j} p_j \tag{35}$$

and some inequalities,

$$p_1^* < p_2^* < .... < p_N^* \tag{36}$$

$$u_1^* > u_2^* > .... > u_N^* \tag{37}$$

$$c_1^* < c_2^* < .... < c_N^* \tag{38}$$

A distributed power control algorithm for a wireless cellular system based on sigmoid like utility function can also be implemented (Xiao et al., 2003). In this algorithm, the power control problem is considered as a multi player non-cooperative game. This algorithm is valid for both voice and data users. The value of SIR for user i with transmission power P can be written as

$$SIR_i = \frac{G_{ii} P_i}{\sum_{j \neq i} G_{ij} P_j + \sigma_i} \tag{39}$$

The main goal of this algorithm is to maximize the net utility by transmission power adjustment and softening the hard SIR requirements as

$$NU_i(SIR_i, P_i) = U_i(SIR_i) - C_i(P_i) \tag{40}$$

where $C_i(P_i) = \alpha_i P_i$ is assumed cost function of power for the user i. The power control problem is then defined as $max_{P \geq i} NU_i$. By solving above equation the optimal power for user i is

$$\hat{P}_i = \frac{R_i}{G_{ii}} f_i^{-1}(\alpha \frac{R_i}{G_{ii}}) = \frac{R_i}{G_{ii}} \widehat{SIR_i} \tag{41}$$

After introducing the iteration factor the above equation can be written as

$$\hat{P}_i(K+1) = \frac{R_i(K)}{G_{ii}(K)} \widehat{SIR_i}(K) = P_i(K) \frac{\widehat{SIR_i}(K)}{SIR_i(K)} \tag{42}$$

Thus, by using utility based power control protocol, a user can control its power by decreasing its SIR and even turn off transmission during heavily loaded network.

2.10 Opportunistic power control technique

In this distributed opportunistic power control algorithm, the transmission power depends on channel gain by observing feedback from the receiver. The transmission rate is managed by SIR at the receiver (Leung & Sung, 2006). The SIR of a terminal i in a cellular system comprising of N mobile terminals can be written as $\gamma_i = \frac{P_i}{R_i}$, where R_i is the effective interference to terminal i, and is given as

$$R_i = \frac{\sum_{j \neq i} G_{ij} + \sigma_i}{G_{ii}} \tag{43}$$

and the power of the terminal i is upgraded as

$$P_i^{n+1} = I_i(R_i^n, P_i^n) \tag{44}$$

The proposed opportunistic power control algorithm is given as

$$I_i^{opp}(R_i^n) = \frac{\varsigma_i}{R_i^n} \tag{45}$$

This algorithm converges and equation $P_i^n R_i^n = \varsigma_i$ is satisfied. The transmission power of terminal i varies directly with ς_i.

2.11 Power control technique based on simple prediction Method

A simple prediction is sometimes useful for power control in wireless networks (Neto et al., 2004). This approach can be used to implement a distributed power control algorithm, based on simple prediction method, and by considering both path gain and SIR as time varying functions using Taylor series. Discrete-time $SINR$ is given as

$$\gamma_i(k) = \frac{g_i(k) p_i(k)}{I_i(k)} \tag{46}$$

where $p_i(k) = \frac{I_i(k)\gamma_i(k)}{g_i(k)}$ is known as necessary transmission power. The transmission power at instant $k+1$ is given by using Taylor series as

$$p_i(k+1) = \gamma_t \frac{\hat{I}_i(k+1)}{\hat{g}_i(k+1)} = \gamma_t \frac{2I_i(k) - I_i(k-1)}{2g_i(k) - g_i(k-1)} \tag{47}$$

3. Ad hoc networks

Wireless networks without any fixed infrastructure are called ad hoc networks, also often called as infrastructure less networks. Generally, ad hoc wireless networks are self-creating, self-organizing, and self-administrating networks (Cayirci & Rong, 2009). Ad hoc network consists of mobile nodes which communicate with each other through wireless medium without any fixed infrastructure. Nodes in mobile ad-hoc network are free to move and organize themselves in an arbitrary fashion. The nodes in a mobile ad hoc network (MANET) must collaborate amongst themselves and each node may acts as a relay when required. Mobile ad hoc networks have a fully decentralized topology and they are dynamically changing (Jindal et al., 2004). Ad hoc networks are very popular in military applications for many years. The concept of ad hoc networks was first used in commercial area in 1990s, at the same time, the idea of a collection of mobile nodes was originated. In the mid of 1990s some routing protocols were standardized by a commission known as Internet Engineering Task Force (IETF). First standard IEEE802.11 for wireless network was introduced in 1997. The latest standard is faster and applied for longer communication. Today, ad hoc networks are attractive and challenging topic of research due to its tremendous applications (Perkins, 2001). The most popular applications of ad hoc networks are temporary communication networks, relief operations, operations in congested and small areas (Ramanathan & Redi, 2002).
Ad hoc networks have many challenges which includes high error probability of transmission, limited capacity, hidden and exposed terminals problem, interference, mobility, node failures, topology maintenance, self healing, node search, synchronization, transmission reliability, and congestion control etc. (Goldsmith & Wicker, 2002).

3.1 Importance of power control in ad hoc networks

Unlike cellular networks, in ad hoc networks the power control is not trivial and is usually managed in a distributed fashion. The nodes in the ad hoc network communicate with all other nodes by sending packets to the neighboring nodes. The choice of an appropriate power level for packets at a particular node is very crucial matter, as it indirectly effects the physical layer, network layer, and transport layer of the system by determining the quality of received signal, range of transmission and magnitude of interference respectively (Kawadia & Kumar, 2005). The nodes in ad hoc networks use different modes of operation such as transmit mode, receive mode, idle mode and sleep mode. As a result, these different types of nodes have different power consumption requirements (**?**).
Power consumption of ad hoc networks can be controlled either by controlling transmission power or by choosing optimal routs for transmission. Transmit power control is a cross layer design problem affecting all layers of the OSI model from physical layer to transport layer (Jia et al., 2005). In general power conservative protocols can be divided into two main categories as transmitter power control protocols and power management algorithms. Second class can be further divided into MAC layer protocols and Network layer protocols (Ilyas, 2003). In the subsequent sections, we present the details of some of these protocols.

4. Power control techniques in ad hoc networks

The power control issue is one of the major challenges prevailing in ad hoc networks. There are many power control algorithms presented by various authors and researchers. Some of these algorithms are discussed in this chapter. We begin by presenting algorithms which are based on 802.11 medium access layer, then discuss some of the challenges faced by CDMA networks as in these types of networks, power control is an essential component. In addition, power control techniques at network layer are also presented. These power control methods are jointly implemented with routing protocols and clustering configurations.

4.1 Simple modifications to 802.11

The 802.11 MAC standard is slightly modified and adapted in order to obtain a distributed power control loop based algorithm which results in lower energy consumption and higher throughput. In this algorithm, in contrast to the original IEEE 802.11 MAC protocol, the transmissions occur at different power levels which are chosen by the algorithm (Agarwal et al., 2001). The main purpose of the algorithm is to calculate a minimum transmit power level for each node to successfully transmit to neighboring nodes. During transmission, a ratio of the signal strength of the last received message to the minimum acceptable signal strength at the node currently transmitting the message is included in the CTS and DATA message headers. The receiver encodes the ratio of received signal strength of RTS message to minimum acceptable signal strength in the header of CTS reply message.

The transmitter will also encode into it the ratio with respect to CTS upon transmitting the DATA message. In this way RTS-CTS-DATA-ACK exchange provides an opportunity to both receiver and transmitter to inform each other not only about their signals strength but also about their transmit power levels. Each node maintains a small table with fields cf-pwr, dr-pwr and a count down timer field. The field cf-pwr maintains an exponential weighted average history of the received signal strength ratio received from each neighbor and the dr-pwr field maintains an exponential weighted average (EWA) history of the cf-pwr field at instances when packet loss occurred. Upon receiving a CTS or DATA message from a node its cf-pwr field in the table is updated by decreasing the transmit power level by one, unless the countdown timer shows zero value. The dr-pwr field in the table is updated by increasing transmit power level by one for the timeout during wait for CTS, DATA or ACK message.

A power control scheme based on modifications to BASIC power control scheme (CTS-RTS hand shake), can be implemented which saves power without degrading throughput (Jung & Vaidya, 2002). In this algorithm just like BASIC power control scheme RTS and CTS, messages are sent at maximum power level P_{max} while DATA and ACK messages are sent with minimum power level. The novelty of this protocol is that ACK-DATA collision avoidance can be made possible by transmitting DATA with maximum power level for a short period so that nodes in CS zone can sense it. P_{max} is achieved periodically during transmission of DATA. The nodes which may interfere with ACK reception stops their transmission by observing that system is busy and power is saved.

In another modification (Lin & Lau, 2003), a protocol for power control named as PCMAC is implemented. This protocol overcomes the problems created by asymmetrical links efficiently. The IEEE 802.11 standard protocol is modified by introducing an extra channel for power control. In contrast to the BASIC scheme for power control, in PCMAC protocol RTS, CTS, DATA, and ACK transmission occur at minimal necessary power level while the broadcast packets at maximal power level. During reception of DATA, the receiver calculates the noise power level by estimating the noise and signal strength. It then informs the neighboring terminals with this information by using power control channel. Keeping in view this information the neighboring terminals take any suitable action. This algorithm replaces the four way handshake by three way hand shake. Also, each terminal manages the three tables named as sent table, receive table for data packet transmission, and a power history table maintaining the record of necessary power level to reach other terminals. This necessary power level is calculated as $P_{nec} = Rx_{th}P_T/E$, Where E is the received signal strength, P_T, the power level at which a packet is transmitted, included in the RTS, CTS and broadcast packet head.

4.2 Link collision avoidance technique

In Asymmetric Link Collision Avoidance (ALCA) based power control protocol the power levels are managed by the announcement of the Current Transmission Duration Information (CTDI) through N different carrier durations (CD) (Pires et al., 2005). This protocol overcomes the problem of DATA, ACK frames collision in BASIC power control scheme due to asymmetric links. ALCA is based on two major steps. Firstly the transmitting node computes the CTDI and then allows the nodes in CS-Zone (CSZ) to recover required CTDI by choosing an appropriate CD from N different CDs. Secondly, the terminal in the CSZ finds a suitable extended inter frame space (EIFS) value based on CD extracted by the DATA carrier. This protocol saves power considerably.

4.3 Power control dual channel protocol

The power control dual channel (PCDC) protocol permits simultaneous interference limited transmissions in the neighboring area of receiver by modifying typical RTS-CTS handshake process in mobile ad hoc networks (Muqattash & Krunz, 2004). This protocol gives much importance to the network layer and MAC layer interaction as power control issue is considered a joint MAC and network layer problem. The MAC layer controls the transmission power of route request (RREQ) packets and affects the network layer. As it is evident from the name, there are two main channels in protocol - data and control channel. The control channel has further two sub channels named as RTS-CTS channel and ACK channel. This protocol is based on the following assumptions:

i. Channel gain remains stationary during transmission of DATA packets.
ii. The gain between two nodes remain same in both sides.
iii. Data and control packets observe same gain between a pair of nodes.

This protocol is distributed in nature and has advantages over other protocols because of the availability of reserved channels. Although functioning of the protocol has relatively stringent assumptions, a relatively smooth and better performance can be achieved under normal channel conditions.

4.4 Power control MAC protocol

This protocol uses an access window and improves the network throughput at low energy consumption by allowing multiple transmissions (Muqattash & Krunz, 2005). It is a distributed, asynchronous and adaptive power control protocol and is named as POWMAC which is based on single channel and single transceiver design. The novel features of POWMAC are described as:

i. Collision avoidance information (CAI) is included in control packets instead of simple RTS/CTS control packets.
ii. Required transmission power is calculated at the intended receiver.
iii. Some CTS and Decide-to-Send (DTS) packets are transmitted towards the potentially interfering terminals.
iv. An access window (AW) is introduced which stops the transmission of DATA packets for a short period and reduces the collisions between control and data packets by informing the transmitters about ensuing transmission.

4.5 Distributed correlative power control technique

The correlative power control can be described as a transmitting node that predicts the interference by using a prediction filter after observing the interference around it. It also includes this information with RTS message. The receiving node assigns a power to CTS by observing this included predicted interference. The receiver repeats the whole procedure and then sends CTS message along with predicted interference to transmitter. The transmitter then assigns power to DATA by observing this predicted value of interference included in CTS message. The same procedure is adopted before sending DATA and ACK messages by transmitter and receiver (Alawieh et al., 2007). The minimum transmission power can be calculated as $P_{min} = k/Gain$, where the channel loss $Gain$ can be measured as a ratio of the received and transmitted powers P_r and P_t. The received signal power can be given as

$$P_r = P_t r^{-4} G^2 h^2 10^{\Im/10} \tag{48}$$

Where r is the distance between two nodes, h is the height of the antenna, G is the antenna gain and $\Im$ is shadowing component. The transmission power of CTS is given as

$$P_{CTS} = max(P_{min}, \zeta \times I/Gain) \tag{49}$$

The transmission power of DATA is given as

$$P_{DATA} = max(P_{min}, \zeta \times I_{+}/Gain) \tag{50}$$

The transmission power of ACK is given as

$$P_{ACK} = max(P_{min}, \zeta \times I_{++}/Gain) \tag{51}$$

Where I is the predicted interference plus noise power.

4.6 Adaptive power control techniques

The adaptive power control technique uses a two ray ground propagation model (Zhang et al., 2005a). This adaptive power control algorithm is based on the relationship between transmission powers of RTS-CTS, CTS-DATA, and DATA-ACK pairs using single channel setup. The relationship between transmit power P_t and receive power P_r can be written as

$$P_r = P_t * G_t * G_r * h_t^2 * h_r^2 / d^4 \tag{52}$$

where h_t and h_r are the heights, and G_t and G_r are the gains of transmitter and reviver's antenna respectively. The relationship between the transmissions powers of RTS/CTS/DATA can be given as

$$P_{RTS,r} = P_{RTS,t} * G_t * G_r * h^4/d^4 \tag{53}$$

$$P_{DATA,r} = P_{DATA,t} * G_t * G_r * h^4/d^4 \tag{54}$$

$$P_{CTS,r} = P_{CTS,t} * G_t * G_r * h^4/d^4 \tag{55}$$

where d is the distance between two nodes, h is the antenna height and P is the power. A successful transmission between receiver and transmitter can take place by satisfying the following necessary conditions:

$$P_{i,t} * P_{j,t} \geq P_w(i,j) \tag{56}$$

and

$$P_{i,t} \geq k/g_{(t,r)} \tag{57}$$

where $g_{(t,r)}$ is the ratio of attenuation gains between transmitter $P_{i,t}$ and receiver $P_{i,r}$, P_w is the cross coefficient of i and j.

In a similar type of protocol the delivery of packets is based on a delivery curve function, which shows a relationship between successfully delivered packet and total transmitted packets (Zhang et al., 2005b). This is also an adaptive power control protocol assuming the successive correlations between the transmission powers of four way hand shake frame for improvement of system throughput and energy saving. It helps the protocol to choose the best working profile and packet correlations are considered in protocol operation. In this protocol transmission power of RTS and CTS are considered same while those of DATA and ACK are similar. The main goal of this protocol is to find minimum powers P_{RTS} and P_{DATA} for successive communication.

4.7 Neighbor detection power control technique

According to this protocol a node initially increases its transmission power until it detects some neighbors around it and again adjusts its power according to the node degree (Abasgholi et al., 2008). After this step, any increase in transmission power decreases the number of one hop neighbors. The umber of neighbors increases with the decrease in transmission power which ultimately enhance the network throughput. The transmission power is varied between a minimum and a maximum value. The change in power can be calculated as

$$P_t = P_c - 5\, log(d_t/d_c) \tag{58}$$

where P_t and P_c are the targeted and current transmission powers. d_t and d_c are targeted and current node degrees which can be calculate as $d_c = D.\pi.r_c^2$ and $d_t = D.\pi.r_t^2$

4.8 Decoupled adaptive power control technique

The objective of these class of protocols is to strictly prohibit the hidden terminals creation (Ho & Liew, 2006). The two protocols named as Decoupled Adaptive Power Control (DAPC) and Progressive Uniformly Scaled Power Control (PUSPC), focus on the hidden terminal avoidance and minimizing mutual interference for enhancing overall network capacity. In the first DAPC protocol each node continuously monitors its surrounding, adjust their powers in a disturbed manner through various iterations by collecting information from neighboring nodes and create hindrance to new hidden terminals and interfering links. The second PUSPC protocol overcomes the deficiencies in DAPC. This protocol deals with two sets named as power control set and finished set. In the beginning of operations all nodes lie in the power control set with same power and they start reducing power through each iteration and after some time few nodes shift to finished set with different powers.

4.9 Autonomous power control technique

This protocol allows nodes to send DATA/ACK packets with power level calculated by keeping in view the distance between transmitter and receiver and RTS/CTS packets with an adjustable power (Chen et al., 2006). This protocol is based on autonomous power control MAC protocol (APCMP). A dynamic network structure is proposed where the main goal of protocol is to reduce energy consumption and improve network efficiency. The protocol describes the initial adjustment of a power level for DATA/ACK messages transmission depending upon the average distance between a transmitter and its neighbors at that time. The power level for RTS/CTS messages is adjusted in proportionality to the above adjusted power for DATA/ACK messages. Usually transmission power level for RTS/CTS is taken a little grater than transmission power for DATA/ACK. The distance between a transmitter and receiver can be estimated as

$$d = k\sqrt{\frac{p^*_{RTS/CTS^{\alpha}}}{p_{rec}}} \tag{59}$$

where k is the coefficient, $p_{RTS/CTS}$ is the transmitting power level for the RTS/CTS packet, p_{rec} is the received signal power level, and α is a constant which depends on the antenna gain, system loss, and wavelength. The average estimated distance from transmitter to n neighboring nodes is calculated as

$$\bar{d} = 1/n\sum_{i=1}^{n} d_i \tag{60}$$

where d_i is the estimated distance from the transmitter to the i^{th} neighbor. The transmission power level for DATA/ACK can be calculated as

$$p_{DATA/ACK} = \bar{d}^k \times Rx_{thresh} \tag{61}$$

where Rx_{thresh} is the minimum necessary received signal strength. The transmission power level for RTS/CTS can be calculated as

$$p_{RTS/CTS} = p_{DATA/ACK} \times \alpha \tag{62}$$

Where α is a proportionality parameter such that $\alpha > 1$.

4.10 Load sensitive power control technique

In these family of protocols, the power is optimized by keeping in view the load, number of stations and grid area of the network (Park & Sivakumar, 2002). The algorithm denies the concept that throughput can always be maximized with minimum transmission power. We present two of these types of transmission control protocols, namely - the Common Power Control (CPC) and Independent Power Control (IPC).

In CPC all nodes prefer to use the same transmission power while in IPC the nodes are independent to use different transmission powers. The operation of CPC and IPC is initially based on the continuous monitoring of contention time (CT). Each node in the network maintains two threshold values for CT, upper threshold and lower threshold by observing its CT values continuously. A node increase its transmission power if its measured CT lies above the upper bound and decrease its transmission power if its measured CT lies below the lower bound, while it maintains transmission power if its measured CT lies between two bounds. In all cases the main purpose of protocol is to maximize throughput per low energy consumption.

5. Power control for CDMA networks

The ad hoc networks which employ CDMA technology benefit the most from power control. While the use of transmission power control in these types of networks benefit in saving overall consumption for the entire network, the power control algorithms substantially increase the throughput of CDMA networks. In the presence of uncontrolled interference, the performance of CDMA networks degrades considerably. The peer to peer nature of ad hoc networks prohibits the nodes to achieve perfect power control, therefore, CDMA networks with all their benefits fail to perform well. In this section we discuss power control algorithms used in CDMA based ad hoc networks.

5.1 Single busy tone power control technique

This protocol utilizes three channels named as Data Channel (DCH), Control Channel (CCH), and a Busy Tone (BT) separated by use of frequency (Zhou et al., 2005). This protocol, known as single busy Tone CDMA (SBTCDMA), is based on the combined action of RTS/CTS hand shake, single busy tone, and power control utilization. This protocol achieves better channel gain at the cost of less energy consumption after successful solution of hidden node problem. All RTS/CTS packets are transmitted through CCH with common code for all nodes and DATA packets are transmitted in DCH with separate code for each node.

In this protocol initially each node maintains network allocation vector (NAV) and a CTS table. The neighbors of a transmitter update their NAV regularly. Initially if CCH is idle for a short period, a node *i* check its NAV and finding it zero starts operation by a sending an RTS packet to another node *j*. After receiving RTS successfully the receiver *j* waits for a short period and then sends the CTS packet to transmitter.

After sending RTS, it immediately turn on busy tone signal and wait for DATA packet. The data packet will be sent by node *i* after successful completion of RTS/CTS packets exchange using DCH and in the mean time it also updates its NAV also. All other neighbors of node *i* except *j* remain silent by updating their NAV only and save power.

5.2 Dual reservation power control technique

The dual reservation power control technique a CDMA based multi channel MAC protocol which utilizes three common code channels (Min et al., 2007). The system configuration consists of a broadcast channel and data channel which considerably improves the network throughput and reduces near far interference. The main features of the protocol are described as,

i. Code synchronization is done through RTS/CTS handshake by using common code channel.
ii. Dual reservation scheme is presented through ACK piggybacking using data channel.
iii. Near-Far interference is reduced dynamically.
iv. Broadcast messages are supported with busy tone.

According to the protocol each node in the network maintains three lists regularly, available code list (ACL), occupied code list (OCL) and forbidden code list (FCL). Initially a node j transmit RTS message along with ACL on common code channel with P_{max} to node j. Upon receiving RTS the node i, after comparing node its ACL, and calculating P_{min} sends a CTS message on common code channel including selected data channel and P_{min}. Then node i sends data on P_{min} and after receiving data successfully the receiving node sends an ACK message on data channel otherwise a piggybacking ACK is used. When a node is busy in transmission it broadcast a message as a busy tone on channel by just switching on its transceiver. This process decreases the collision probability and data is transmitted with less power.

A similar protocol (Muqattash & Krunz, 2003), also based on CDMA, efficiently solves the near-far effect problem and allow simultaneous transmission in the vicinity of receiver. This Protocol operates at two frequency channels namely Data and Control channels. Available bandwidth, split into two frequency bands, is for simultaneous transmission to take place. All the nodes on control channel use the common code while all nodes on data channel use different codes. The RTS/CTS hand shake takes place through control channel and all interfering nodes are allowed to transmit concurrently. In addition, the transmitter and receiver must agree on spreading code and transmission power. The minimum required transmit power can be given as

$$P_{CDMA} = \frac{\xi_{max}\mu^* P_{thermal} d^n}{k} \tag{63}$$

where $P_{thermal}$ is the thermal noise power, ξ_{max} is maximum planned noise rise, and μ^* is the ratio needed to achieve the target bit error rate at that receiver. The minimum transmission power at which the data is transmitted and decoded correctly, is given as

$$P_{min} = \frac{\mu^*(P_{thermal} + P_{MAI})}{G} \tag{64}$$

where G is the channel gain.

5.3 Power control technique using channel access method

In this algorithm a distributed power control algorithm along with channel access protocol for CDMA based ad hoc networks to maintain the quality of service is used (Sun et al., 2003). Dynamic range of power for all terminals is considered as the ratio of maximum transmission power and minimum transmission power. The i^{th} link's transmission power in a distributed power control algorithm proposed with adaptive protection margin can be calculated as

$$P_i(k+1) = \frac{\delta\gamma_i}{SIR_i(k)} \times P_i(k) = \delta \times [\gamma_i \times (\sum_{j\neq i} G_{ij}P_j(k) + \eta_i)/G_{ii}] \tag{65}$$

Where protection factor δ, that provides a protection margin for active links, should be greater than one as $\delta > 1$. This increases overall network performance.

5.4 Joint distributed power control and routing protocol

In joint distributed power control and routing protocol, a joint distributed power control and routing protocol for CDMA based ad hoc networks keeping in view the quality of service aspect obtained under low energy and acceptable BER constraints is used (Comaniciu & Poor, 2003). All retransmission are statistically independent of one another and a packet transmission from a node wait for the successful reception from previous transmitter. Probability of correct packet reception depends on SIR, described as

$$P(\gamma) = (1 - BER)^M \tag{66}$$

where M is the packet length. A link can operate on minimum power if received SIR is equal to the optimal SIR γ^*, that can be achieved by the solution of following equation

$$\gamma\frac{d\tilde{P}_c(\gamma)}{d\gamma} - \tilde{P}_c(\gamma) = 0 \tag{67}$$

As minimum $SIR = \gamma^*$, this gives for a link (i,j) the value of P_i as

$$\underset{r(i,j)}{\mathbf{min}} \frac{h_{ij}P_i}{\frac{1}{L}\sum_{k\neq i,k\neq j}^{N} h_{(k,j)}P_k + \sigma^2} = \gamma^* \tag{68}$$

The solution is possible by using iterative power control algorithm as

$$P_i(n+1) = T(\mathbf{P(n)}) \tag{69}$$

If $SIR < \gamma^*$, then the system consume more energy as many retransmission occur and if $SIR > \gamma^*$, then the energy is consumed to overcome the surplus gain. Therefore, a better quality of service the necessary condition achieved by power control is given as

$$SIR_{(i,j)} \geq \gamma^*, \forall(i,j) \tag{70}$$

where $(i,j) = 1,2,.....N$. All new entries will follow the above necessary condition for active transmission and the power vectors converge to minimum power solution. The algorithm operation stops if further decrease in transmission power is not possible.

6. Joint power control, routing, and clustering

In joint power control, routing, and clustering, the algorithm is implemented at network layer. The routes are carefully chosen such that the impact of interference or power consumption is minimum. The information at the network layer is accessed from the physical layer parameters, thus making it a cross layer system. Information exchange between layers contribute in making routing decisions.

We present some protocols used for power control with joint power control and routing or joint power control and clustering techniques.

6.1 Dynamic forwarding nodes

We can jointly address the transmission power assignment problem by using the concept of power control, routing and clustering. In this protocol we propose a mechanism which is based on careful selection of dynamic forwarding nodes for the enhancement of system throughput while keeping the energy consumption low (Yener & Kishore, 2004). A node i with an intended receiver j update its transmission power with the knowledge of received SIR and channel gain as

$$P_i(n+1) = \frac{\gamma^*}{h_{ij}}(\gamma_j(n) - \frac{P_i(n)h_{ij}}{N}) \tag{71}$$

where γ_j is the received interference, and γ^* is the target SIR. Now two clusters of nodes are considered say C_1 has at least $L+2$ nodes and C_2 having at least one node. If a node in C_1, say A wants to communicate with a node in C_2 say X and in the mean time a node B in C_1 also wants to communicate with another node D in the same cluster C_1, then there are two possibilities. In the first option node A transmit to node X directly and transmission between other two nodes of C_1 can also take place while in the second option the node A transmit to X by using $L-1$ hops in C_1 to another node E in C_1 and then E will transmit to X. During the transmission of nodes E and X the transmission between B and D nodes can also take place. Here node E is considered as forwarding node. The necessary transmission powers levels for node A and node B in the first option are calculated as

$$P_{AX} = \frac{N\sigma^2(d_{AX}^4(K-1) + d_{BD}^4)}{K-2} \tag{72}$$

$$P_{BD} = \frac{N\sigma^2(d_{BD}^4(K-1) + d_{AX}^4)}{K-2} \tag{73}$$

where d_{AX} is the distance between node A and X, d_{BD} is the distance between node B and D, and $K = N/\gamma^* + 1$.

The total transmission power for first option is therefore calculated as

$$P_1 = P_{AX} + P_{BD} = \frac{N\sigma^2}{K-2}(d_{AX}^4 + d_{BD}^4) \tag{74}$$

Similarly the total power for second option is calculated as

$$P_2 = \frac{N\sigma^2}{K-2}(d_{EX}^4 + d_{BD}^4 + \frac{K-2}{K-1}\sum_{i=E_1,E_2,\ldots E_{L-1}} d_{i,i+1}^4) \tag{75}$$

6.2 Power control by clustering in CDMA ad hoc networks

While clustering in ad hoc networks has many benefits, this approach can significantly improve power consumption and performance (Hasan et al., 2003). A clustered system for ad hoc networks based on combination of a broadcast channel CSMA and two CDMA uplink and downlink channels using the joint concept of successive interference cancellation (SIC), user ordering, and open loop power control can improve network throughput. CSMA also helps in the cluster management, routing and mobility control. All nodes in the network communicate through cluster heads using above described three channels. The received power P_r at the cluster head can be written as

$$P_r = \rho^2 * 10^{-\zeta/10} \bar{P} \frac{P_t}{\gamma^{\alpha}} \tag{76}$$

where $\bar{P}$ is the constant revived power at a distance of one meter, ζ is the shadowing factor, α is the path loss exponent, and ρ is the fading amplitude.

The system describes two types of communications, intra cluster and inter cluster. In first type, all communication is done through cluster heads which are usually one hop or two hops away from its member nodes and maintain three tables namely routing table, membership table and a forwarding table. The communications from nodes to cluster head take place by RTS/CTS/ACK handshake on CSMA channel.

In the second type of communication the nodes transmit packets to their respective cluster head and then it is responsible for successful transmission to nearby cluster head using gateway nodes. Ultimately the packet reached the cluster head of the destination node.

6.3 Common power control technique

In this protocol a distributed, asynchronous and adaptive method named as COMPOW is based on the concept, that all homogeneously dispersed nodes in the network use a common necessary power level (Narayanaswamy et al., 2000). It is important to note that link between transmitter and receiver should be bidirectional. As all receivers, even using common power level may not have common $SINR$, so the transmission powers of all nodes should be kept small so that nodes can have nearly equal $SINR$ value and also create less interference to others. Moreover it is also proved by the proposed protocol, that power per route can be saved and MAC contention is minimized on using low power levels at all nodes. A routing table is maintained for each power level by sending and receiving HELLO messages at that power level. The number of entries in the table for a power level describe the number of nodes that can access the specific power level in minimum hops. The minimum power level whose routing table has the same number of entries as the routing table with maximum power level, is known as optimum power level. The routing table of this optimum power level is considered as master routing table. This protocol can easily be implemented with OSI model.

6.4 Joint power control and clustering techniques

According to this protocol the node clusters are made on the basis of transmit power level without taking into consideration their physical location (Kawadia & Kumar, 2003). The joint problem of power control and clustering can be effectively used for a non homogeneously build network. There are three protocols namely CLUSTERPOW for network capacity enhancement, tunneled CLUSTERPOW for optimization achievement, and implementation of MINPOW for optimal routing.

A high transmit power level is required for communication between two separate clusters but intra cluster communication can be done at low transmission power level with multiple hops. Along with source node the CLUSTERPOW protocol is implemented at each node from source to destination route. The dynamic routing daemons are proposed for each power level which maintains their own routing table by communicating with their daemons of same power level on other nodes by sending HELLO messages at specific power level. The choice of next hop depends upon the minimum necessary power routing table. This protocol provides loop free routes for minimum power assignment.

The second protocol, tunneled CLUSTERPOW is an advance form of CLUSTERPOW protocol which is responsible for the successful transmission of packets to its destination by transmitting packet at small power level hop by hop instead of direct transmission to destination. In this protocol a dynamic tunneling mechanism is required for each packet delivery, which makes it more complicated than CLUSTERPOW protocol.
These protocols play an important role in network capacity maximization. To minimize power consumption during communication MINPOW protocol based on the concept of link cost is proposed and implemented at network layer by sending HELLO packets with each power level. The HELLO packets with maximum power level have routing information while others, considered as beacons, have knowledge of total consumed power, packet transmission power and sequence number of the HELLO packets. Transmission power level can be calculated by knowing receiver power level and distance between receiver and transmitter. Total consumed power can be calculated as

$$P_{total} = P_{rec} + P_{trans}(p) \tag{77}$$

where p is the transmission power level of a beacon packet. Link cost is calculated as

$$Link\,Cost = min_{beacons}(P_{total}) + P_{rec} \tag{78}$$

6.5 Joint power control and routing in ad hoc networks

Power can be controlled in ad hoc networks by choosing optimal routes. The choice of existing routes depends on a complicated cost metric. This cost metric takes in to account the minimum energy requirements of a particular route, while the routing protocol manages the power consumption for the entire network. The existing routing protocols may be classified as, uniform, non uniform, proactive, reactive, hybrid, source, and non source routing protocols (Kadu & Chaudhari, 2002).

6.6 Minimum average transmission power routing technique

In minimum average transmission power routing technique, a power control routing protocol named as minimum average transmission power routing (MATPR) is used (Cai et al., 2002). This protocol is used for CDMA based ad hoc networks using the concept of blind multi-user detection to achieve the task of minimum power consumption. It is applicable to both real time services and data services. Multi-user interference, appropriate coding scheme and acknowledgment scheme is jointly considered for the protocol design.
In normal data service, if a node say B receives a packet with errors from another node say A, it will transmit the same packet with error to A and then A will retransmit the packet to B. Now upon successful reception of error free packet B will send a correct received message to A to inform other party. This explains that packet transmission latency from source to destination does not matter in normal data service. The average power for successful transmission of packet can be calculated as $P_{av} = \frac{\alpha P_i}{(1-P_e)}$. In real time service it has great importance as BER is very low. Thus the error correction takes place through error correcting codes rather than retransmission process. MATPR protocol acts as proactive, where as the blind detector is installed at receiving node.

6.7 Power aware routing optimization technique

Power aware routing optimization techniques are implemented at network layer. The Power Aware Routing Protocol (PARO) uses the same principle of power aware routing optimization (Gomez et al., 2003). This protocol minimizes transmission power in ad hoc networks and is based on the concept of node to node power conservation using intermediate nodes usually called as redirectors. The redirectors play their role in transmission even if the source and destination pairs are in direct transmission range. The increasing number of redirectors between source and destination lowers the transmission power of packets. According to the PARO a node keeps its transmitter on for L/C seconds during transmission where L and C are length of frame and speed of channel respectively. PARO is efficient in both static and dynamic environments. This protocol is based on three main operations namely overhearing, redirecting, and route maintenance.

7. Conclusion

In this chapter we presented the power control techniques used in ad hoc networks. Traditionally, the power control has been implemented and used effectively in cellular networks. While the use of transmission power control in infrastructure based networks has proven to work well and improve performance, the application of power control techniques to ad hoc networks has many challenges and implementation complexities. We presented power control algorithms which are applicable to ad hoc networks. The power control is of great significance in ad hoc networks because of their organizational structure and lack of central management. It is seen that with the implementation of efficient power control techniques, ad hoc networks can improve their vital parameters, such as power consumption, interference distribution, throughput, routing, connectivity, clustering, backbone management, and organization.

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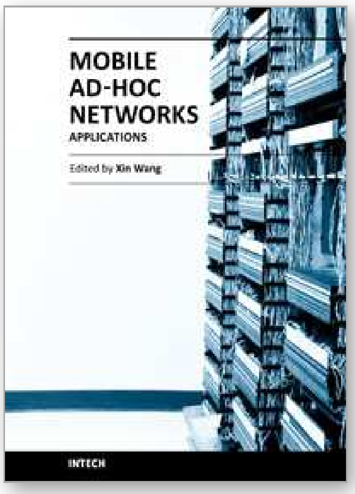

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Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: vehicular ad-hoc networks, security and caching, TCP in ad-hoc networks and emerging applications. It is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.

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University Campus STeP Ri
Slavka Krautzeka 83/A
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中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821