Chapter 2 System Model and Power Control Policies

2.1 System Model

We consider a network of high data rate (HDR) system having M access point transmitters (**APT**s). The APTs are located in linear space and indexed from 1 to M, as shown in Figure 2-1. They provide data service to the access terminal (**AT**) in the corresponding cells through a shared forward link channel. In order to reflect infinite linear service areas in simulations, APTs 1 and M are assumed to be adjacent to each other. The antennas of APTs are all omni-directional, and the packet transmission is time-division scheduling, i.e., each APT can serve only one AT in a given slot. Therefore, the system is discrete-time, and time is slotted.

In simulations, we consider data traffic arrives according to the Poisson distribution of rate λ for each APT. Also, each arrival could be uniformly distributed in the linear coverage area of the APT, or other distributions. Additionally, each arrival has a data size according to the Geometric distributions with probability P_{DS}. That is, the probability of the data size N is given by

$$\begin{cases} P(N=1) = p_{DS} \\ P(N=n) = (1-p_{DS})^{n-1} \times p_{DS} \end{cases} \tag{2-1}$$

Assume that each APT has information of all its serving ATs' directions, in the left hand coverage area or the right hand coverage area of the APT. Besides, assume that each APT has perfect information of its serving ATs' feasible forward link data rates. The information can be obtained from AT's feedback message over reverse link. Hence the APT can exactly know the transmission rate of each AT. Note that we do not consider fast fading. Also, user mobility, virtual handoff and ATP selection issues are not considered in this work.

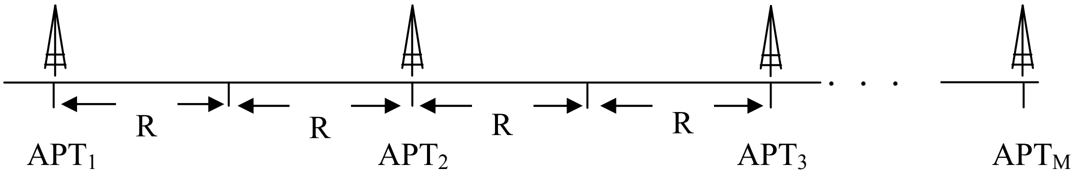

Figure 2-1 The Linear Network Topology

2.2 Path Loss Model 、SINR Expression and Peak Data Rate function

The distance-related path losses can be modeled by

$$\tau(i,j) = \left(\frac{1}{d(i,j)}\right)^{\alpha} \tag{2-2}$$

where $d\,(i, j)$ is the distance from AT_i to APT_j and α is the path loss exponent. In fact, we further consider slow fading effect from the serving APT to a target AT in (2-2); that is, $\tau(i,j) \leftarrow \tau(i,j) \times y$, where y is a lognormal random variable with E[log y]=0. With the notation of (2-2) the signal-to-noise-and-interference ratio received by AT_i in APT_j is given by

$$(SINR)_{i,j} = \frac{\tau(i,j) \times P_j}{\eta + \sum_{k \neq j}^{M} \tau(i,k) \times P_k} \tag{2-3}$$

where P_j denotes the transmit power from the reference cell APT_j, and η is thermal noise power. The received bit energy to interference and noise power spectrum density ratio ($\frac{E_b}{N_o}$) of a code channel can be modeled as follows:

$$\left(\frac{E_b}{N_o}\right)_{i,j} = \frac{W}{R_i} \times SINR_{i,j} \tag{2-4}$$

where W is a given system bandwidth and the R_i is the information bit rate for AT_i. For a given modulation scheme and acceptable bit error probability, it is necessary that E_b/N_0 is preserved above some minimum value. Let the minimum required E_b/N_0 be denoted by γ. Then, we can see from (2-4) that feasible forward link data rate R_i is proportional to SINR received by the target AT. Using equation (2-3) and (2-4), we can deduce the peak data rate function by

$$R_i = \frac{W}{\gamma} \times \frac{\tau(i,j) \times P_j}{\eta + \sum_{k \neq j}^{M} \tau(i,k) \times P_k} \qquad (2\text{-}5)$$

Since γ is a constant, feasible data rate R_i has a continuous value and is proportional to APT transmission power P_j. Limited by the available channel coding and modulation schemes, there are, however, only a finite set of feasible data rates. Using each data rate $R_i=c_i$ to be supported, the associated E_b/N_0 requirement, and W=1.288MHz in (2-4), we obtain the minimum required SINR to support the data rate c_i. Let (c_k, $SINR_k$) denote the pair of feasible data rate and the associated minimum required SINR, k=1,2, …, K. The instantaneous data rate for an AT_i receiving SINR is then

$$c_j \quad \text{, where } j = \arg \min_{\text{k}} \left(SNR - SNR_k \right) > 0 \qquad (2\text{-}6)$$

Therefore, we can separate all active ATs in a cell into K classes according to their SINR levels.

2.3 Packet Scheduling Policy

Possible candidates of scheduling policy for forward link data service are the simple round robin (**RR**) scheme which decides the user-served sequence in advance and the maximum carrier-to-interference ratio (**CIR**) scheme [17] which chooses one AT with maximum data service rate. However, neither of them considers channel conditions and the fairness issue simultaneously. In HDR system, to balance the system throughput and fairness effectively, the proportional fair (PF) algorithm is suggested [3, 7, and 18]. We select the **PF** scheme as our packet scheduling policy, given by

$$i = \arg\max_j \frac{R_j(t)}{\overline{R}_j(t)} \qquad \text{j=1,2,…,N} \qquad (2\text{-}7)$$

where i is the selected AT for next slot, N is the number of ATs in the same cell at the moment, $R_i(t)$ is instantaneous data rate for AT i in the given slot, and $\overline{R}_i(t)$ is the short term average data rate which is recorded and updated over a time windows Δ_{WS} as in [7]. Note that the user-selection strategy is choosing the last one without average data rate and pickup one from the users with the same priority randomly [1]. Further detail about the user-selection strategy (2-7) is that if there exists any AT without receiving any average data rate, the strategy first gives priority to them but chooses them by LCFS rule, and then if there exists a number of i satisfying (2-7) (i.e., having the same priorities), the strategy randomly picks one of them.

2.4 Power Control Policies

We consider that the APT transmission power is partially adjustable at *high* and *low* power levels. Let P_{max} and $\theta \cdot P_{max}$ be the high and low power levels, respectively. P_{max} is considered as the default power level. The parameter, θ, is the ratio(factor) of the power reduction, where $0 \le \theta \le 1$. Now, we introduce three power control schemes to decide when the APT transmission power is reduced to low level or when it should be returned to high level.

2.4.1 Simple Power Control Scheme

The simple power control scheme (**SPCS**) for high data rate in the CDMA data networks has been presented in [6]. We repeat the scheme in the thesis for comparison. The author assumed that each APT has a unique numeric identifier and identifiers are generated randomly. In the odd-numbered slot, the odd-identifier APTs have high-level power; otherwise, they have low-level power in the even-numbered slot. For even-identifier APTs, their power is set low level in odd-numbered slot; high level in even ones. The authors setup the ratio of 0.5 for assigning slots to high-level power, i.e. low-level power has the same ratio. The SPCS is illustrated in Figure 2-2. This scheme has the same probability of using high-level or low-level power to serve ATs, resulting in higher system throughput than one of the system without power control (**NPC**)[6].

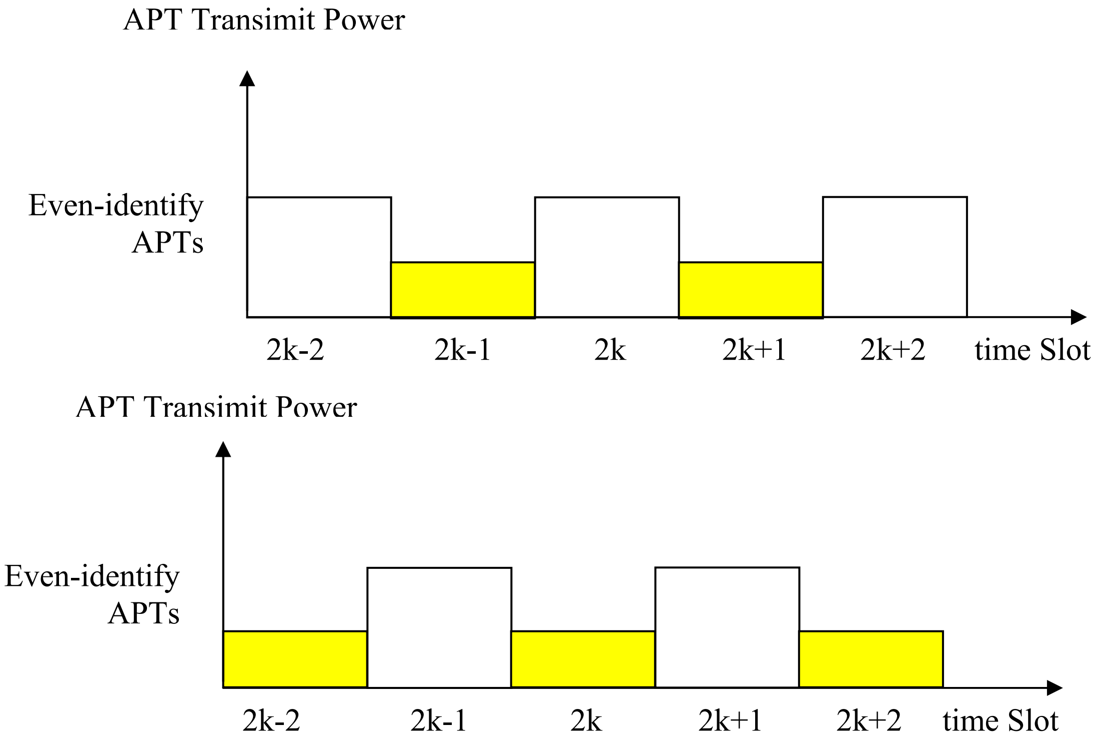

Figure 2-2 Two types of power pattern in SPCS

2.4.2 Adaptive power level control with one threshold

Let $Q_{i,j}(t)$ be the number of bits remaining in the buffer of APT j to be sent to active AT *i* at the beginning of time slot t. Let $R_{i,j}(t)$ be the feasible data rate from APT *j* to active AT *i* during time slot t-1. The feasible data rate can be discrete or continuous depending on the assumed forward link transmission data rate. Let $n_j(t)$ be the number or set of active ATs in cell j at the beginning of time slot t. Then, define $\beta_j(t) = \sum_{i=1}^{n_j} \frac{Q_{i,j}(t)}{R_{i,j}(t)}$ as the traffic loading of cell j at the end of time slot t-1 (i.e., at the beginning of time slot t). Assume that $n_j(t) = n_{j,L}(t) + n_{j,R}(t)$, where $n_{j,L}(t)$ and $n_{j,R}(t)$ indicate the set of active AT indices in the left hand coverage area of cell j and in the right hand coverage area of cell j, respectively. Then, the left hand side loading of cell j is $\beta_{j,L}(t) = \sum_{i \in n_{j,L}} \frac{Q_{i,j}(t)}{R_{i,j}(t)}$ and the right hand side loading is $\beta_{j,R}(t)=\beta_j(t)-\beta_{j,L}(t)$ at the beginning of time slot t. In particular, we define the *relative loading factor* of cell j at the end of slot t-1 by

$$Z_j(t)=\frac{\beta_j(t)}{\beta_{j-1,R}(t)+\beta_{j+1,L}(t)}. \tag{2-8}$$

Considering the advantage of power level patterns, APT should serve the cell central (**CC**) user when the APT transmit power is low level. It then serves the cell boundary (**CB**) user after the power is returned to high level. We consider a constant ρ as a threshold used for determining whether APT can reduce transmit power or not. In fact, we attempt to use the decision rule

$$\begin{cases} P_j(t)=\theta\times P_{Max} & \text{, If } Z_j(t)\le\rho \\ P_j(t)=P_{Max} & \text{, Otherwise.} \end{cases} \tag{2-9}$$

where $P_j(t)$ is the transmit power of the APT j in a given slot.

Our first adaptive power control scheme is based on a single threshold ρ, in (2-9). Essentially, the approach is first to find a candidate set of APTs to reduce power levels. Then, search from the candidate set for an APT with minimum relative loading factor. If one is available, its transmission power level is set to LOW and its direct neighboring APTs are locked in HIGH transmission power level, i.e., if any of the neighboring APTs is in the candidate set, it is removed from the candidate set. The procedure is repeated until the candidate set is empty. Specifically, the algorithm at the beginning of time slot t can be stated as follows:

Cs(t)={j ; $Z_j(t) \leq \rho$ };
All APT power levels → set to HIGH //The default state;

While Cs(t) $\neq \varnothing$
    $i = \arg\min_{j \in Cx(t)} Z_j(t)$;
    APT i power level → set to LOW
    Cs(t)←Cs(t) − {i, (i mod M)+1, [(i−2)mod M]+1};
End while

Figure 2-3 Antenna power level control algorithm with one threshold

Figure 2-4 illustrates the concept of the adaptive power control scheme with one threshold (**AP**). Note that the proposed power control scheme is used slot by slot, and the default power level is HIGH. The pseudo code of AP is given in chapter 3.

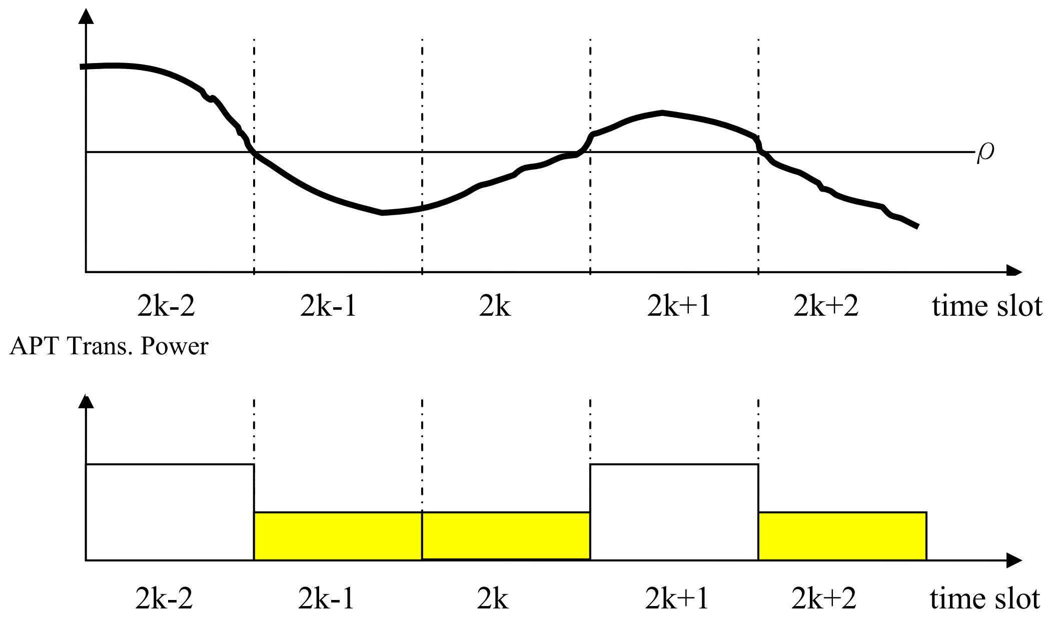

Figure 2-4 The adaptive power control scheme with one threshold

2.4.3 Adaptive Power level control with two hysteresis thresholds

In order to reduce the frequency of changing APT power levels that results from using a single threshold, we introduce a second threshold φ, $\varphi > 1$, for hysteresis control. We modify formula (2-9) as follows:

Initially, all APTs are set to HIGH power level.

$$\begin{cases} P_j(t) = P_{Max} & \text{, If } P_j(t-1) = \theta \times P_{Max} \text{ and } Z_j(t) \le \varphi \times \rho \\ P_j(t) = \theta \times P_{Max} & \text{, Else If } P_j(t-1) = P_{Max} \text{ and } Z_j(t) \le \rho \\ P_j(t) = P_j(t-1) & \text{, Otherwise} \end{cases} \qquad (2\text{-}10)$$

The concept of the adaptive power control scheme with two hysteresis thresholds (**APH**) is illustrated by Figure 2-5.

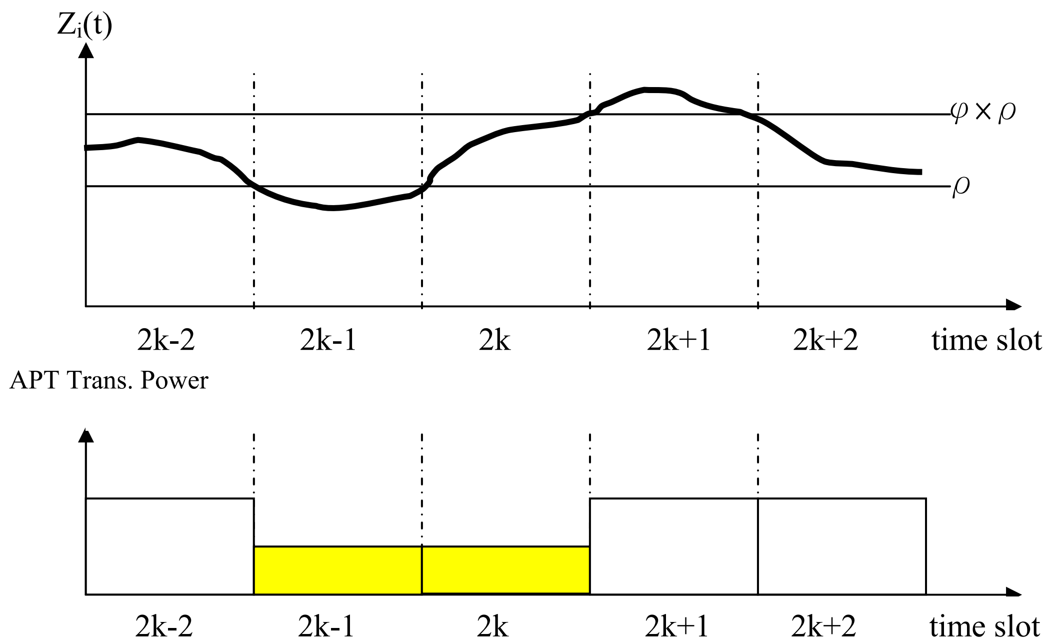

Figure 2-5 The adaptive power control scheme with two hysteresis threshold

The adaptive power control scheme is similar to FPCS, except that after tuned to low power level, the APT cannot raise the power until the inequality

$Z_j(t) \geq \varphi \times \rho$ is true. The second adaptive power control scheme has two more steps: Search all the APTs with $Z_j(t) > \varphi \times \rho$, change their power level to HIGH, and put them into the unlocked set of APTs. Meanwhile, its direct neighboring APTs are UNLOCKED if they are not also locked at HIGH due to other APT's LOW power level. The algorithm at the beginning of time slot t can be stated as follows:

```
Us(t)={j; Zj(t) > φ×ρ }
While Us (t)≠∅
        For any j ∈ Us(t)
        APTj power level →set to HIGH
        Us(t)←Us(t)－{j};
        If the neighboring APTs of APT j are not locked due to other APT's
                LOW power level, they are UNLOCKED.
End While

Cs(t)={j ; Zj(t) ≦ ρ };
While Cs(t)≠∅
        i = arg min_{j∈Cx(t)} Z_j(t);
        APT i power level → set to LOW
        Cs(t)←Cs(t)－{i, (i mod M)+1, [(i－2)mod M]+1};
End while
```

Figure 2-6 Antenna power level control algorithm with two hysteresis thresholds.