Chapter 2

Base Station Receiver Design

2.1 Overview

In mobile cellular radio transmission between a base station and a mobile telephone, the signal transmitted from the base station to the mobile receiver is usually reflected from surrounding buildings, hills, and other obstructions. As a consequence, we observe multiple propagation paths arriving at the receiver at different delays. Moreover, the speed that the mobile (automobile, train, etc.) is travelling results in frequency offsets, called Doppler shifts, of the various frequency components of the signal. Therefore, at the receiver three main components which are Path searcher, Rake Receiver and, Channel Estimator are used to estimate, correct, and detect the transmitted bits.

2.2 Mobile Station Transmitter

The baseband model of WCDMA uplink transmitter is shown in Figure 2.1. While the slot structure of dedicated physical data channel (DPDCH) and dedicated physical control channel (DPCCH) are shown in Figure 2.2. For DPCCH each slot containing N_D data symbols (e.g. N_{TFCI}, N_{FBI}, N_{TPC} and N_p pilot symbols (N_{pilot}), Other details for pilot slot format are described in Appendix B.

The transmitted equivalent baseband signal $s(t)$ can be presented as

$$s(t) = [d_d(t)w_d(t) + j\beta d_c(t)w_c(t)]c(t), \tag{2.1}$$

where
β indicates the relative level of DPCCH to DPDCH (more details in Appendix A),
$d_d(t)$ and $d_c(t)$ are the information streams of DPDCH and DPCCH respectively,
$w_c(t)$ and $w_d(t)$ denote the orthogonal spreading codes of DPCCH and DPDCH respectively, having possible values from the set {+1,-1} and
$c(t)$ is the complex scrambling code waveform of the user.

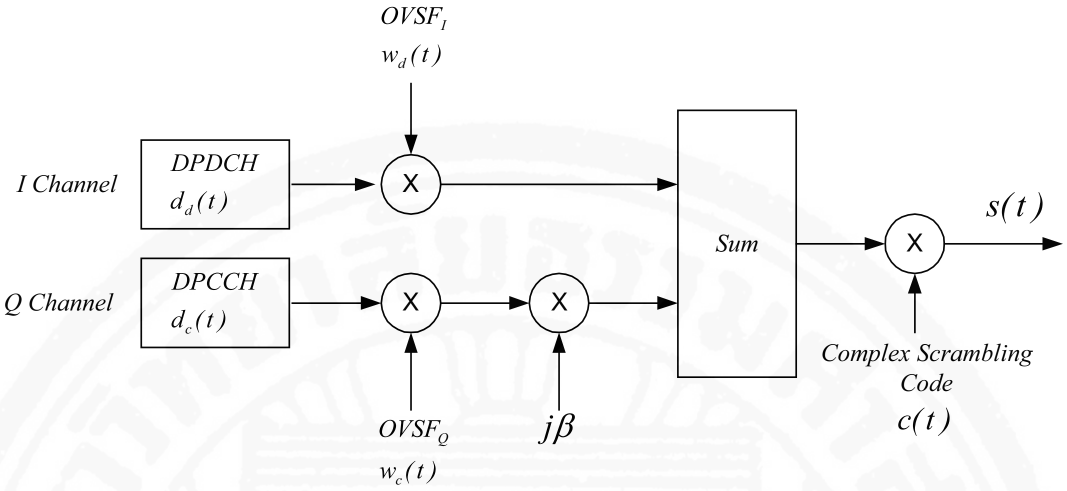


Figure 2.1 Uplink Transmitter Model

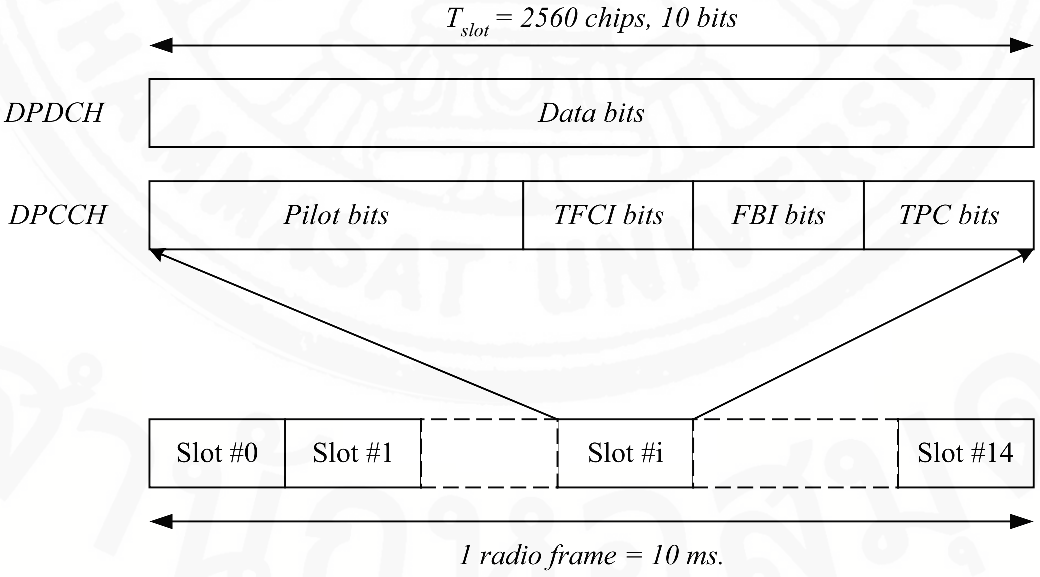


Figure 2.2 Frame structure for uplink DPDCH/DPCCH

2.3 The Multipath Channel Model

We assume that there are L propagation paths having different channel gains and time delays. The impulse response $h_l(t)$ of the l^{th} path at time t can be represented by

$$\begin{aligned} h_l(t) &= \alpha_l(t)e^{j\phi_l(t)}, \qquad (2.2) \\ &= \alpha_{d,l}(t)e^{j\phi_l(t)} + \alpha_{r,l}(t)e^{j\phi_l(t)}, \qquad (2.3) \end{aligned}$$

where

$\alpha_l(t)$ and $\phi_l(t)$ are the amplitude and the phase response of the l^{th} path at time t, respectively,
$\alpha_{r,l}(t)$ and $\phi_{r,l}(t)$ are the amplitude and the phase response of the scattered components of the l^{th} path respectively, and
$\alpha_{d,l}(t)$ and $\phi_{d,l}(t)$ denote the amplitude and the phase response of the direct-path of the l^{th} path respectively given by

$$\begin{aligned} \alpha_{d,l}(t) &= \sqrt{P_l}, \qquad (2.4) \\ \phi_{d,l}(t) &= 2\pi f_d t\cos(\theta_l), \qquad (2.5) \end{aligned}$$

Here, P_l and θ_l are respectively the power and the arrival angle of the direct path ray of the l^{th} path signal, f_d denotes the maximum Doppler frequency,

$$f_d = \frac{vf_c}{c}, \qquad (2.6)$$

where f_c is the carrier frequency, c and v are the speed of the light and the mobile, respectively. We can assume that θ_l and P_l are constant over a few seconds. It is also assumed that the direct-path component and the scattered components are statistically independent.

Assuming that the signals from each path are independent and their relative delays are spaced by a multiple of chip intervals, the impulse response of the channel $h(t)$ at time t can be described using a tapped-delay line model as

$$h(t) = \sum_{l=0}^{L-1} h_l(t)\delta(t - t_l), \qquad (2.7)$$

where

L is the total number of resolvable paths,
$\delta(t)$ is Dirac delta function, and
t_l denotes the time delay of l^{th} resolvable path.

2.3.1 Tapped Delay Line Channel Model

A general model for a time-variant multipath channel is illustrated in Figure 2.3. The channel model consists of a tapped delay line with uniformly spaced taps. The tap spacing between adjacent taps is $1/W$, where W is the bandwidth of the signal transmitted through the channel. Hence, $1/W$ is the time resolution that can be achieved by transmitting a signal of bandwidth W. The tap coefficients, denoted as $\{h_n(t) \equiv \alpha_n(t)e^{j\phi_n(t)}\}_{n=0}^{L-1}$ are usually modelled as complex-valued, Gaussian random processes which are mutually uncorrelated. The length of delay line corresponds to the amount of time dispersion in the multipath channel, which is usually called the multipath spread. We denote the multipath spread as $T_m = L_m/W$, where L_m represents the maximum number of possible multipath signal components.

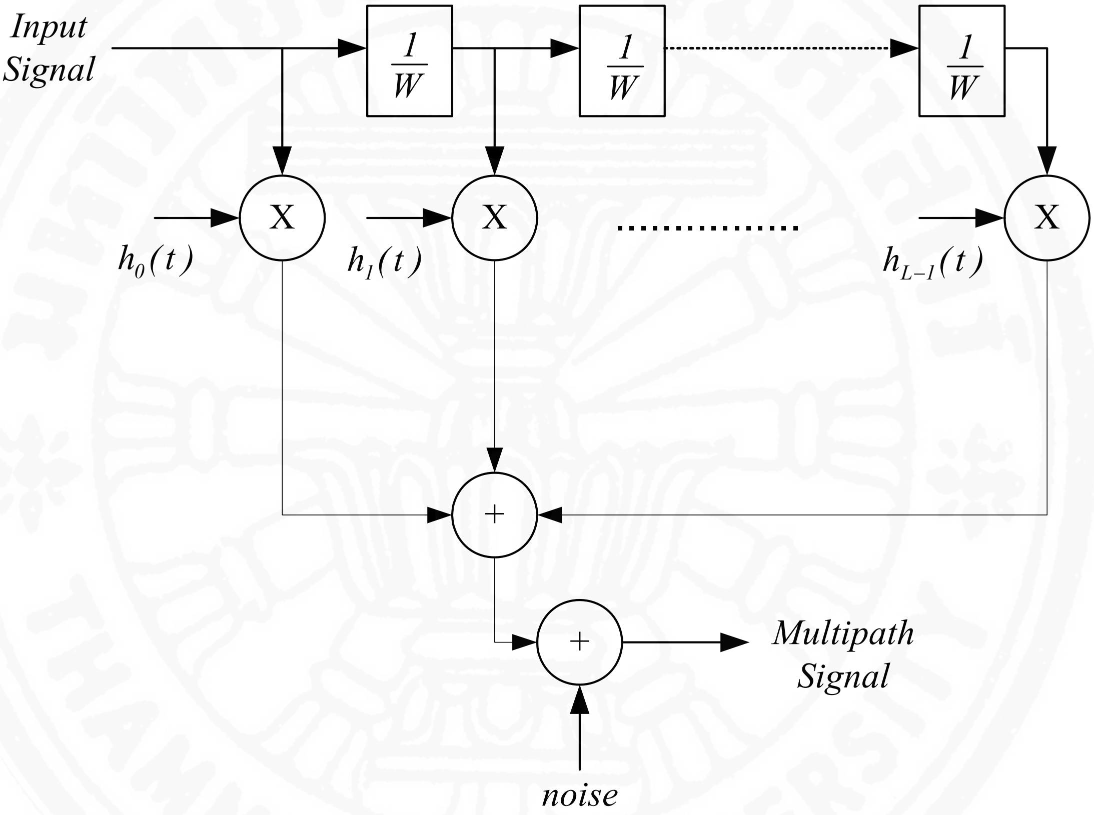


Figure 2.3 Tapped Delay Line Model

2.4 Base Station Receiver

After being baseband filtered at the receiver, the received l^{th} path signal can be expressed as

$$\begin{aligned} r(t) &= \sum_{l=0}^{L-1} r_l(t), && (2.8) \\ r_l(t) &= s(t)h_l(t) + n(t) + i(t), && (2.9) \end{aligned}$$

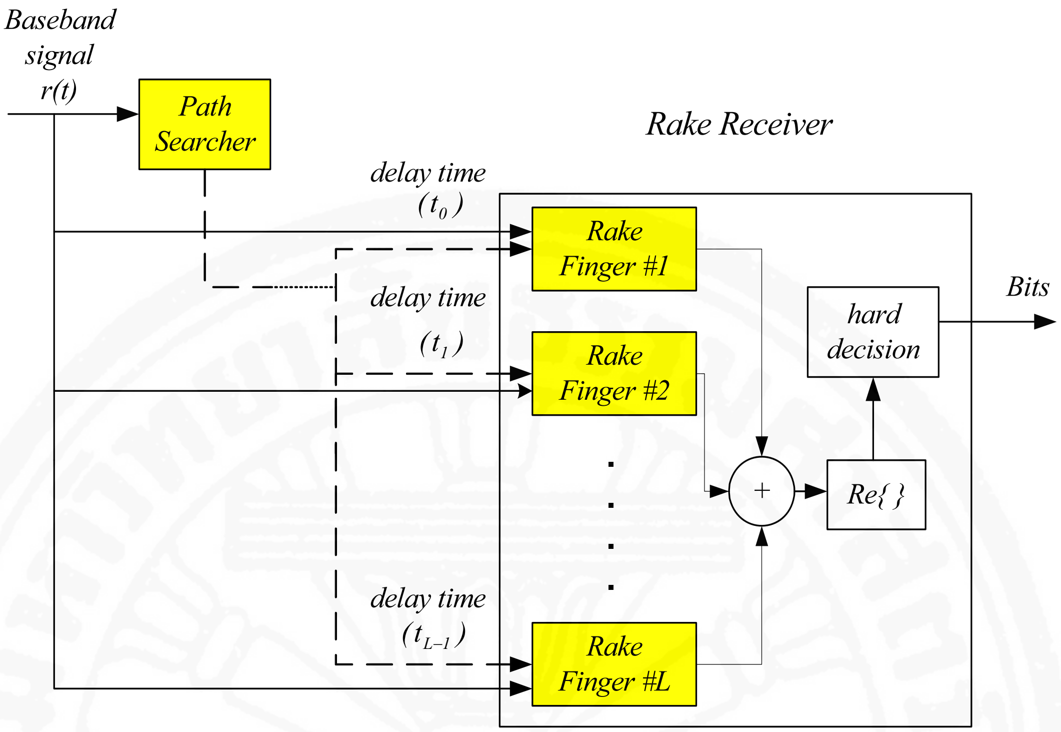


Figure 2.4 WCDMA Base Station Receiver Model

where $r(t)$ is the total received signal, $r_l(t)$ is the received l^{th} path signal, $n(t)$ is the background noise, and $i(t)$ is the interference from other users.

2.5 Multipath Searcher

The propose of multipath searcher is to find the multipath delay time of the signal which arrives at the receiver and supply to each rake finger in the Rake receiver.

The principle of working employs the correlation of received signal and reference signal (the complex conjugate of the product between pilot symbol and primary scrambling code) for searching time delay which is shown in Figure 2.5.

2.5.1 Correlation

In each slot of DPCCH, there are 10 symbols which are always spreaded by channelization code, $C_{ch,256,0}$, with spreading factor of 256. Since each slot has only 6 pilot symbols, therefore the correlation is done by using conjugation between known pilot symbols and long

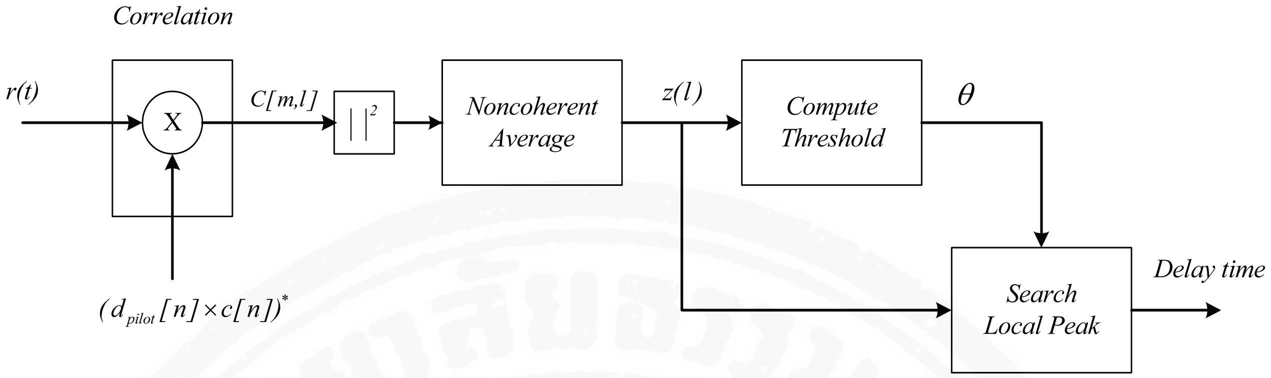


Figure 2.5 Block diagram of Multipath searcher

scrambling code. Maximum time delay will be the length selector in each signal correlation. Each path searching will get the result of correlation as described in Eq. 2.10 as follow

$$\begin{aligned} C[m,l] &= \frac{1}{N}\sum_{n=0}^{N-1}(j\cdot d_{pilot}[n]\cdot c[n])^{*}\cdot r[m,l+n], \\ \text{for}\quad l &= 0,1,2,...,L_T-1, \end{aligned} \tag{2.10}$$

where
$C[m,l]$ is the correlation result at l^{th} delay sample of m^{th} frame,
$d_{pilot}[n]$ is the pilot data at n^{th} bit,
L_T is an index of maximum time delay $(L_T = \tau_{max}/T_{chip})$, and
N is the window size (no. of Taps) of correlation.

Afterward, power delay profiles are found by searching squared magnitude of the correlator outputs in order to use for finding peak of the result of signal correlation.

2.5.2 Noncoherent Averaging

Noncoherent averaging is the process to find the average power delay profile amount M (no. of frame) before in order to decrease the results from spurious peak signal in a fading channel which make the result of correlation being wrong. Then the average power delay profile can be expressed as

$$\begin{aligned} z(l) &= \frac{1}{M}\sum_{m=0}^{M-1}|C[m,l]|^{2}, \\ \text{for}\quad l &= 0,1,2,...,L_T-1, \end{aligned} \tag{2.11}$$

where $z(l)$ is the average power delay profile.

2.5.3 Threshold Computation

Threshold computation is the method to select threshold value for deciding the result of correlation that whether it is strong enough to be signal path. By threshold setting can be either computed from statistical properties (mean and variance) of power delay profile or use fixed threshold value which will result lower than adaptive threshold value. And some techniques for computing the threshold (θ) are described below

2.5.3.1 A fraction of the power of the strongest path

This method will compute threshold from the proportion of the highest power

$$\theta = Z_{max}/\alpha_{TH}, \tag{2.12}$$

where
α_{TH} values as 2 or 4 (values as 3 or 6 dB),
Z_{max} is the highest power of averaged power delay profile.

2.5.3.2 NTT method

This method will select the threshold from the highest value between the ratio of maximum threshold value and the ratio of minimum threshold value

$$\theta = \text{max}\{Z_{max}/\alpha_{TH}, Z_{min} \cdot \beta_{NTT}\}, \tag{2.13}$$

where α_{TH} = 5dB and β_{NTT} = 3dB

2.5.3.3 Base the selection threshold on the statistical of the noise-only path

This method will compute threshold from the statistic of power profile which do not compute from the first K of the highest peaks (K is the number of finger).

$$\theta = m_{z,noise} + \gamma_{z,noise}\sigma, \tag{2.14}$$

where
$m_{z,noise}$ is a proportion of power profile only noise paths,
$\gamma_{z,noise}$ is a standard deviation of power profile only noise paths, and,
σ is a parameter which is able to select from field experiment.

2.5.3.4 Base on statistical properties of the involved random processes

This method will compute threshold from the statistic of all power delay profiles. By developing from a proceeding method will decrease the complication in separating compute only the power of noise paths

$$\begin{aligned} \theta &= m_z(1 + \frac{\gamma}{\sqrt{N_s}}), \\ &= m_z(a + bN_s^{c_z}), \end{aligned} \tag{2.15}$$

where

c_z values 0.5,

a and b are parameters depending on designing,

m_z is a proportional of averaged power delay profile,

N_s is a number of instantaneous power delay profile which will be averaged to find the averaged power delay profile.

2.5.4 Peak Searching

Once average power delay profile are obtained, the position of index time which has peak values are compared with selected threshold. By selecting index time of peak from the highest one which passed threshold to be a number as many as the fingers of rake receiver to be multipath delay for rake receiver.

2.6 Rake Receiver and Channel Estimator

Ideally, the RAKE receiver should have L fingers and each finger is illustrated by Figure 2.6. However, RAKE is normally designed to have M_L fingers $(M_L \leq L)$ due to the complexity and hardware constrains. Hence, the remaining $L - M_L$ paths become self-interference.

At the rake receiver, the first process is descrambling; multiply the input signal with complex conjugate of the scrambling code. After unscrambled at the receiver, the received l^{th} path signal can be expressed as

$$\begin{aligned} r_{l,Descramb}(t) &= [s(t)h_l(t) + n(t) + i(t)]c^*(t), \\ &= s(t)h_l(t)c^*(t) + Z_l(t), \\ &= [d_d(t)w_d(t) + j\beta d_c(t)w_c(t)]h_l(t) + Z_l(t), \end{aligned} \tag{2.16}$$

where $Z_l(t)$ represents thermal noise and interference from other users.

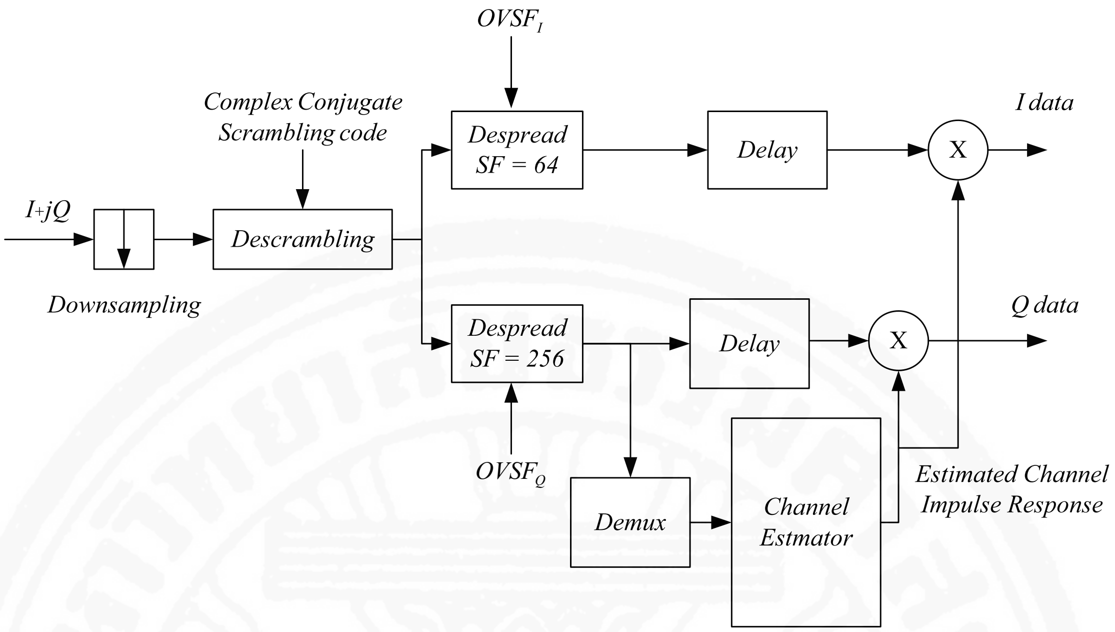


Figure 2.6 Rake finger components

Since the channel estimation is a crucial for the performance of mobile communication systems. In WCDMA uplink, it has been decided to employ uncoded pilot symbols for channel estimation and coherent detection. Channel estimation can be based on linear interpolating, Wiener filtering, simple pilot symbol averaging and weighted multi-slot averaging (WMSA). In this thesis, the channel estimation filter based on WMSA method are employed.

2.6.1 Channel Estimation based on Weighted Multi-Slot Averaging Technique

From Eq. 2.16, after descrambled then despread, the DPCCH signal with $w_c(t)/j$ becomes

$$\begin{aligned} r_{l,DPCCH}(i,n_c) &= \frac{1}{jT_c}\sum_{t=iT_{cslot}+n_cT_c}^{iT_{cslot}+(n_c+1)T_c-1}[r_{l,Descramb}(t)\times w_c(t)], \\ &= d_c(i,n_c)h_l(i,n_c)\beta+\frac{1}{jT_c}\sum_{t=iT_{cslot}+n_cT_c}^{iT_{cslot}+(n_c+1)T_c-1} n(t)c^*(t)w_c(t)+ \\ &\quad \frac{1}{jT_c}\times\sum_{t=iT_{cslot}+n_cT_c}^{iT_{cslot}+(n_c+1)T_c-1} i(t)c^*(t)w_c(t), \end{aligned} \tag{2.17}$$

where T_c denotes the symbol duration of DPCCH, T_{cslot} is the slot length for DPCCH which is equal to $10T_c$. The despreaded DPCCH signal of n_c^{th} symbol at i^{th} slot is denoted as $r_{l,DPCCH}(i,n_c)$.

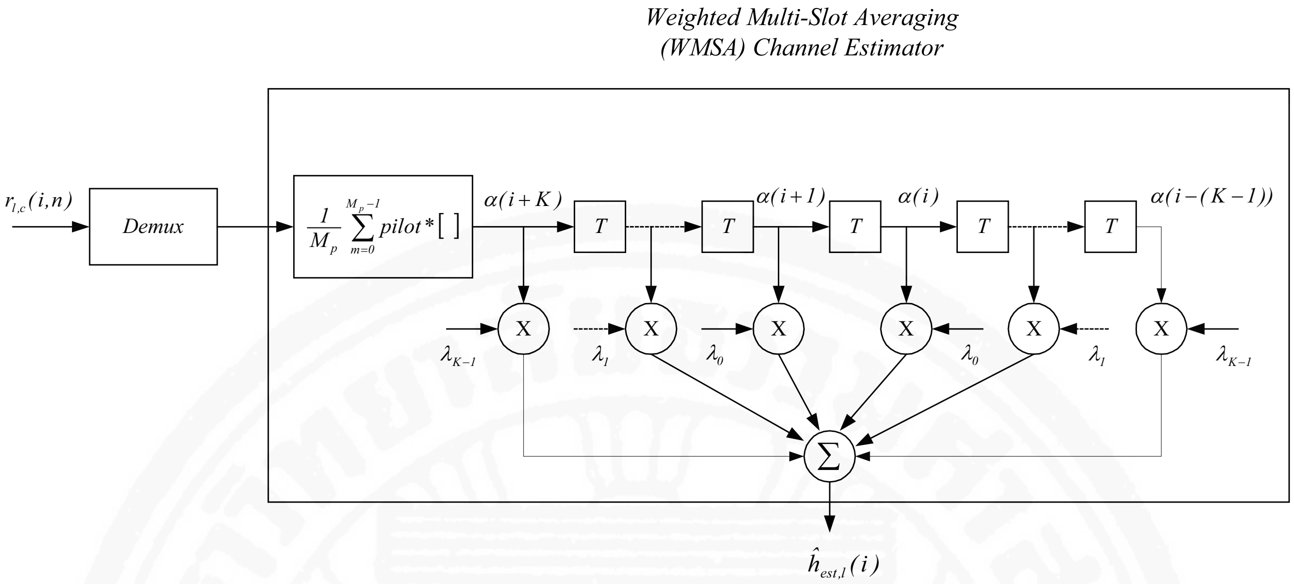


Figure 2.7 WMSA Structure

And then despreading the DPDCH signal with $w_d(t)$ yields the n^{th} symbol of the i^{th} slot associated l^{th} path

$$\begin{aligned} r_{l,DPDCH}(n_d) &= \frac{1}{T_d} \times \sum_{t=n_dT_d}^{(n_d+1)T_d-1} r_{l,Descramb}(t)w_d(t), \\ &= d_d(n_d)h_l(n_d) + \frac{1}{T_d}\sum_{t=n_dT_d}^{(n_d+1)T_d-1} n(t)c^*(t)w_d(t) + \\ &\quad \frac{1}{T_d}\sum_{t=n_dT_d}^{(n_d+1)T_d-1} i(t)c^*(t)w_d(t), \end{aligned} \tag{2.18}$$

where T_d denotes the symbol duration of DPDCH which is depending on the spreading factor (SF). And DPDCH signal at bit n_d^{th} despreads as $r_{l,DPDCH}(n_d)$.

At the DPCCH channel, first, using the N_p pilot symbols to perform an instantaneous channel estimation. The estimated channel impulse response of l^{th} path can be found by multiplying demultiplexed signal with known reference pilots after signal was demultiplexed. It shows in Figure 2.6 and can be expressed as

$$\begin{aligned} h_{est,l}(i,n_c) &= r_{l,DPCCH}(i,n_c) \cdot d_{pilot}(i,n_c), \\ &= h_l(i,n_c)\beta + \frac{d_{pilot}(i,n_c)}{jT_c} \times \sum_{t=iT_{cslot}+n_cT_c}^{iT_{cslot}+(n_c+1)T_c} n(t)c^*(t)w_c(t) + \\ &\quad \frac{d_{pilot}(i,n_c)}{jT_c}\sum_{t=iT_{cslot}+n_cT_c}^{iT_{cslot}+(n_c+1)T_c} i(t)c^*(t)w_c(t), \end{aligned} \tag{2.19}$$

for

$$n_c = 0, 1, 2, ..., N_p - 1.$$

The estimated impulse response at l^{th} path of slot i^{th} bit n_c^{th} is denoted as $h_{est,l}(i, n_c)$. Applying a linear filter having $2K$ taps to extend the observation period to $2K$ slots can describe as the WMSA channel estimation method shown in Figure 2.7 according to DPCCH slot structure in Figure 2.2. Demultiplexing N_p pilot symbols of the i^{th} slot is used for calculating their average $\alpha(i)$ and reducing Gaussian noise and interference.

A remaining estimated impulse response l^{th} path at present slot is $\alpha(i)$ and can be described as below

$$\alpha(i) = \frac{1}{N_p} \sum_{n_c=0}^{N_p-1} d_{pilot}(i, n_c) \cdot r_{l,DPCCH}(i, n_c). \tag{2.20}$$

The filter output is expressed as

$$\hat{h}_{est,l}(i) = \sum_{k=0}^{K-1} \lambda_k[\alpha(i-k) + \alpha(i+1+k)], \tag{2.21}$$

where λ_k and K are positive integer. Because WMSA has lowpass characteristic so $\lambda_{K-1} < \cdots < \lambda_1 < \lambda_0$.

The estimated channel impulse response of all remaining positions of the i^{th} slot is represented by $\hat{h}_{est,l}(i)$, where

$$h_{est,l}(i, n_c) = \hat{h}_{est,l}(i), \tag{2.22}$$

for

$$n_c = N_p, ..., N_p + N_D - 1.$$

The channel equalizer will be applied after the estimated channel impulse responses were found. The impulse response can be derived by

$$\begin{aligned} y_{l,DPCCH}(i, n_c) &= r_{l,DPCCH}(i, n_c) \cdot h^*_{est,l}(i, n_c), & (2.23) \\ y_{l,DPDCH}(n_d) &= r_{l,DPDCH}(n_d) \cdot h^*_{est,l}(n_d), & (2.24) \\ h^*_{est,l}(n_d) &= h^*_{est,l}(i, n_c), & (2.25) \end{aligned}$$

for

$$n_d = \frac{256}{SF}n_c, ..., \frac{256}{SF}n_c + (\frac{256}{SF} - 1),$$
$$n_c = 10i, ..., 10i + 9.$$

The equalized signal of DPCCH channel at path l^{th} of slot i^{th} bit n_c^{th} is denoted as $y_{l,DPCCH}(i, n_c)$ while the equalized signal of DPDCH channel at path l^{th} of bit n_d^{th} is denoted as $y_{l,DPDCH}(n_d)$. The spreading factor is represented by SF.

After equalized signals from M_L fingers were found, the maximum ratio combining (MRC) was employed and the output of the rake receiver can be expressed as

$$d_I(n_d) = Re\{\sum_{l=0}^{M_L-1} y_{l,DPDCH}(n_d)\}, \tag{2.26}$$

$$d_Q(i,n_c) = Re\{\sum_{l=0}^{M_L-1} y_{l,DPCCH}(i,n_c)\}. \tag{2.27}$$

An estimated I data in DPDCH channel at bit n_d^{th} is denoted as $d_I(n_d)$. An estimated Q data in DPCCH channel of slot i^{th} bit n_c^{th} is denoted as $d_Q(i,n_c)$, and the number of total fingers is M_L where $(M_L \leq L)$. The signum function was used as a hard decision to represent the roughly estimated binary data symbols.

2.7 Simulation Results

In this thesis, the design of the base station receiver are separated into 3 steps as follows:

1) We created algorithms by using C++ in the part of multipath channel model and using Matlab v.6.5 for both transmitter side and receiver side.

2) We simulated the performances for both floating point and fixed point by employing Matlab v6.5 and observed the different of performance between them, since the FPGA board operates only for fixed point.

3) We transfer optimized the suitable receiver algorithms from Matlab to VHDL codes preparing for implement to the FPGA board.

In the simulation, we tested over 4 cases of the information bit rate which are 12.2 kbps, 64 kbps, 144 kbps and 384 kbps with 3 path channel model. The bit rate of DPCCH for all cases are the same and equal to 15 kbps which the spreading factor is equal to 256, the number of bits per frame is equal to 150. The power ratio (DPCCH/DPDCH) for all cases are also the same and equal to -5.46 dB. While bit rate of DPDCH are different depending on the information bit rate. It is said that at 12.2 kbps, DPDCH bit rate is 60 kbps, the number of bits per frame is 600 and the spreading factor is equal to 64. At 64 kbps, DPDCH bit rate is 240 kbps, the number of bits per frame is 2,400 and the spreading factor is equal to 16. At 144 kbps, DPDCH bit rate is 480 kbps, the number of bits per frame is 4,800 and the spreading factor is equal to 8. And at 384 kbps, DPDCH bit rate is 960 kbps, the number of bits per frame is 9,600 and the spreading factor is equal to 4.

In the DPCCH, the number of pilot bits is equal to 6 and because the information in Matlab will be kept as array, so it has the limitation when we tested too many frames. In this thesis, we tested over 10 frames for all cases that is mean for DPCCH, we can test only 1,500 bits while for DPDCH, we can test 600 bits for the case of 12.2 kbps, 24,000 bits for 64 kbps, 48,000 bits for 144 kbps and 96,000 bits for 384 kbps. We assumed that for the best case the signal to noise ratio is equal to 9 dB and equal to -3 dB for the worst case.

Figure 2.8 shows the output performance of the multipath searcher algorithm when the system model has three multipath signals at Doppler speed is 3 km/hr with vary levels of signal to noise ratio. It is shown that when signal-to-noise ratio decreases, noise floor increases but it has not effect to the performance of the multipath searcher.

Figure 2.9-Figure 2.11 show the output of the channel estimator which is estimated channel impulse response of path one, two, and three respectively, when Doppler speed is 3 km/hr with vary levels of signal to noise ratio. We can see that the signal from the other paths become self-interference. Thus, noise occur in the case of noiseless channel; the estimated channel impulse response is mixed with noise (the signal from other paths). Then the performance degrades as noise increases.

2.7.1 Single User Detection

2.7.1.1 Floating point performances

Table 2.1-2.2 show the floating point performance of the complete receiver system by representing through the bit error rate (BER).

For every cases; when mobile speed having range from 0 to 80 km/hr, the performances between SNR of 9 dB and -3 dB are approximately the same in each case of mobile speed. When the mobile speed having range from 120 to 240 km/hr, at rate of 12.2 kbps, 64 kbps, 144 kbps and 384 kbps; the performances between SNR of 9 dB and -3 dB are approximately different for 1%, 3%, 5% and 14% respectively in I channel. For Q channel, for all speeds and for all bit rates; the performances between SNR of 9 dB and -3 dB are approximately the same in each case of mobile speed.

On the other hand, we can compare performances among those the information bit rates; when SNR of 9 dB, the performances at rate of 12.2 kbps, 64 kbps, and 144 kbps are approximately the same in each case of mobile speed while at rate of 384 kbps, the performances degrade by 3% in I channel compare to the others. And when SNR of -3 dB, at rate of 64 kbps for all mobile speeds; the performances degrade by 1% in I channel compare with the rate of 12.2 kbps. At rate of 144 kbps when mobile speed having range from 40 to 240 km/hr; the performances degrade by 5% in I channel compare with the rate of 12.2 kbps but at speed of 0 km/hr, the performance is approximately the same in each case of mobile speed. At rate of 384 kbps when mobile speed having range from 40 to 240 km/hr;

Table 2.1 BER for Dedicated Physical Data Channel of Floating Point

Bit Error Rate for DPDCH (I) Channel					
SNR (dB)	Speed (km/hr)	Information bit rate (kbps)			
		12.2	64	144	384
-3	0	0.0034	0.0042	0.0055	0.0320
	40	0.0034	0.0126	0.0546	0.1257
	80	0.0034	0.0172	0.0546	0.1257
	120	0.0211	0.0437	0.0673	0.1414
	160	0.0315	0.0498	0.0747	0.1501
	200	0.0500	0.0766	0.0995	0.1753
	240	0.0623	0.1004	0.1342	0.1840
9	0	6.9266e-4	6.9266e-4	6.9266e-4	0.0032
	40	7.4627e-4	7.4627e-4	9.7948e-4	0.0161
	80	8.8619e-4	8.8619e-4	0.0016	0.0196
	120	0.0114	0.0120	0.0140	0.0298
	160	0.0201	0.0206	0.0201	0.0369
	200	0.0379	0.0386	0.0340	0.0509
	240	0.0593	0.0664	0.0698	0.0742

Table 2.2 BER for Dedicated Physical Control Channel of Floating Point

Bit Error Rate for DPCCH (Q) Channel					
SNR (dB)	Speed (km/hr)	Information bit rate (kbps)			
		12.2	64	144	384
-3	0	7.462e-4	7.462e-4	7.462e-4	0.0022
	40	0.0015	0.0015	0.0015	0.0052
	80	0.0015	0.0015	0.0045	0.0060
	120	0.0095	0.0095	0.0095	0.0129
	160	0.0201	0.0201	0.0201	0.0600
	200	0.0306	0.0306	0.0306	0.0601
	240	0.0634	0.0664	0.0746	0.0776
9	0	6.9266e-4	6.9266e-4	6.9266e-4	0.0022
	40	6.9266e-4	6.9266e-4	6.9266e-4	0.0022
	80	6.9266e-4	6.9266e-4	0.0016	0.0037
	120	0.0112	0.0112	0.0052	0.0052
	160	0.0097	0.0097	0.0097	0.0134
	200	0.0172	0.0172	0.0172	0.0433
	240	0.0560	0.0560	0.0560	0.0642

the performances degrade by 13% in I channel compare with the rate of 12.2 kbps but at speed of 0 km/hr, the performance is approximately 3% different.

2.7.1.2 Fixed point performances

Since the hardware performance is represented as a fixed point performance therefore the tables of the fixed point performance are necessary. Table 2.3-2.4 show the fixed point performance of the complete receiver system by representing through the bit error rate (BER).

Table 2.3 BER for Dedicated Physical Data Channel of Fixed Point

Bit Error Rate for DPDCH (I) Channel					
SNR (dB)	Speed (km/hr)	Information bit rate (kbps)			
		12.2	64	144	384
9	0	7.4627e-4	7.4627e-4	7.4627e-4	0.0027
	40	0.0125	0.0013	0.0147	0.0611
	80	0.0088	0.0099	0.0108	0.0396
	120	0.0369	0.0351	0.0374	0.0577
	160	0.0506	0.0421	0.0367	0.0685
	200	0.0767	0.0790	0.0689	0.1039
	240	0.0866	0.0914	0.1067	0.1209
-3	0	0.0022	7.462e-4	7.6959e-4	0.0028
	40	0.0132	0.0121	0.0229	0.0597
	80	0.0084	0.0135	0.0118	0.0430
	120	0.0390	0.0389	0.0414	0.0587
	160	0.0416	0.0455	0.0341	0.0694
	200	0.0797	0.0813	0.0684	0.1086
	240	0.0888	0.0917	0.1113	0.1179

For every cases; the performances between SNR of 9 dB and -3 dB are approximately the same in each case of mobile speed for both I and Q channel. And for Q channel, for all speeds and for all bit rates; the performances between SNR of 9 dB and -3 dB are approximately the same.

On the other hand, we can compare performances among those the information bit rates; when SNR of 9 dB and -3 dB, the performances at rate of 12.2 kbps, 64 kbps, and 144 kbps are approximately the same in each case of mobile speed. At rate of 384 kbps, when the mobile speed having range from 40 to 240 km/hr the performances degrade by 2% in each

Table 2.4 BER for Dedicated Physical Control Channel of Fixed Point

Bit Error Rate for DPCCH (Q) Channel					
SNR (dB)	Speed (km/hr)	Information bit rate (kbps)			
		12.2	64	144	384
9	0	7.4627e-4	7.4627e-4	7.4627e-4	0.0022
	40	0.0179	0.0060	0.0201	0.0672
	80	0.0149	0.0149	0.0127	0.0373
	120	0.0604	0.0493	0.0485	0.0560
	160	0.0604	0.0478	0.0500	0.0507
	200	0.0925	0.0970	0.0754	0.0925
	240	0.1090	0.1000	0.1254	0.1254
-3	0	0.0022	7.4627e-4	7.6959e-4	0.0022
	40	0.0172	0.0149	0.0269	0.0664
	80	0.0134	0.0231	0.0164	0.0328
	120	0.0537	0.0545	0.0500	0.0530
	160	0.0545	0.0545	0.0433	0.0470
	200	0.0978	0.0970	0.0724	0.1007
	240	0.1112	0.1037	0.1313	0.1201

case of mobile speed for I channel compare to the others while the mobile speed of 0 km/hr, the performance is approximately the same compare to the others.

2.7.2 Multiuser Detection

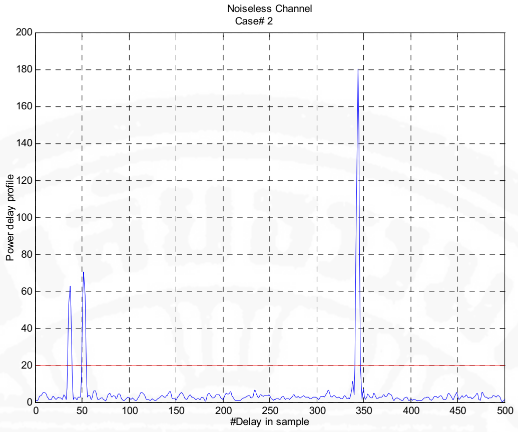
In this thesis, each base station contains three rake fingers, therefore our base station prototype can support two users depending on the limitation of the resource of the hardware.

All information bit rates are tested in four cases which are $SNR_1 = SNR_2 = -3dB$, $SNR_1 = SNR_2 = 9dB$, $SNR_1 > SNR_2 = 3dB$ when SNR_1 is 9dB, and $SNR_1 = SNR_2 = dB$ when $SNR_1 = -3dB$ where SNR_1 and SNR_2 represent the signal-to-noise ratio of user 1 and user 2 respectively. The results can be represented from Table 2.5-Table 2.8.

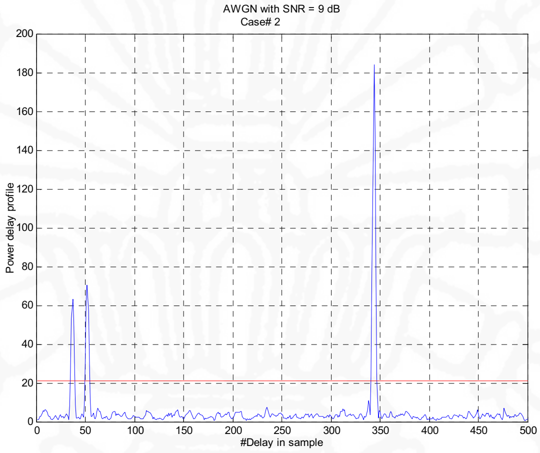
The simulation results show that bit error rate of received signal is less than 3% at the information bit rate of 12.2 kbps, 6% at the information bit rate of 64 kbps, 10% at the information bit rate of 144 kbps, and 14% at the information bit rate of 384 kbps for I channel while bit error rate for Q channel is less than 3% for all information bit rate.

Table 2.5 BER for Dedicated Physical Data Channel of user 1

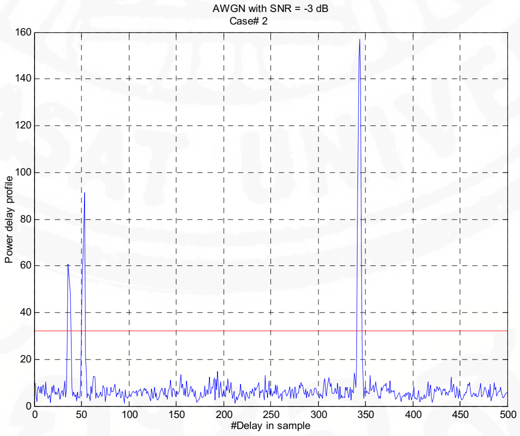
Bit Error Rate for DPDCH (I) Channel					
SNR	Speed	Information bit rate (kbps)			
(dB)	(km/hr)	12.2	64	144	384
$SNR_1 = SNR_2 = -3$	0	0.0506	0.0042	0.0284	0.0798
	40	0.0257	0.0546	0.0546	0.1146
	80	0.0293	0.0512	0.0712	0.1250
	120	0.0247	0.0510	0.0974	0.1374
$SNR_1 = SNR_2 = 9$	0	0.0104	0.0022	0.0039	0.0250
	40	0.0076	0.0131	0.0200	0.0299
	80	0.0065	0.0248	0.0248	0.0692
	120	0.0211	0.0529	0.0329	0.0523
$SNR_1(9dB) > SNR_2(6dB) = 3$	0	0.0022	0.0022	0.0032	0.0268
	40	0.0049	0.0182	0.0216	0.0331
	80	0.0093	0.0114	0.0280	0.0749
	120	0.0101	0.0215	0.0409	0.0563
$SNR_1(-3dB) > SNR_2(-6dB) = 3$	0	0.0022	0.0061	0.2230	0.1014
	40	0.0174	0.0721	0.1207	0.1547
	80	0.0207	0.0633	0.0974	0.2031
	120	0.0368	0.0707	0.1200	0.1686



(a) Power delay profile (noiseless channel)

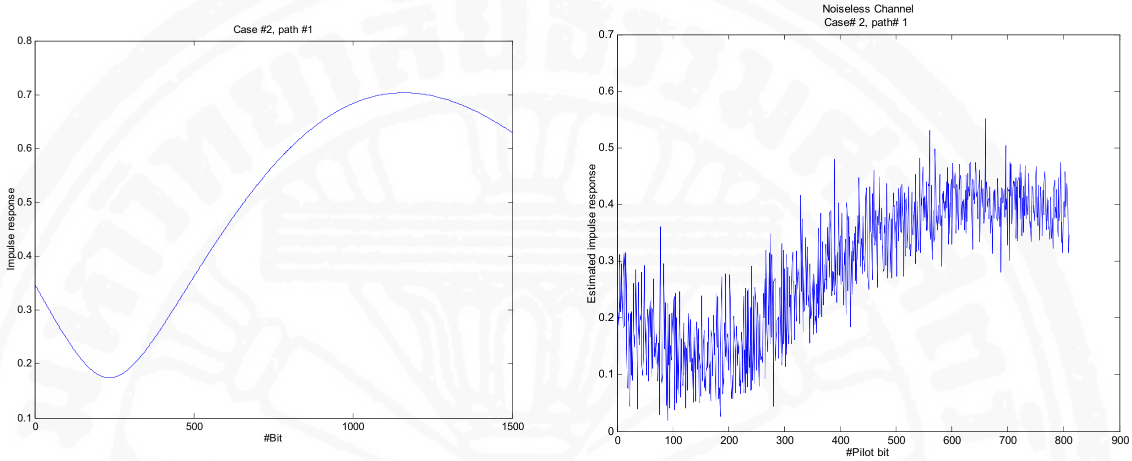


(b) Power delay profile (SNR = 9 dB)



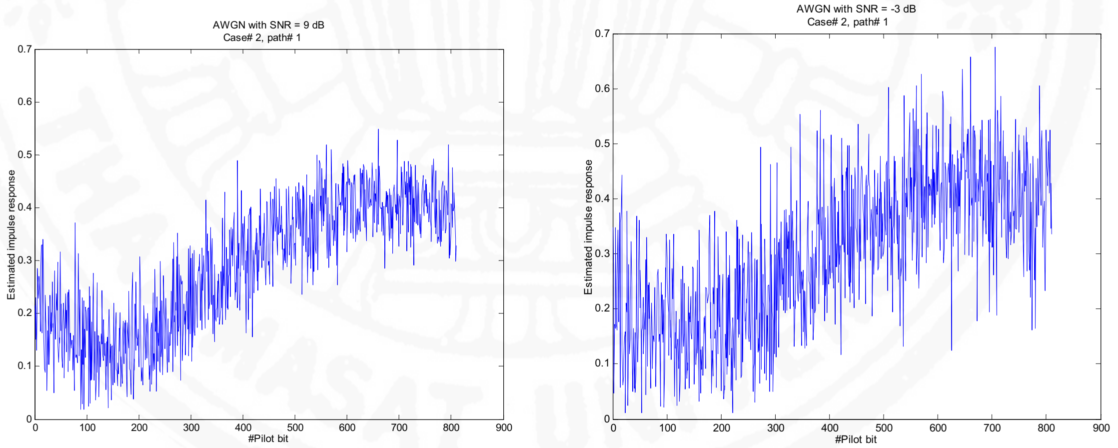
(c) Power delay profile (SNR = -3 dB)

Figure 2.8 Power delay profiles of three path signals at Doppler speed of 3 km/hr



(a) Original channel impulse response
of path one

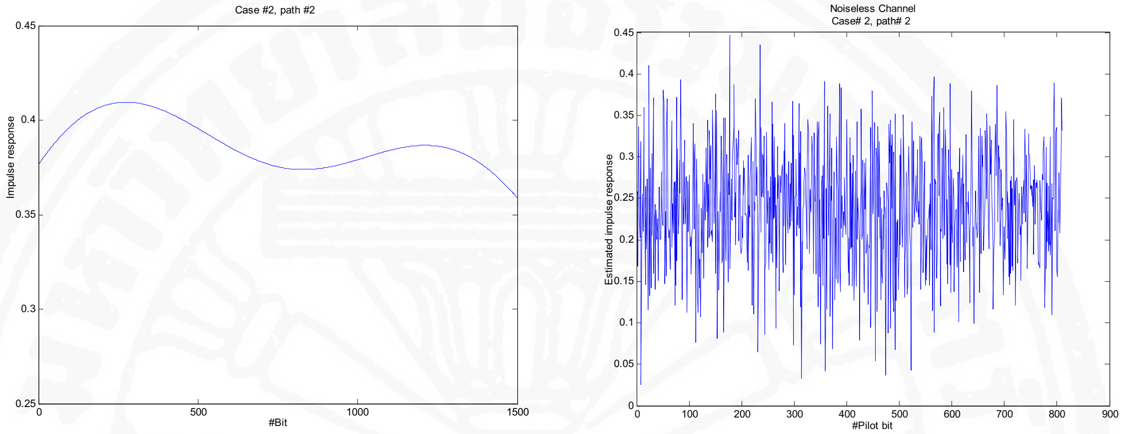
(b) Estimated impulse response
of path one (noiseless channel))



(c) Estimated impulse response
of path one (SNR = 9 dB)

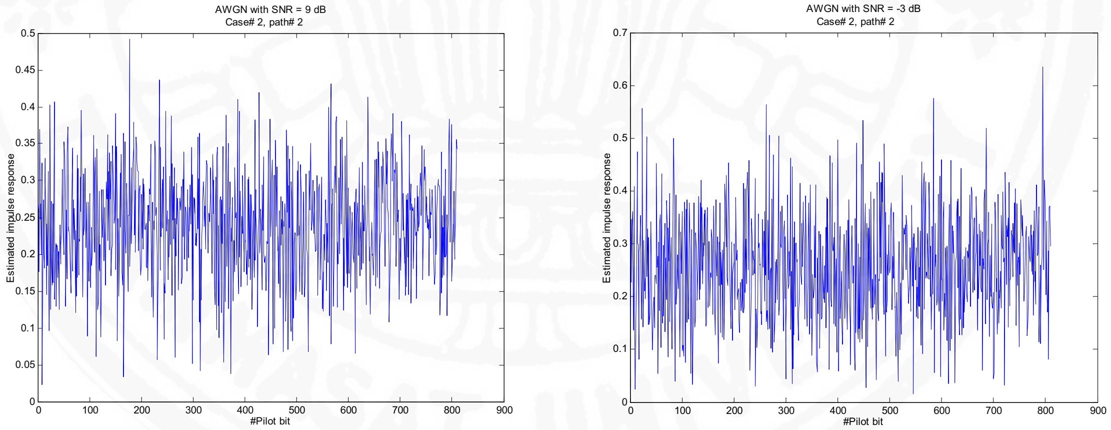
(d) Estimated impulse response
of path one (SNR = -3 dB))

Figure 2.9 Performance comparisons of the channel impulse response for path one



(a) Original channel impulse response of path two

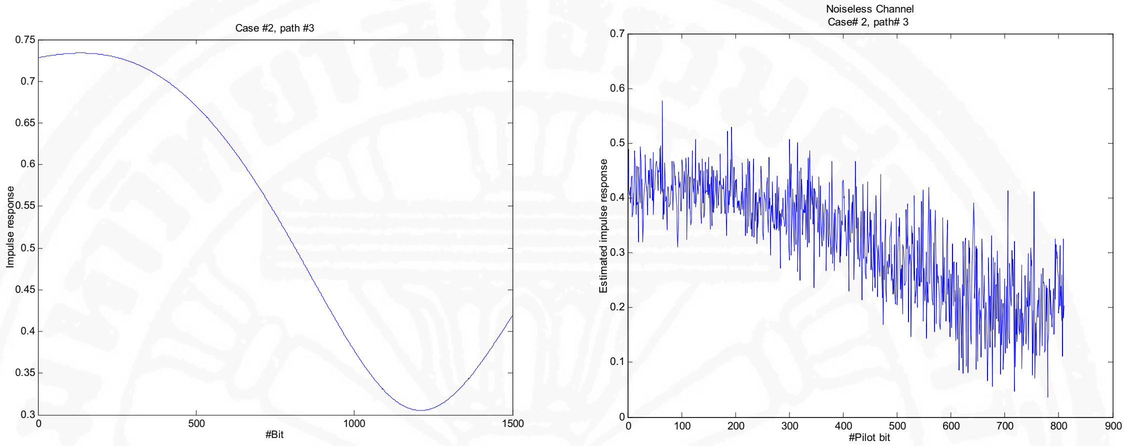
(b) Estimated impulse response of path two (noiseless channel))



(c) Estimated impulse response of path two (SNR = 9 dB)

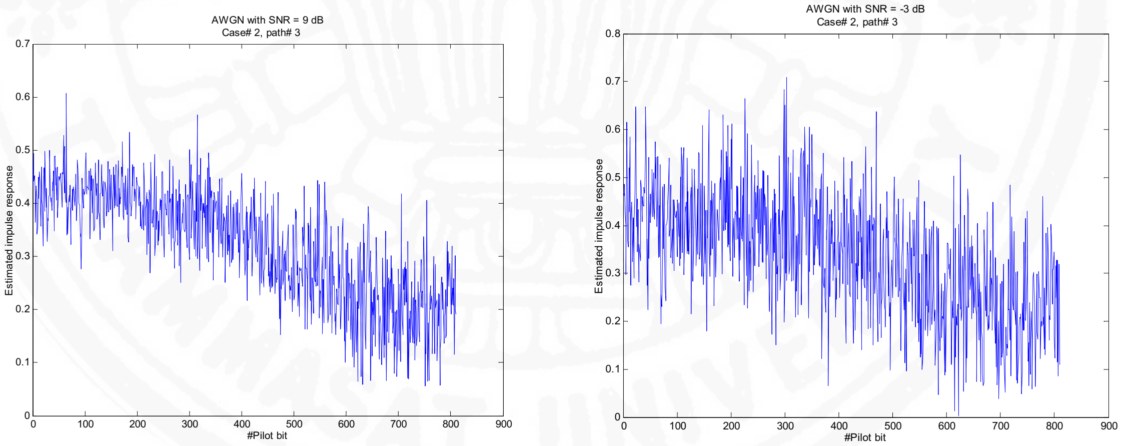
(d) Estimated impulse response of path two (SNR = -3 dB))

Figure 2.10 Performance comparisons of the channel impulse response for path two



(a) Original channel impulse response
of path three

(b) Estimated impulse response
of path three (noiseless channel))



(c) Estimated impulse response
of path three (SNR = 9 dB)

(d) Estimated impulse response
of path three (SNR = -3 dB))

Figure 2.11 Performance comparisons of the channel impulse response for path three

Table 2.6 BER for Dedicated Physical Data Channel of user 2

Bit Error Rate for DPDCH (I) Channel					
SNR	Speed	Information bit rate (kbps)			
(dB)	(km/hr)	12.2	64	144	384
$SNR_1 = SNR_2 = -3$	0	0.0022	0.0032	0.0265	0.0760
	40	0.0129	0.0514	0.0890	0.1123
	80	0.0177	0.0415	0.0703	0.1260
	120	0.0215	0.0503	0.0947	0.1379
$SNR_1 = SNR_2 = 9$	0	0.0022	0.0022	0.0022	0.0252
	40	0.0037	0.0164	0.0205	0.0309
	80	0.0175	0.0099	0.0266	0.0712
	120	0.0106	0.0195	0.0394	0.0532
$SNR_1(9dB) > SNR_2(6dB) = 3$	0	0.0112	0.0457	0.0039	0.0847
	40	0.0062	0.0167	0.0543	0.1013
	80	0.0073	0.0277	0.0847	0.1190
	120	0.0160	0.0532	0.0831	0.1613
$SNR_1(-3dB) > SNR_2(-6dB) = 3$	0	0.0631	0.1529	0.0479	0.1969
	40	0.0412	0.0967	0.1995	0.2982
	80	0.0444	0.1158	0.1989	0.2682
	120	0.0677	0.1470	0.1991	0.3002

Table 2.7 BER for Dedicated Physical Control Channel of user 1

Bit Error Rate for DPCCH (Q) Channel					
SNR (dB)	Speed (km/hr)	Information bit rate (kbps)			
		12.2	64	144	384
$SNR_1 = SNR_2 = -3$	0	0.0022	0.0000	0.0055	0.0037
	40	0.0119	0.0090	0.0060	0.0060
	80	0.0209	0.0187	0.0090	0.0231
	120	0.0228	0.0273	0.0254	0.0115
$SNR_1 = SNR_2 = 9$	0	0.0022	0.0022	0.0000	0.0022
	40	0.0126	7.4627e-4	7.4627e-4	0.0082
	80	0.0172	0.0045	0.0045	0.0067
	120	0.0437	0.0254	0.0154	0.0149
$SNR_1(9dB) > SNR_2(6dB) = 3$	0	0.0022	0.0022	0.0000	0.0022
	40	0.0022	0.0037	0.0015	0.0022
	80	0.0067	0.0052	0.0030	0.0045
	120	0.0142	0.0097	0.0179	0.0060
$SNR_1(-3dB) > SNR_2(-6dB) = 3$	0	0.0022	0.0022	0.0179	0.0022
	40	0.0097	0.0104	0.0067	0.0060
	80	0.0134	0.0134	0.0097	0.0127
	120	0.0254	0.0224	0.0343	0.0157

Table 2.8 BER for Dedicated Physical Control Channel of user 2

Bit Error Rate for DPCCH (Q) Channel					
SNR	Speed	Information bit rate (kbps)			
(dB)	(km/hr)	12.2	64	144	384
$SNR_1 = SNR_2 = -3$	0	0.0022	0.0022	0.0022	0.0022
	40	0.0037	0.0104	0.0060	0.0030
	80	0.0112	0.0097	0.0090	0.0140
	120	0.0194	0.0157	0.0254	0.0112
$SNR_1 = SNR_2 = 9$	0	0.0022	0.0022	0.0022	0.0022
	40	0.0022	0.0037	0.0015	0.0022
	80	0.0127	0.0045	0.0030	0.0045
	120	0.0134	0.0067	0.0157	0.0052
$SNR_1(9dB) > SNR_2(6dB) = 3$	0	0.0037	0.0037	0.0000	0.0022
	40	0.0052	0.0015	7.4627e-4	0.0082
	80	0.0119	0.0052	0.0045	0.0067
	120	0.0201	0.0201	0.0246	0.0172
$SNR_1(-3dB) > SNR_2(-6dB) = 3$	0	0.0201	0.0209	7.4627e-4	0.0030
	40	0.0179	0.0134	0.0142	0.0321
	80	0.0246	0.0187	0.0269	0.0269
	120	0.0463	0.0388	0.0410	0.0507