# Chapter 5

# Conclusions

## 5.1 Summary of Contribution for Base Station Receiver

1) Modification of correlation algorithm in the Multipath searcher.

2) Threshold selection algorithm in the Multipath searcher.

3) Complete base station receiver algorithms.

4) Modification of average block in the WMSA channel estimation.

5) Hardware optimization by using VHDL codes in the complete base station receiver.

6) System performance evaluation.

### 5.1.1 Summary of Multipath Searcher Algorithm

Multipath searcher has a duty to find multipath delay of signal and supply to each finger of rake receiver. Multipath searcher working uses the correlation principle of signal. If both signals have the same appearance at any time, it will result of correlation which is the highest peak at that time. Index time that has a peak will perform the time delay which arrives to the receiver from different ways or called multipath delays.

According to the simulation in chapter 3, the relative mean power which has much differences (e.g. -10 dB less than the highest peak), so the multipath searcher can be found only the first path (highest peak). Also, in case of the relative mean power is less than -6 dB; this algorithm cannot detect paths correctly. In some cases that the delay of each path is very closed to the others; then the peak will conflict to the other peaks beside. And the performance of the multipath searcher is not depending on the signal to noise ratio.

### 5.1.2 Summary of Rake Receiver and Channel estimator Algorithms

Rake receiver is a diversity receiver which can utilize from random nature of radio propagation using for collecting and summing the received signal from many paths.

Channel estimator is the core part in the rake receiver which has a duty to estimate the channel impulse response of each signal that found from path searcher. In WMSA schemes, the more slots are used for channel estimate, the stronger the ability of reducing noise is, however the weaker the capability of tracking channel variation is. Therefore, WMSA scheme should be selected depending on channel variation speed. For certain WMSA scheme, the performance first improves and then degrades as the Doppler frequency shift increases. In the case that the number of rake fingers is less than the number of resolvable paths, BER increases as the number of finger decreases. The simulation results in chapter 3 were obtained without power control. These results illustrate qualitatively the impacts of rake and channel model on link performance. These numerical results may vary depending on the fading model (e.g. Rayleigh or Rician), interleaving size, and channel coding method.

The performance of the rake receiver mainly depends on the signal-to-noise ratio (SNR) in the system. The tap size of the WMSA should be selected depending on channel variation speed because the performance degrades as the Doppler speed increases. And in case that the number of rake fingers are less than the number of resolvable paths, bit error rate (BER) increases because the remaining paths become self-interference.

### 5.1.3 Summary of The Hardware Performances

The reason of using FPGA board is that it is employing VHDL codes which are comfortable to be reused, so it can be changed and corrected like a software program. It has ability to support both transmission and reception at rate of 3.84 Mchip/sec which is the standard for WCDMA system and it also has faster computation than DSP board (DSK) in case of correlation, multiplication, and summation.

The performances when SNR is 9 dB, the fixed point are always worse than floating point. While the information bit rate are 144 kbps and 384 kbps, with SNR of -3 dB the performances of fixed point are greater than floating point.

Since our algorithms did not use the interleaving, an algorithm which has ability to estimate the power of the transmitted signal, and turbo code, therefore we assumed that it is acceptable for single user detection when bit error rate is not greater than 5%, so when the information bit rate are 12.2 kbps, 64 kbps, and 144 kbps, each receiver has ability to support the speed of the users up to 160 km/hr while at rate of 384 kbps; each receiver can be supported up to 120 km/hr. For multi-user detection, 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.

## 5.2 Summary of Contribution for SIR Estimators

1) Improve the performance of the SIR estimator by employing the post processing stage.

2) Performance comparisons among filters used in the post processing stage.

### 5.2.1 Conclusion of SIR Estimators

Conventional SIR estimator estimates the SIR by averaging the received pilot symbols over a fixed interval of one slot regardless of the channel condition. While the adjustable SIR estimator improves the estimation by considering the signals in the adjacent slots; it is desirable that the number of slots is adjusted in response to the channel condition. And the post-processing stage, a filter is applied at the post processing to further smooth out the estimation error occurred at the estimator output.

The adjustable SIR estimate scheme with the post-processing stage has been presented as an alternative to the estimation of SIR in WCDMA mobile system. It has been proposed on ground that it could improve the estimation accuracy because it is the much smoother estimate and thus a large reduction of the estimation error which is reducing the root mean square error. It is noted that the average in the post-processing stage is done and the tap size $N$ has to be considered after adding any filters.

- Moving Average Filter: This non-causal FIR filter which window size, $W$, could be adjusted according to the channel condition. It gives the best performance among the filters considered in this thesis, but it needs to use a filter per each channel condition.

- Exponential Moving Average Filter: This causal filter depends on the weight parameter, $w$. It gives the worst performance among filters considered in this thesis and it needs to use a filter per each channel condition as the MA filter. However, it requires the lowest implementation complexity.

- IIR Filters: These kind of filters depend on the filter coefficients (e.g. order and normalized cut-off frequency). From the simulations and the lookup table, almost of order $X$ for all kind of IIR filters are in low order (i.e. $1^{st}$ order or $2^{nd}$ order). Since each of IIR filter, the minimum root mean square values are almost the same (i.e. Table 3.5-3.7), for the sake of convenient, therefore the Butterworth filter is used. It gives the better performance than EMA but worse than MA and LMS and it also has to use one filter per one channel condition either.

- Least-Mean-Squared Adaptive Filter: After the possibility of using an adaptive filter for SIR approximation is studied, then the results of the experiment that an adaptive filter has rather than the same efficiency in estimating the value of signal-to-interference ratio (SIR). Actually, the errors produced from estimating SIR by using an adaptive filter are nearly equal to those produced by moving average filter at the optimum window size. At low Doppler frequency, the RMSE produced from the adaptive filter are slightly lower than those produced from the moving average filter and the RMSE increses as filter length $M$ decreases. The main advantages of LMS algorithm are
1) Simplicity of implementation.
2) Robust performance.
3) Small $\mu$, slow convergence, small steady-state excess RMSE.

Finally, an adaptive filter has many significant advantages over a moving average filter such as low computational complexity, and the ability of adapting itself to the changing environment without having to re-enter any parameters or it is said that for the LMS adaptive filter; the lookup table is not needed and it can be implemented only one filter for every channel condition.

## 5.3 Topics for Suggested Future Works

The following research topics can be considered as the topics for suggested future works.

1) Hardware interface testing between base station and baseband processing with 2 users communicating to the base station.

The propose of the future works is to use in a real time environment. Since the base station employs the input parameters from the baseband processing and send the output data back to the baseband processing unit; the parameters are shown in Table 4.1, therefore the interface testing is needed. It is noted that the baseband processing is implemented on another FPGA board.

2) Hardware debugging.

Since our algorithms are tested by using VHDL codes that means self-testing for the codes are already corrected but not for the actual hardware, so when implementing on the final platform; the problems will occur in the hardware part such as in wireline, etc. and noise will be increased from interface testing between two FPGA boards. Then these problems must be carefully solved.

3) Improving the performance of the complete base station receiver system.

Because of the limitation of the hardware and the resource consumption shown in Table 4.2, so we can implement only two user transceivers on one FPGA board. Then optimizing the related algorithms is needed, especially for the channel estimator algorithm because the performance of the base station mostly depends on channel estimator part that means the better algorithm for the channel estimator, the better performance of the system.