# Part II. Synchronization

## 1. Time and Frequency Synchronization

According to the model we built in Part I, for transmitting side and receiving side, both the carrier frequency and sampling rate are generated locally. As a result, there are mainly two factors concerning the synchronization of the communication:

* The carrier frequency offset (CFO) and sampling clock offset(SCO). Assuming the carrier frequency at the TX end is and sampling time is , at the receiving end, CFO and SCO would cause carrier frequency to be , and sampling time .
* Carrier phase error , and sample time shift , may also occur, since the TX and RX are physically in different places.

It could be shown that the effect of synchronization could be adapted to baseband as following model:



*figure 1 Baseband model for synchronization*

In this study, firstly, we demonstrate the impact of the synchronization errors by adding the errors to our baseband model and show the result of simulation. Then synchronization algorithms are designed and applied to improve the performance of the communication considering the effect of synchronization.

## 2. Impact of the synchronisation errors

### 2.1 Impact of phase offset and CFO

The receive signal r(t) could be expressed as , considering the effect of CFO and phase shifting, according to the model in part 1 the signal could be written as

The effect could be observed in constellations plot and in the BER performance as well. Considering the phase shift only, if could be observed from figure 2 that the receiving symbol is rotated by the same angle. The CFO and phase shift together contributes to the ISI effect and degrading the BER performance, which is simulated and showed in figure 3. From the result, we could find that after some point the phase shift is too large for the receiver to reconstruct the symbol, which dominates the performance of the receiver, larger EbN0 over the channel would not help increase the BER.



*figure 2 16QAM with phase offset pi/8 figure 3 16QAM with phase offset BER performance*

Simulating the ISI effect caused by the CFO, the result is showed in figure 4, where we could find that for 16QAM, CFO causes a great performance degrading especially when the EbN0 is large, which indicates the CFO dominates the BER when the channel noise is small.



*figure 4 16QAM with CFO BER performance*

### 2.2 Time shift and SCO

The time shift and SCO cause a sampling shift and would in further generate the ISI. Analytically, the model could be expressed as:

The effect of the time shifting could be observed in figure 5, the performance degraded with the increase of the time shift as the ISI is becoming more profound.



*figure 5 16QAM with time shift BER performance*

## 3. Gardner Algorithm

Synchronization structures are proposed to synchronize the communication system, depending on whether known data symbols are sent at the transmitter, the synchronizer could be classified as data aided(DA) and non data aided(NDA) synchronization.

Basically, the signal at the RX end could be expressed as:

where I stands for the symbol, n is the noise over the channel, and is the synchronization parameters. In this study, we applying a NDA method, to carry out the Maximum Likely (ML) estimation for the

In this study, we specifically applying the feedback loop of Gardner algorithm to give the ML estimation of time error, which is supposed to be only caused by time shift t0 without SCO. The algorithm is described as following:

## 4. Key-Points:

### 4.1 Simulation Concerning

1) Derive analytically the baseband model of the channel including the synchronisation errors.

Please refer to Part 1, for analytical expression, please refers to the Equation in part2.1 and 2.2.

2) How do you separate the impact of the carrier phase drift and ISI due to the CFO in your simulation?

3) How do you simulate the sampling time shift in practice?

4) How do you select the simulated Eb/N0 ratio?

5) How do you select the lengths of the pilot and data sequences?

4.2

1) In which order are the synchronisation effects estimated and compensated. Why?

2) Explain intuitively how the error is computed in the Gardner algorithm. Why is the Gardner algorithm robust to CFO?

3) Explain intuitively why the differential cross-correlator is better suited than the usual cross-correlator? Isn’t interesting to start the summation at k = 0 (no time shift)?

4) Are the frame and frequency acquisition algorithms optimal? If yes, give the optimisation criterion.