COMPNESATION OF SYMBOL CLOCK OFFSET AND CARRIER FREQUENCY OFFSET IN THE MULTI-BAND DFT SPREADING OFDM SYSTEM

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CONTENTS

1st Introduction

Spectrum Aggregation

- For the next generation mobile communication, the bandwidth of 100MHz for the transmission speed of 1Gbit/s are required.

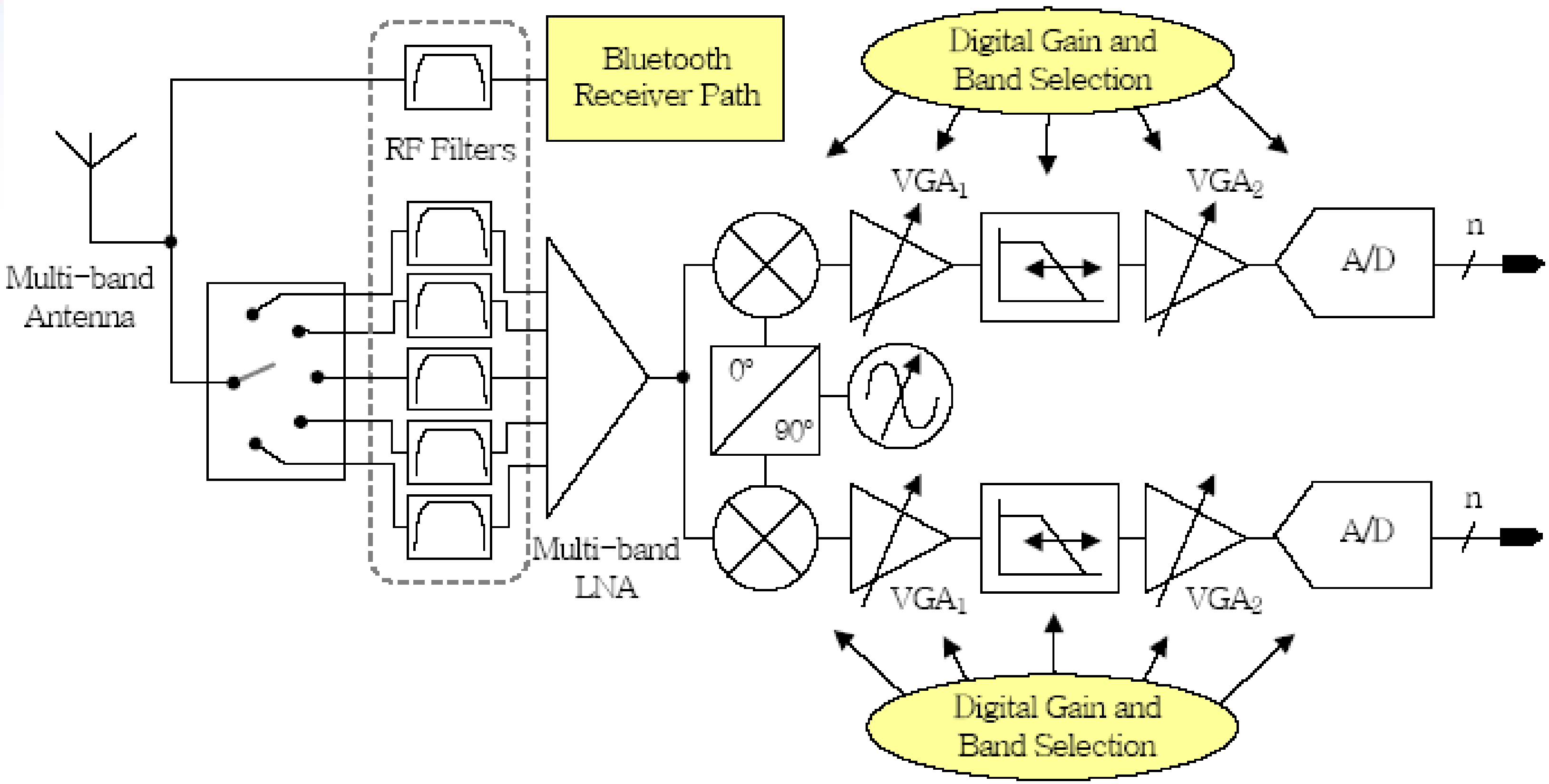
- Due to the shortage of the frequency bandwidth, it is basically impossible to get continuous frequency channels.

- So, Spectrum aggregation is necessary technique, and receiver should have simultaneous muti-band signal processing capability even over the non-contiguous frequency bands.

What kind of problems occur?

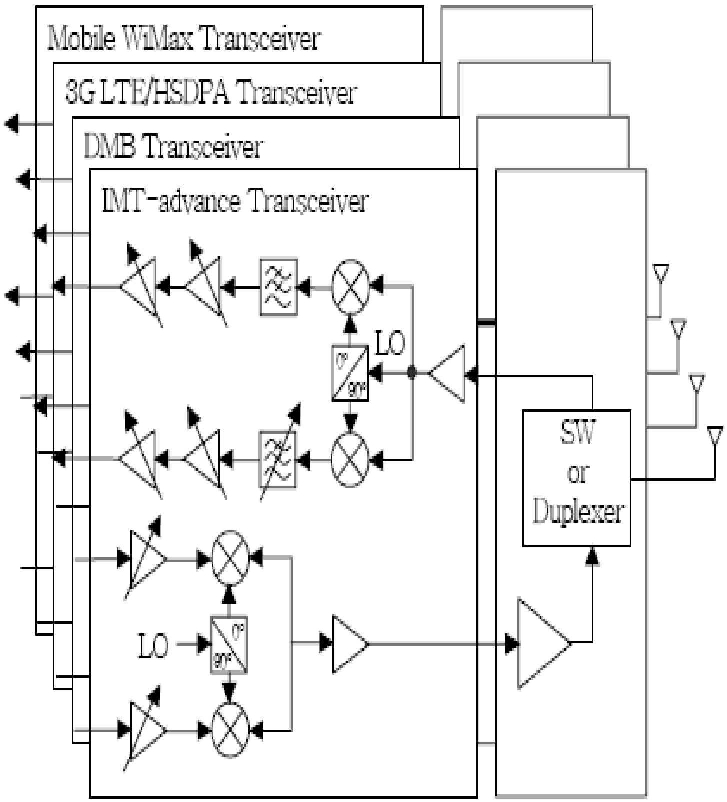
- Multiband receiver based on the TDM method are vulnerable to the interferences from the symbol timing error, sampling clock offset and carrier frequency offset and phase noise problems.
- Block size for the IDFT and DFT should be increased according to the number of multiple bands.
- System performance become degraded by symbol timing error, sampling clock offset , phase noise and carrier frequency offset.
- Estimation and compensation in each bands is very important.

Already existing researches



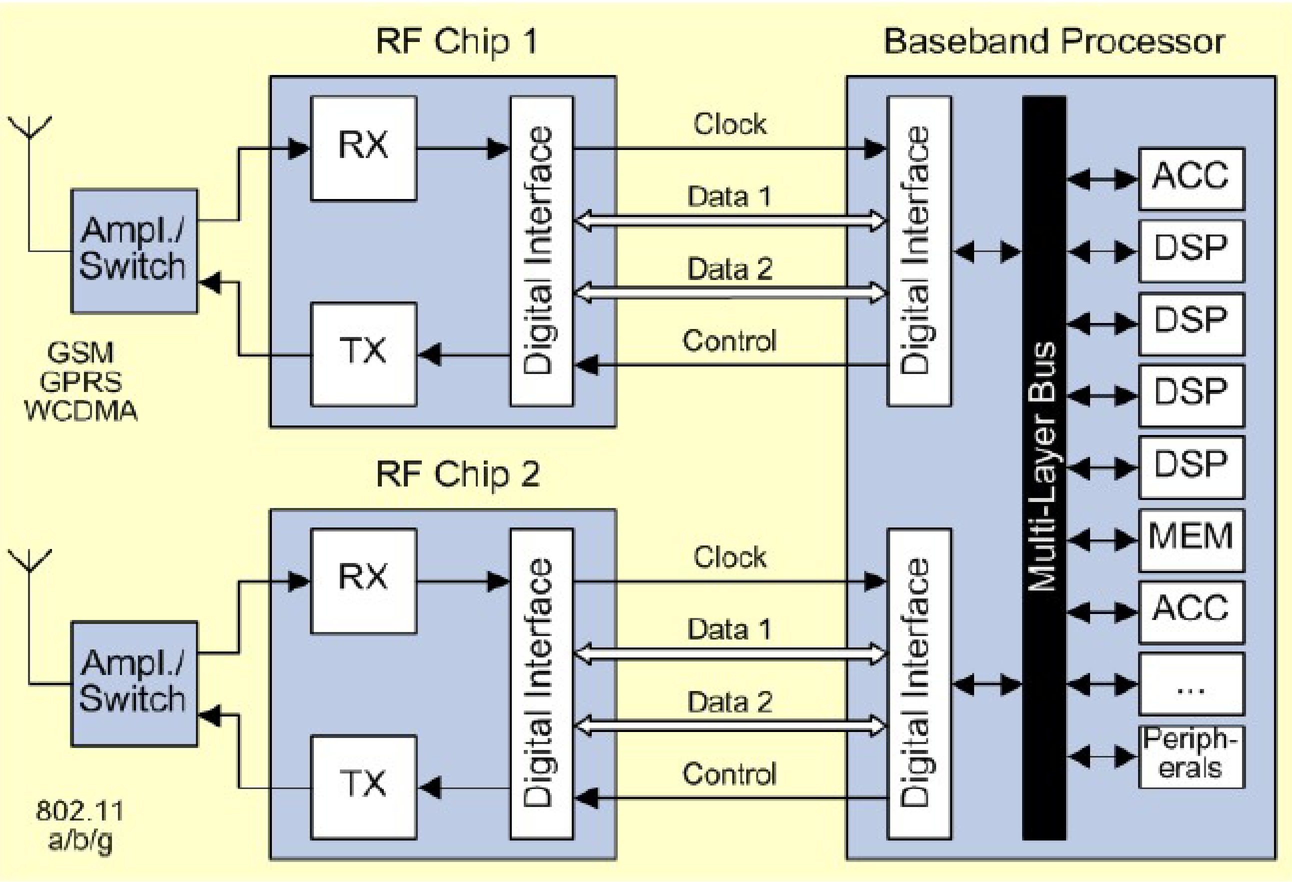
Multi-Chain Receiver Structure

Multi-Chain structure



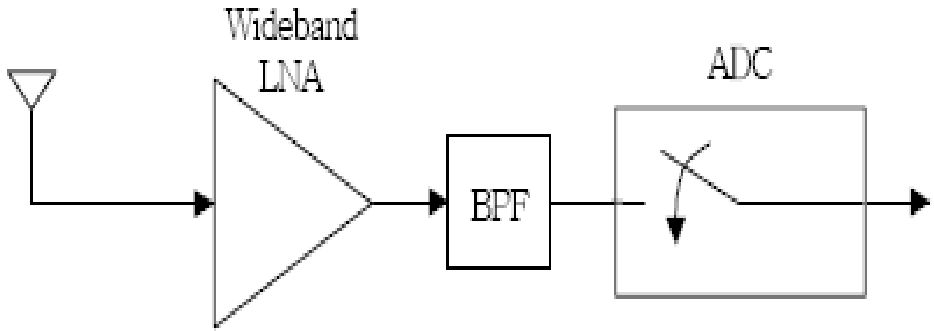
- Integrated circuits of the existing circuit.
- Easy to make multi-band receiver.
- Inefficient power
- limitation of integration and increasing the number of path.
- Difficult to be small size.

Already existing researches



Multi-standard radio system

SDR receiver structure for receiving multi-band



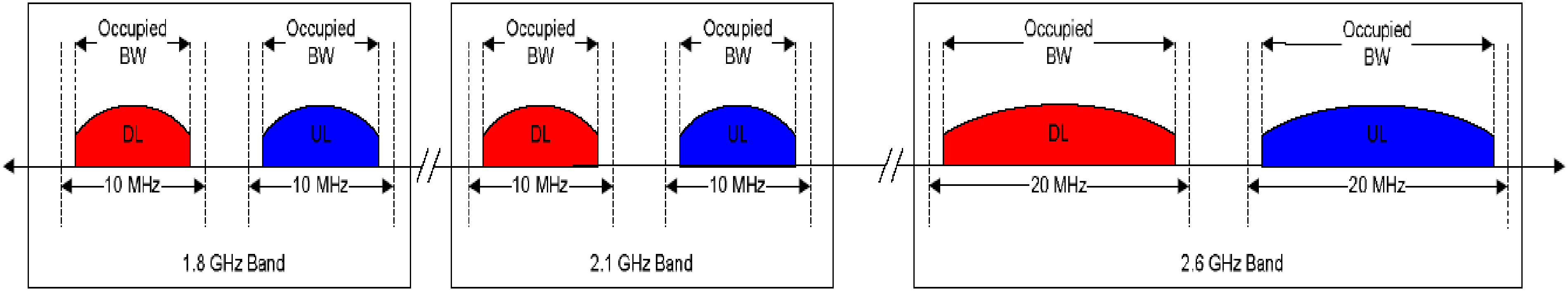
- Sample RF signals without down-converting.
- Complicated process for multi-band signals.
- It needs very fast ADC.
- Difficult to implement currently.
- Digital IF structure is another possibility.

LTE Carrier Aggregation

LTE-Advanced DEPLOYMENT SCENARIOS

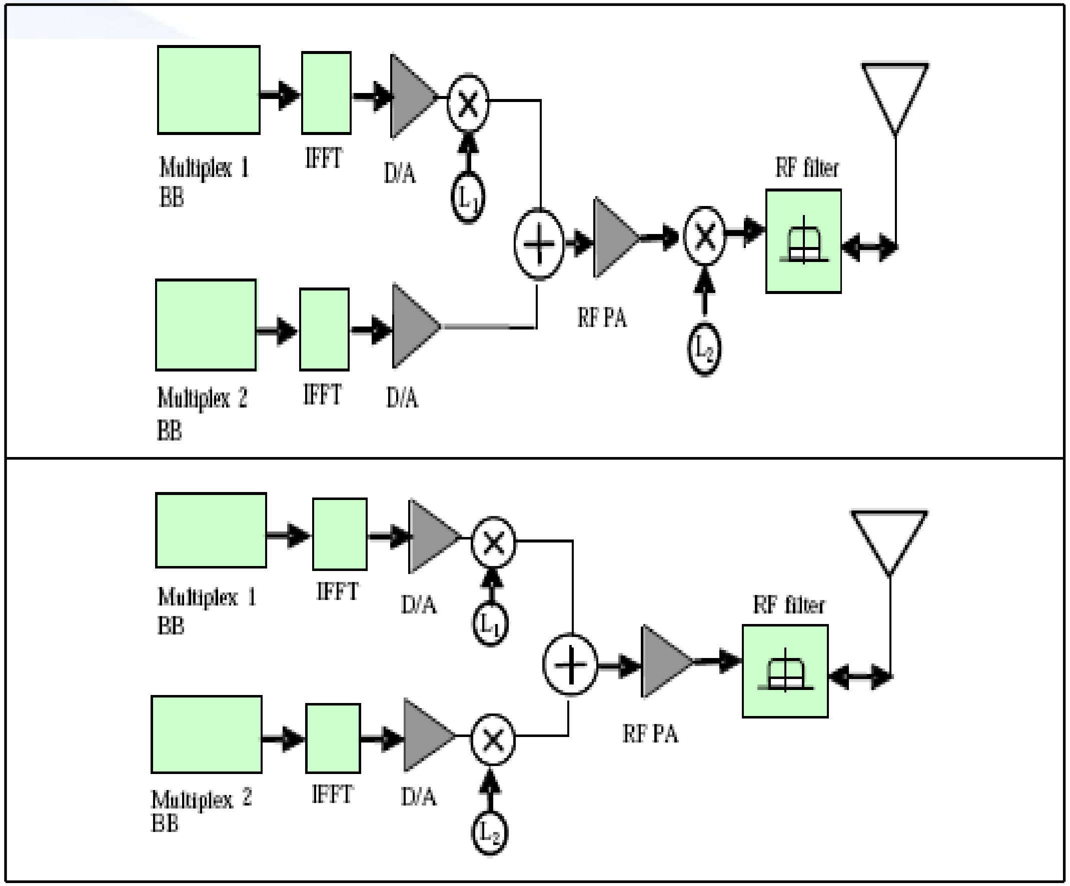
FDD	Contiguous single band, UL: 40 MHz DL: 80 MHz	UL: 2x20 MHz (3.5 GHz) DL: 4x20 MHz (3.5 GHz)
	Non-contiguous multiple bands, UL: 40 MHz DL: 40 MHz	UL: 10 MHz (1.8 GHz) + 10 MHz (2.1 GHz) + 20 MHz (2.6 GHz) DL: 10 MHz (1.8 GHz) + 10 MHz (2.1 GHz) + 20 MHz (2.6 GHz)
TDD	Contiguous single band, 100 MHz	5x20 MHz (2.3 GHz)
	Non-contiguous single band, 80 MHz	2x20 MHz (2.6 GHz) + 2x20 MHz (2.6 GHz)

LTE Carrier Aggregation



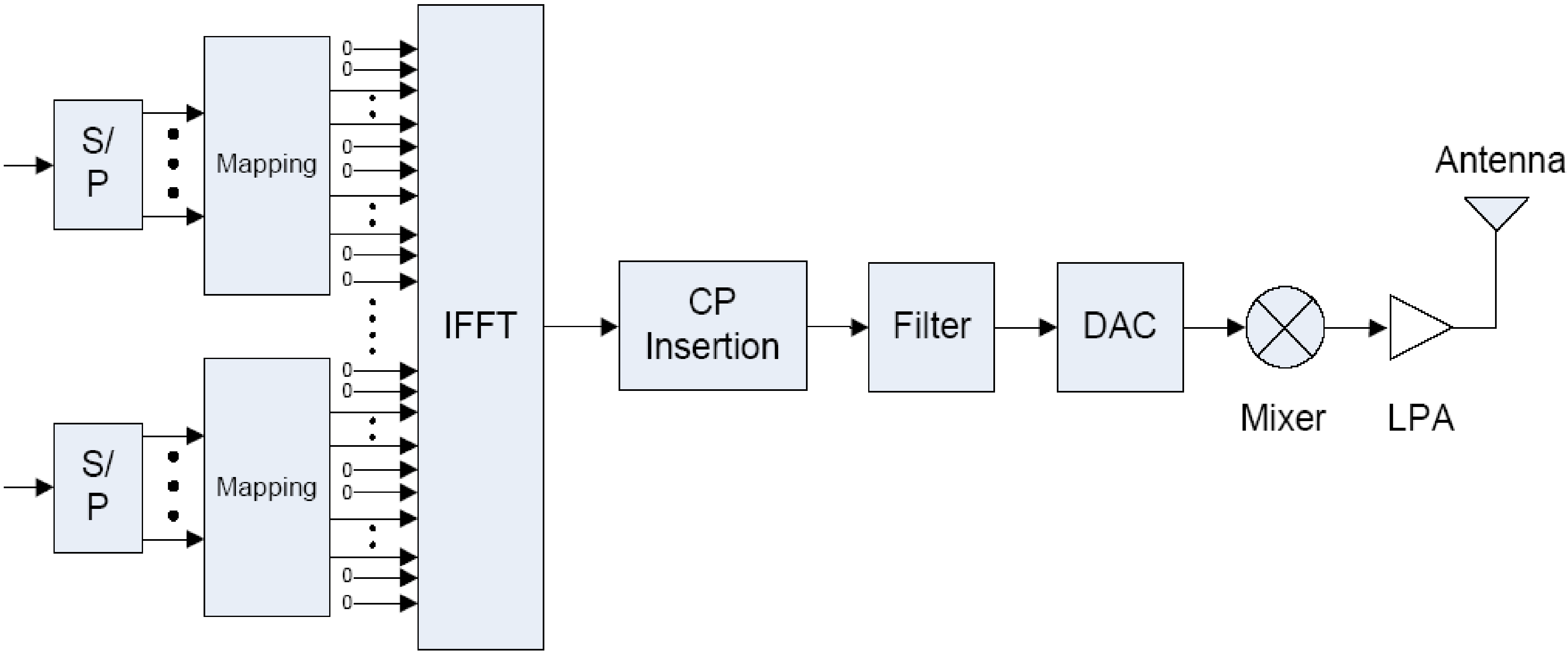
Non-contiguous FDD deployment over multiple bands.

LTE Transmitter architecture models



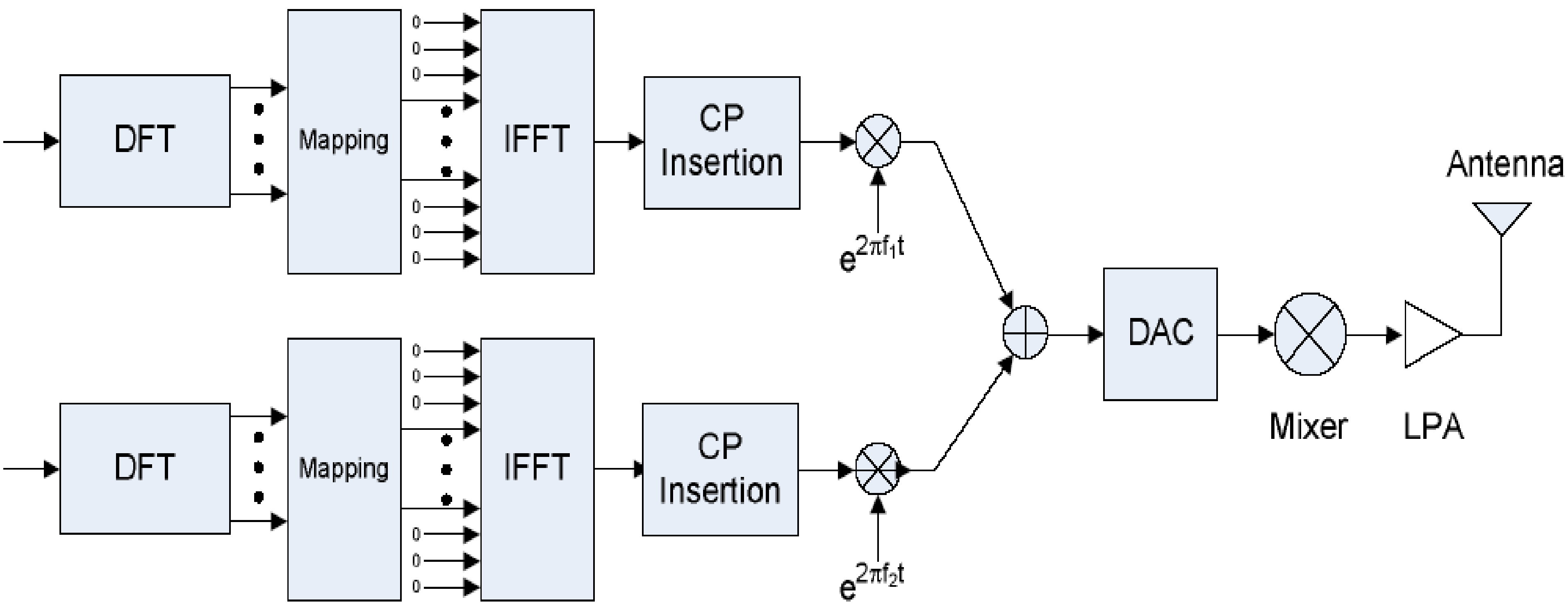
- When the component carrier is **contiguous or non-contiguous**, the feasibility architecture is like this.
- These architectures have two DAC, two mixer, and one PA.

LTE Carrier Aggregation



Transmitter block diagram for downlink carrier aggregation

LTE Carrier Aggregation



Transmitter block diagram for uplink carrier aggregation

2nd System Model and RF Impairment

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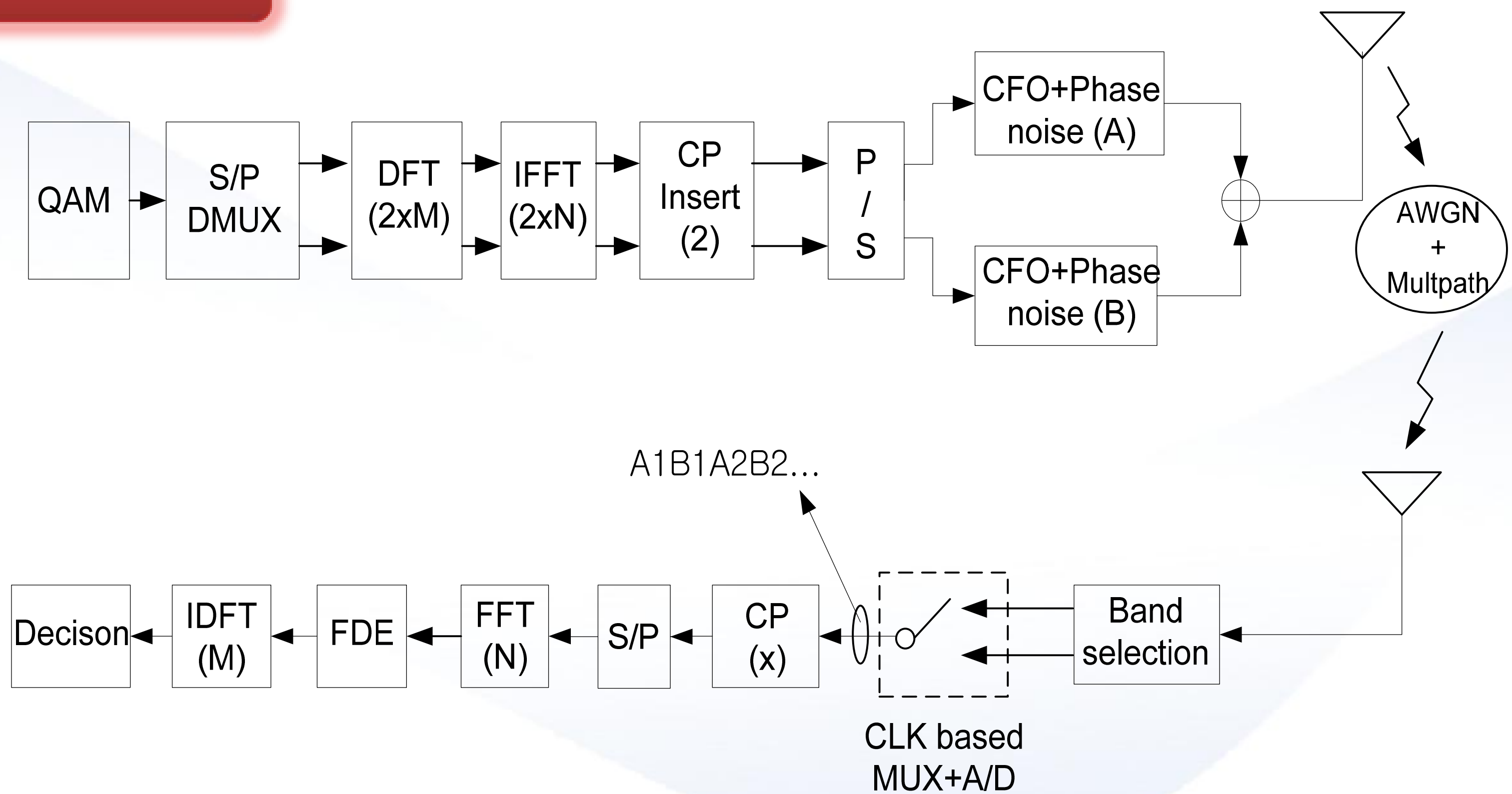
System Model



Multiband DFT spreading OFDM communication system (Uplink)

Phase noise

- **Phase noise is generated at the oscillators of transceiver**

❖ It occur around the carrier frequency. It is made by cross product component

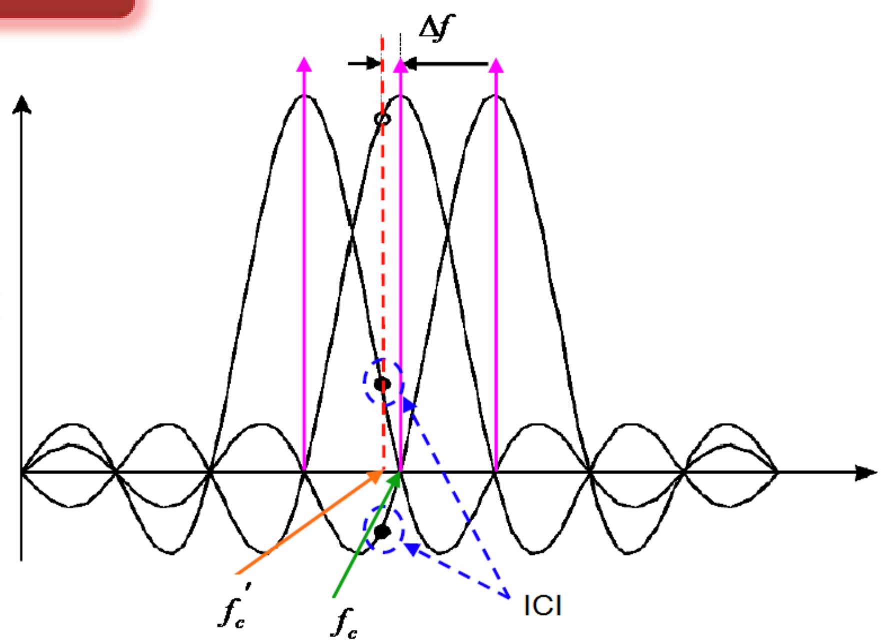
- **General phase noise model**

❖ Lorentzian model : PSD = $\dfrac{1/(\pi \cdot f_{3dB})}{1+ f^2 / f_{3dB}^2}$

❖ Phase noise variance : $\sigma_\phi^2 = \int_{-b}^{+b} \left(\dfrac{N_{op}}{C} \right)_f df = \int_0^b \left(\dfrac{2N_{op}}{C} \right)_f df \quad rads^2$

❖ PSD to carrier ratio of phase noise : $(N_{op} / C)_f \, [dBc]$

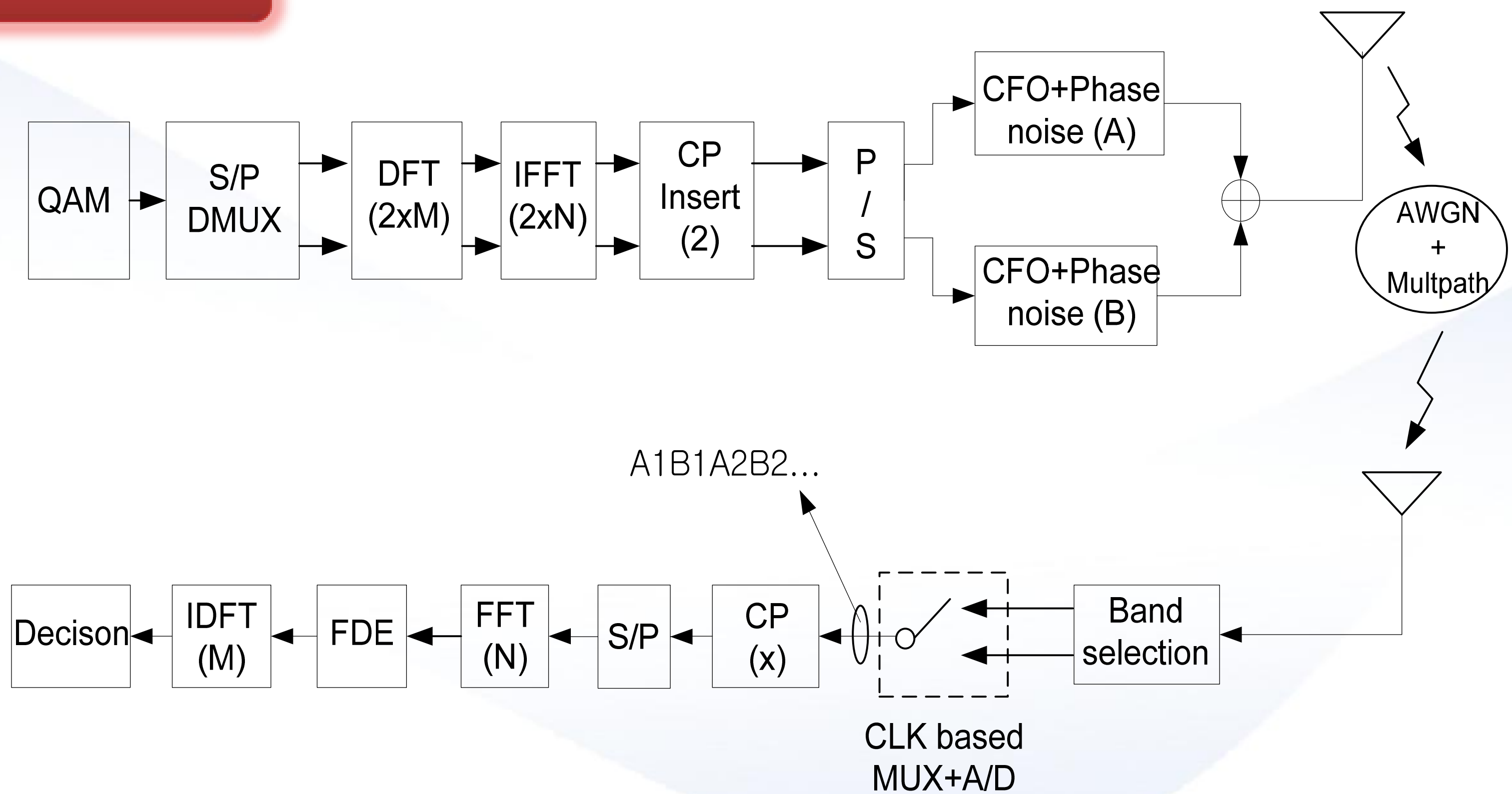
Frequency offset : FO



Effect of frequency offset

- FO: Difference of LO between transceiver and receiver
- Normalized frequency offset : $\varepsilon = (f_c - f_c')T$

System Model



Multiband **DFT spreading** OFDM communication system

Signal Distortion

- Each band has different frequency offset and phase noise.

$$x(t) = \begin{cases} \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^A e^{j\left(\frac{2\pi k}{N} + f_A\right)t}, & x_A(t) \\ \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^B e^{j\left(\frac{2\pi k}{N} + f_B\right)t}, & x_B(t) \end{cases}$$

- Influence of phase noise and frequency offset: $e^{j(2\pi(L+\varepsilon)n/N+\theta(n))}$
- Normalized frequency offset: $\varepsilon = \Delta f T$
- T is symbol period, $\Theta(n)$ is phase noise.
- For convenience, $2\pi(L+\varepsilon)n/N+\theta(n)=\Phi(n)$ is used.

Signal Distortion

- If $\Phi(n) << 1$ in frequency domain, CPE and ICI are expressed as follows

Received signal : $$Q_L = \frac{1}{N}\sum_{n=0}^{N-1} e^{j\frac{2\pi}{N}Ln} \cdot (1 + j\Phi(n))$$

CPE : $$Q_0 = 1 + \frac{j}{N}\sum_{n=0}^{N-1} \Phi(n)$$

ICI : $$Q_{l-k} = \frac{j}{N}\sum_{n=0}^{N-1} e^{j\frac{2\pi}{N}(l-k)n} \cdot \Phi(n)$$

Signal Distortion

- Transmitting signal including phase noise and frequency offset :

$$s(t) = x_A(t)\cdot e^{j\Phi_A(t)} + x_B(t)\cdot e^{j\Phi_B(t)}$$

- Sampled data of received signal: $r(n) = s(n)\otimes h(n) + v(n)$
- After band selection by filtering received signal, the received signal at k-th subcarrier is represented as below because there is no X_B signal during transmission time of X_A. (**symbol timing offset**: δ_A)

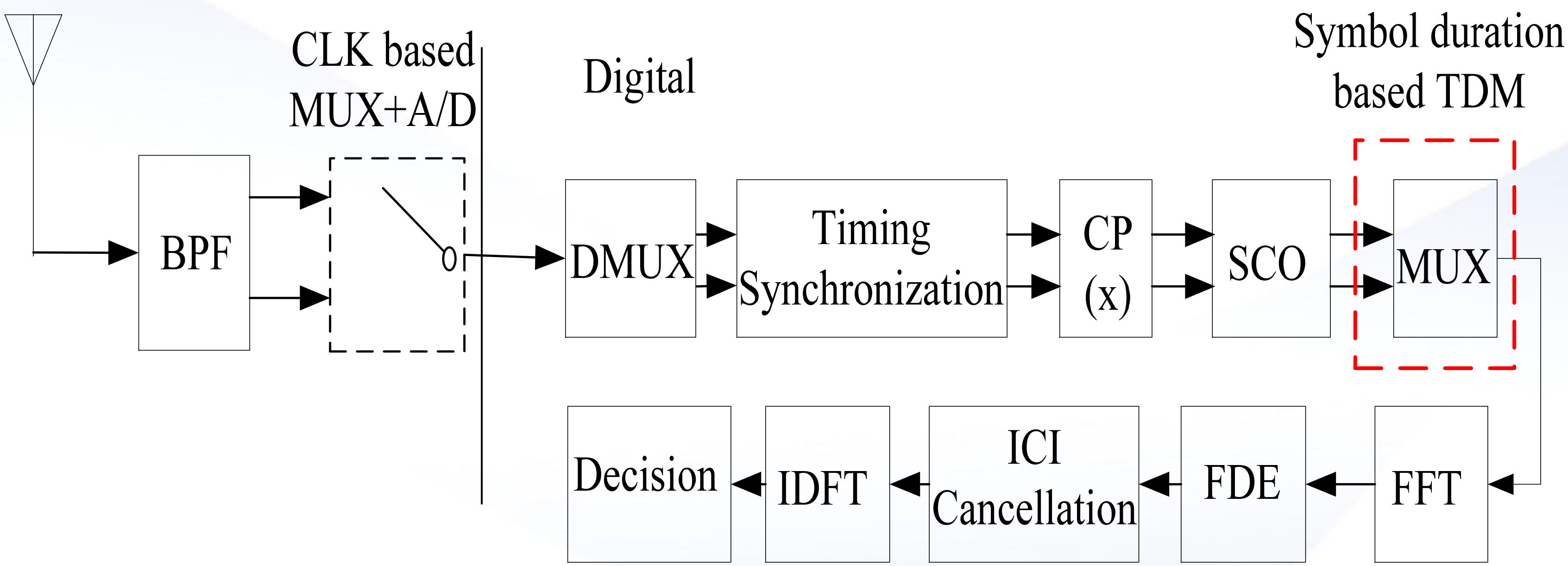
$$Y_k^A = \frac{1}{N}\sum_{n=0}^{N-1} r_A[n]\cdot e^{-j\frac{2\pi}{N}kn}$$

$$= \frac{1}{N}\sum_{n=0}^{N-1}\{x_A(n)\cdot e^{j\Phi_A(n)}\otimes h(n) + \upsilon_A(n)\}\cdot e^{-j2\pi(n+\delta_A)/N}\cdot e^{-j\frac{2\pi}{N}kn}$$

$$= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{i=0}^{N-1} X_i^A\cdot H_i\cdot e^{j\left[\frac{2\pi}{N}n\{(i-k)+\Phi_A(n)+\delta_A\}\right]} + N_k$$

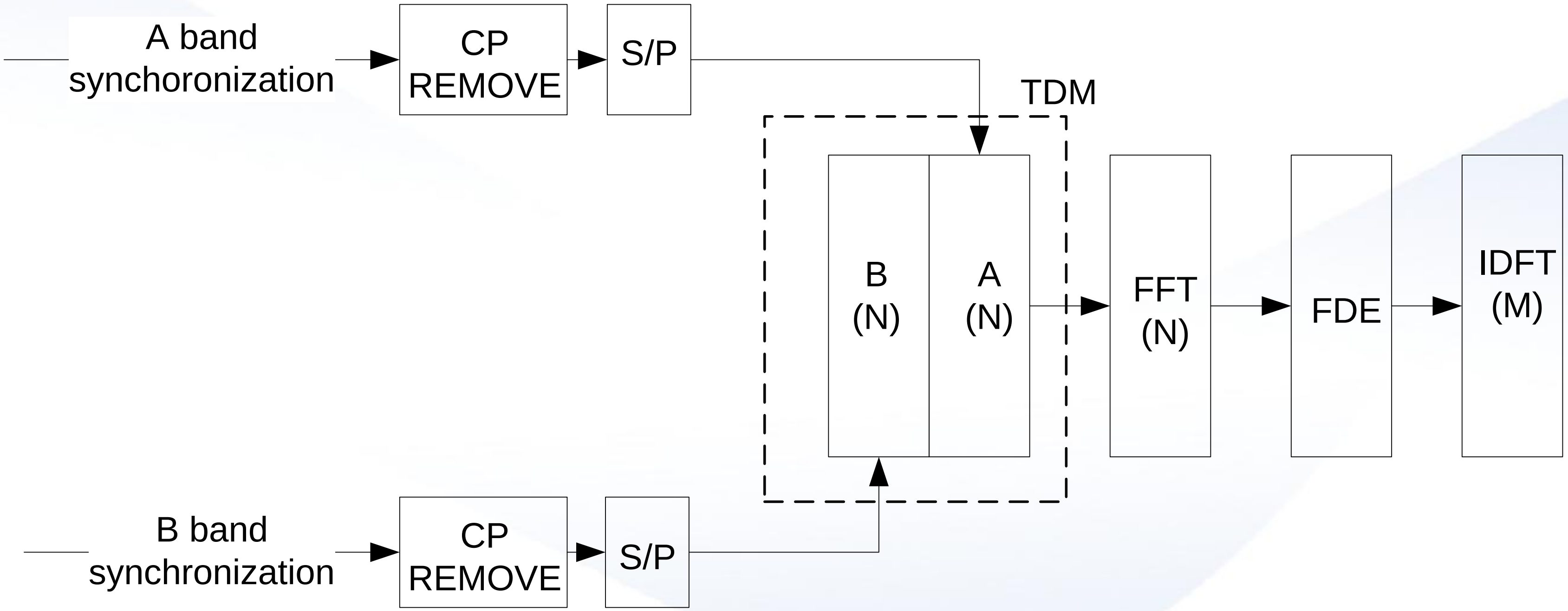
3rd Symbol Synchronization and Proposed Single Chain Receiver

Proposed Multiband DFT Spreading OFDM Receiver



Block diagram of proposed DFT spreading OFDM receiver for multiband communication

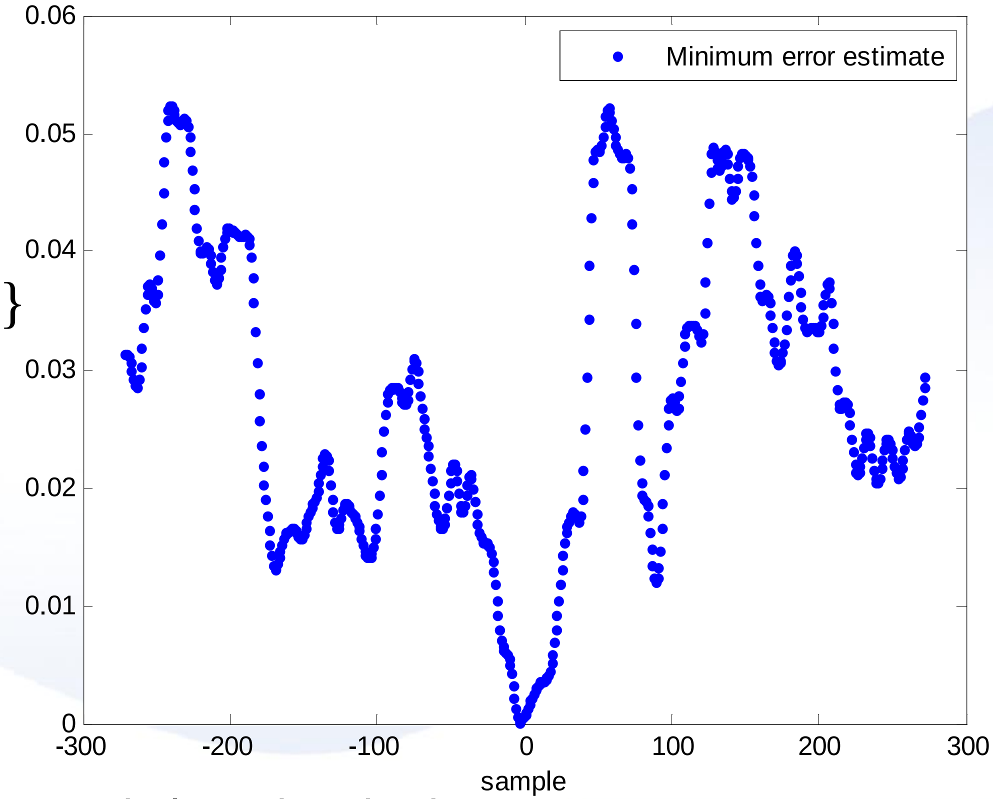
Proposed TDM for single chain receiver



Symbol Timing Synchronization

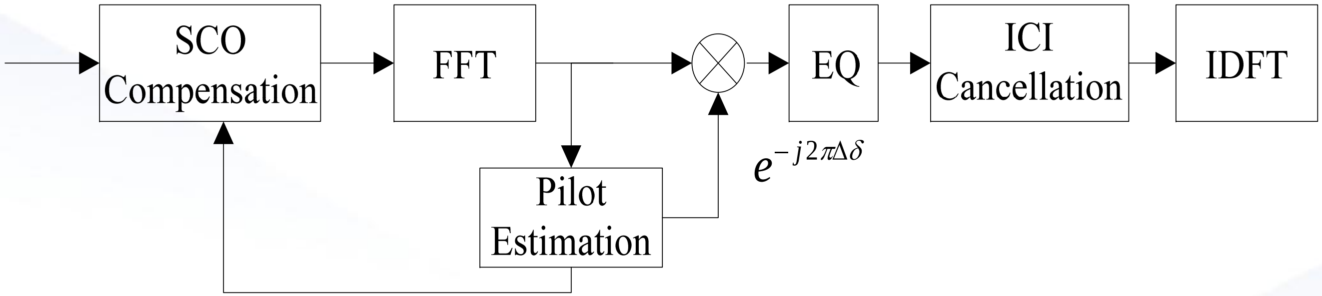
- Step 1) **estimate and compensate the symbol timing offset** by using cyclic prefix.

$$\hat{\delta} = \arg\min_{\delta} \left\{ \sum_{i=\delta}^{N_G - 1 + \delta} \left| r^A[n+i] - r_l^{A^*}[n+N+i] \right|^2 \right\}$$



Estimation of OFDM Symbol synchronization

Sampling Clock Offset



Estimation and Compensation of sampling clock offset.

- Step 2) **estimate** clock offset in frequency domain by using training symbol and compensate clock offset.

$$P_k = P(k) \cdot e^{-j2\pi k\Delta\delta / N}$$

$$P_{offset} = \sum P_k P_{k+2}^* \approx \sum |P|^2 \cdot e^{j\pi\Delta\delta}$$

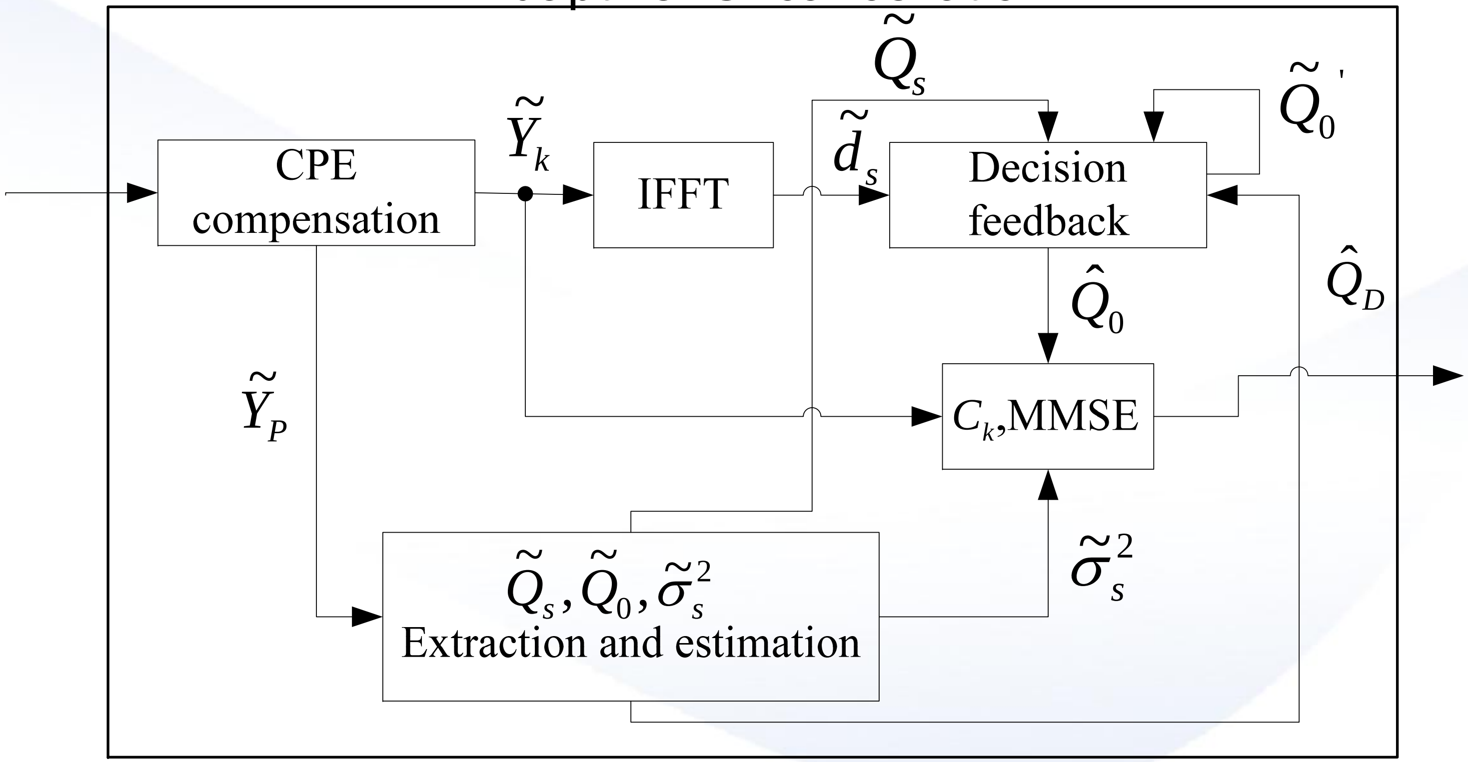
$$\Delta\delta = \arctan\left(\frac{\mathrm{Im}(P_{offset})}{\mathrm{Re}(P_{offset})}\right) / \pi$$

- Step 3) **estimate and compensate** the residual clock offset using pilot of received signal after FFT.

4rd Estimation and Compensation of Phase noise and Frequency offset

ICI Cancellation

Adaptive ICI cancellation



- Extraction and compensation of phase noise and frequency offset

ICI Cancellation Process

Step 1. We calculate the CPE by comb type pilot and find the **average CPE component,** r_{cpe} .

$$CPE_k = \frac{Y_k}{X_k} = Q_0 + \frac{ICI + N_k}{X_k} = Q_0 + W_k \qquad (1)$$

$$r_{cpe} = \frac{1}{N_p} \sum_{k \in s_p} CPE_k = Q_0 + \left(\frac{X_p^{\#}}{X_p} \right) Q_0 + {}^{1}\!/\!{}_{N_p} \sum_{k \in s_p} W_k \qquad (2)$$

Step 2. Dividing by r_{cpe} , we **get removed the CPE from the received signal using (3) :** CPE compensation

$$\tilde{Y}_k = \left(X_k \cdot Q_0 + \sum_{\substack{l=0 \\ l \neq k}}^{N-1} X_l \cdot Q_{l-k} + V_k \right) / r_{cpe} = X_k \tilde{Q}_0 + W_{ICI+AWGN} \qquad (3)$$

ICI Cancellation Process

Step 3.

We calculate the step size, $\tilde{Q}_s$ by (4).

In order **to make equalizer criterion** from the pilot symbol without CPE.

And we compute the initial ICI component $\tilde{Q}_0$ and the initial detected data $\hat{Q}_D$ by (5) and (6).

We calculate $\tilde{\sigma}_s^2$ that is sum of estimated ICI and noise power by (7).

$$\tilde{Q}_s = \left(\frac{1}{N_P} \sum_{k \in s_p} \left| (Y_p - \tilde{Y}_p) \right| \right)^2 \qquad (4)$$

$$\tilde{Q}_0 = \frac{\sum_{k \in s_p} \tilde{Y}_p D_p^*}{\sum_{k \in s_p} \left| D_p \right|^2} \qquad (5) \qquad\qquad \hat{Q}_D = \frac{\sum_{s \in s_d} \tilde{d}_s d_s^*}{\sum_{s \in s_d} \left| d_s \right|^2} \qquad (6)$$

$$\tilde{\sigma}_s^2 = \frac{1}{N_P} \sum_{k \in s_P} \left| Y_P - \tilde{Y}_k \right|^2 \qquad (7)$$

ICI Cancellation Process

Step 4.

We plug the 4 estimated components, $\tilde{Q}_0$, $\tilde{Q}_s$,$\hat{Q}_D$ and $\tilde{\sigma}_s^2$ into eq. (8).

Next, we can update the $\hat{Q}_0$ through **decision feedback process.**

$$\hat{Q}_0 = \tilde{Q}_s \tilde{Q}_0 + (1 - \tilde{Q}_s)\hat{Q}_D \qquad (8)$$

Step 5.

The above $\hat{Q}_0$ can be used for the **MMSE criterion ,** C_k **by (9).**

This calculation should be done for the each subcarrier N.

$$C_k = \frac{\hat{Q}_0^*}{\left|\hat{Q}_o^*\right|^2 + \frac{\tilde{\sigma}_s^2}{E_x}} \qquad (9)$$

ICI Cancellation Process

Step 6. We estimate the desired data from the received signal by (10).

$$\hat{X}_k = \tilde{Y}_k \cdot C_k \qquad (10)$$

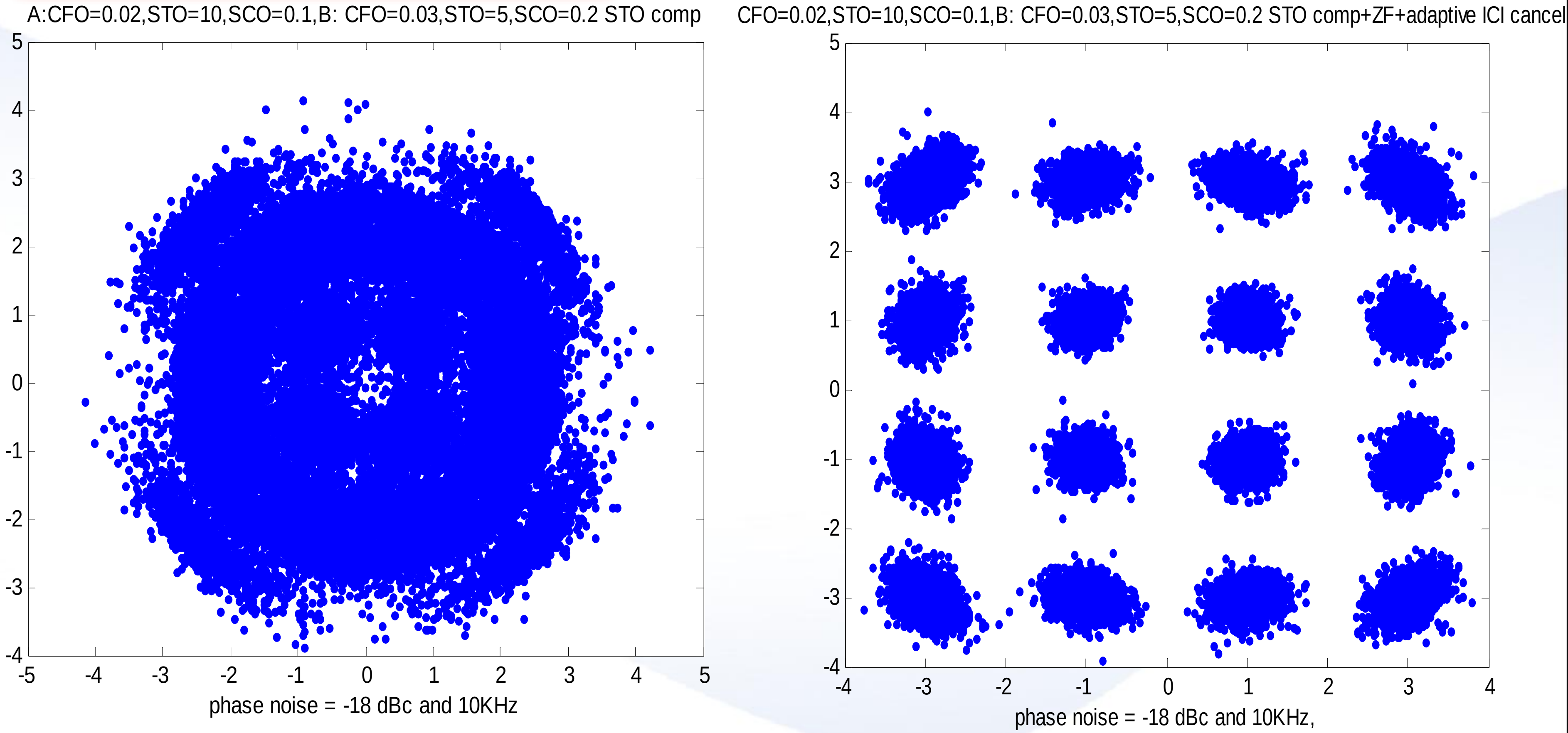
Step 7. We estimate and compensate the total symbol data of the whole subcarrier by the above step 1) ~ 6) process .

5th Simulation results and Discussion

Simulation Parameters

- Modulation level: 16 QAM
- OFDM parameter: A band=M(60), B band=M(60), pilots=4, N=512.
- Channel: AWGN + Multipath
- Phase noise parameter: -20dBc~-18dBc, cutoff 10KHz
- Frequency offset parameter: CFO=0.01~0.03
- Cyclic prefix: 32 each
- Sampling timing offset: 10~4 sample
- Sampling clock offset: 0.1~0.4 sample
- Multipath channel: ITU-R model (TS 25.104), No Doppler, No Fading
- Multipath channel 1: Pedestrian A channel
- Multipath channel 2: Vehicular A channel

The constellation

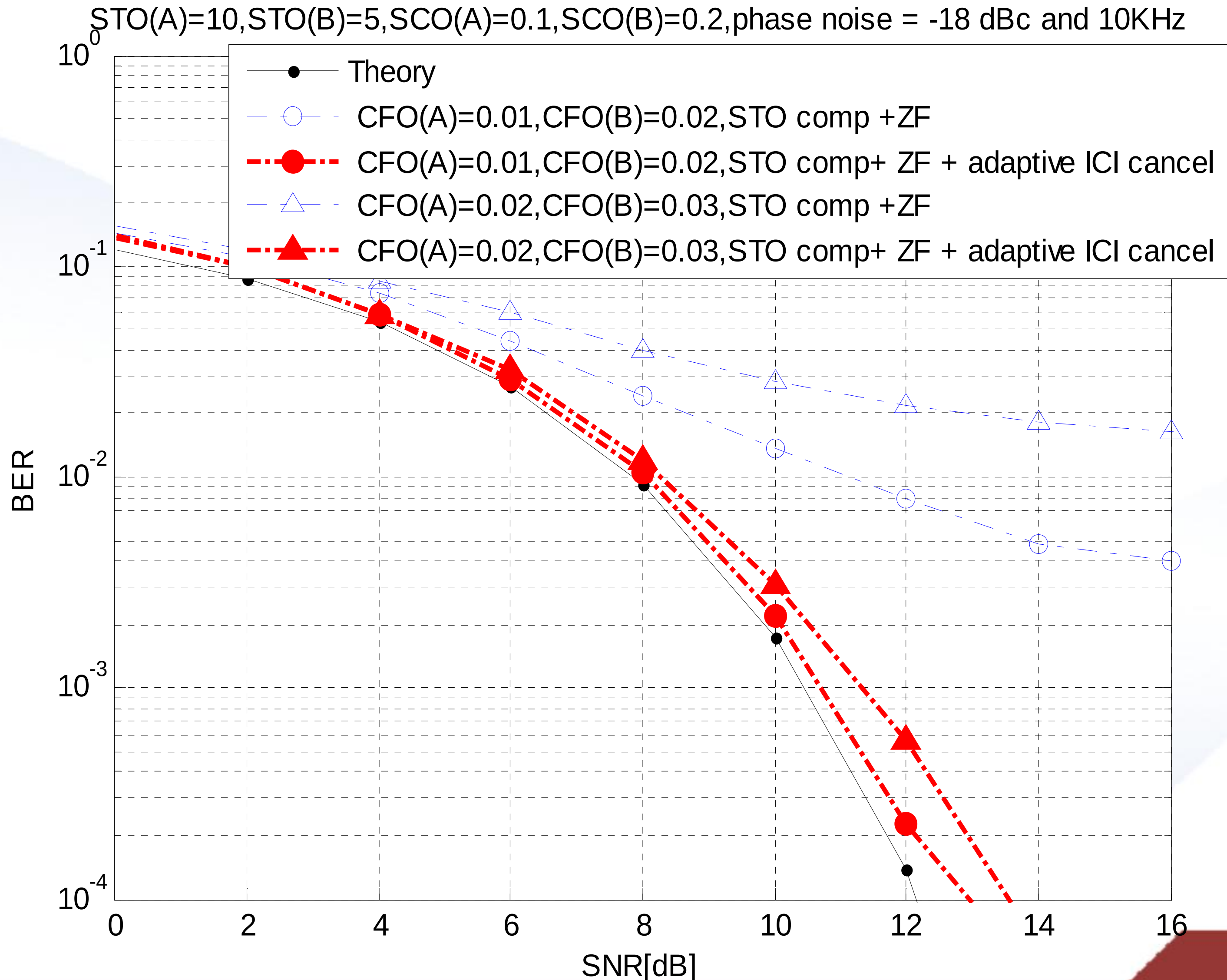


Only STO and SCO compensation (SNR=18dB,16QAM)

Adaptive ICI cancellation (SNR=18dB,16QAM)

5th

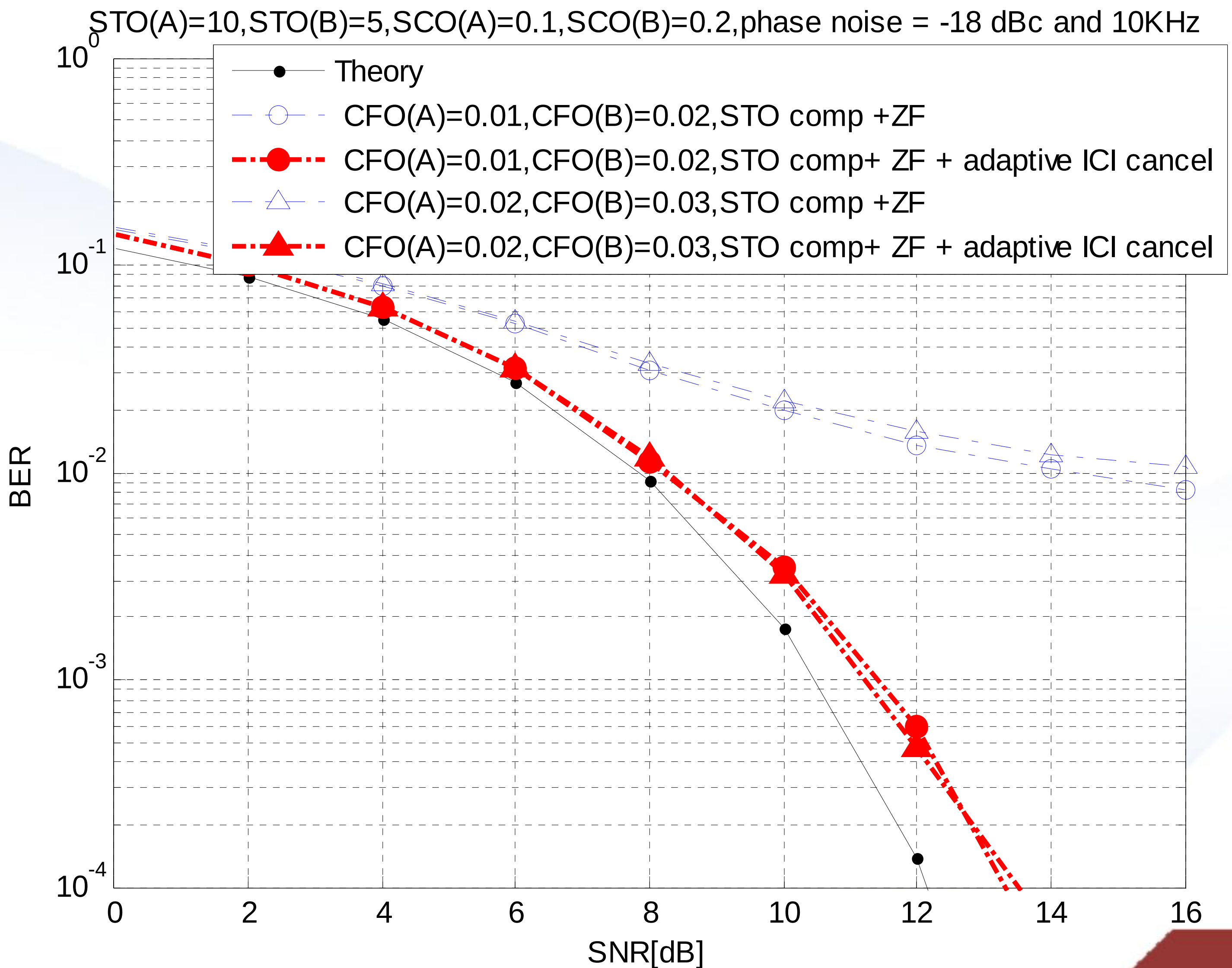
Simulation results and Discussion



BER comparison according to frequency offset AWGN, 16QAM

5th

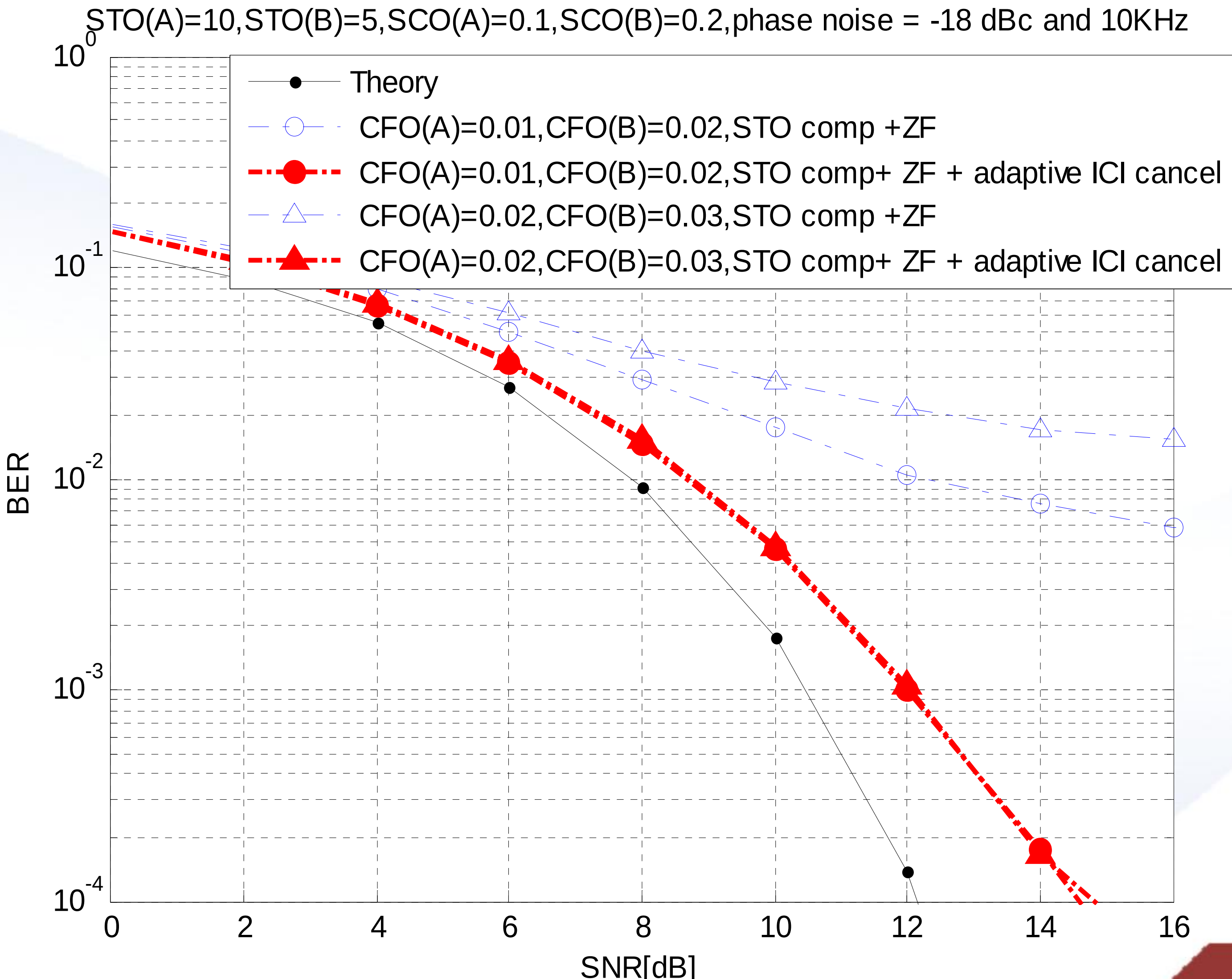
Simulation results and Discussion



- **BER comparison according to SCO in multipath 1 16QAM.**

5th

Simulation results and Discussion



- **BER comparison according to SCO in Multipath 2 16QAM, (different subcarrier mapping).**

6th Conclusion

Conclusion

- By the proposed receiver with single chain, we can get reasonable performance and reduce complexity in the multi-band receiver.

- Also we reduce interference in the multiple bands with phase noise and offset.

- This system can be useful for LTE-uplink system.

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