A Robust Timing and Frequency Offset Estimation Scheme for Orthogonal Frequency Division Multiplexing (OFDM) Systems

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Bruce McNair, Len Cimini, Nelson Sollenberger
AT&T Labs - Research
Red Bank, NJ

{bmcnair, ljc, nelson} @research.att.com

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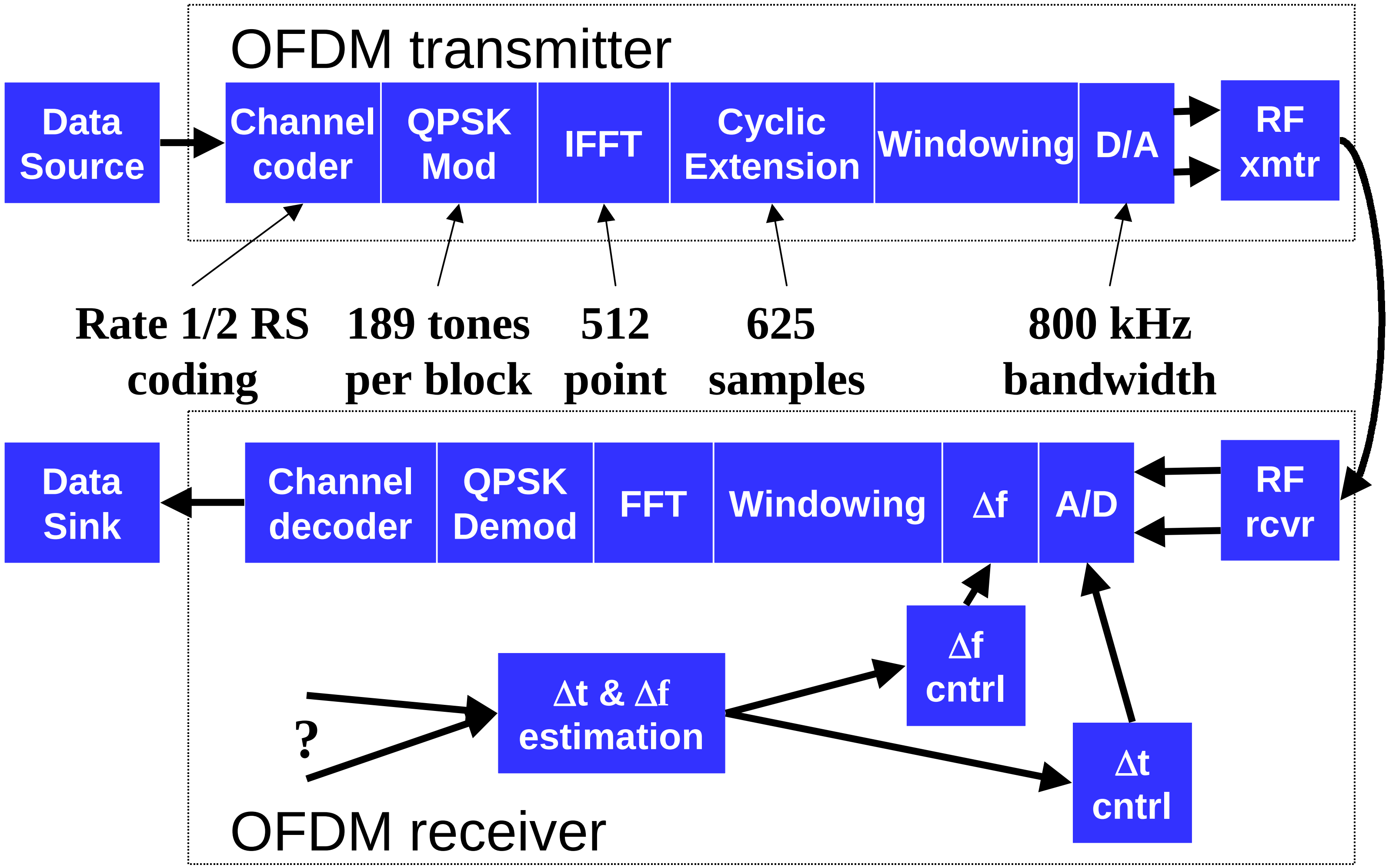
Outline of Talk

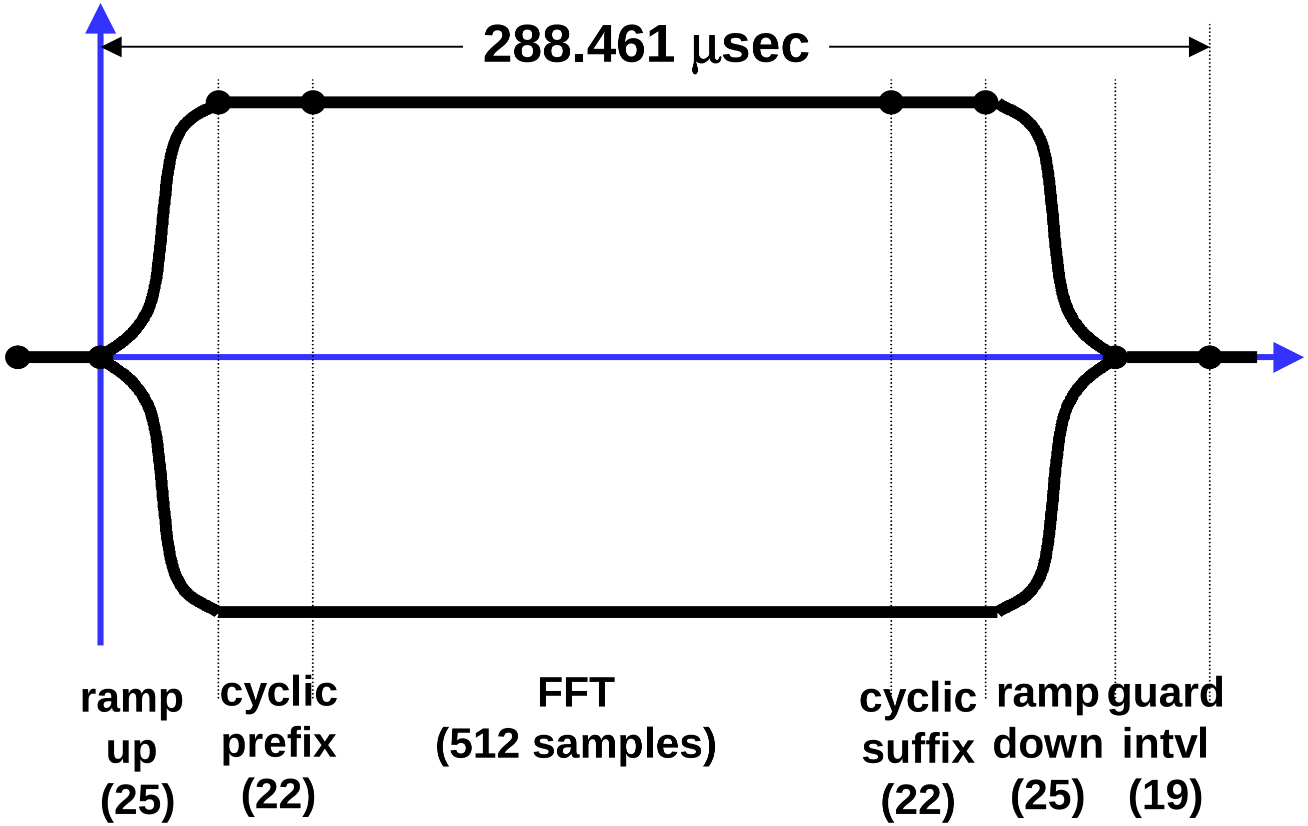
- OFDM system architecture
- Representative system parameters
- Prior synchronization techniques
- Proposed approach
- Discussion of system advantages
- Conclusion

OFDM System Architecture



Example OFDM Parameters

(time domain)



f_s = 2.166 MHz

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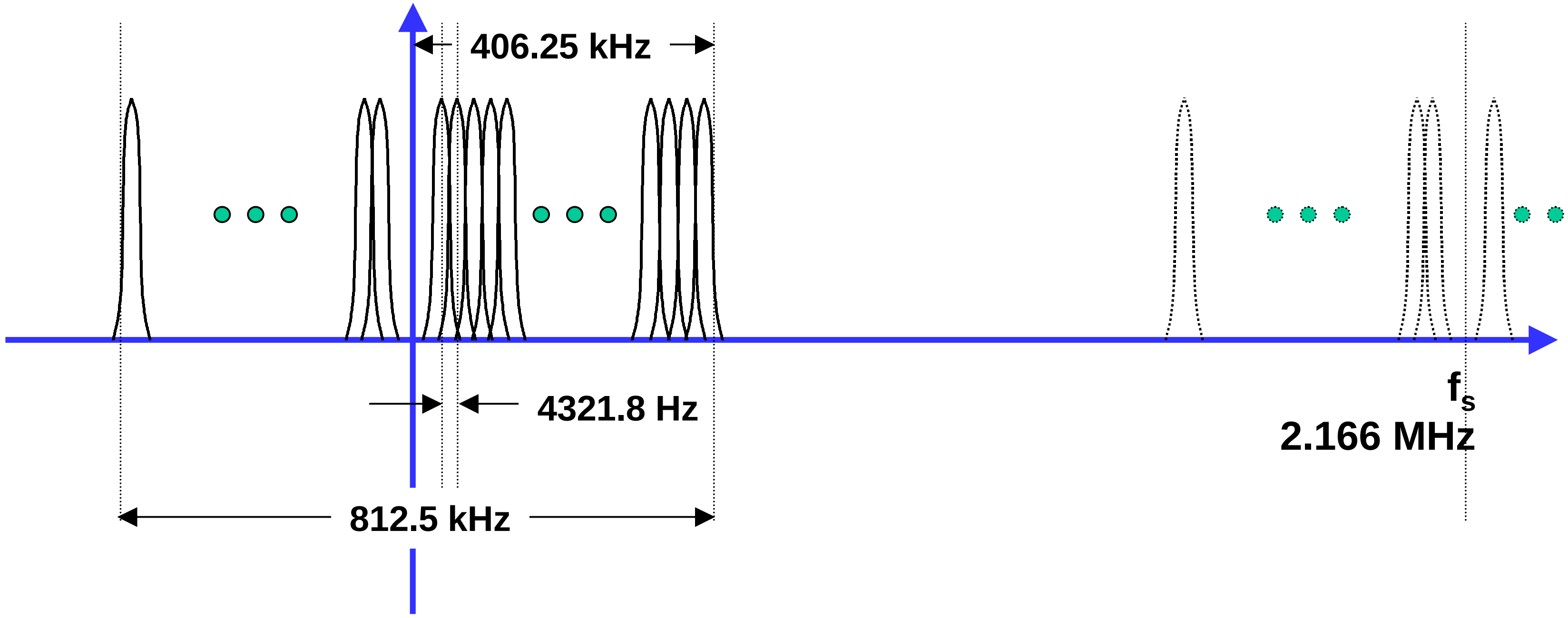
Example OFDM Parameters

(frequency domain)

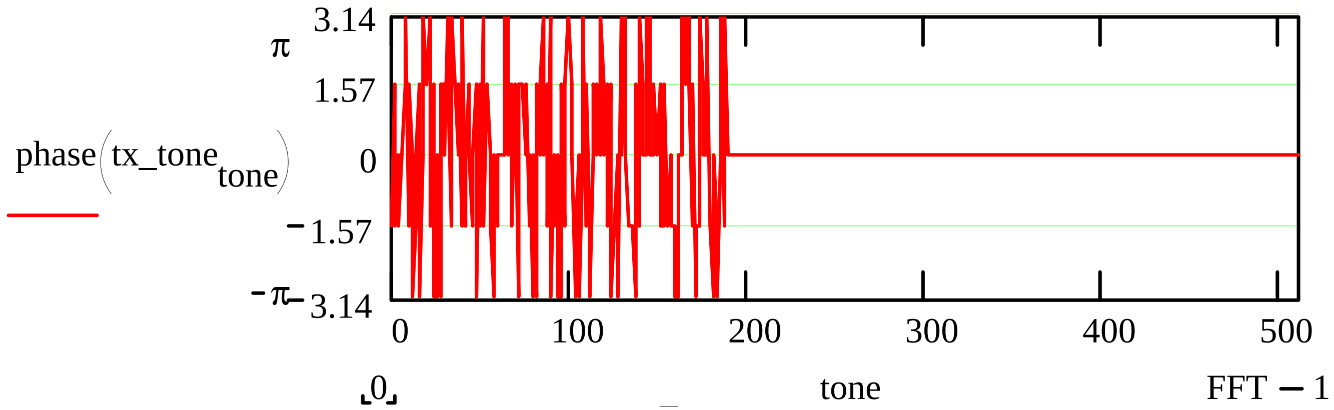


Some Prior Synchronization Techniques

	Time domain	Frequency domain
Pilot Assisted*	Moose (Δf) Schmidl (Δt, Δf) Park (Δf)	Park (Δt)
Not Pilot Assisted	Landstrom (Δt, Δf)	

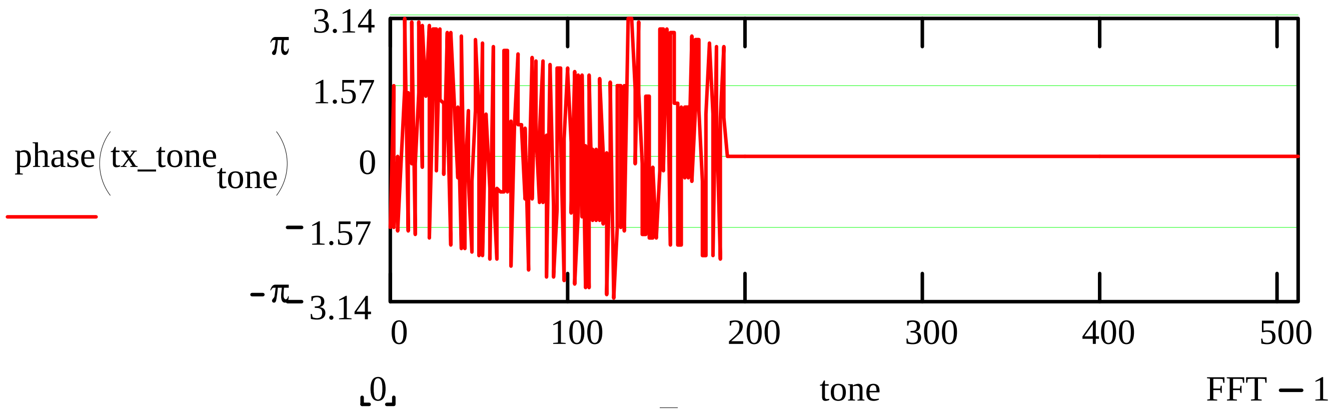
* or some assumed knowledge of transmit data

The Transmitted OFDM Signal



Transmitter generates a set of QPSK modulated tones
- the phase of each tone is a multiple of π/2

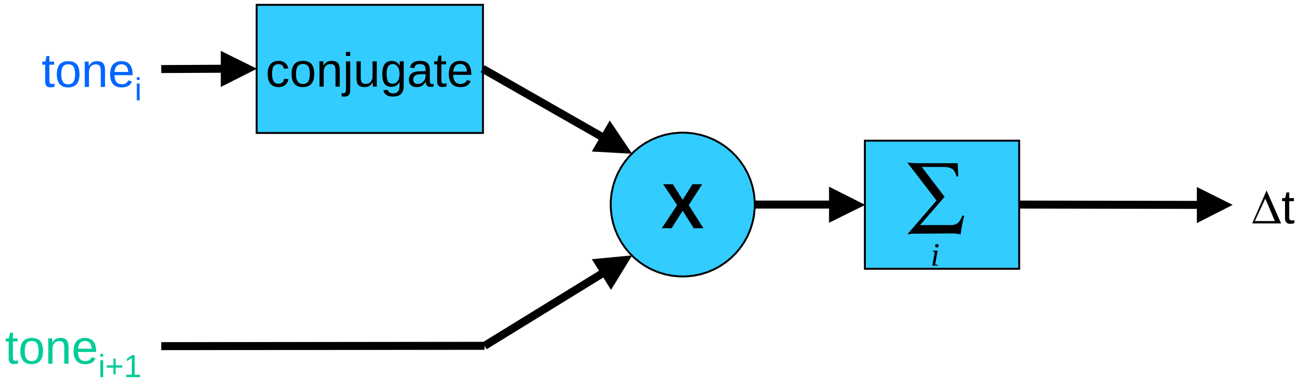
The Received OFDM Signal - With Timing Offset

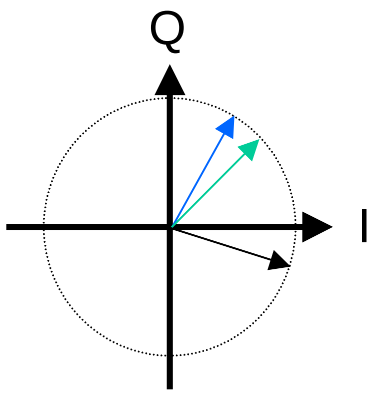


At the receiver, each transmit tone phase is shifted by an amount proportional to the tone frequency and the timing offset (by the Fourier Transform shifting property)

Estimating Timing Offset

(neglecting modulation and other impairments)





Each tone phase is differentially detected (in frequency) with respect to its neighbor

- what about effects of modulation of tones?
- what are the effects of impairments?
- how many tone pairs are needed?

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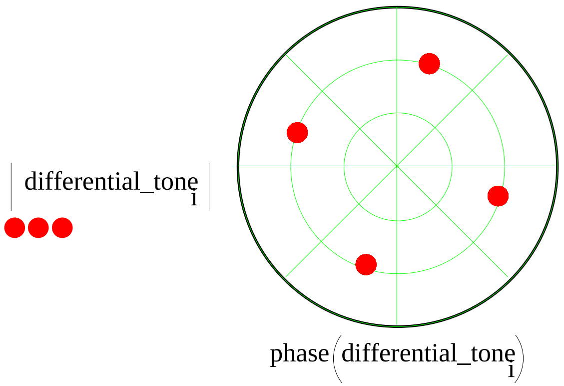
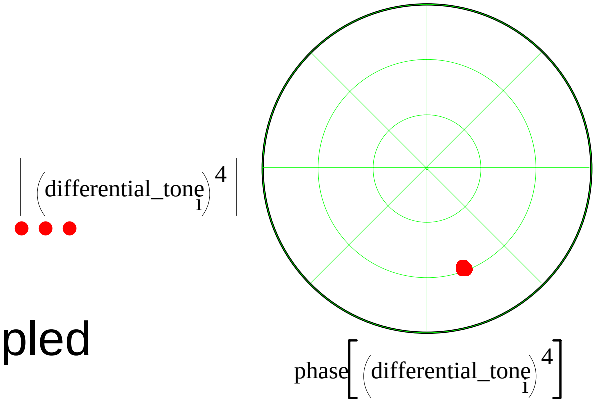
Estimating Timing Offset
(dealing with modulation)

Received signal (I vs. Q) with
QPSK modulation and timing offset

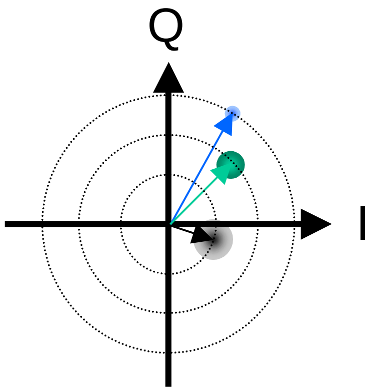


Raising the signal to the 4th power:
$(1+j0)^4 = (0+j1)^4 = (-1+j0)^4 = (0-j1)^4$
but the angle of other points is quadrupled

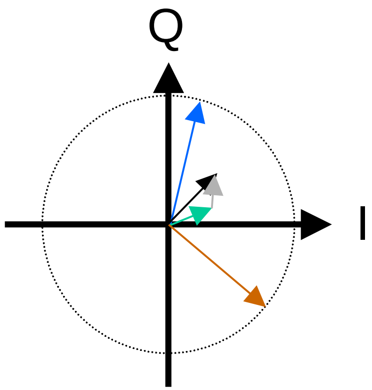


Estimating Timing Offset
(with noise and fading)

- A time dispersive channel creates frequency selective fading.
- Faded tones will have poorer SNR yielding poorer estimates of tone phase
- But, poorer estimates can readily be weighted less heavily



- Noise pertubation of a tone_{i+1}'s phase, relative to tone_i is opposite in direction to the pertubation relative to tone_{i+2}'s phase, providing a level of noise cancellation



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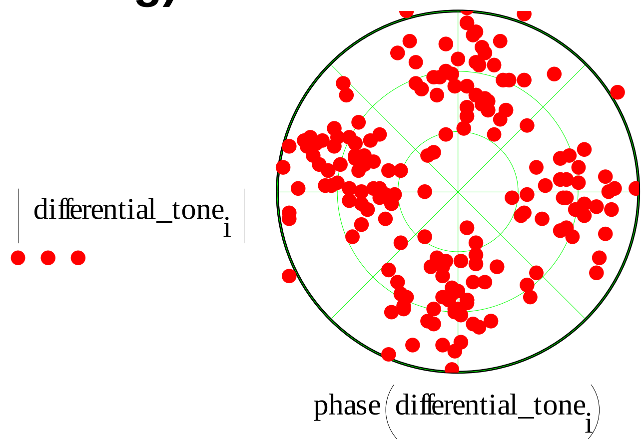
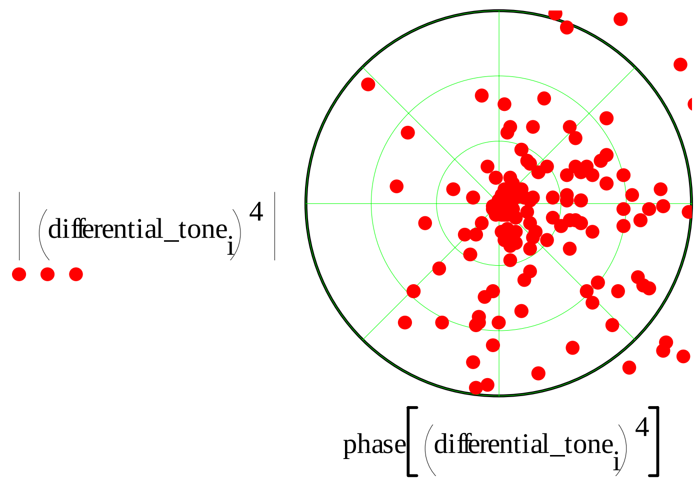
Estimating Timing Offset
(with noise and fading)

Received signal (I vs. Q) with
6 dB SNR, 10 samples timing offset



4th power constellation



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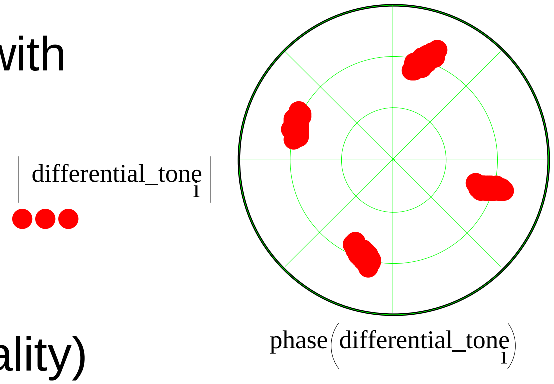
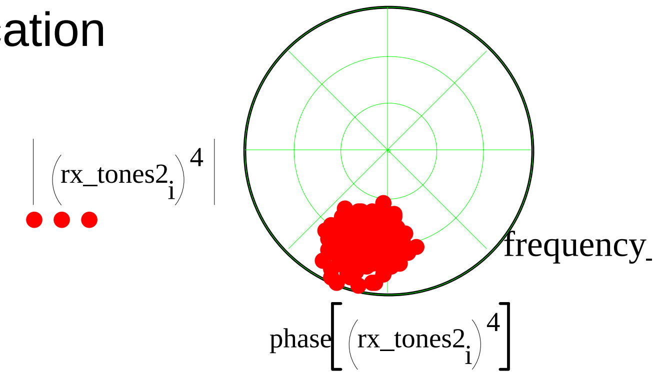
Estimating Timing Offset
(with frequency offset)

Received signal (differential I vs. Q) with
25 samples timing offset and
1/4 tone spacing frequency offset

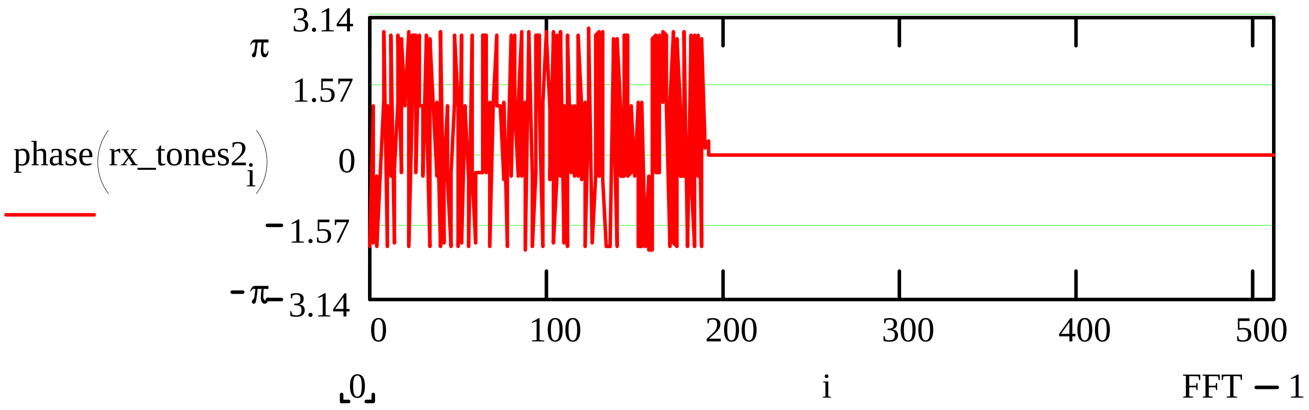


Points get fuzzy as ICI (nonorthogonality) creates modulation of tone amplitude (mixing of tone frequencies), but average location of points is unchanged



Centroid of 4th power constellation depends only on timing offset.

The Received OFDM Signal - With Frequency Offset



At the receiver, each transmit tone phase is shifted proportionally to frequency offset, plus some frequency dependent phase modulation, due to "beating" between tones

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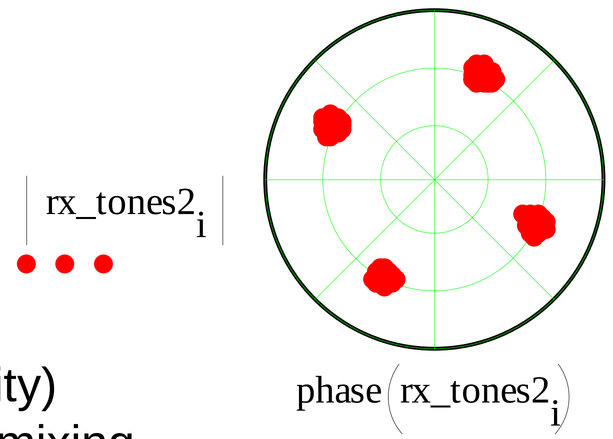
Estimating Frequency Offset

Received signal (I vs. Q) with
1/4 tone spacing frequency offset



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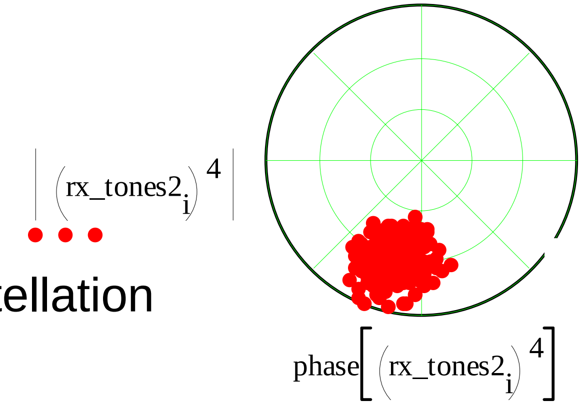
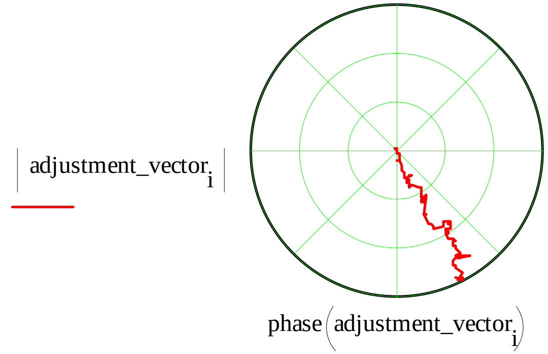


Rotation of centroid of 4th power constellation is proportional to frequency offset.

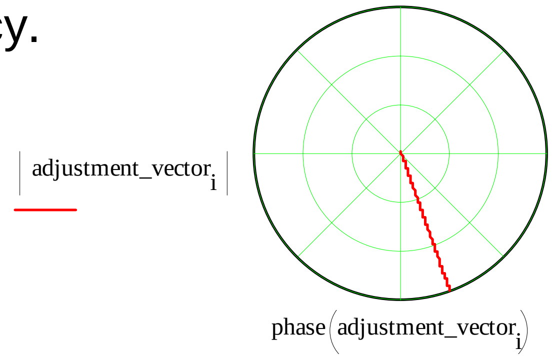
Why does it work?

(The effect of accumulating corrections)

- Each carrier (or carrier pair for timing) provides a consistent estimate of offset
- There is an inherent weighting of contributions, according to accuracy. (even more so for timing)
- The weighting is accentuated by 4th power and by frequency selective fading
- Noise effects tend to cancel



Δt = 25 samples
Δf = .2 tones
SNR = 5 dB



Δt = 25 samples
Δf = .2 tones
SNR = 12 dB

$$adjustment\_vector_j = \left(\sum_{i=0}^{j} \overline{R_i} \cdot R_{i+1}\right)^4$$

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Conclusion

- The proposed OFDM synchronization algorithm allows estimation of time and frequency offset without the use of additional pilots, saving bandwidth and signal energy, relying on inherent characteristics of the frequency domain signal

- It operates in the presence of high levels of noise, channel dispersion, and other impairments

- Direct tradeoffs are possible between signal processing power required and the algorithm's performance