Aalto University

School of Electrical Engineering

Department of Signal Processing and Acoustics

S-88.4212 Signal Processing in Telecommunications II

Fall 2013

Lecture 3: Synchronization: Overview

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Timetable

L1	Introduction; models for channels and comms. systems
L2	ML Estimation principles
L3	**Synchronization: Overview**
L4	Carrier frequency estimation I
L5	Carrier frequency estimation II
L6	Carrier phase estimation I
L7	Carrier phase estimation II
L8	Symbol timing estimation I
L9	Symbol timing estimation II
L10	Channel estimation I
L11	Channel estimation II, course review

Exam **12.12. Thursday 12-15 (Check!)**

Contents of Lecture 3

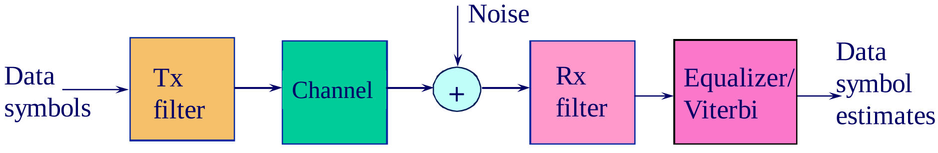
I Passband PAM transmission
II Different estimation strategies
III Other system considerations

The material in this lecture is based mostly on the book by Meyr *et al*, *Digital Communication Receivers*, Wiley 1998, Chapters 4 and 5.

I. Passband PAM transmission

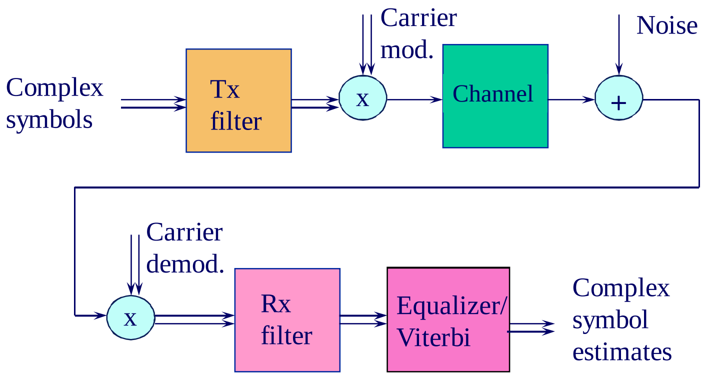
Passband PAM transmission

- In the previous course, we used the following simplified model for *baseband* PAM transmission



Passband PAM transmission...

- Simplified model for *passband* PAM transmission:



Passband PAM transmission...

Functional blocks of the communication link:

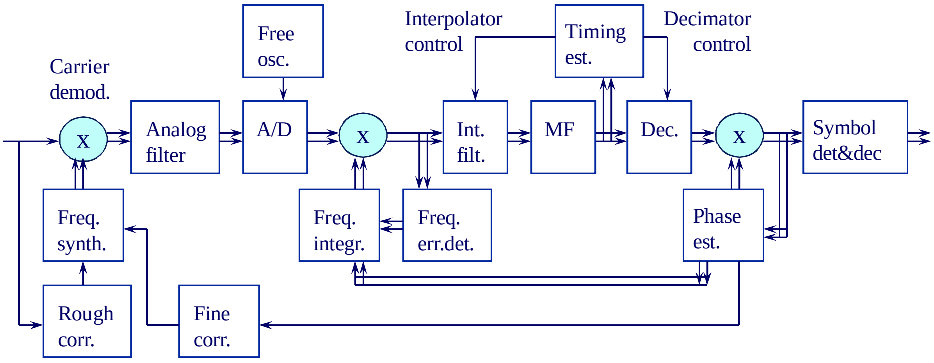
- Complex symbol generation from input bit sequence
- Load symbols on continuous Tx pulse waveforms
- Modulate with sinusoidal carrier to desired frequency range (real and imaginary parts (I&Q) to cosine and sine components of the real-valued signal)
- Channel: linear distortion + additive noise (real-valued)
- Demodulate: separate cosine and sine terms to I and Q branches (baseband channel and noise complex-valued!)
- Receiver processing: matched filter, equalizer/Viterbi etc.

Passband PAM transmission...

- The previous model neglects important estimation functions
- Next we will study a more realistic PAM system

Passband PAM transmission...

- Typical passband PAM *receiver* structure (~ Meyr Fig. 4-2):



Passband PAM transmission...

1) Downconversion (approximately) to baseband by multiplying with complex output of oscillator
   - due to freq. error, this signal is slowly rotating
2) Analog prefilter + A/D (clock from free oscillator!)
3) Interpolation to correct timing, matched filtering, and decimation at symbol rate
4) Symbol detection and decoding

and...

Passband PAM transmission...

...and

5) Frequency error detection and correction
6) Phase estimation for carrier frequency correction and removing of rotation
7) Symbol timing estimation for interpolator and decimation control

II. Different estimation strategies

Different estimation strategies

- Synchronization or estimation algorithms typically operate in two phases or modes:

1) Acquisition

- initial estimation of the parameters: getting the system started

- must be fast, need not be very accurate

2) Tracking

- improving the initial estimate

- following small variations in channel parameters

- accurate, not fast

Different estimation strategies...

- A key point in the design of sync estimation algorithms is how to eliminate the effect of data modulation

1) Data-aided (DA) synchronization
   - data symbols are known (training sequence, preamble etc.)
   - safe, but reduces data rate
   - good for sync acquisition

2) Decision-directed (DD) synchronization
   - decisions are used
   - errors are a problem in bad conditions
   - good for sync tracking

Different estimation strategies...

3) Non-Data-Aided (NDA)

- data symbols are neither known nor estimated
- average out the effect of data modulation
- usually complex and poor performance
- use only when the only possibility

Different estimation strategies...

- Taxonomy using the ML criterion
- Joint timing and phase estimation assuming perfect carrier synchronization.
- PDF with unknown data **a**: $p(\mathbf{r};\theta,\tau,\mathbf{a})$

$$(\hat{\theta},\hat{\tau})_{NDA} = \arg\max_{\theta,\tau} \sum_{i=1}^{M} p(\mathbf{r};\theta,\tau,\mathbf{a})P[\mathbf{a}=\mathbf{a}_i]$$

$$(\hat{\theta},\hat{\tau})_{DA} = \arg\max_{\theta,\tau}\, p(\mathbf{r};\theta,\tau,\mathbf{a}_0)$$

$$(\hat{\theta},\hat{\tau})_{DD} = \arg\max_{\theta,\tau}\, p(\mathbf{r};\theta,\tau,\hat{\mathbf{a}})$$

Different estimation strategies...

Feedforward vs. feedback algorithms

1) Feedforward

- estimate is derived from the received signal *before* it is corrected

2) Feedback

- derive an error signal and use that for correction of the next value
- *error feedback* algorithms
- tracking ability for slow parameter changes
- possible stability/error propagation problems

Different estimation strategies...

- Feedback usually iterative

$$\hat{\theta}_{k+1} = \hat{\theta}_k + \frac{\partial}{\partial \theta} p(\mathbf{r}; \hat{\theta}, \hat{\tau}, \mathbf{a})$$

$$\hat{\tau}_{k+1} = \hat{\tau}_k + \frac{\partial}{\partial \tau} p(\mathbf{r}; \hat{\theta}, \hat{\tau}, \mathbf{a})$$

where we assume an estimate of $\mathbf{a}$ or that $\mathbf{a} = \mathbf{a}_0$ is known (pilot)

III. Other system considerations

Analog vs. digital implementation

- Traditionally, synchronization algorithms have been implemented by analog means
- With high-speed DSP, most of the synchronization tasks can be done (or fine-tuned) digitally

Choice of sampling rate

- Symbol-rate sampling NOT sufficient for synchronization
- Theoretically, excess bandwidth based sampling rate is sufficient
- In practice, integer multiple (2-3-4) of symbol rate is a convenient choice
- High enough oversampling eases requirements for analog filtering

Quality factors of sync. algorithms

- Convergence speed
  - especially critical in mobile communications with fast fading channels, and in TDMA (burst-based transmission)
- Carrier frequency error, carrier phase error, timing error
  - usually error variance (MSE) used
- Self-noise
  - noise contribution at the detector due to sync method
- Phase noise
  - oscillator nonideality

Quality factors of sync. algorithms...

- Hang-up
  - locking into wrong carrier frequency or phase
- Cycle slip
  - losing a symbol or more
- Symbol error rate
- Bit error rate

Summary

Today we discussed

I Passband PAM transmission

II Different estimation strategies

III Other system considerations

Next time:

- Carrier frequency estimation