

## OFDM-based PHY proposal for 802.16 TG3

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Purpose:

To present an OFDM based PHY proposal for 802.16.3 TG3

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# OFDM-based PHY Proposal for 802.16.3 PHY

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# Overview

## ¥ Very short OFDM intro

- GI, FFT size, constellations, coding

- See 802163p-00\_30.ppt for more details

## ¥ Relation to the MAC philosophy

- Framing, Adaptive Rate, Concatenation,  
Polling, Random Access, Headers

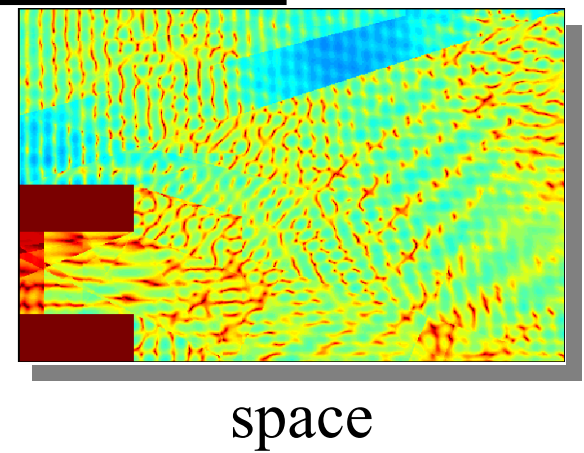
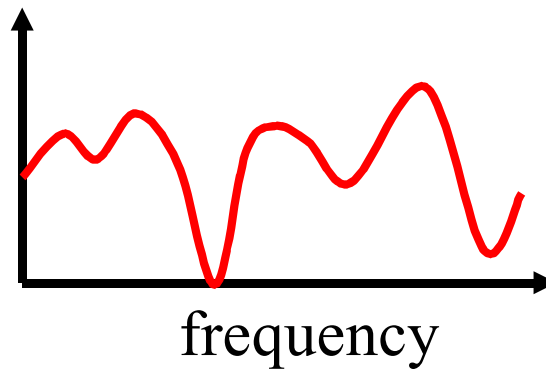
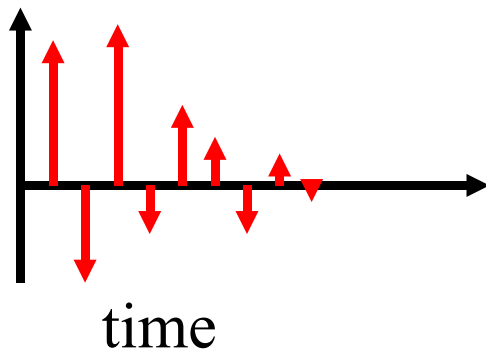
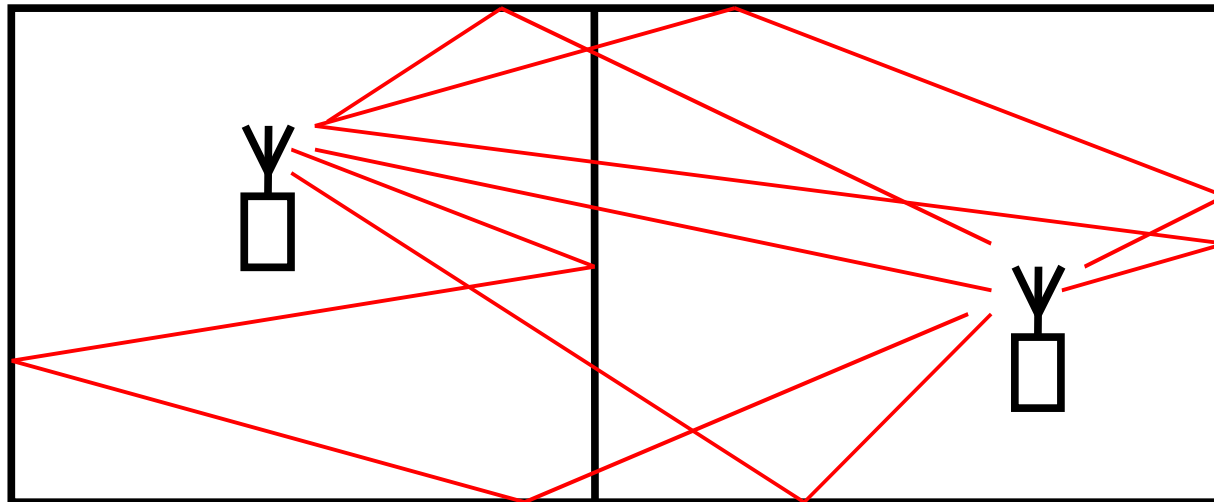
## ¥ High Efficiency modes

- Improved ECC, longer FFT

# Why OFDM?

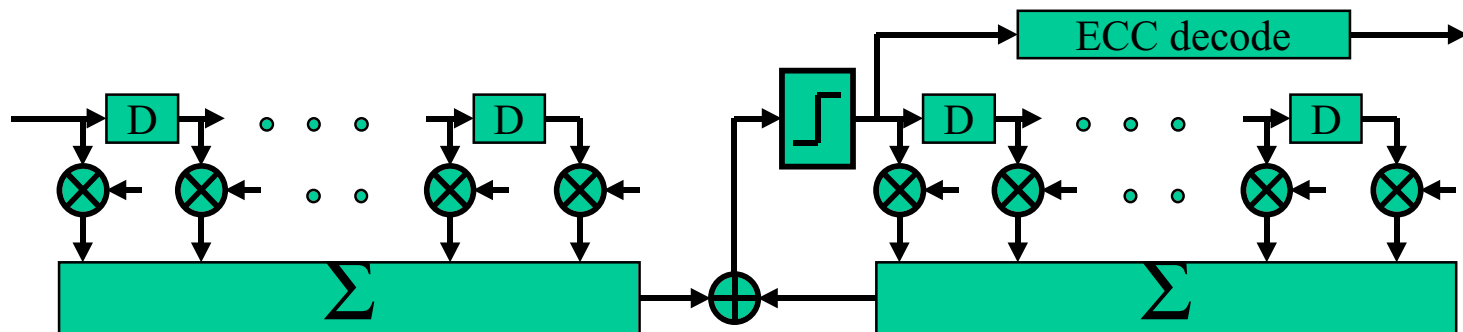
- ∓ Multipath robustness
- ∓ Incorporated in data-oriented standards
  - 802.11a, HIPERLAN/2: WLAN with QoS
- ∓ Incorporated in broadcast standards
  - DAB, DVB-T
- ∓ Facilitates smart antenna techniques in multipath environment
- ∓ Enables fast parallel polling
- ∓ Enables OFDMA

# Multipath



# Solution 1 - Equalization

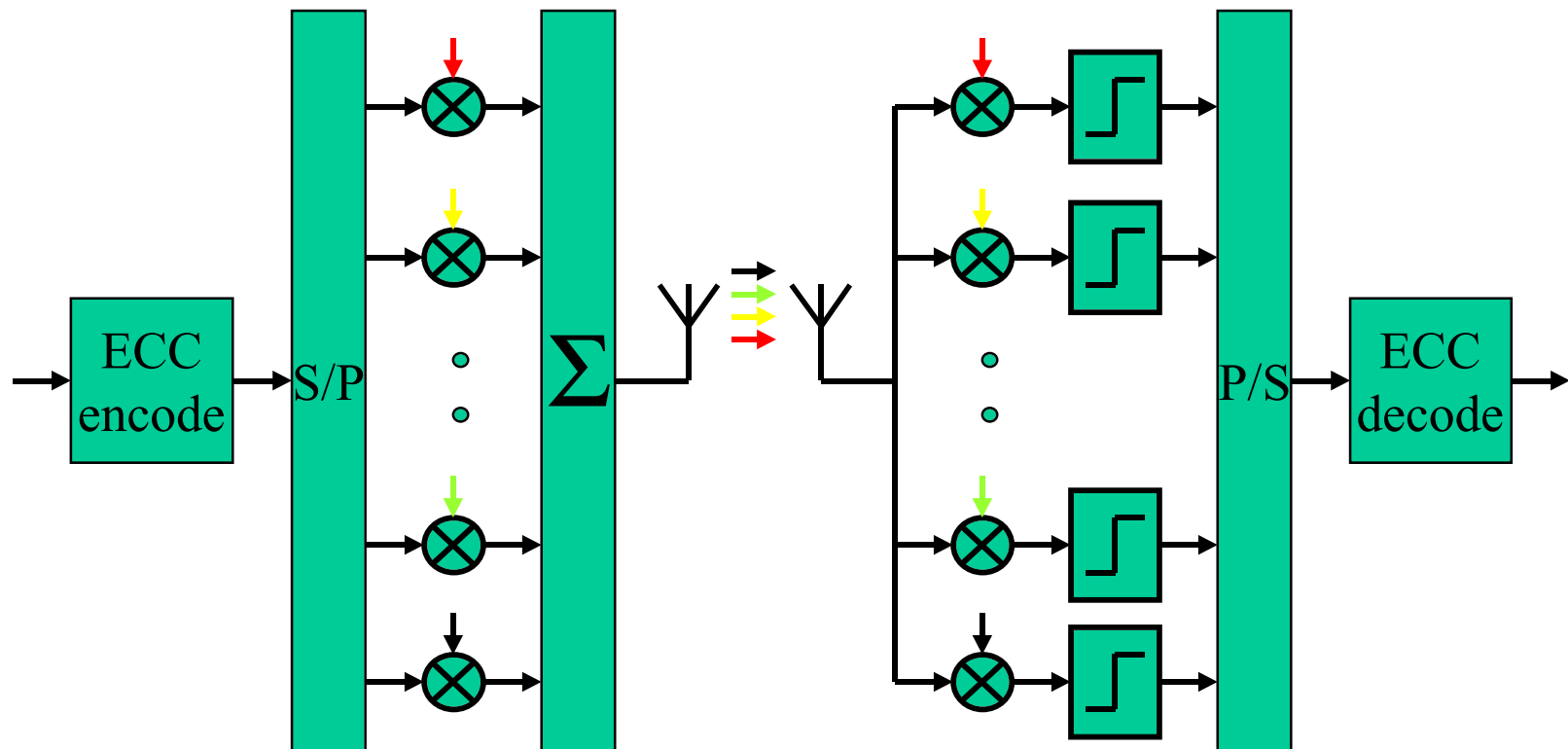
- ≠ Equalization is building an inverse filter
- ≠ If channel has nulls, you cannot inverse
- ≠ Decision Feedback Equalizer (DFE) can handle also channels with nulls
  - **In coded systems past decisions may be unreliable (not solved by Freq. Domain Equ.)**
- ≠ In long channels — complexity problem



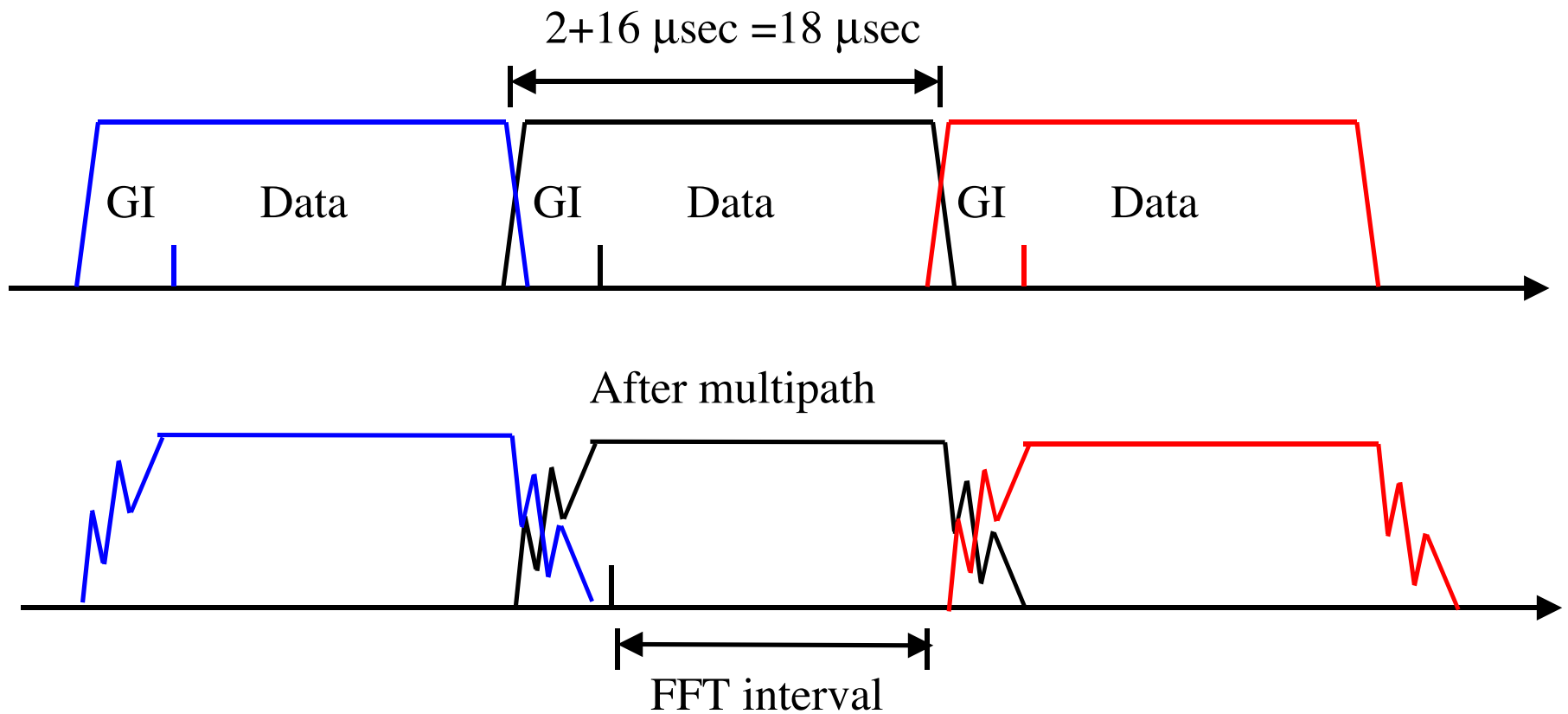
# Solution 2 — Parallel Channels

∓ Send several long symbols in parallel

∓ OFDM uses complex exponential waveforms



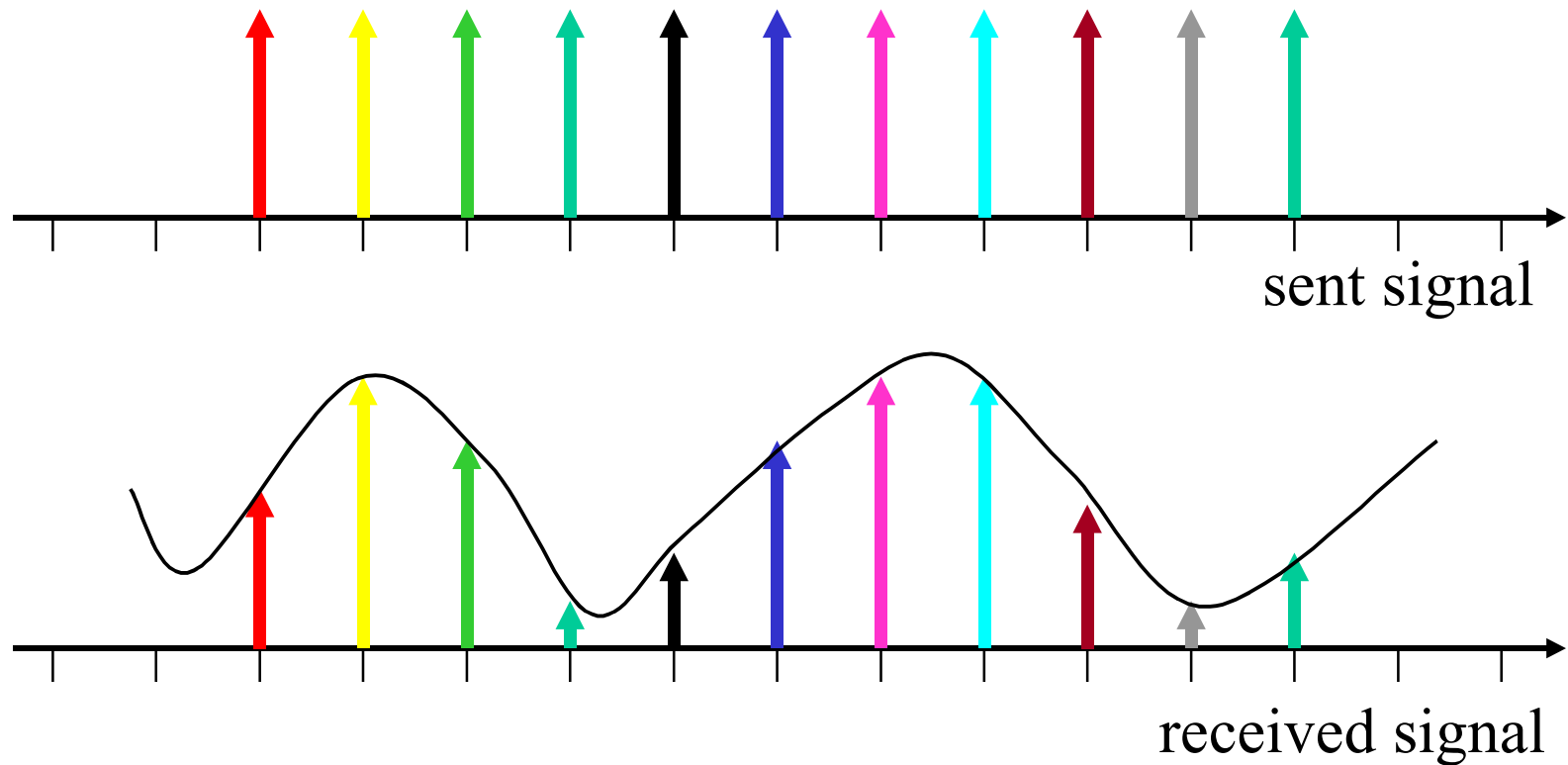
# Guard Interval and FFT Interval





# Multipath effect on subcarriers

∴ Each subcarrier is scaled according to the channel, but they still do not interfere with each other



# Modulation Constellations

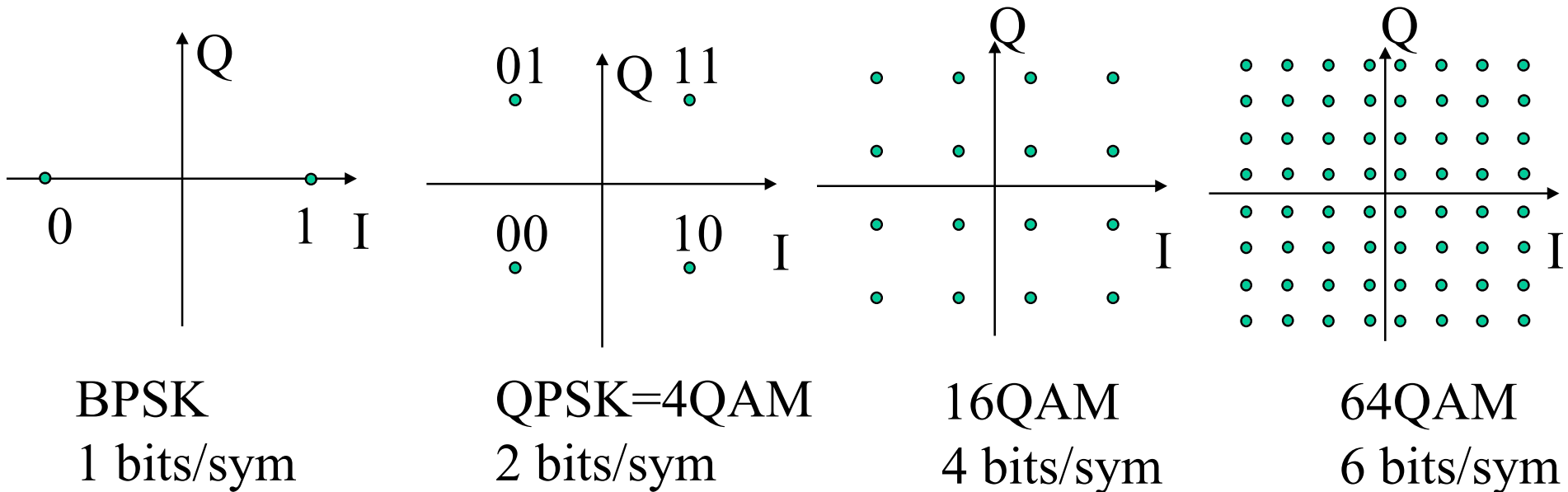
¥ Use square QAM constellations only

¥ BPSK+4/16/64 QAM on downlink

—256 QAM optional

¥ BPSK+4/16 QAM on uplink

—64,256 QAM optional



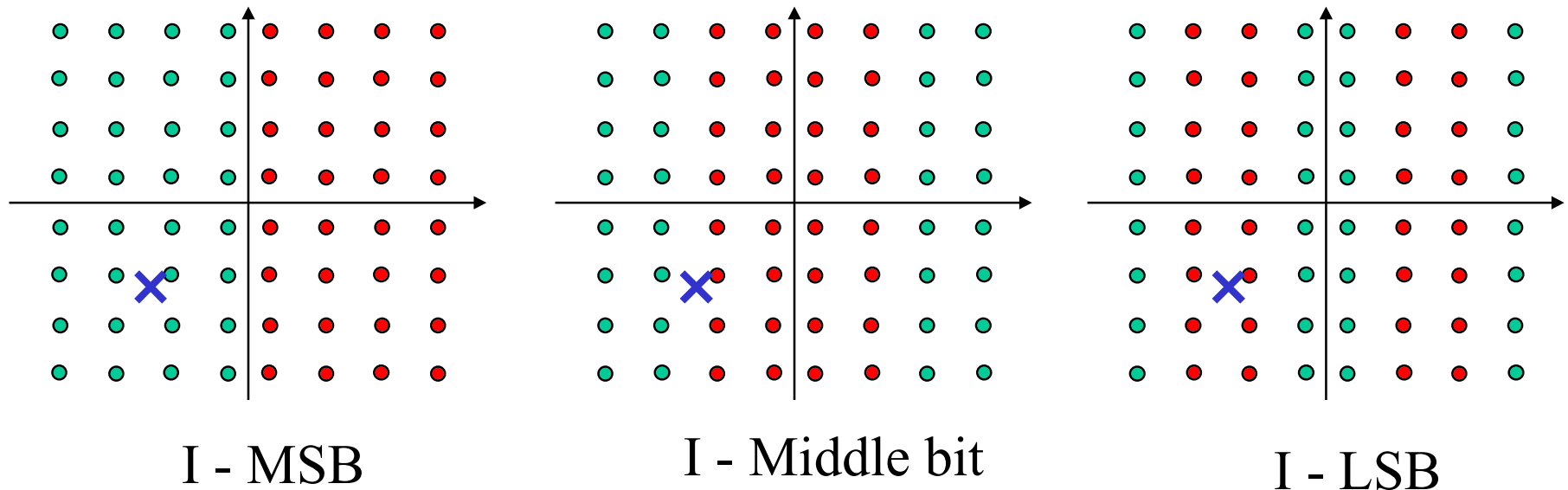
# Rx - QAM to metrics conversion

⚡ Bit metric is generated based on

- proximity to nearest 0 and 1
- Subcarrier strength

⚡ Gray coding → One bit unreliable at a time

⚡ Square constellation → separate I & Q processing



# Error Correction Coding

¥ Convolutional code shall be used as a baseline mandatory mode.

— $K=7$ ,  $R=1/2, 2/3, 3/4$ ; terminated tail

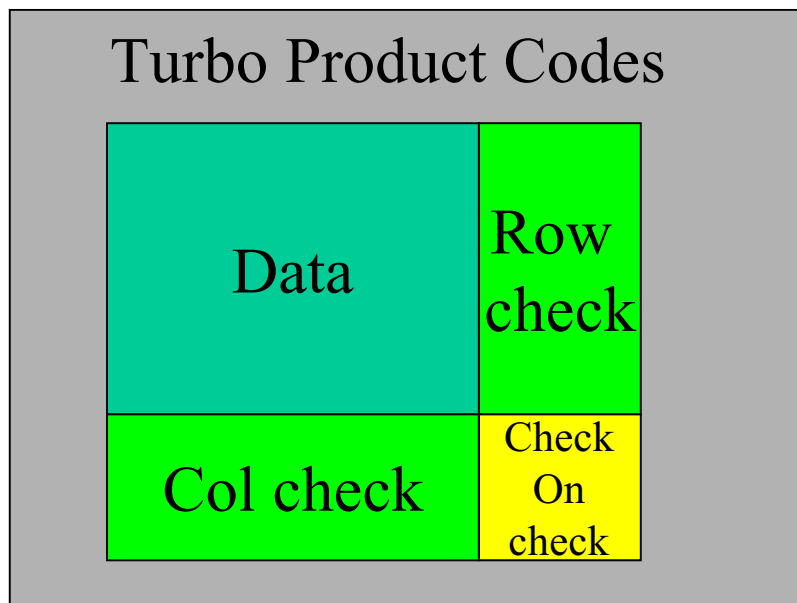
¥ Interleaver is needed to avoid adjacent faded bits

¥ Turbo Codes shall be used as an option

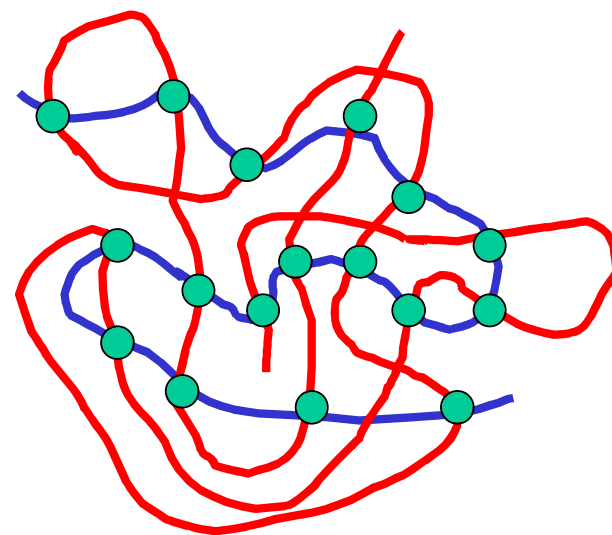
Data	Row check
Col check	Check On check

# Turbo Codes

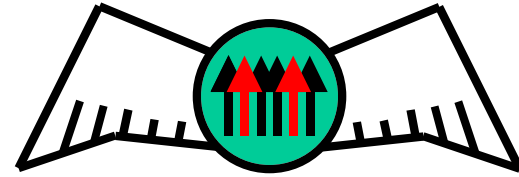
- ¥ Turbo codes are like crosswords
  - Solve rows, then use reliable bits to solve columns, then use the new reliable bits for rows etc. etc. till convergence
- ¥ TPC are proposed for compatibility with 802.16.1 and implementation maturity
  - Better performance at very low BER



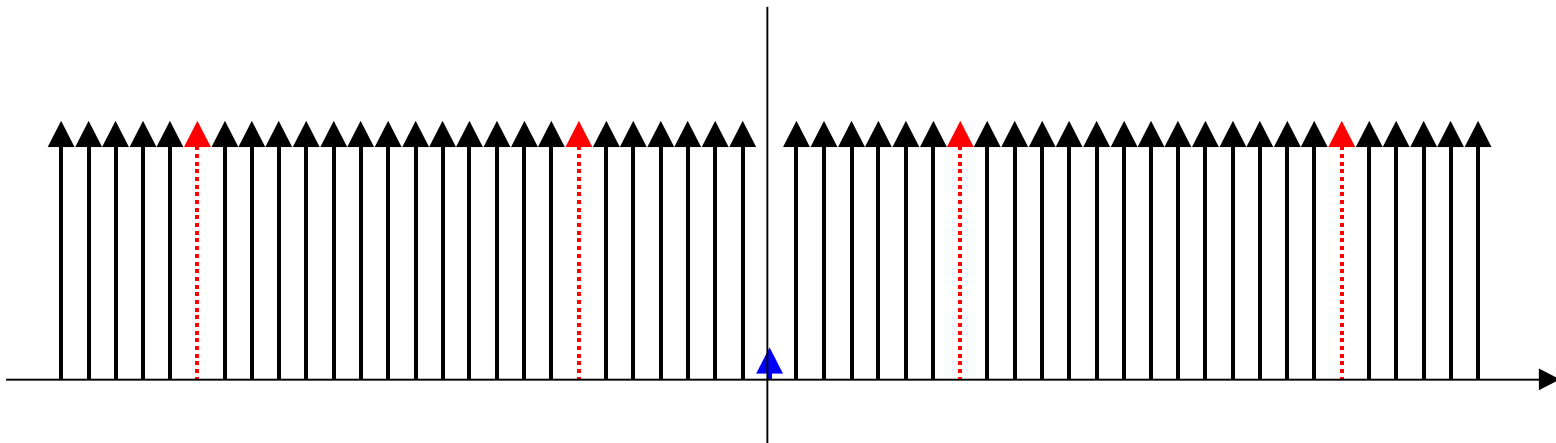
## Convolutional Turbo Codes



# Pilot subcarriers



- ¥ Pilot subcarriers are needed for carrier tracking
- ¥ Several are needed for:
  - Fading Diversity → spread pilots in frequency
  - SNR accumulation
- ¥ 802.11a uses 4 pilots per 48 data subcarriers
- ¥ For 256pt FFT eight pilots are sufficient
  - Smaller overhead



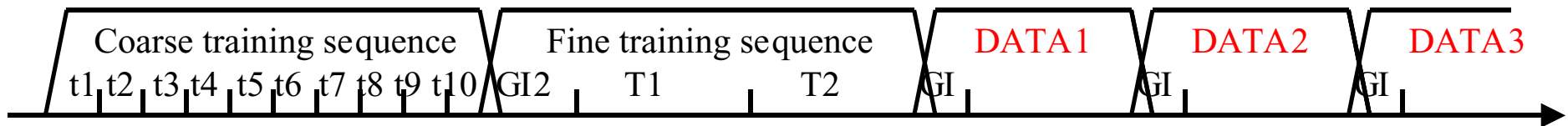
# Preamble Structures

¥ The preamble is used to estimate

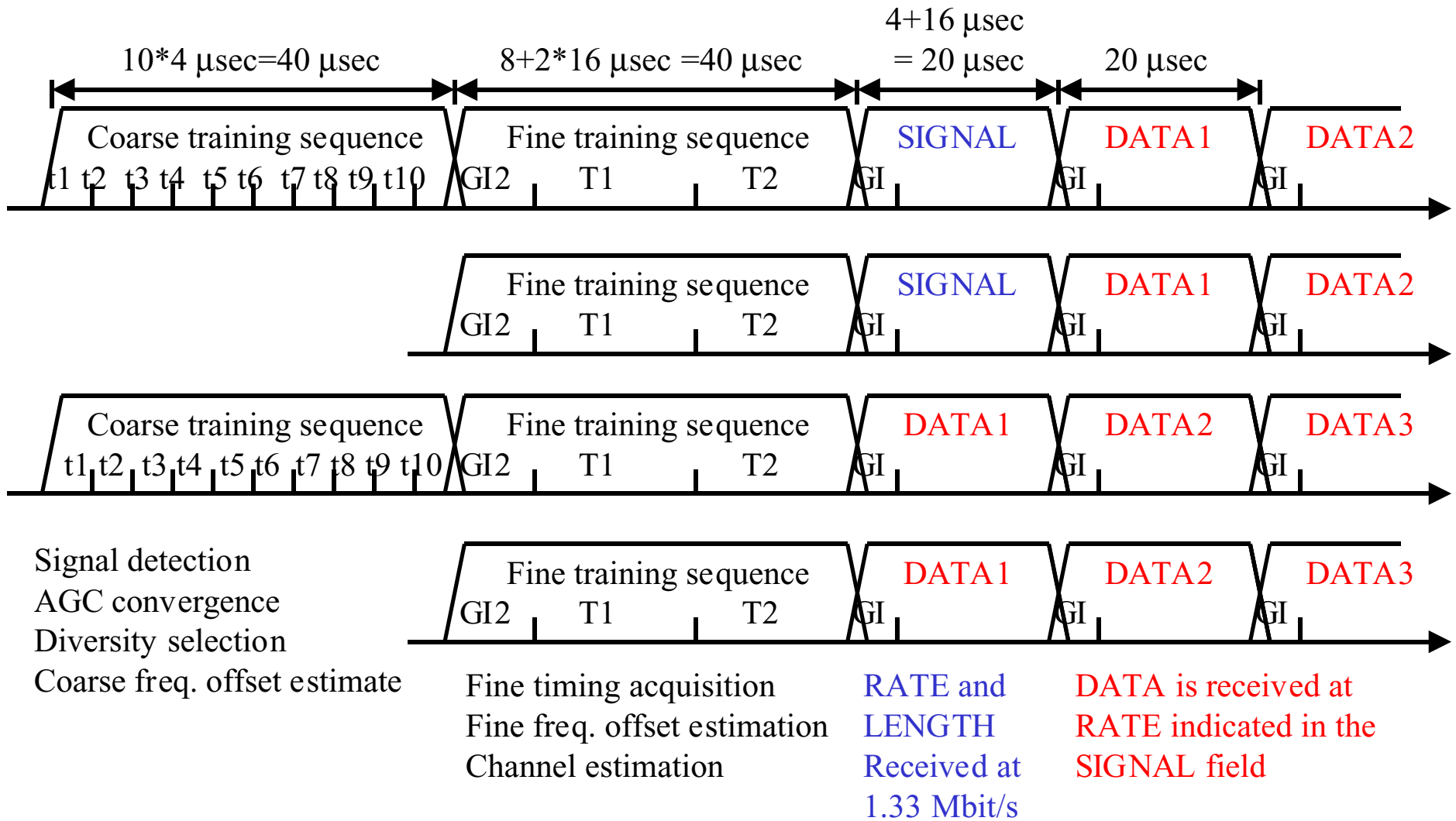
- Antenna diversity selection and AGC convergence
- Coarse, then fine **frequency** offset
- Coarse, then fine **timing** offset
- Channel response

¥ More prior knowledge allows shorter preambles

- Gain preadjusted by transmit power control
- Coarse frequency offset known from prior transmissions
- Timing preadjusted by ranging and timing advance



# Preambles for Initial and Re-Acquisition



Or: DATA is received at RATE set by the MAC



# FFT size tradeoffs

¥ GI is dictated by multipath duration

¥ Short FFT advantages

—Shorter training sequences

—Lower payload size granularity

—Phase noise tolerance

¥ Long FFT advantages

—Lower GI overhead and pilot symbol overhead

—Steeper spectrum falloff

—Facilitates OFDMA

# Throughput vs. FFT size

¥ 64 pt FFT mode

—48 data subcarriers, 4 pilot subcarriers

¥ 256 pt FFT mode (optional gear shift)

—208 data subcarriers, 8 pilot subcarriers

¥ Faster spectral falloff is utilized to increase the fraction used.

¥ The 256 subcarrier mode provides

—27% rate improvement with 16 pt GI, 18% with 8 pt GI

¥ Little is bought by longer FFTs

# Data Rates and Sensitivities

**3.5 MHz wide channels, 52 or 216 subcarriers, 8 pt guard interval**

Modulation	ECC rate	Rate, 64pt	Rate, 256pt	Sensitivity
BPSK	R=1/2	1.33 Mbit/s	1.57 Mbit/s	-94 dBm
BPSK	R=3/4	2.00 Mbit/s	2.36 Mbit/s	-93 dBm
QPSK	R=1/2	2.66 Mbit/s	3.15 Mbit/s	-91 dBm
QPSK	R=3/4	4.00 Mbit/s	4.73 Mbit/s	-89 dBm
16QAM	R=1/2	5.33 Mbit/s	6.30 Mbit/s	-86 dBm
16QAM	R=3/4	8.00 Mbit/s	9.45 Mbit/s	-82 dBm
64QAM	R=2/3	10.67 Mbit/s	12.60 Mbit/s	-78 dBm
64QAM	R=3/4	12.00 Mbit/s	14.18 Mbit/s	-77 dBm
256QAM	R=2/3	14.22 Mbit/s	16.81 Mbit/s	-73 dBm
256QAM	R=3/4	16.00 Mbit/s	18.91 Mbit/s	-71 dBm

**Sensitivity assumes NF=6 dB and 4 dB implementation loss**

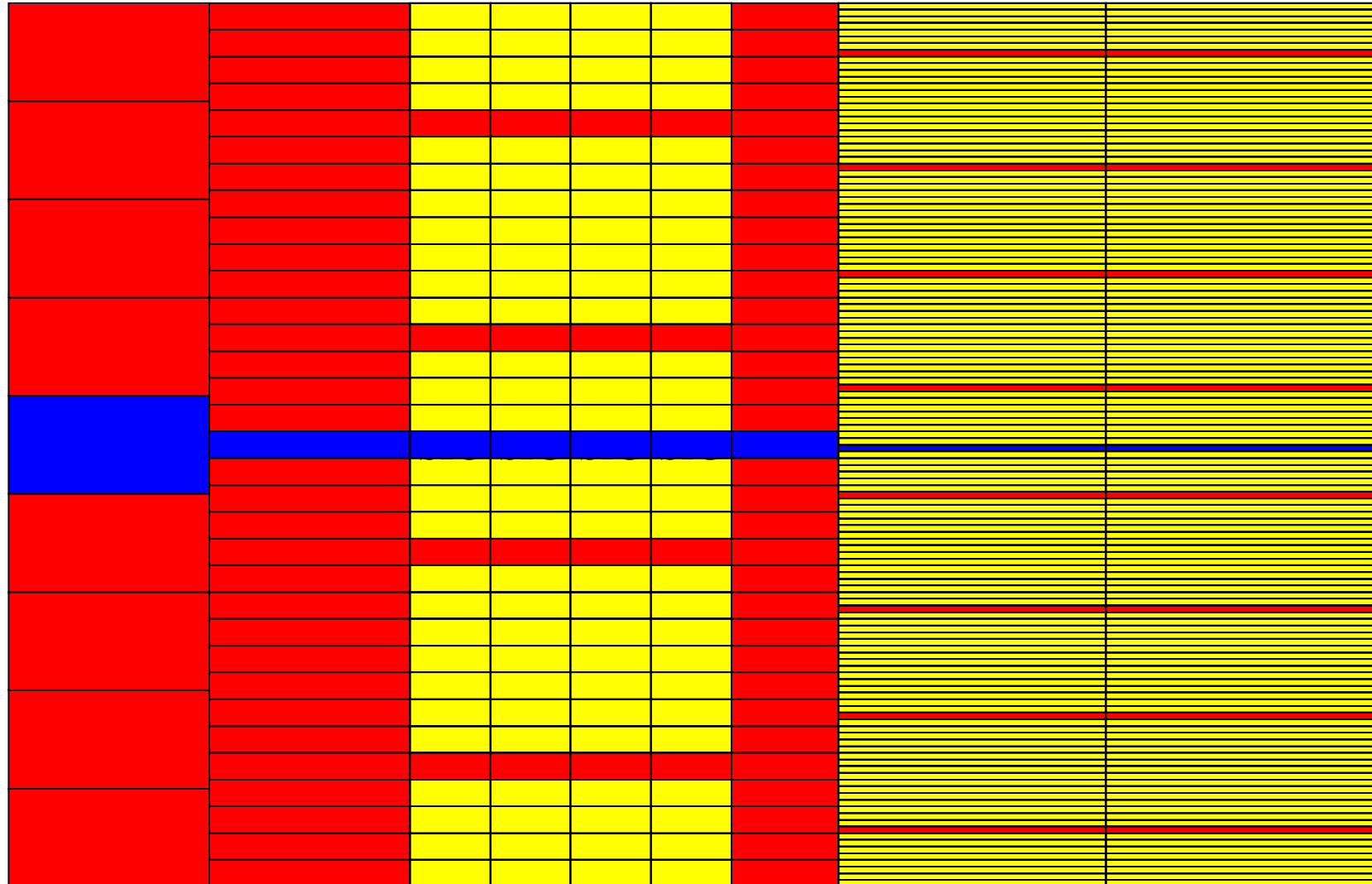
# Mixing 64 and 256 FFT modes

- ¥ Reuse 64 pt mode preambles and signaling
  - Compatibility
  - Smaller overhead
- ¥ Payloads may be sent at 256pt mode
  - Channel estimation can be interpolated from the 64pt mode estimate
  - The carrier tracking loop achieves better frequency accuracy during the 64pt mode, then gears into the 256pt mode
- ¥ Concatenated payloads may use either 64 point or 256 point mode, depending on CPE s capabilities

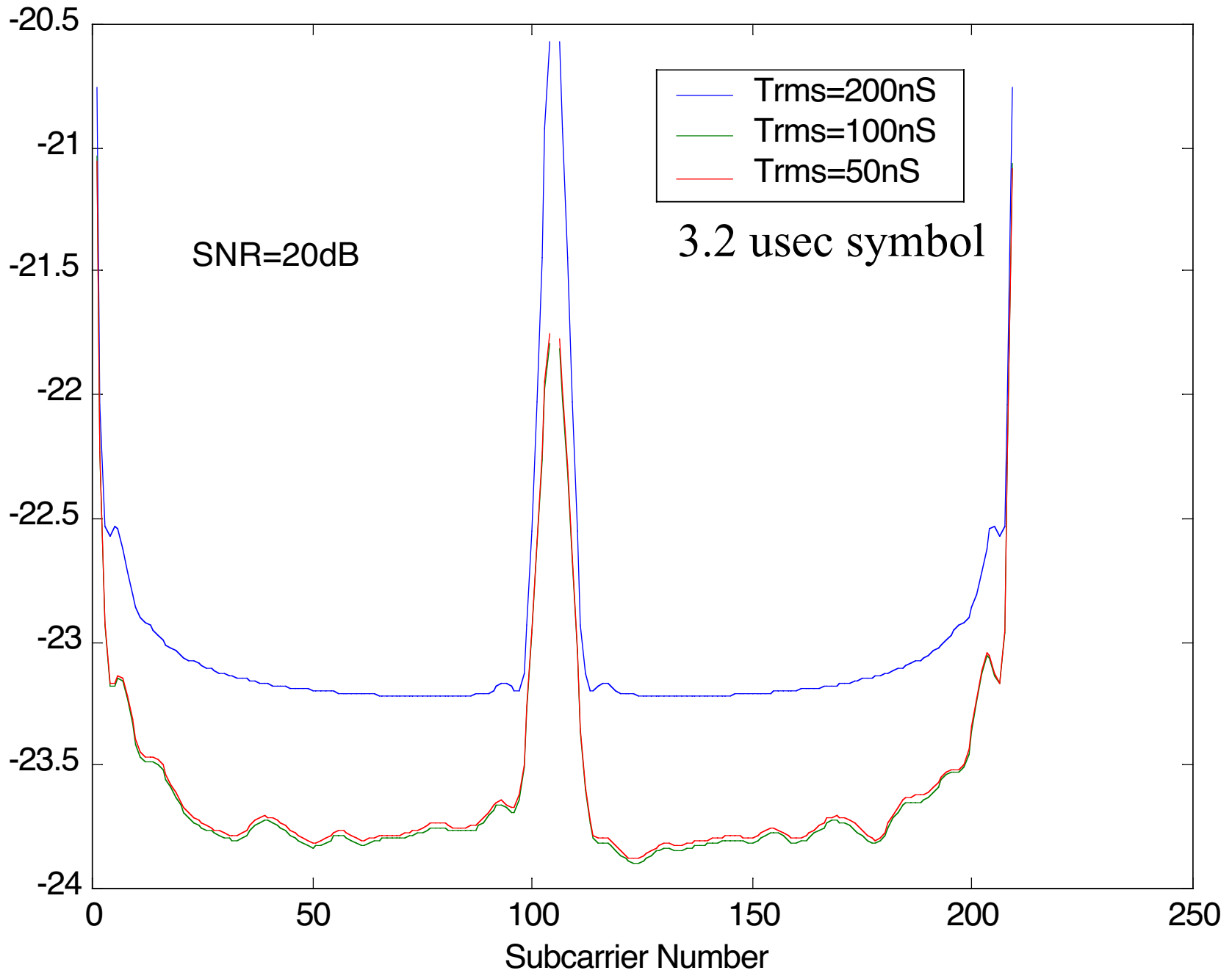
# Time-frequency view

Training

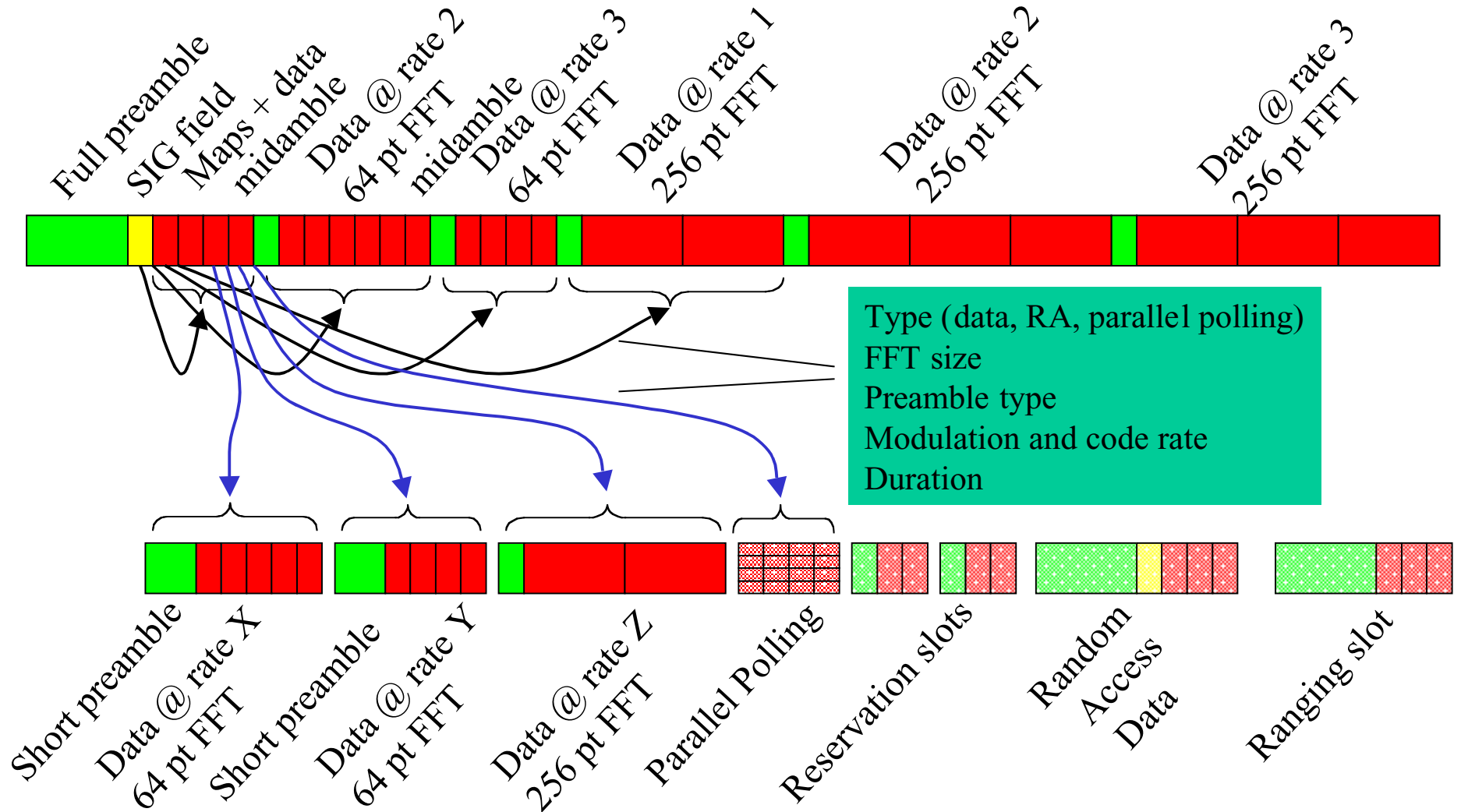
Data



208 subcarriers Worst case assumed to be 200nSec



# Mixing FFT and modulation modes

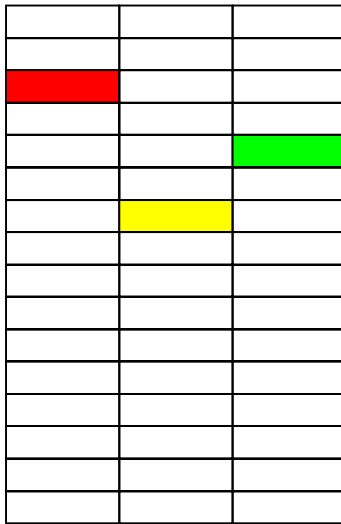


# Subcarrier based parallel polling

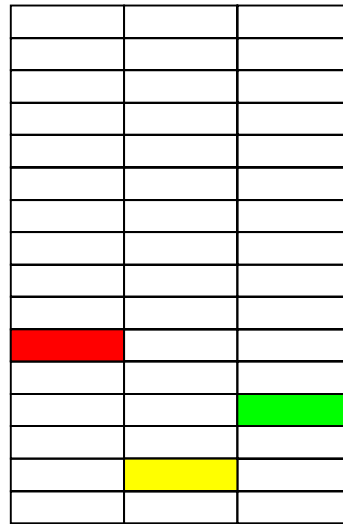
- ⌘ Fourier Transform allows simultaneous detection of multiple subcarriers sent by multiple users
  - Extreme case of OFDMA combined with On-Off Keying with 1 subcarrier per user.
  - Demands preranging
- ⌘ CDMA-like, but preserves orthogonality
- ⌘ Concentrates power, allows higher SNR
- ⌘ Permute frequencies in each superframe to avoid prolonged fades



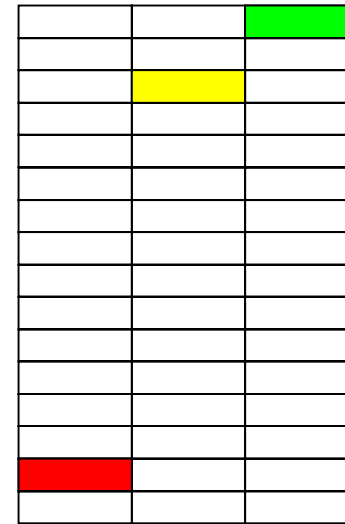
# Subcarrier based polling



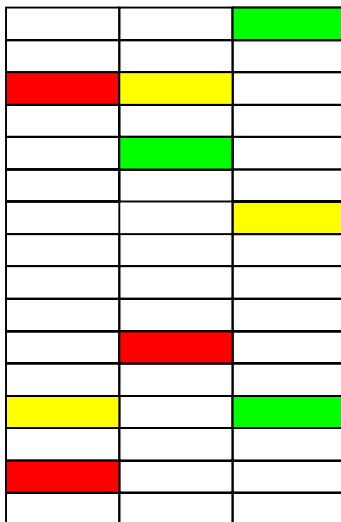
Frame 1



Frame 2



Frame 3



Several subcarriers can be sent for higher detection reliability in each attempt or convey a few-bit message, at expense of polling time

# Optional Advanced Techniques

## ¥ OFDMA

- The OFDM preserves orthogonality between transmissions of different users
- Allows survival at higher path loss

## ¥ Space-Time coding

- The decoupling between equalization and coding plays important role in making those techniques practical
- New preambles need to be designed for training of response from multiple antennas

# BRZE s OFDM proposal Summary

¥ Parameters draw on 802.11a+HIPERLAN/2 standards

—Available technology

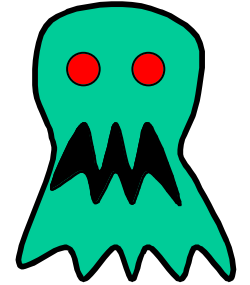
¥ Improved performance modes

—Longer FFTs, improved ECCs

¥ Fast Parallel Polling for fast demand discovery

¥ Ready for advanced antenna and multiaccess techniques

# Peak2Avg Problem- How bad?



- ¥ Worst case peaks are  $kN$  times the average
  - $N$  is the number of subcarriers
  - $k$  is constellation dependent, about 3 dB for QAM
  - 20 dB for  $N=52$ , 26 dB for  $N=216$
- ¥ Central Limit Theorem (sum of many small contributions)  $\rightarrow$  amplitude is Rayleigh
- ¥ Worst peak in a typical packet is +10 dB
- ¥ Some clipping can be tolerated!!
  - OFDM spreads clips over subcarriers
  - Error Correction Coding improves robustness
- ¥ Typical PA backoff — 7-9 dB
  - Depends on constellation and on regulatory masks

# PAPR — back of an envelope



∄ Central Limit Theorem (sum of many small contributions)  $\rightarrow$  amplitude is Rayleigh

$$\∄ P(P > P_{th}) = \exp(-P/P_{avg})$$

∄ Typical packet is about 20,000 samples  
—Look for threshold with crossing probability  
 $5 * 10^{-5}$

$$\∄ P_{th}/P_{avg} = -\ln(5 * 10^{-5}) = 9.9 = 10 \text{ dB}$$

∄ Remember that some clipping can still be tolerated

# Freq. Domain.Equ — Uplink Option

- ¥ The CPEs have the most to gain at PA
- ¥ The processing burden is at BST
- ¥ Frees CPE chip manufacturers to work

