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

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

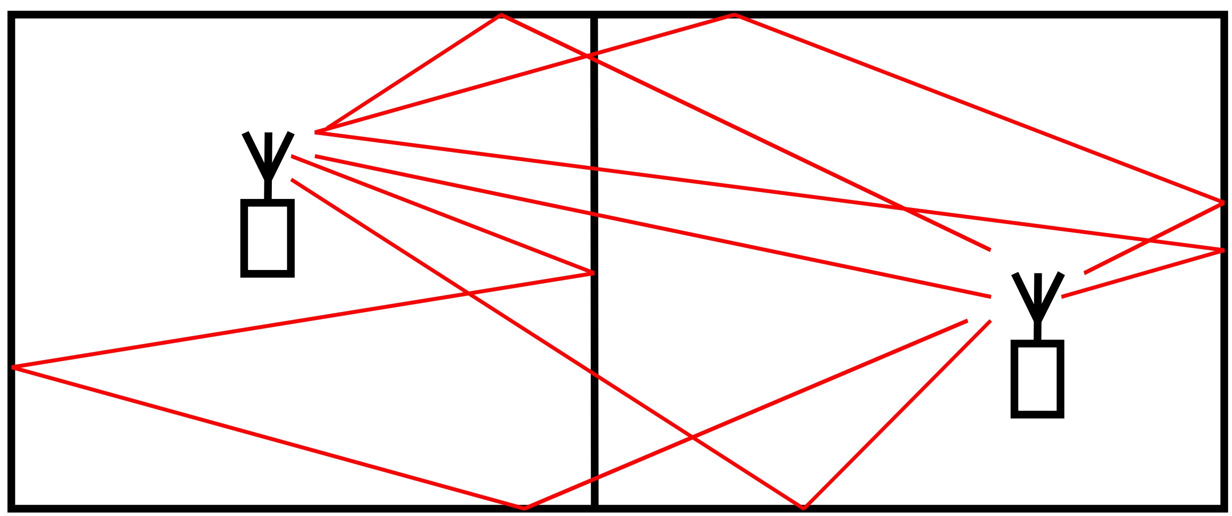
—DAB, DVB-T

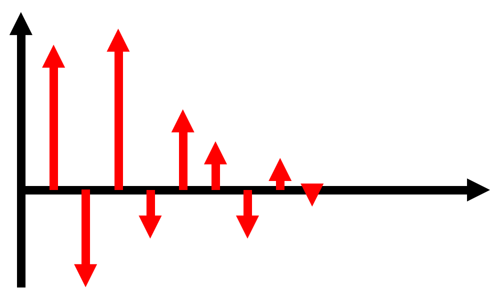
¥ Facilitates smart antenna techniques in multipath environment

¥ Enables fast parallel polling

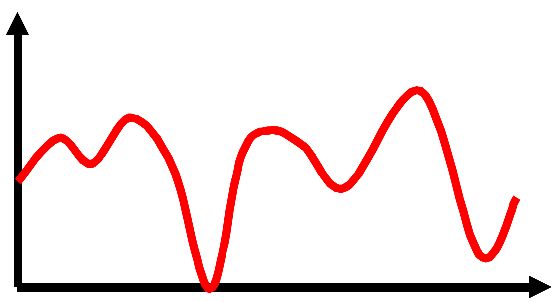
¥ Enables OFDMA

Multipath

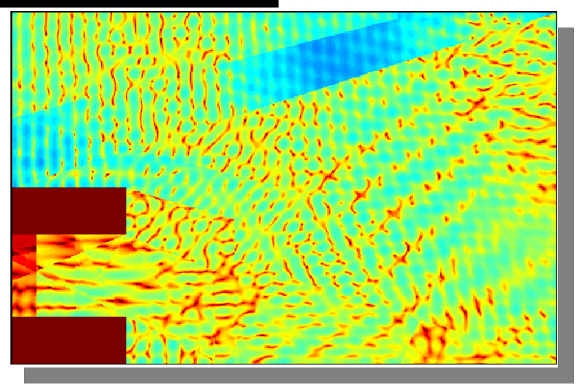




time



frequency



space

Solution 1 - Equalization

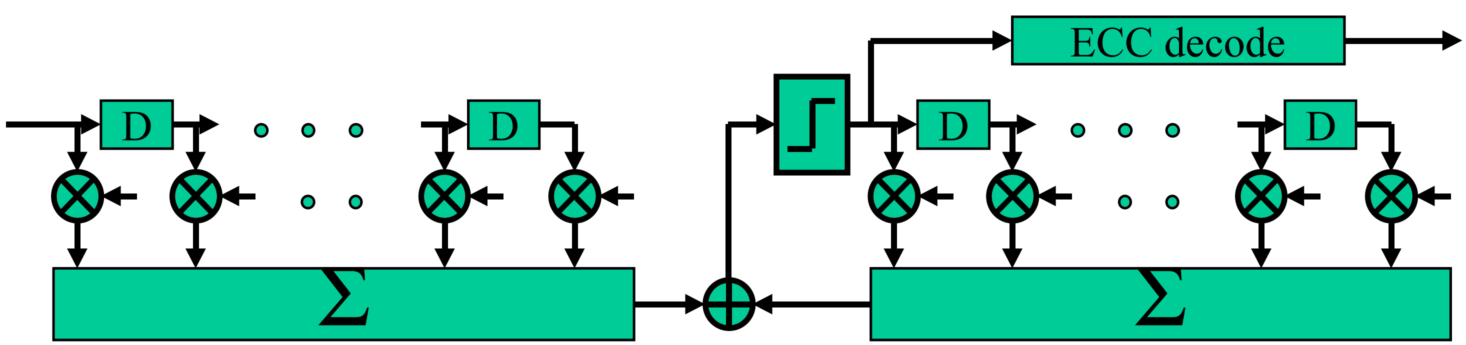
¥ Equalization is building an inverse filter

¥ If channel has nulls, you cannot inverse

¥ Decision Feedback Equalizer (DFE) can handle also channels with nulls

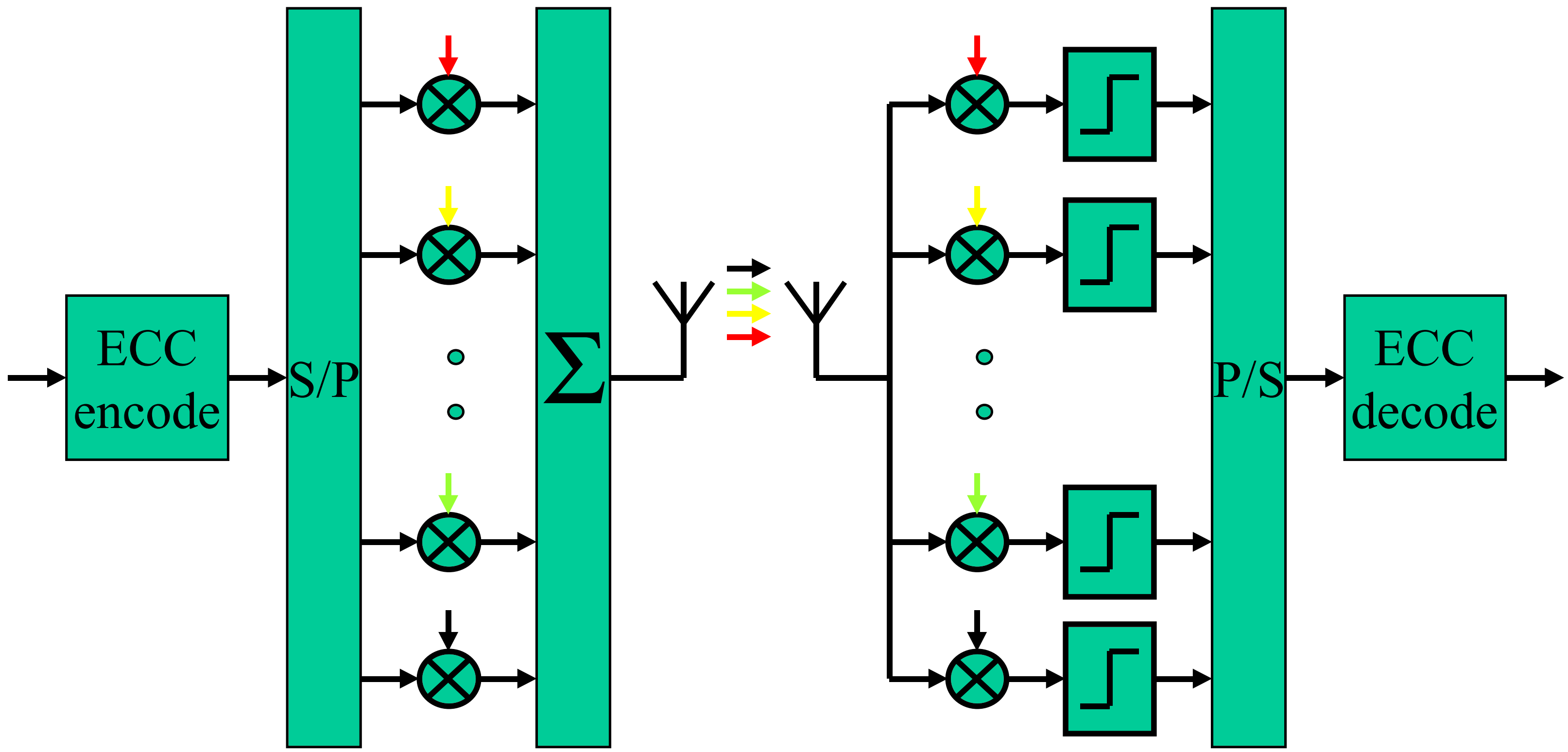
—**In coded systems past decisions may be unreliable (not solved by Freq. Domain Equ.)**

¥ In long channels — complexity prblem

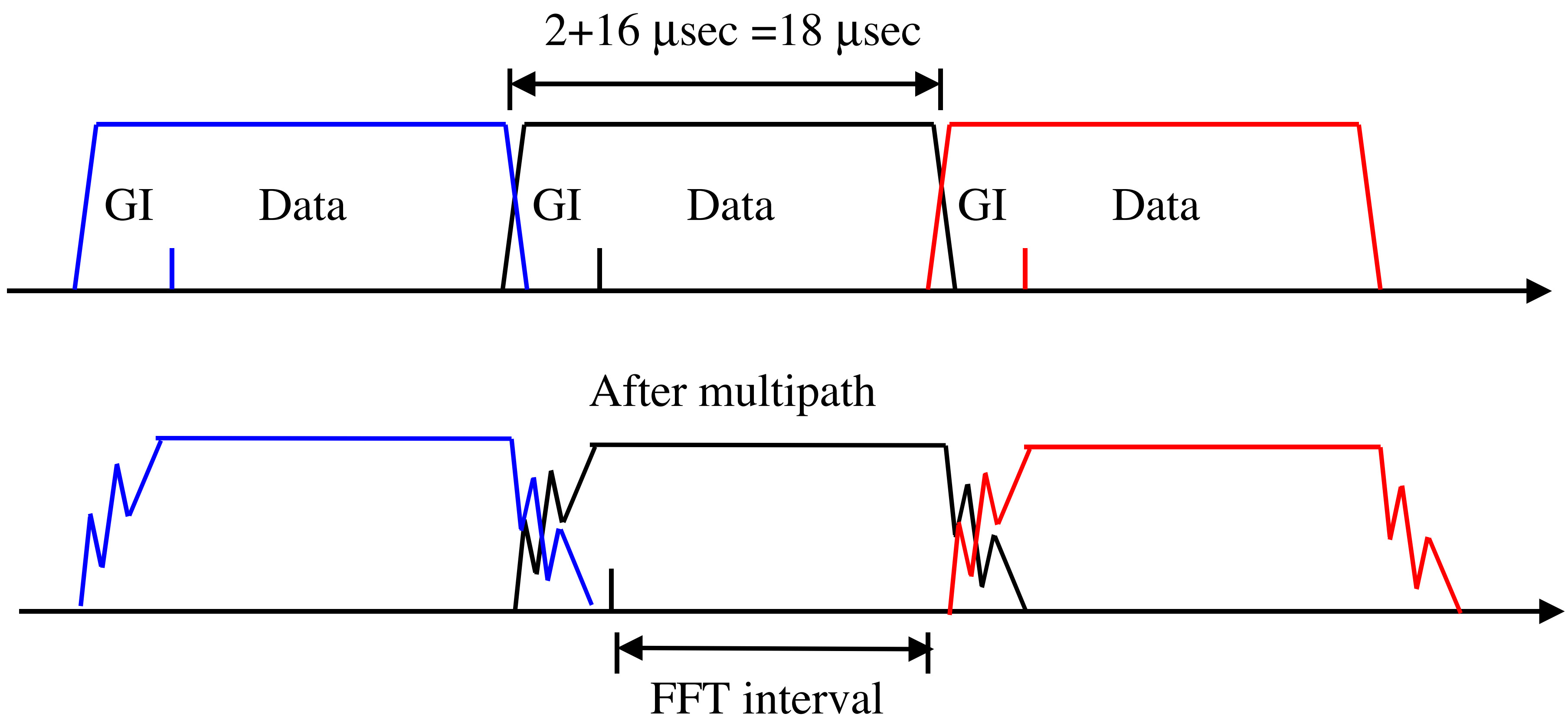


Solution 2 — Parallel Channels

- Send several long symbols in parallel
- OFDM uses complex exponential waveforms

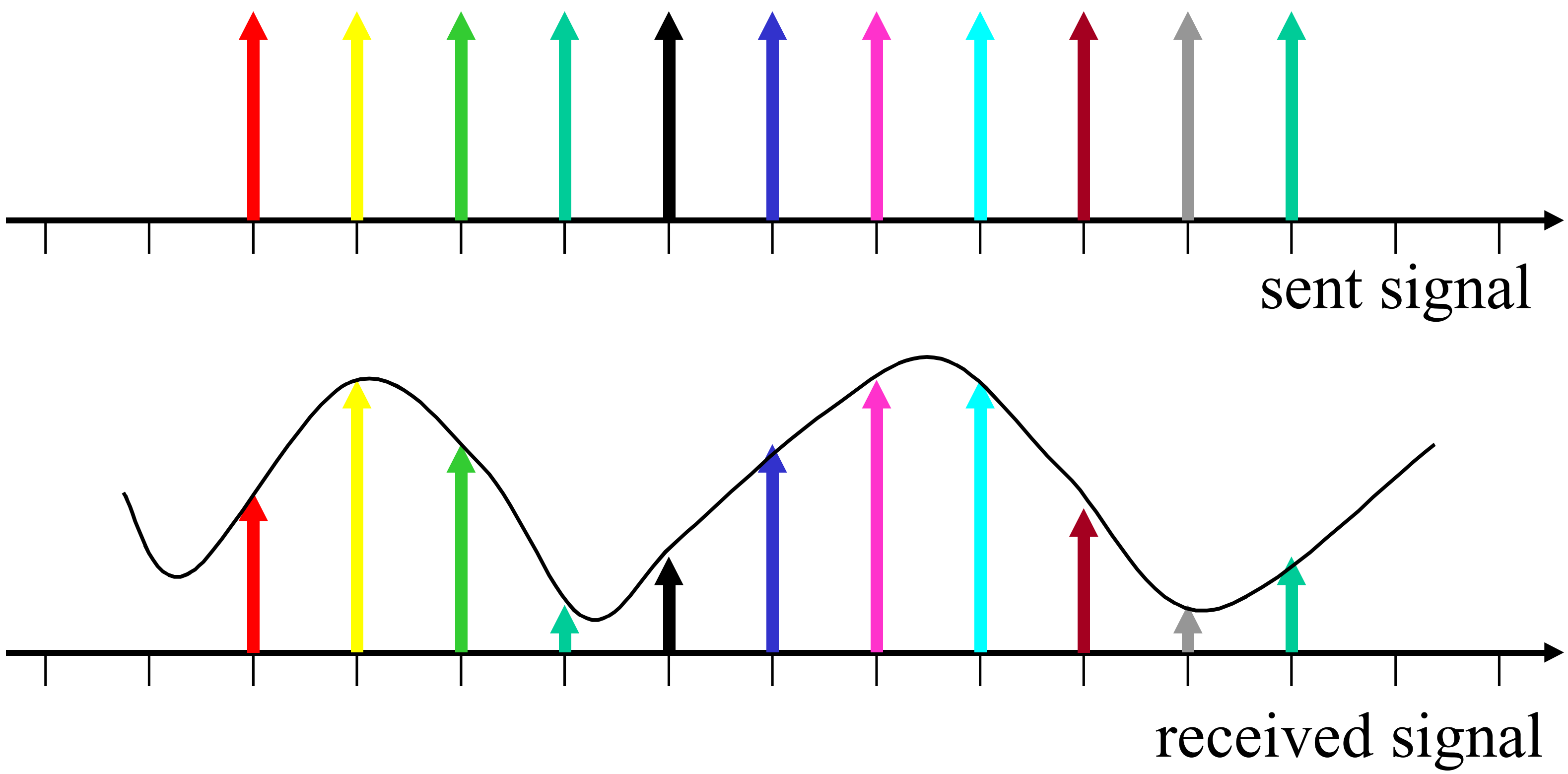


Guard Interval and FFT Interval



Multipath effect on subcarriers

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



Modulation Constellations

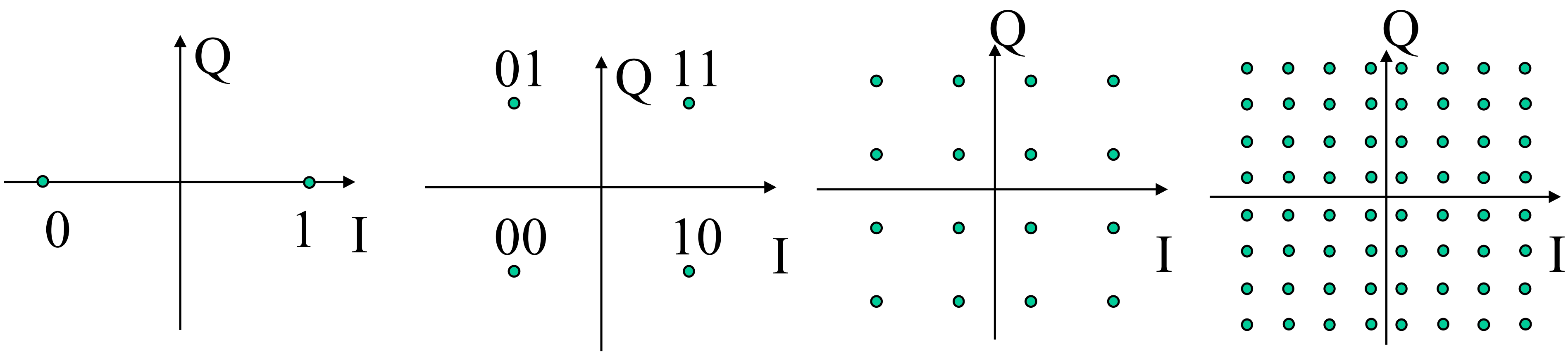
¥ Use square QAM constellations only

¥ BPSK+4/16/64 QAM on downlink

—256 QAM optional

¥ BPSK+4/16 QAM on uplink

—64,256 QAM optional



BPSK
1 bits/sym

QPSK=4QAM
2 bits/sym

16QAM
4 bits/sym

64QAM
6 bits/sym

Rx - QAM to metrics conversion

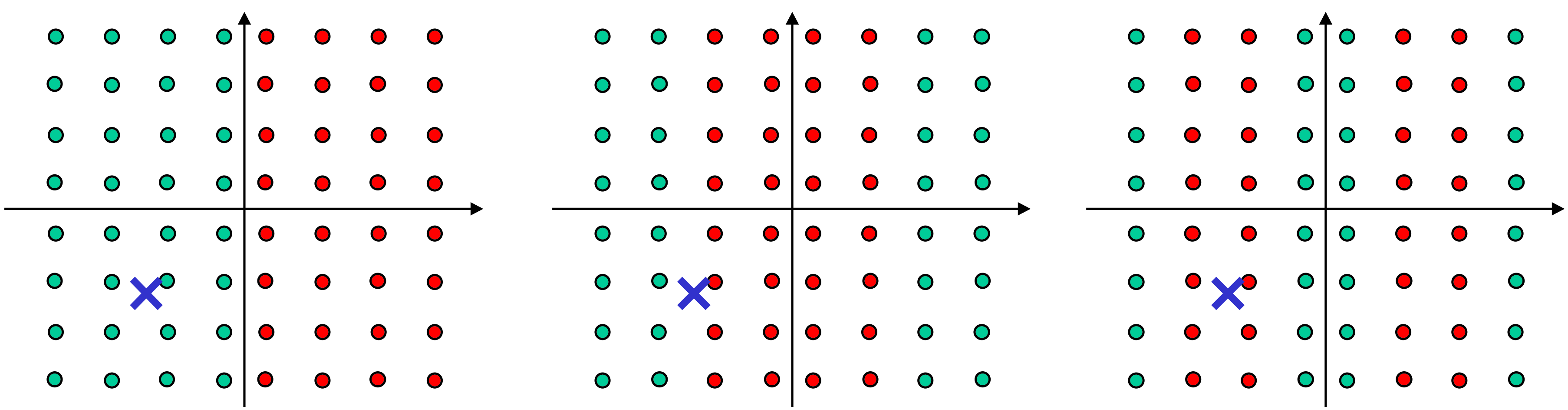
¥ Bit metric is generated based on

—proximity to nearest 0 and 1

—Subcarrier strength

¥ Gray coding → One bit unreliable at a time

¥ Square constellation → separate I & Q processing



I - MSB   I - Middle bit   I - LSB

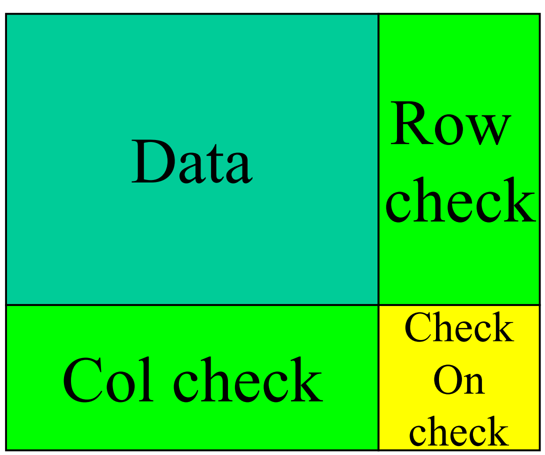
Error Correction Coding

¥ 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



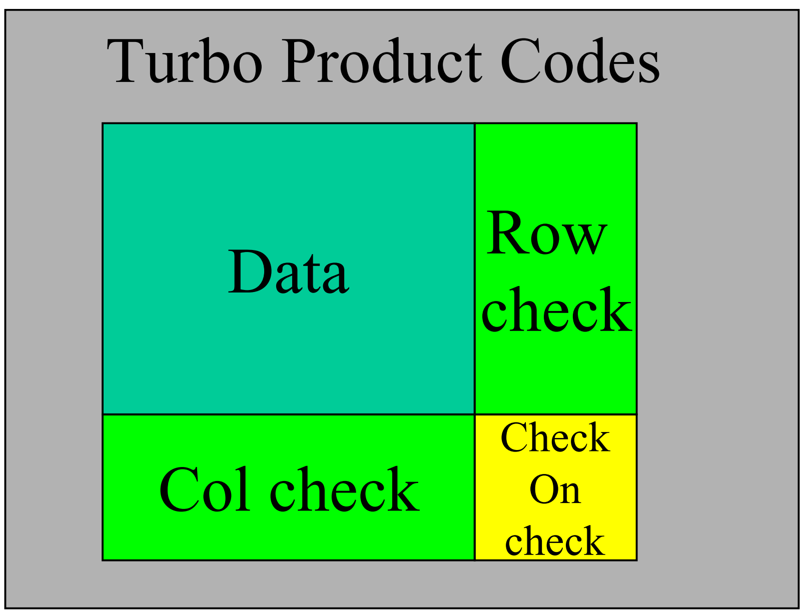
Turbo Codes

¥ Turbo codes are like crosswords

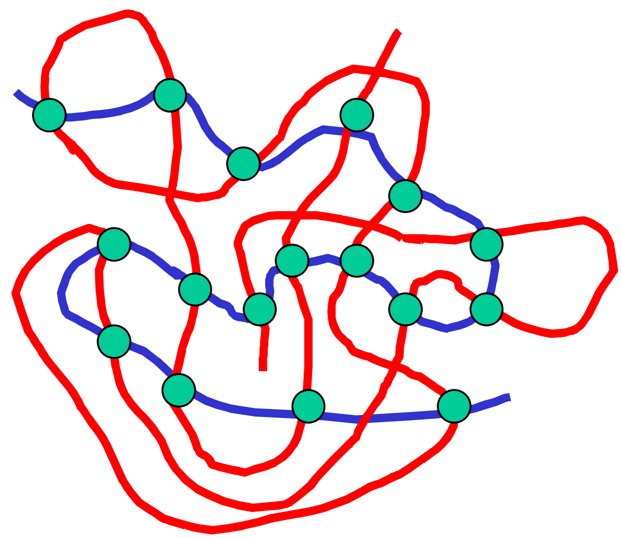
— Solve rows, then use reliable bits to solve columns, then use the new reliable bits for rows etc. etc. till convergence

¥ 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:

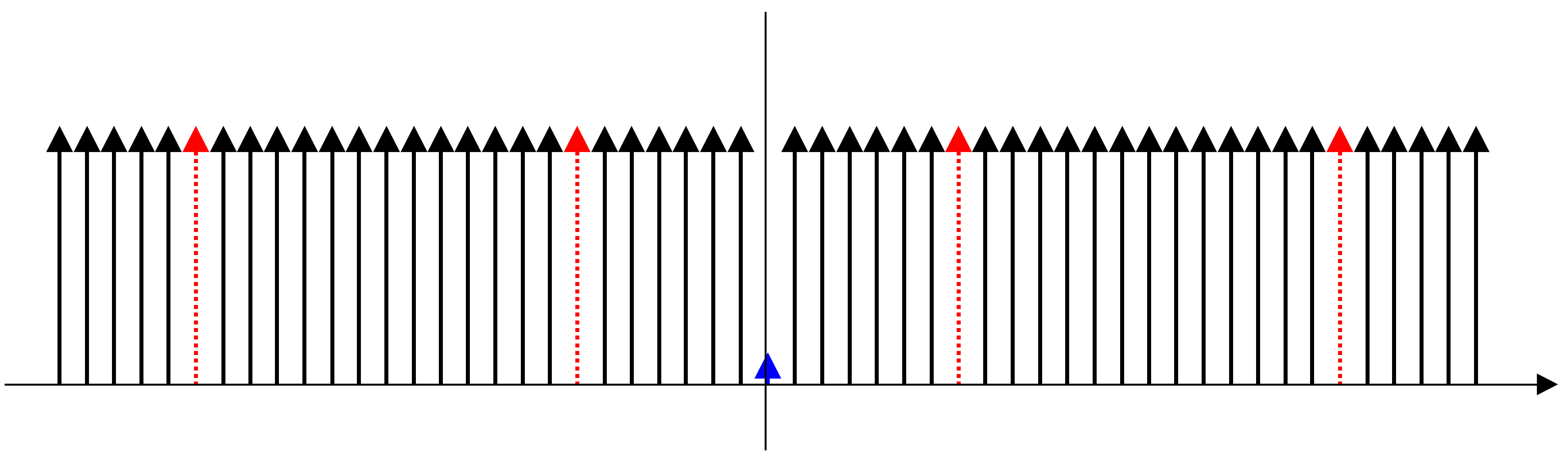
—Fading Diversity → spread pilots in frequency

—SNR accumulation

¥ 802.11a uses 4 pilots per 48 data subcarriers

¥ For 256pt FFT eight pilots are sufficient

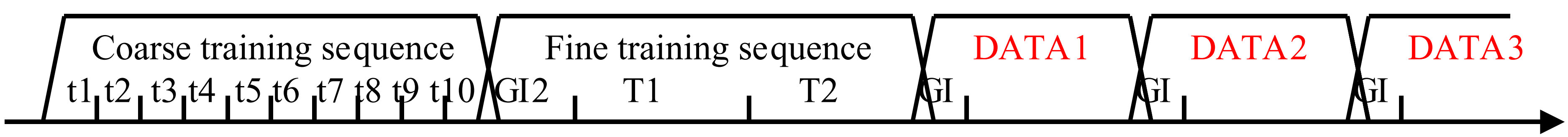
—Smaller overhead



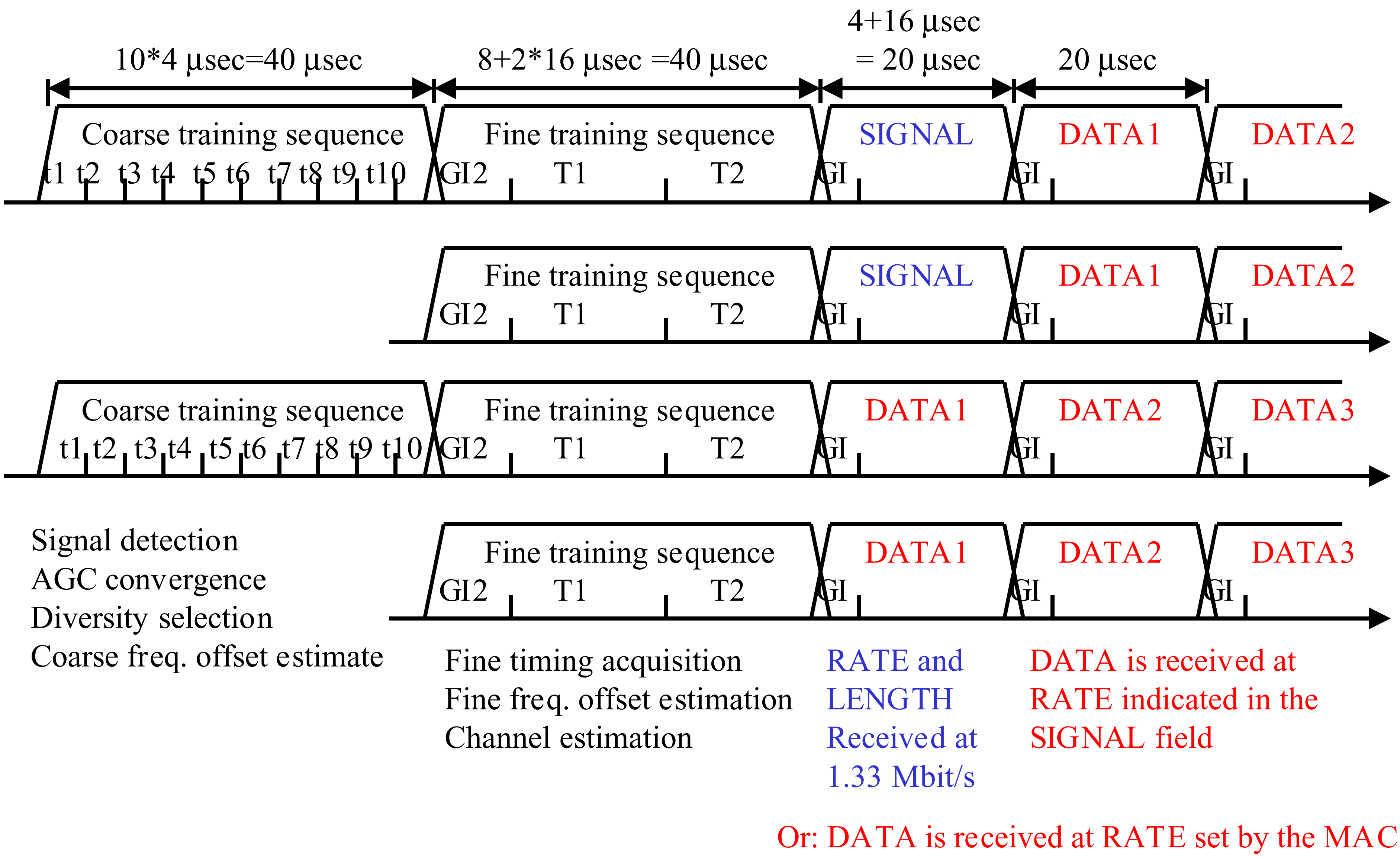
Preamble Structures

¥ 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



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

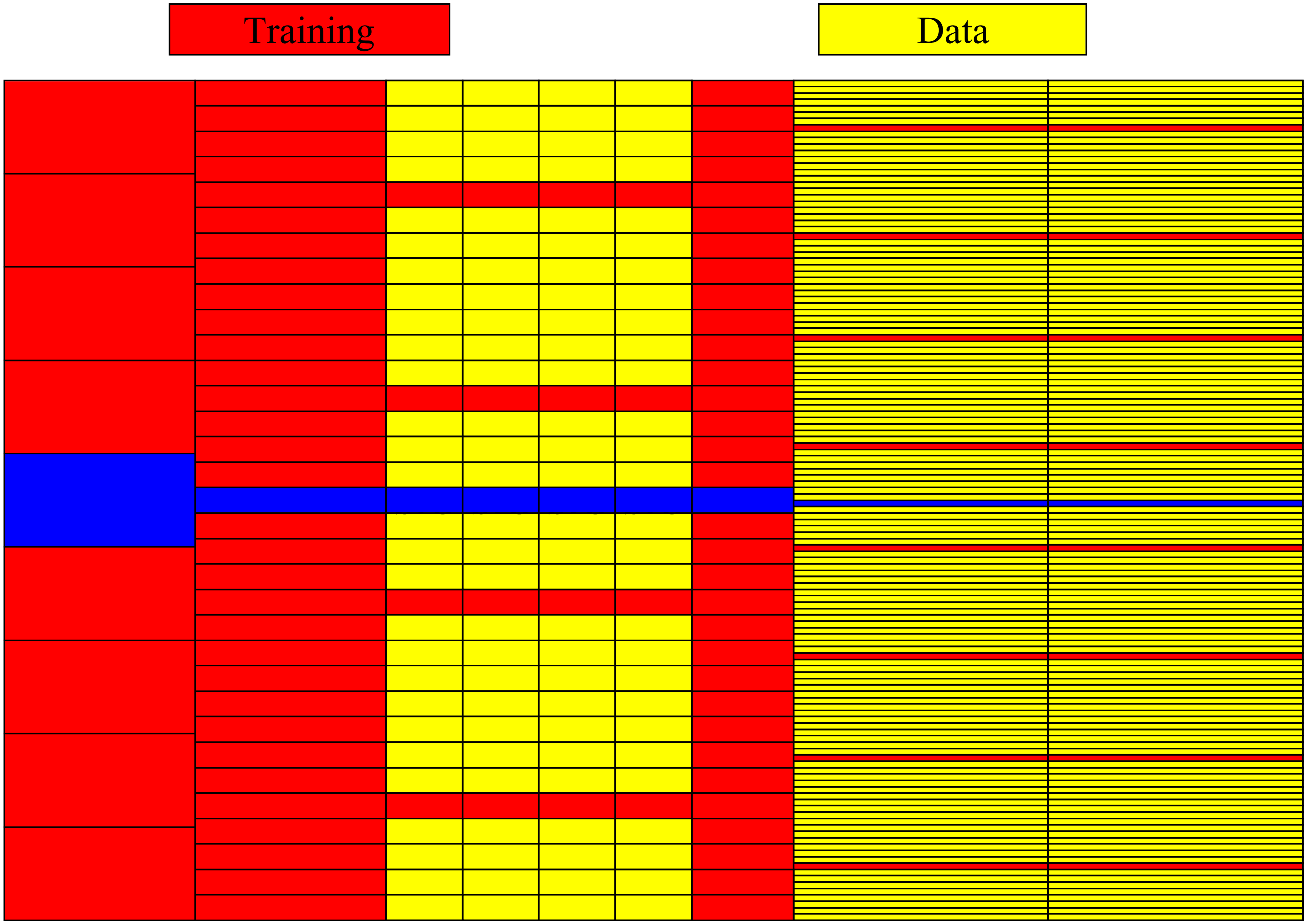
Modulation	ECC rate	Rate, 64pt	Rate, 256pt	Sensitivity ◦
BPSK	R=1/2	1.33 Mbit/s	1.57 Mbit/s	-94 dBm
BPSK	R=3/4	2.00 Mbit/s	2.36 Mbit/s	-93 dBm
QPSK	R=1/2	2.66 Mbit/s	3.15 Mbit/s	-91 dBm
QPSK	R=3/4	4.00 Mbit/s	4.73 Mbit/s	-89 dBm
16QAM	R=1/2	5.33 Mbit/s	6.30 Mbit/s	-86 dBm
16QAM	R=3/4	8.00 Mbit/s	9.45 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

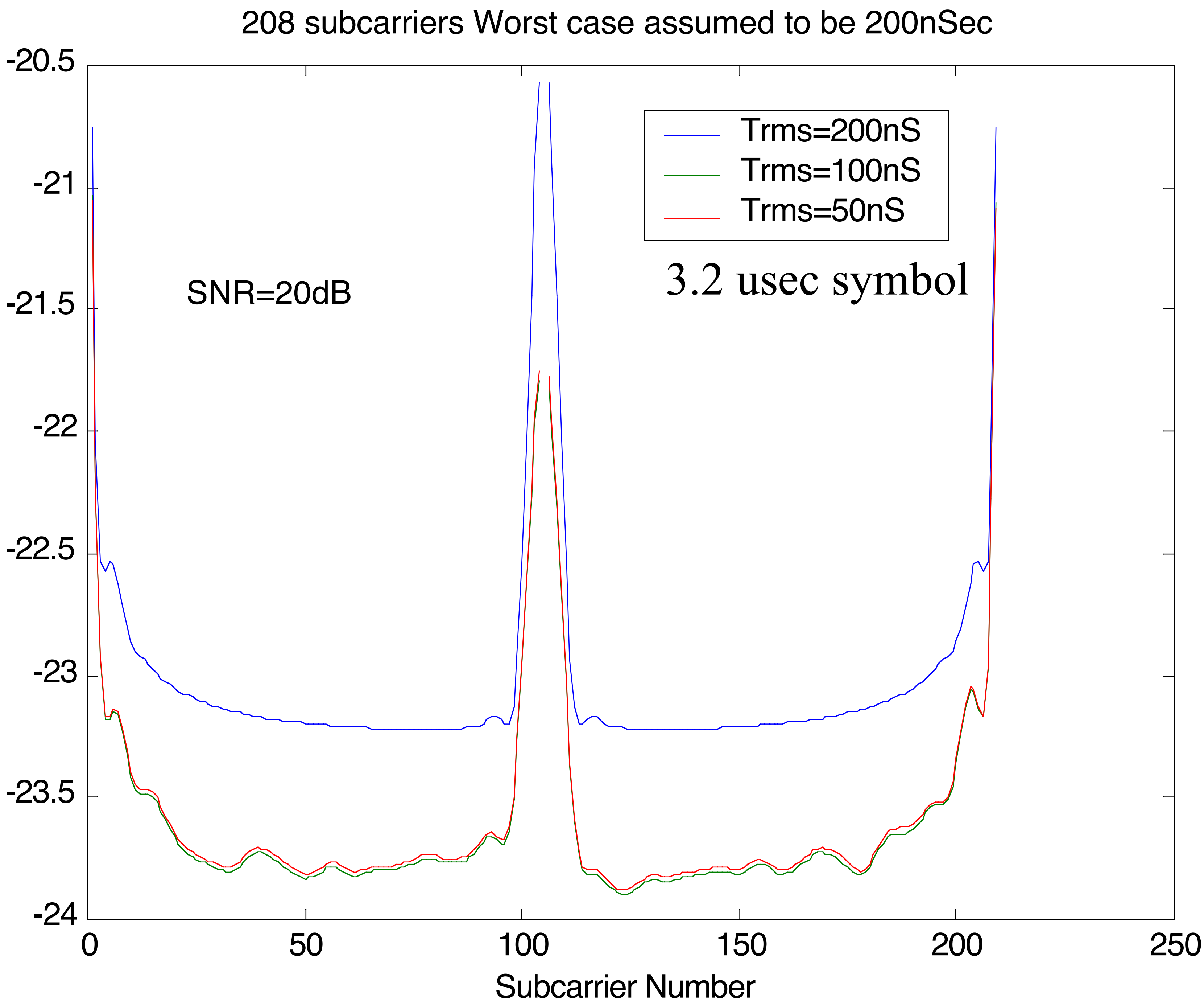
Sensitivity assumes NF=6 dB and 4 dB implementation loss

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

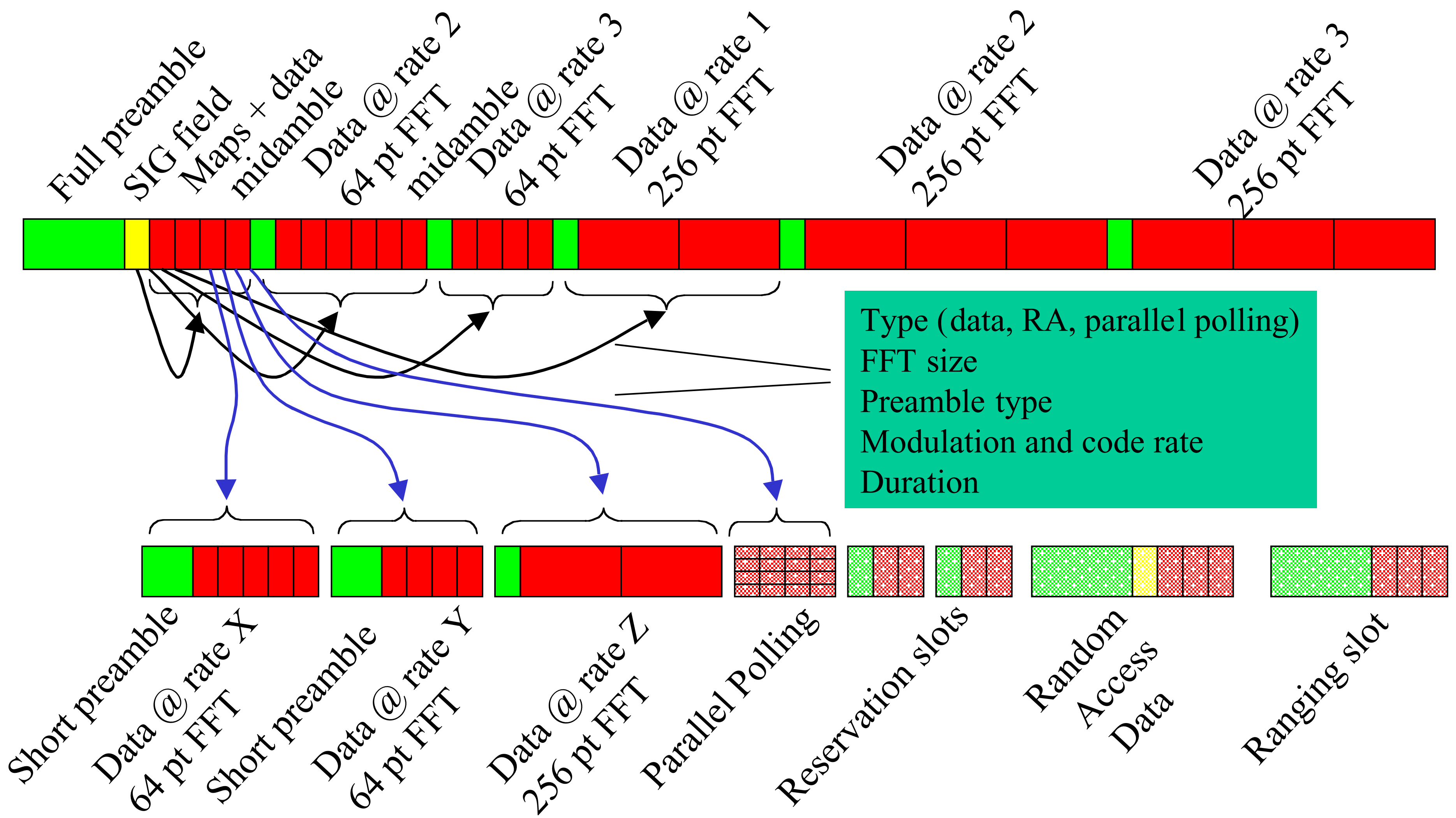
Time-frequency view





208 subcarriers Worst case assumed to be 200nSec
Trms=200nS
Trms=100nS
Trms=50nS
3.2 usec symbol
SNR=20dB
-20.5
-21
-21.5
-22
-22.5
-23
-23.5
-24
0
50
100
150
200
250
Subcarrier Number

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.

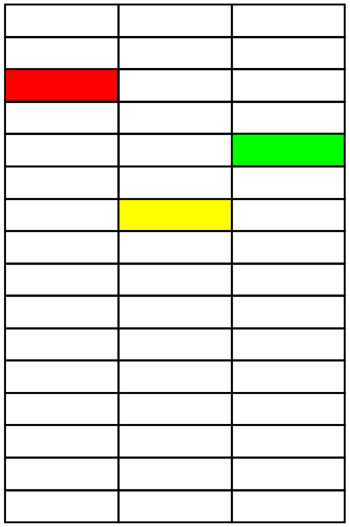
—Demands preranging

¥ CDMA-like, but preserves orthogonality

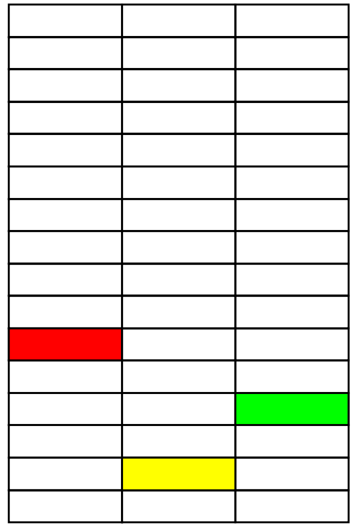
¥ Concentrates power, allows higher SNR

¥ Permute frequencies in each superframe to avoid prolonged fades

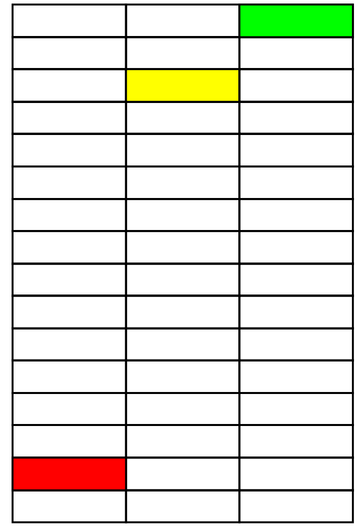
Subcarrier based polling



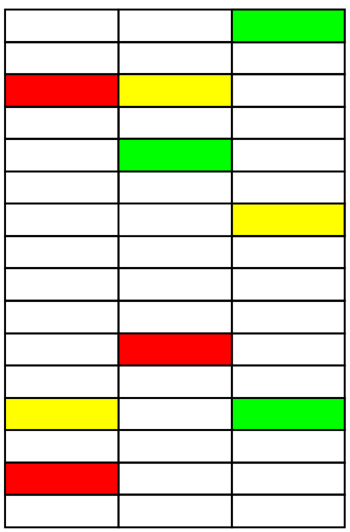
Frame 1



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

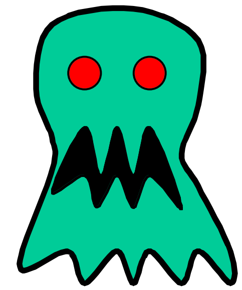
¥ Improved performance modes

— 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) → amplitude is Rayleigh

¥ Worst peak in a typical packet is +10 dB

¥ Some clipping can be tolerated!!

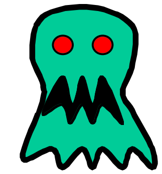
—OFDM spreads clips over subcarriers

—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) → amplitude is Rayleigh

¥ $P(P>P_{th})=\exp(-P/P_{avg})$

¥ Typical packet is about 20,000 samples

— Look for threshold with crossing probability $5*10^{-5}$

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