SC-FDE PHY Layer System Proposal for Sub 11 GHz BWA (An OFDM Compatible Solution)

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IEEE 802.16.3c-00/31r2 and IEEE 802.16.3c-00/32

Purpose:
This contribution is presented and discussed within Task Group 3 in Session #12 for possible adoption as baseline for a Sub 11 GHz BWA PHY standard.

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PHY Layer System Proposal for Sub 11 GHz BWA Having OFDM and SC-FDE

SC-FDE PHY Layer System Proposal for Sub 11 GHz BWA (An OFDM Compatible Solution)

A Presentation to

IEEE 802.16.3 Task Group

March 12, 2001, Hilton Head, SC, USA

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Team Proposal Objectives

- The 802.16.3 PHY standard should allow **BOTH** Single Carrier (SC) and OFDM technologies to fully benefit from the features of each technology
- The standard should support TDD and FDD systems and leave the selection of each system to the vendors /operators decision on implementation complexity, traffic scenario and cost objectives
- Compatibility of SC–FDE and OFDM
- Frame Structure supporting both SC and OFDM schemes in relation with 802.16 MAC Layer

Presentation Sequence

- Overview of Merged Proposal (Anader)
- Performance Comparison (Lek)
- Adaptive Antenna & Power Amplifier Considerations (David & Paul)
- MAC / PHY Interface (Brian, Joe)
- Support of OFDM (Manoneet)
- System Throughput and Link Budget (John, Anader)
  Summary & Conclusion (Anader)
- Discussion (All)

Options: SC-FDE and OFDM

Main Options:

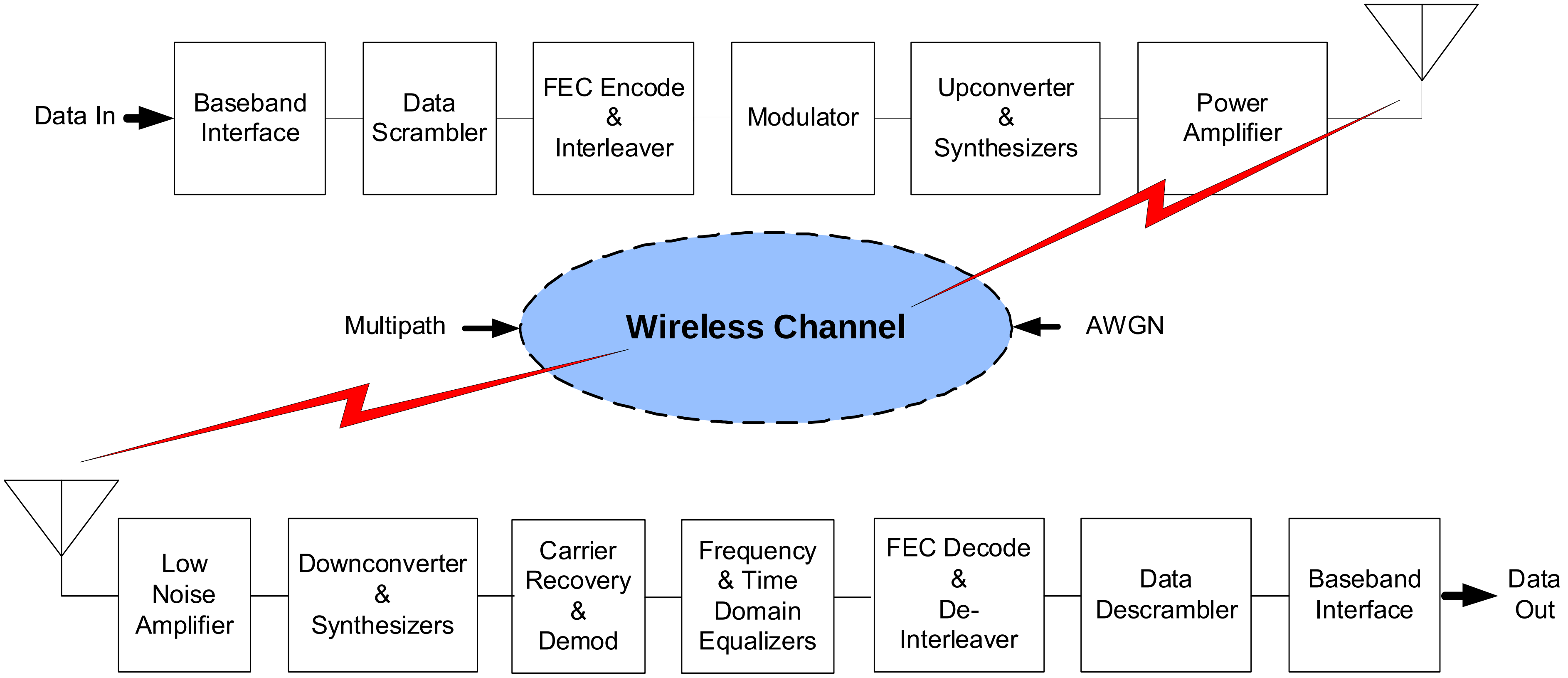
- Single Carrier - Frequency Domain Equalizer (SC-FDE) and / or DFE in time domain
- OFDM
- Compatibility of SC-FDE and OFDM schemes:
  - Convertible SC-FDE and OFDM
  - Mixed Mode Possible (SC-FDE for U/S and OFDM for D/S)
- Support of both SC - FDE and OFDM

PHY Layer System Proposal
for Single Carrier – Frequency Domain Equalizer

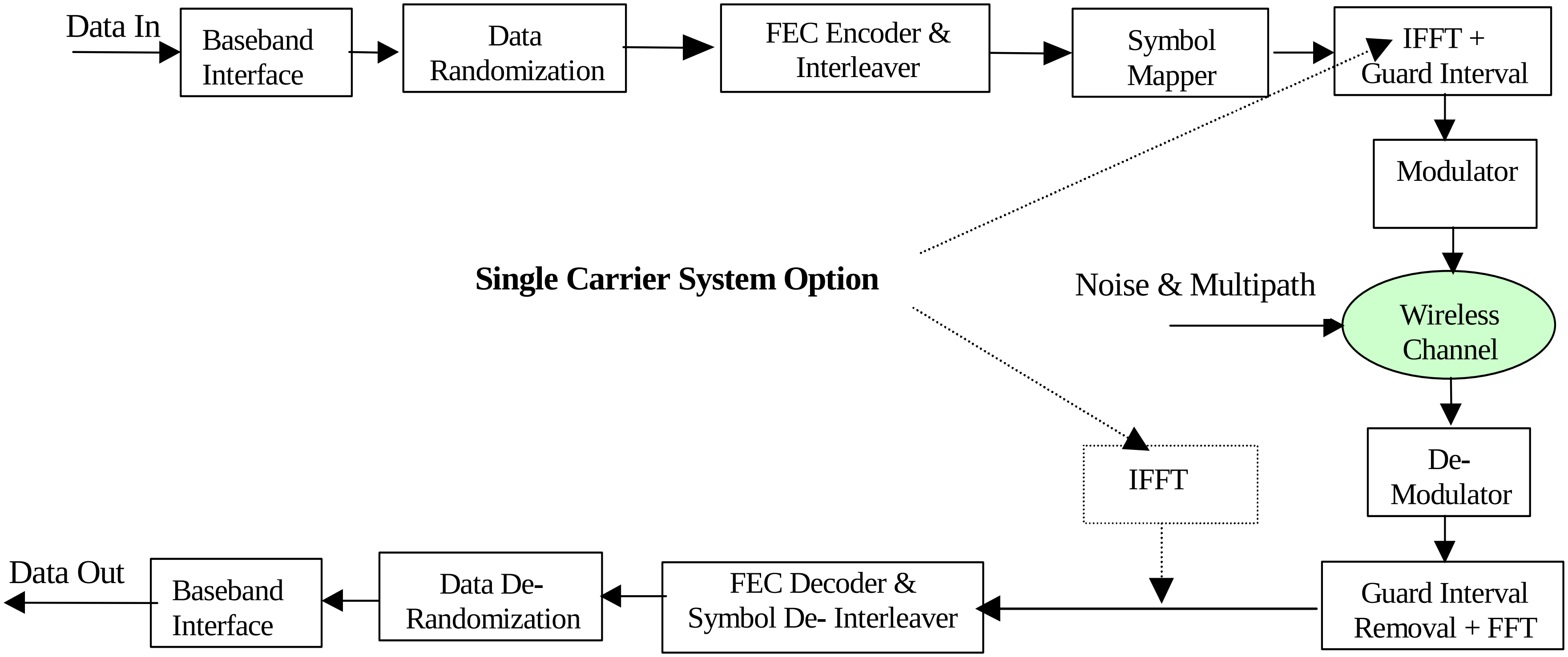
The main features of the PHY proposal are the following:

- Upstream multiple access scheme is based on TDMA
- Downstream multiple access scheme is based on TDM/ TDMA
- Duplex schemes are based on either TDD, FDD, or Half Duplex FDD
- PHY uses Adaptive modulation and FEC coding in both U/S & D/S paths
- Flexible Frame Structure supports SC - FDE and OFDM (FDD or TDD)
- Easy Migration from SC with Time Domain Equalizer (SC-TDE) to SC-FDE
- Same or better Severe Multi-path mitigation as OFDM with higher efficiency
- Lower cost and complexity SS and BS
- The PHY is flexible in terms of geographic coverage, in the use of frequency band, and capacity allocation in both LOS and NLOS situations
- Full compatibility with the 802.16 MAC
- Base Station can use multiple sector antennas. Support for future use of Smart antennas is provided in the PHY design. Supports diversity schemes (SIMO, MIMO technologies)
- The proposed PHY has added feature of Configurability to OFDM.

The Proposed PHY Layer Block Diagram

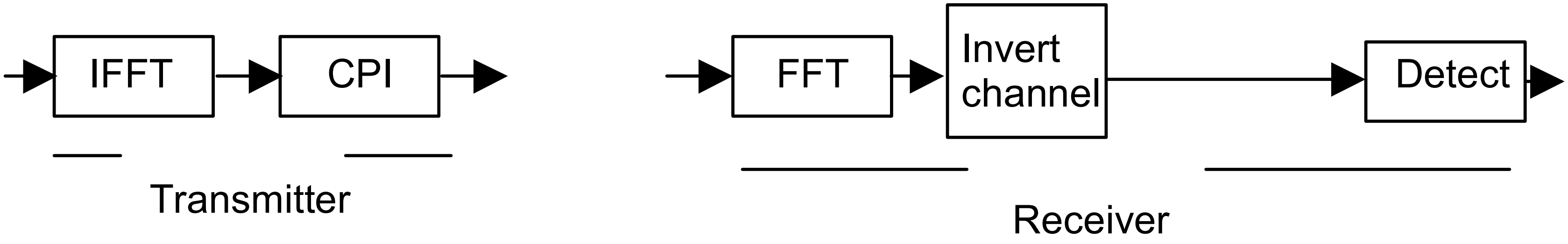


A Compatible OFDM and Single Carrier PHY Proposal Block Diagram



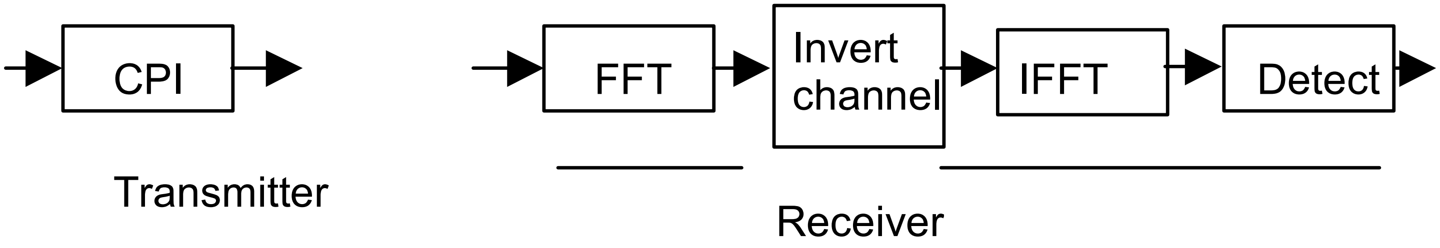
Single Carrier-Frequency Domain Equalization (SC-FDE) and OFDM

(a) OFDM :



IFFT
CPI
Transmitter
FFT
Invert channel
Detect
Receiver

(b) Single-Carrier Modulation (SC-FDE):

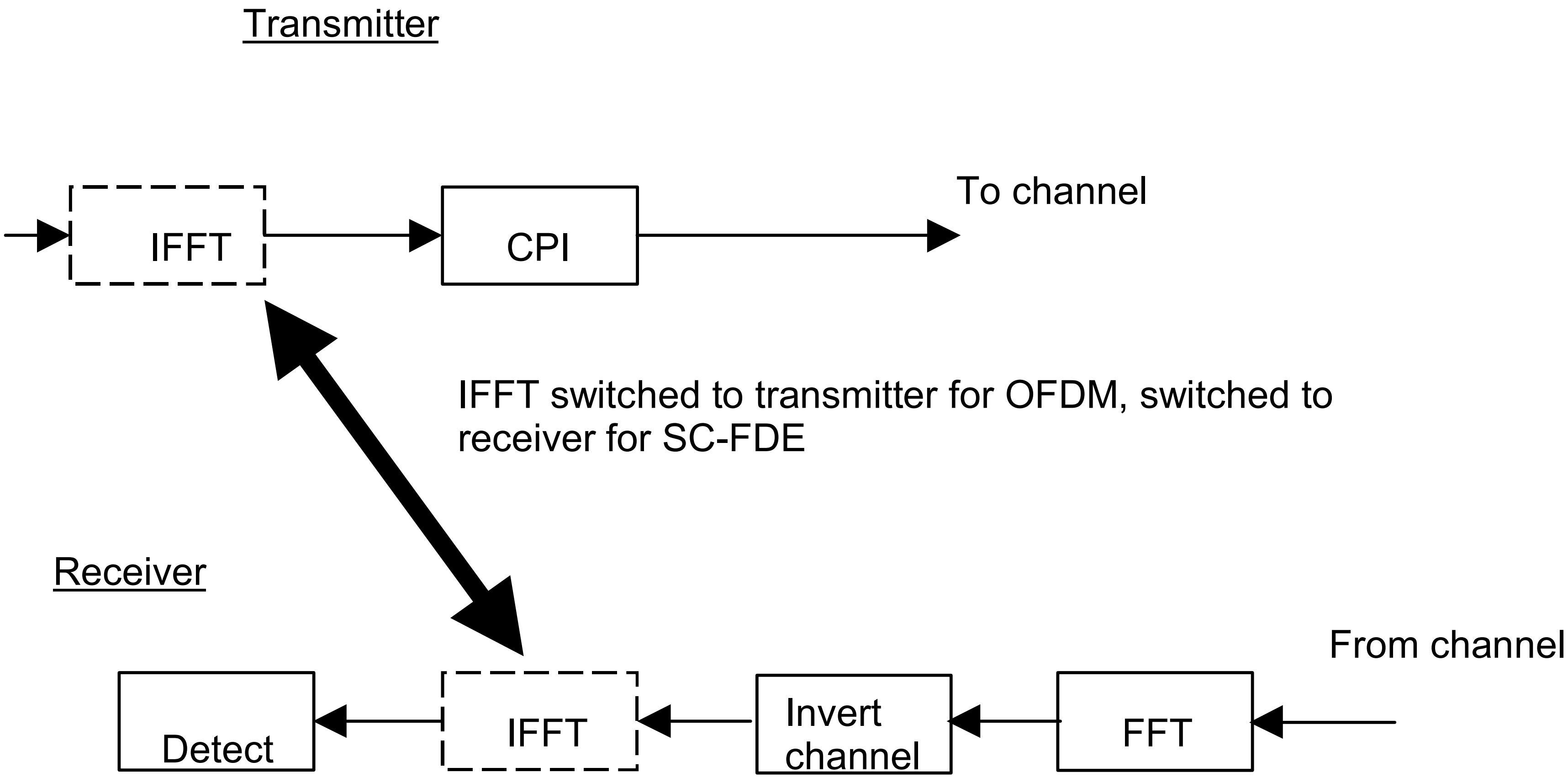


CPI
Transmitter
FFT
Invert channel
IFFT
Detect
Receiver

CPI: cyclic prefix insertion
FFT: fast Fourier transform
IFFT: inverse FFT

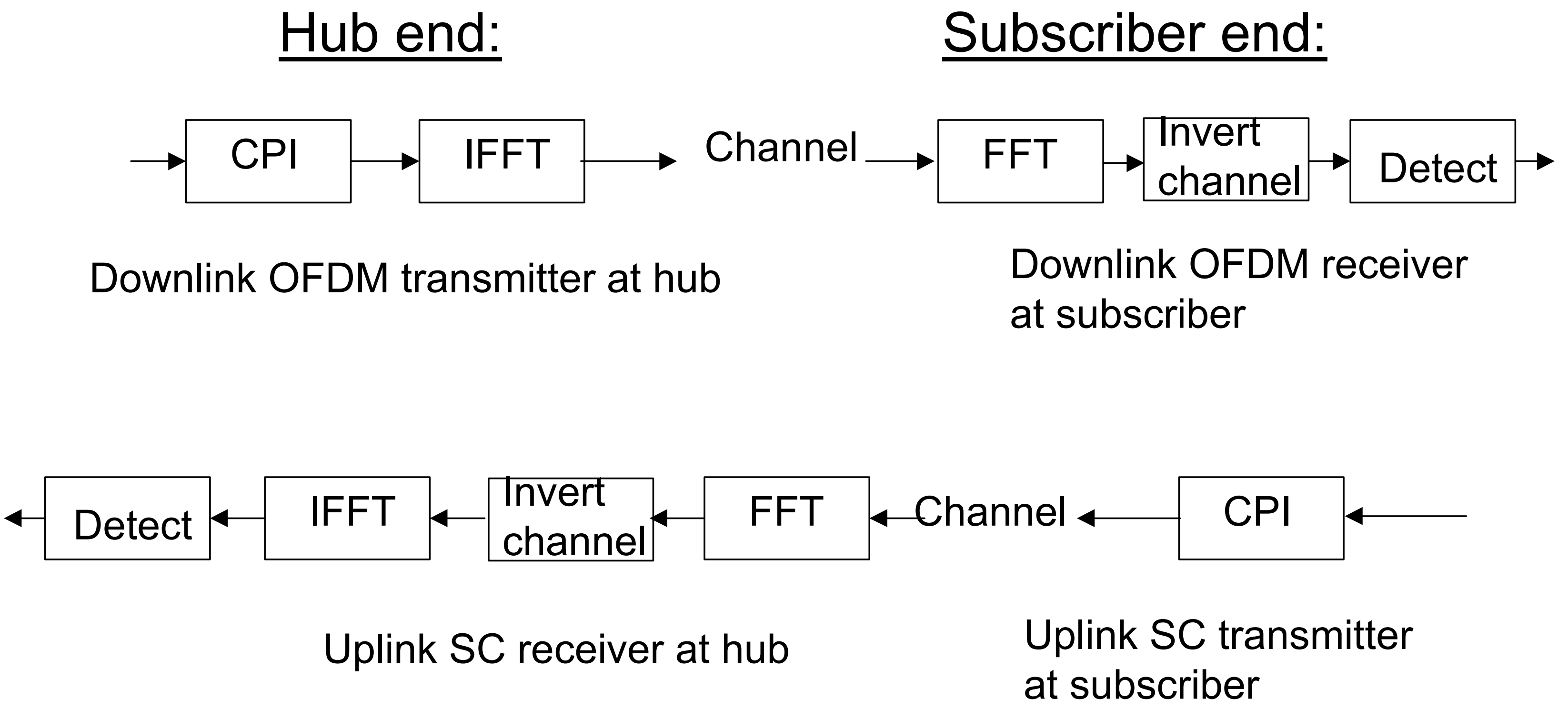
Coexistence of OFDM and SC-FDE:

A "Convertible" Modem



IFFT switched to transmitter for OFDM, switched to receiver for SC-FDE

Coexistence of OFDM and SC-FDE:
Uplink/Downlink Mixed Mode


Hub end:

Subscriber end:

Downlink OFDM transmitter at hub

Downlink OFDM receiver at subscriber

Uplink SC receiver at hub

Uplink SC transmitter at subscriber

Adaptive Modulation and Coding

Modulation:

- The proposed BWA system shall use Adaptive QPSK, 16QAM or 64 QAM modulation for the downstream transmission and
- Adaptive QPSK, 16QAM, or 64 QAM modulation for the upstream transmission.

Codings:

- Block Turbo Coding (TPC with SISO), or
- Concatenated Reed-Solomon and Convolutional coding (as used in DVB-S), or
- ARQ (MAC level) with or without FEC

Performance Evaluation of Single Carrier and OFDM in 2-11 GHz Broadband Wireless Systems

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Outline

- SC-FDE vs. OFDM performance comparison - Lek
- FD-DFE performance with a small number of feedback taps - Dave
- Number of training blocks and performance - Dave
- Low-complexity TD-DFE performance - Lek

SC-FDE vs. OFDM Comparison

- Performance with different code rates
- Performance with high-level Modulation
- Bottom Line

SC-FDE vs. OFDM Comparison

Summary

Both are wonderful*!

* In their own ways

Basic Understanding

- Uncoded OFDM does not exploit frequency selectivity

  Uncoded OFDM performance = av. performance of each tone

  = flat fading performance

  The only way OFDM can exploit multipath energy is through coding

- FD-LE suffers from noise enhancement loss

  Noise enhancement loss increases with av. input SNR

Simulation Assumptions

- Monte-Carlo simulation with 20,000 channel samples
- Modulation: QPSK, 16QAM, 64QAM with 10% roll-off , 5 Mbaud
- Channel models: SUI2 and SUI5 with omni antennas (latest version)

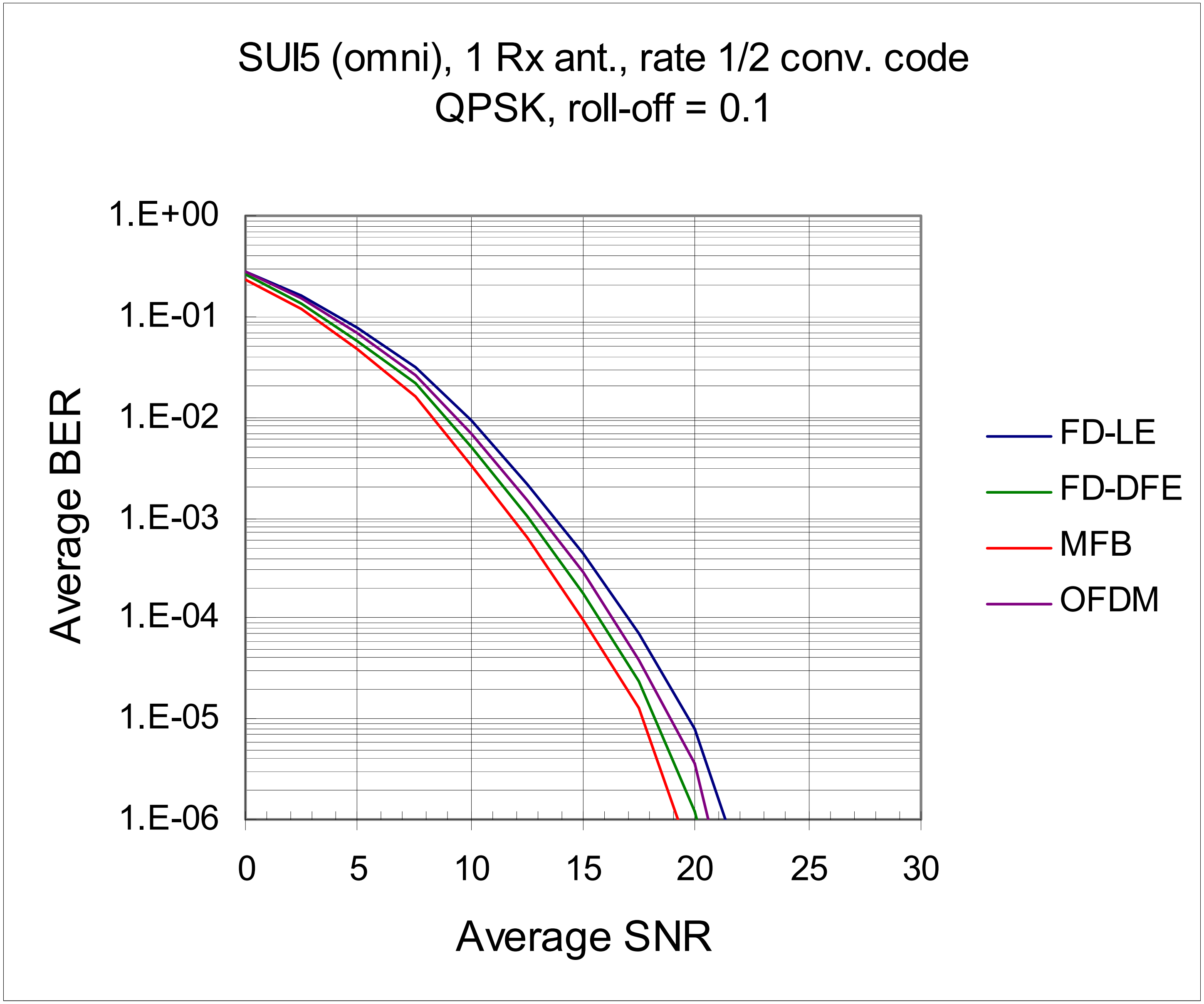
  Block fading is assumed
- 512-point FFT. No channel estimation errors, MMSE receiver adaptation

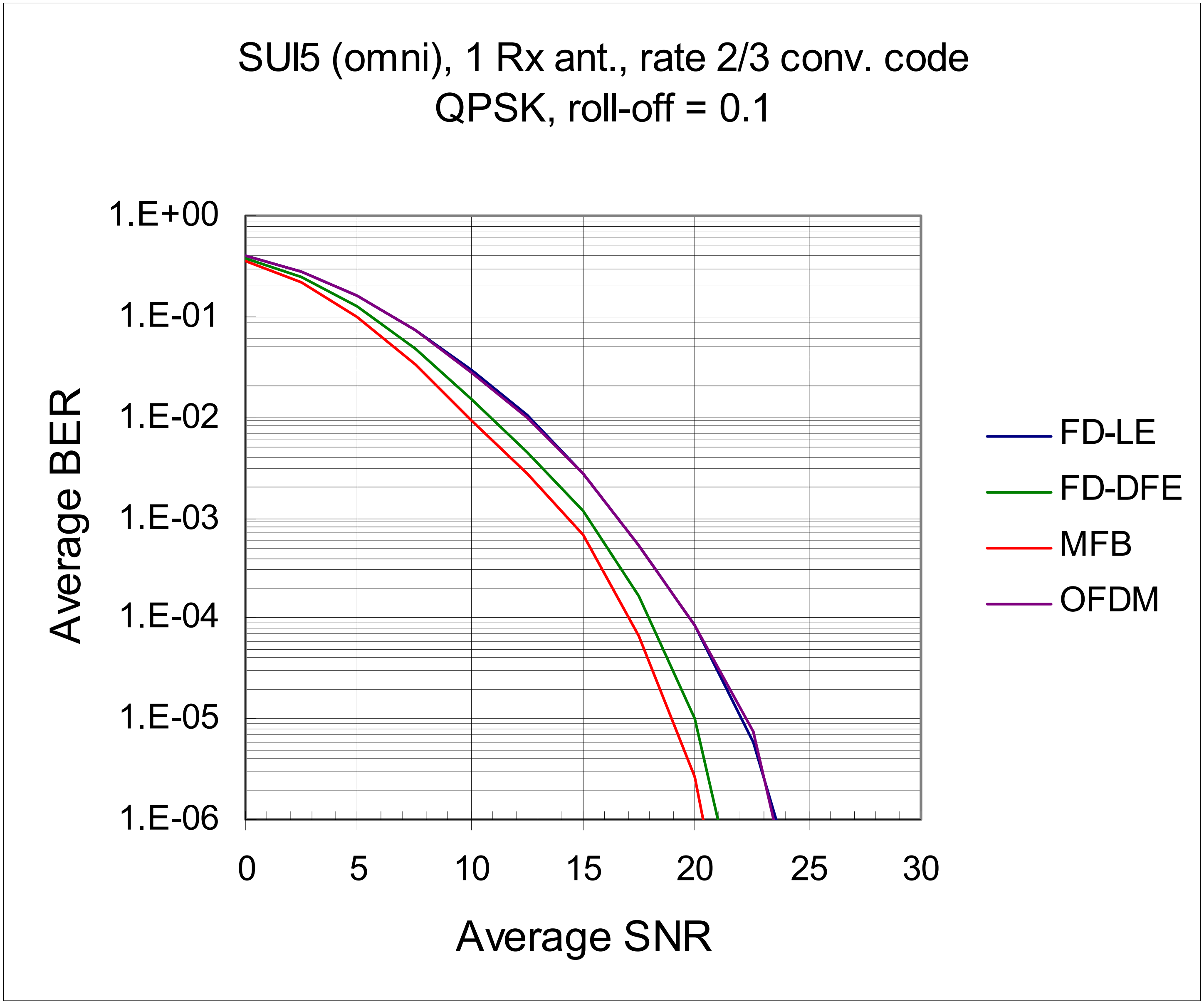
  No power penalty due to pilot/overhead transmission
- Coding: BICM using punctured conv. codes with k=7 and Gray mapping.

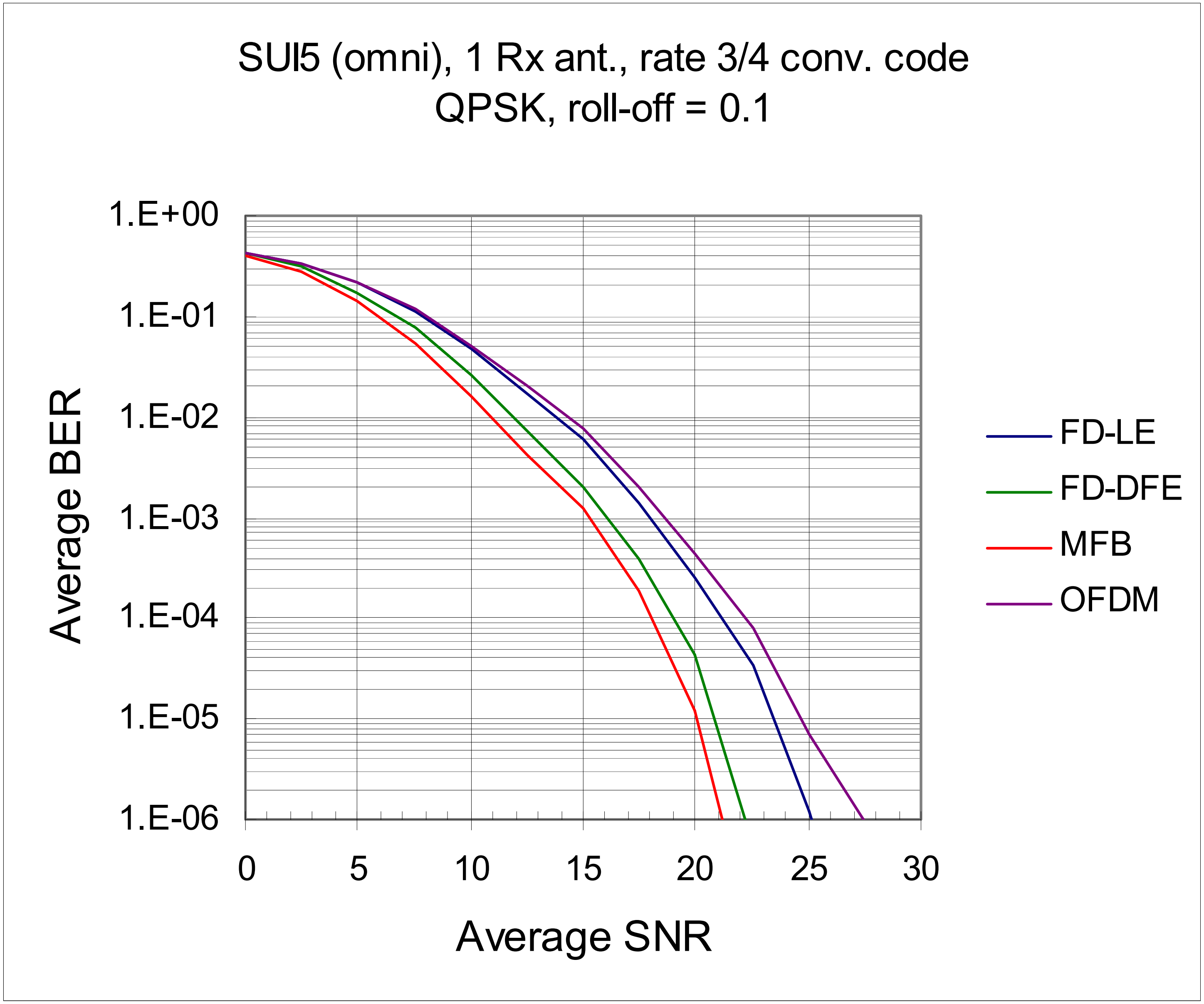
  Block interleaver with depth = 16m, where m = number of bits per symbol

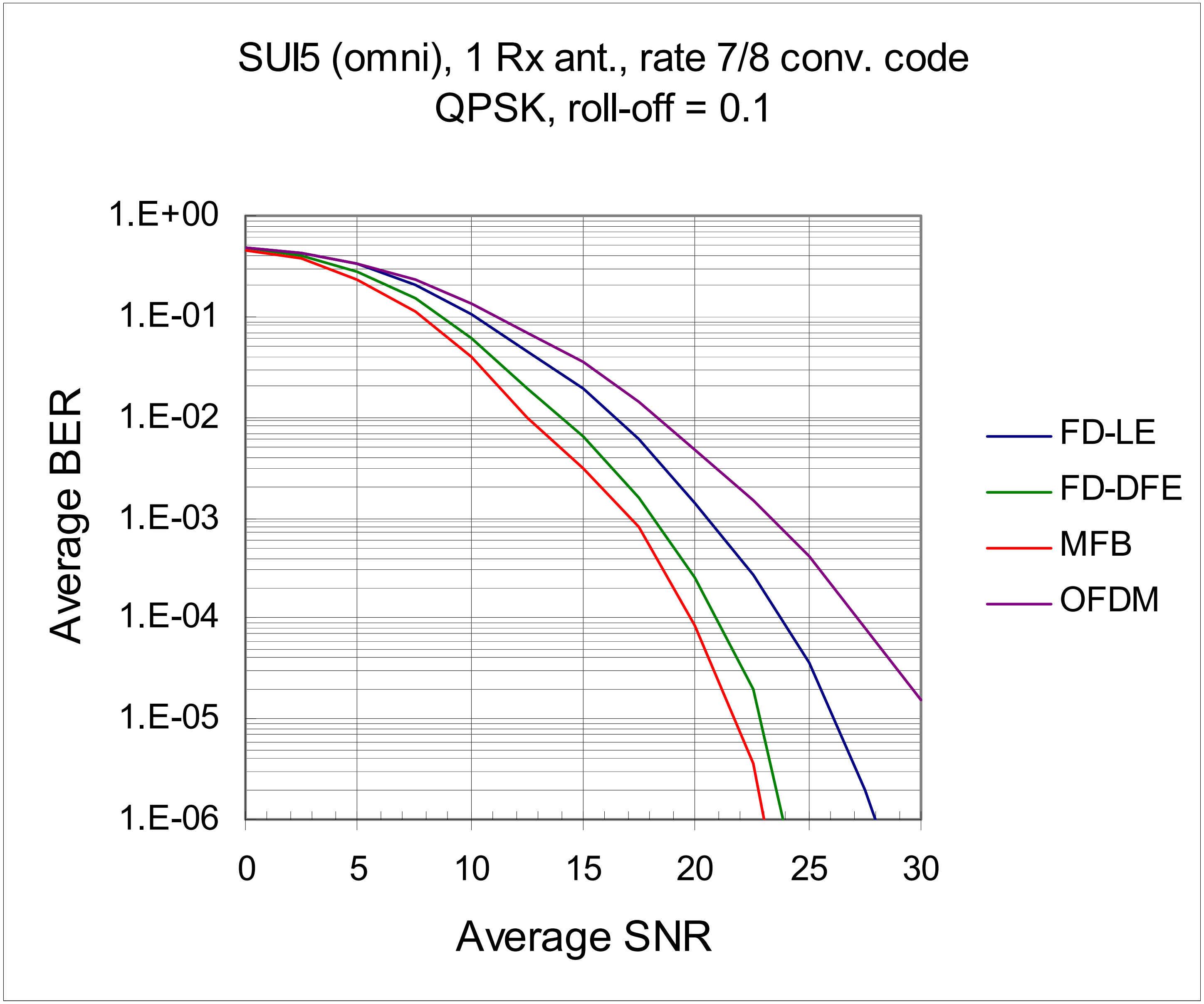
  BICM and BTC with similar code rates have similar performances

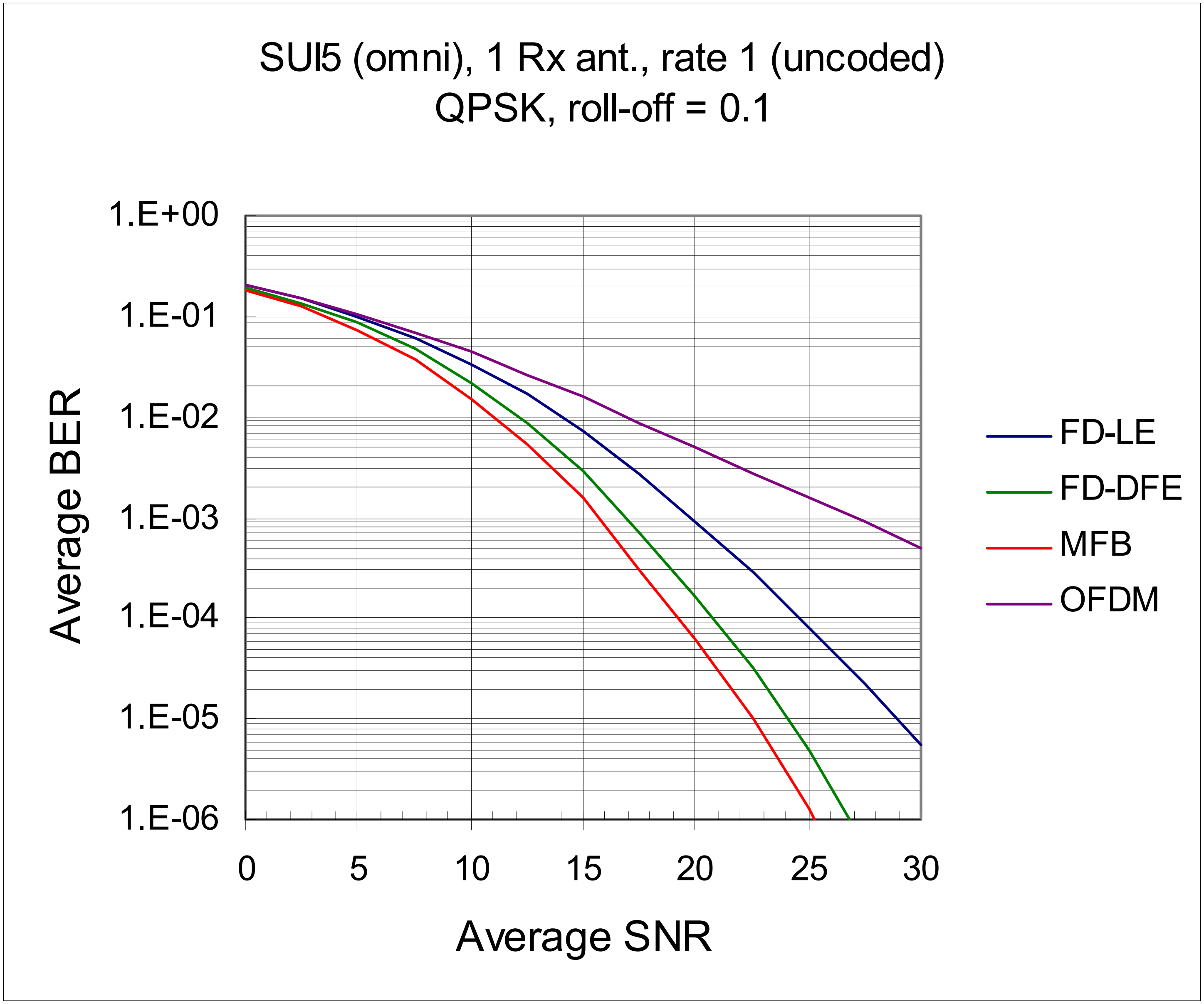
  Optimally weighted soft decision MLSE decoding is assumed for OFDM
- Performance measures: ABER, ABLER, outage probability


SUI5 (omni), 1 Rx ant., rate 1/2 conv. code
QPSK, roll-off = 0.1
Average BER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
5
10
15
20
25
30
Average SNR
FD-LE
FD-DFE
MFB
OFDM

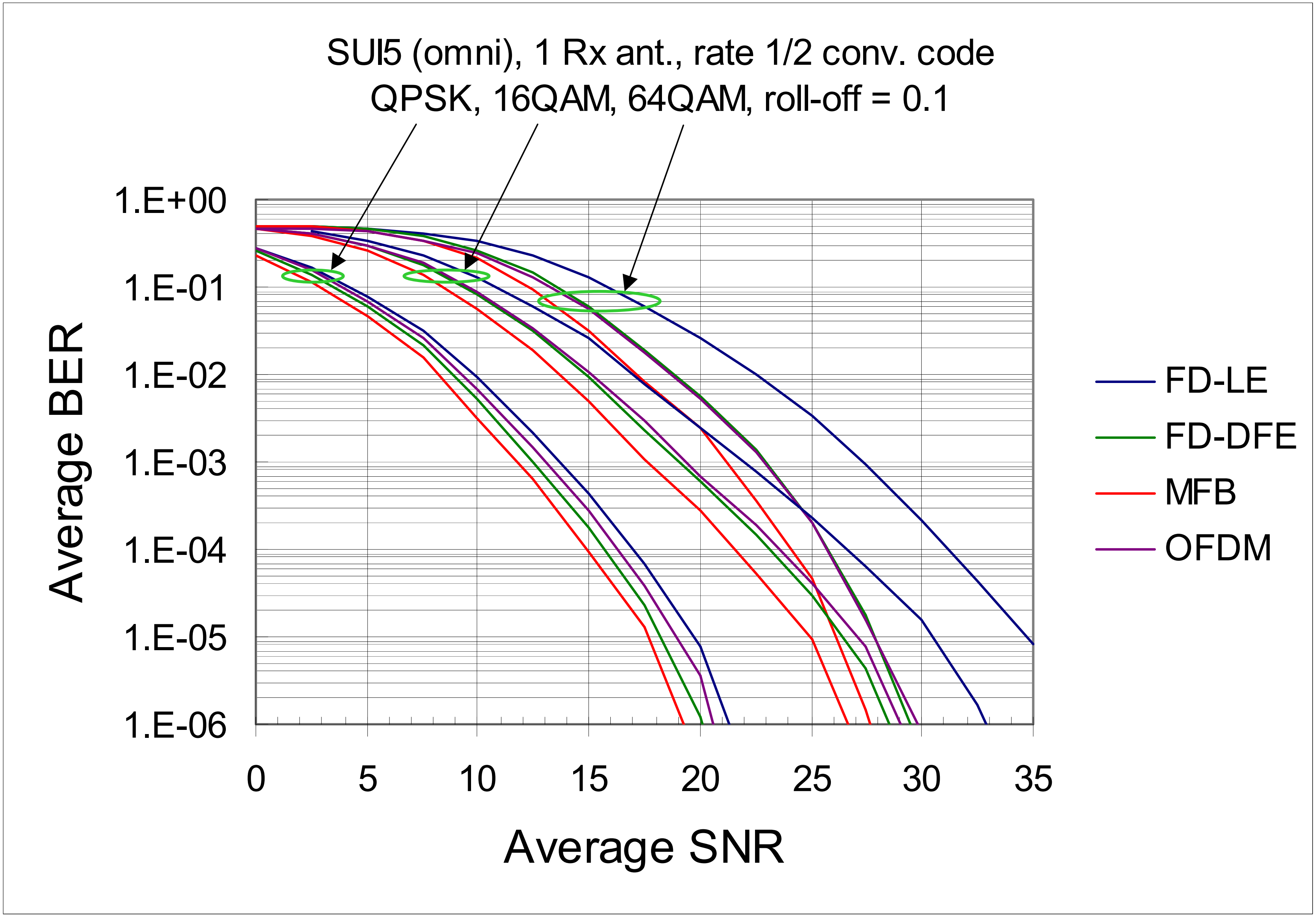

SUI5 (omni), 1 Rx ant., rate 2/3 conv. code
QPSK, roll-off = 0.1
Average BER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
5
10
15
20
25
30
Average SNR
FD-LE
FD-DFE
MFB
OFDM


SUI5 (omni), 1 Rx ant., rate 3/4 conv. code
QPSK, roll-off = 0.1
Average BER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
5
10
15
20
25
30
Average SNR
FD-LE
FD-DFE
MFB
OFDM


SUI5 (omni), 1 Rx ant., rate 7/8 conv. code
QPSK, roll-off = 0.1
Average BER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
5
10
15
20
25
30
Average SNR
FD-LE
FD-DFE
MFB
OFDM



SUI5 (omni), 1 Rx ant., rate 1 (uncoded)
QPSK, roll-off = 0.1


SUI5 (omni), 1 Rx ant., rate 1/2 conv. code
QPSK, 16QAM, 64QAM, roll-off = 0.1
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
Average BER
0
5
10
15
20
25
30
35
Average SNR
FD-LE
FD-DFE
MFB
OFDM

SC-FDE vs. OFDM Comparison

- Performance with different code rates

  OFDM is sensitive to high code rates

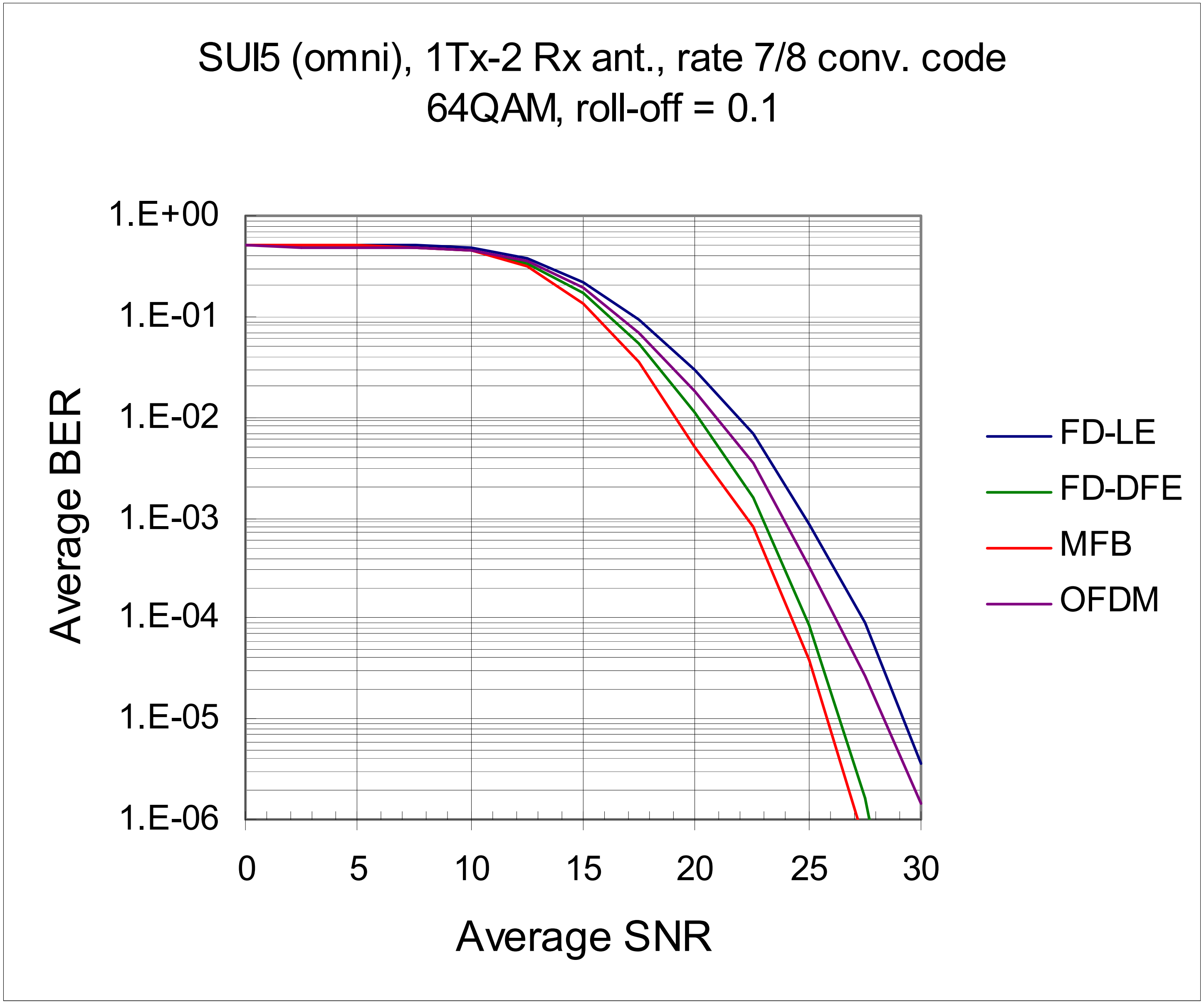
- Performance with high-level Modulation

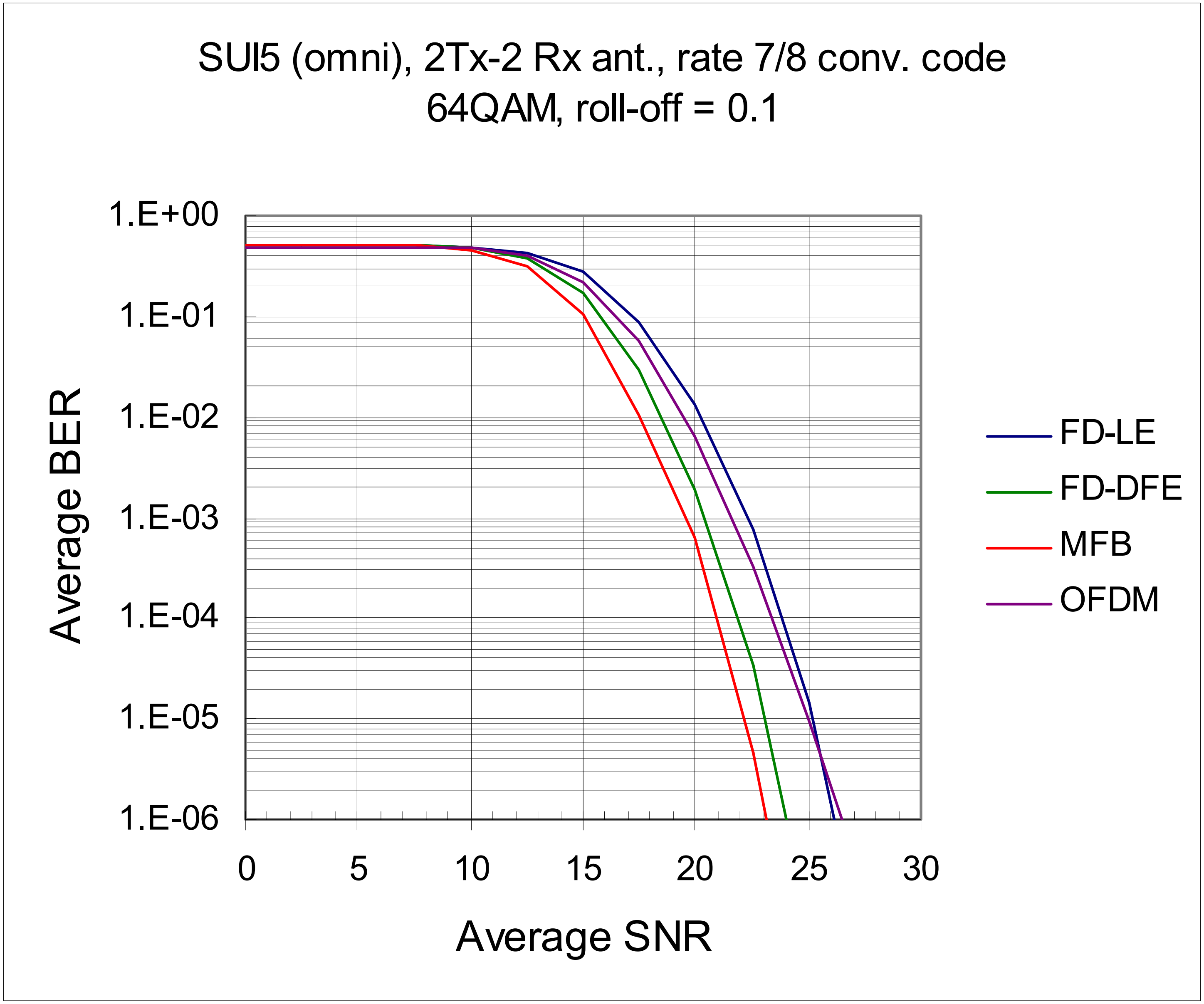
  FD-LE suffers from increased noise enhancement at high M-ary

- Bottom Line

  high capacity = high code rate + high-level modulation

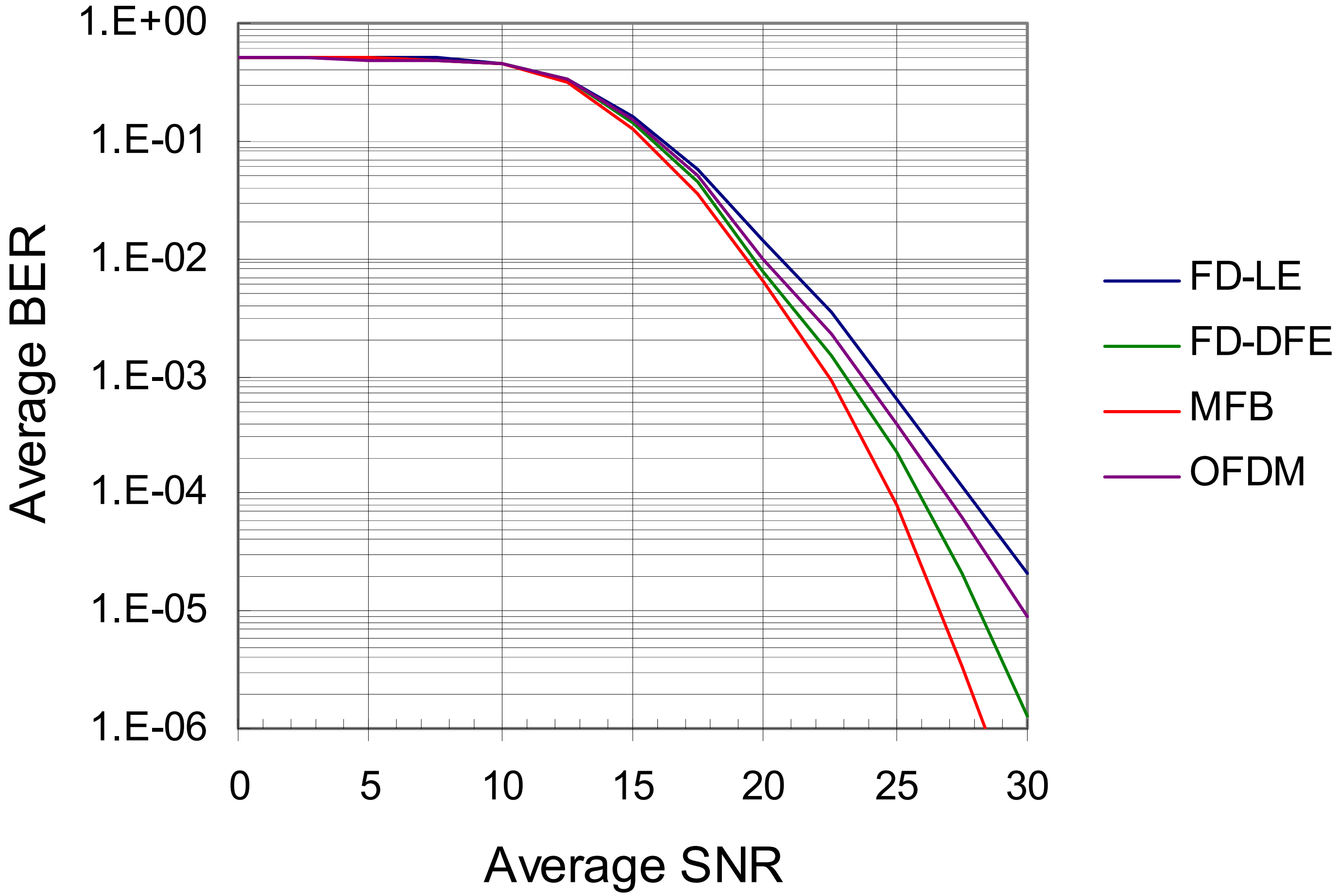
  + antenna diversity (SIMO or MIMO)


SUI5 (omni), 1Tx-2 Rx ant., rate 7/8 conv. code
64QAM, roll-off = 0.1
Average BER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
5
10
15
20
25
30
Average SNR
FD-LE
FD-DFE
MFB
OFDM

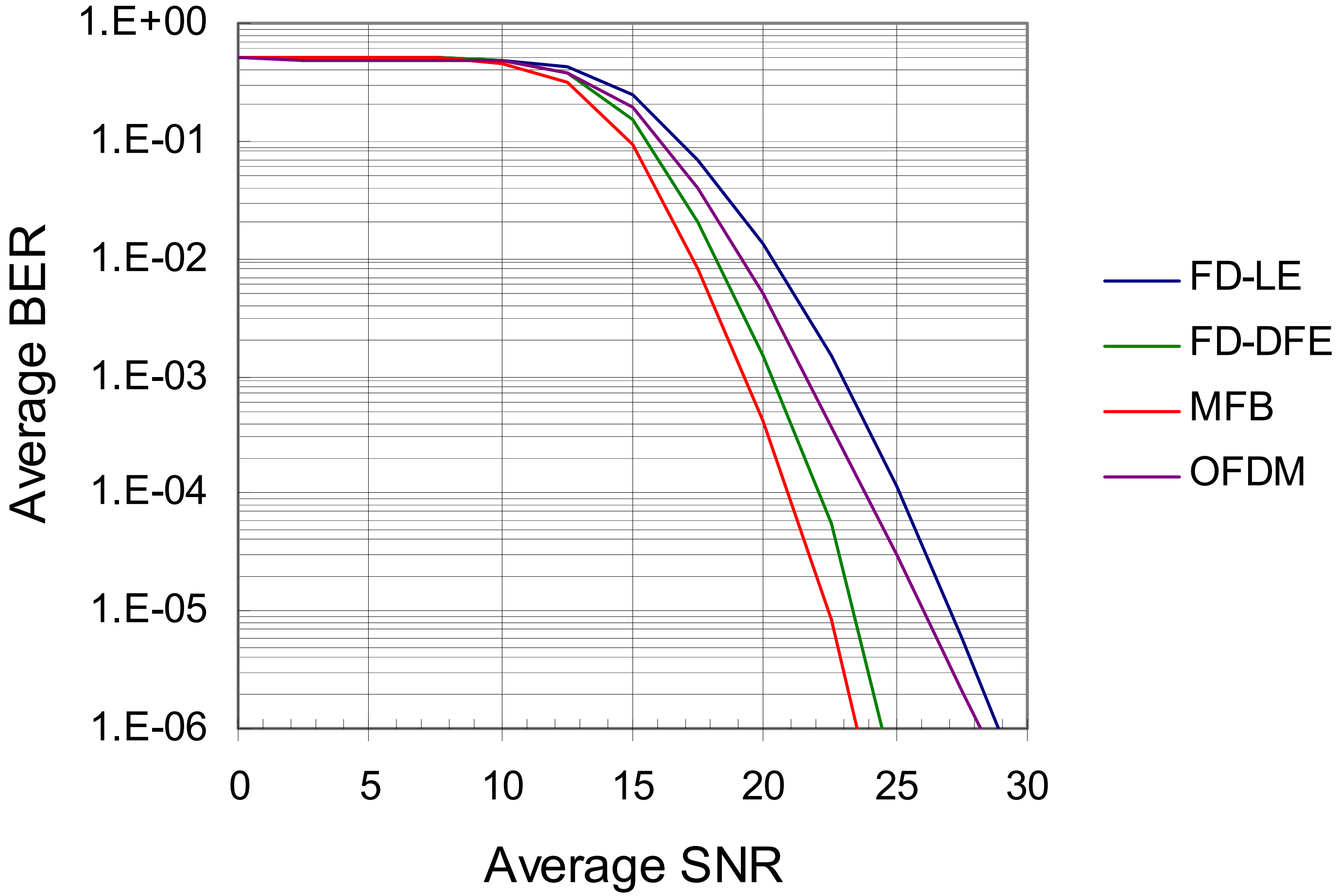


SUI5 (omni), 2Tx-2 Rx ant., rate 7/8 conv. code
64QAM, roll-off = 0.1

SUI2 (omni), 1Tx-2 Rx ant., rate 7/8 conv. code
64QAM, roll-off = 0.1



SUI2 (omni), 2Tx-2 Rx ant., rate 7/8 conv. code
64QAM, roll-off = 0.1



SC-FDE vs. OFDM Comparison

- Performance with different code rates

  OFDM is sensitive to high code rates

- Performance with high-level Modulation

  FD-LE suffers from increased noise enhancement at high M-ary

- Bottom Line

  For 64QAM with high rate coding and antenna diversity, OFDM performs slightly better (by about 1 dB) than FD-LE

  Ideal FD-DFE performs universally better than OFDM by up to 3 dB

Effect of the number of feedback taps on SC-decision feedback FDE performance

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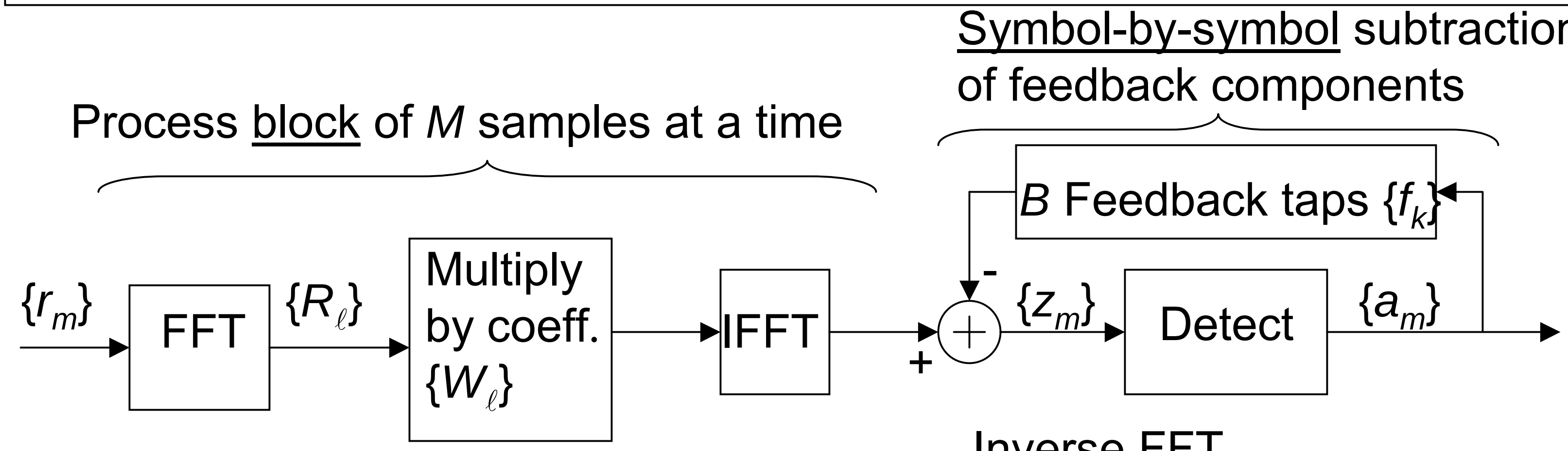
SC-FDE Decision Feedback Equalizer (FD-DFE)

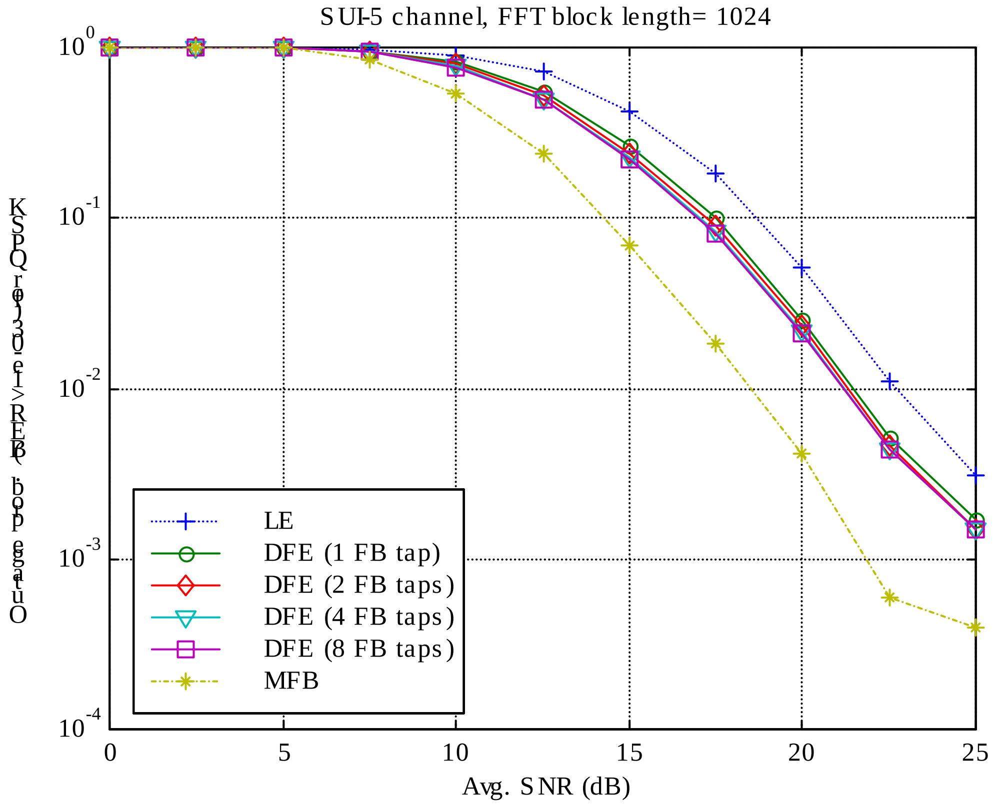


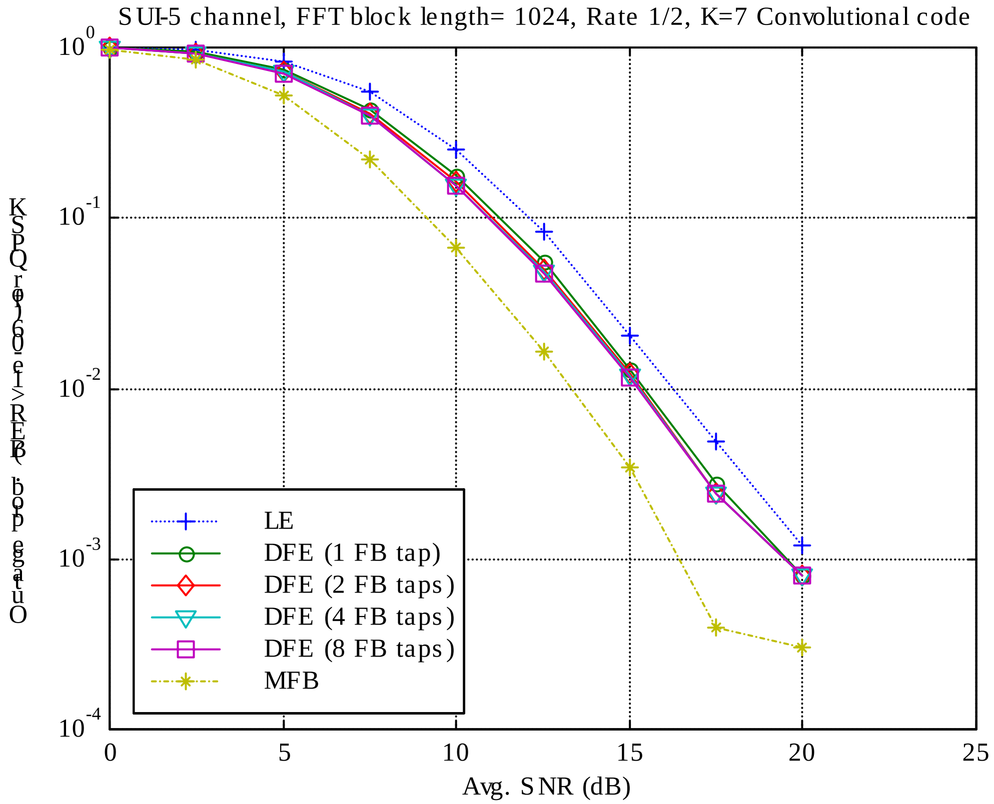
$$\text{DFE output} = z_m = \overbrace{\frac{1}{M}\sum_{\ell=0}^{M-1} W_\ell R_\ell \exp(j\frac{2\pi}{M}\ell m)}^{\text{Inverse FFT}} - \sum_{k\in F_B} f_k^* a_{m-k}$$

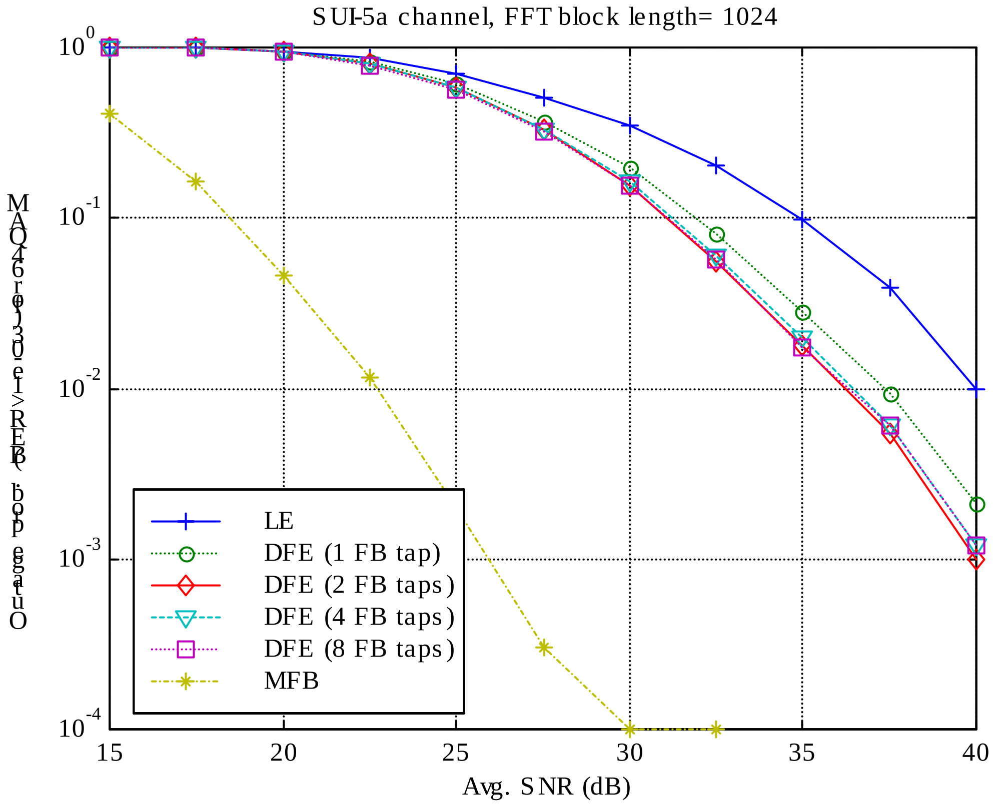
$$\text{where } R_\ell = \underbrace{\sum_{m=0}^{M-1} r_m \exp(-j\frac{2\pi}{M}\ell m)}_{\text{FFT}}$$

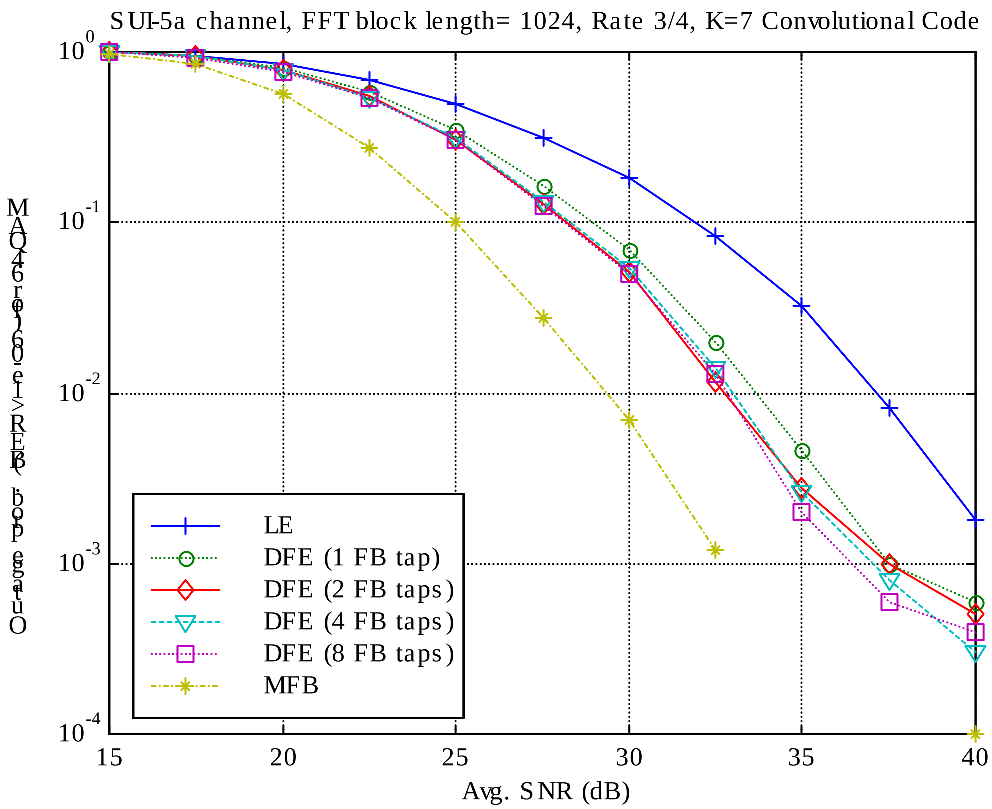
F_B is a set of B feedback tap delays corresponding to the B largest channel Impulse response postcursors.

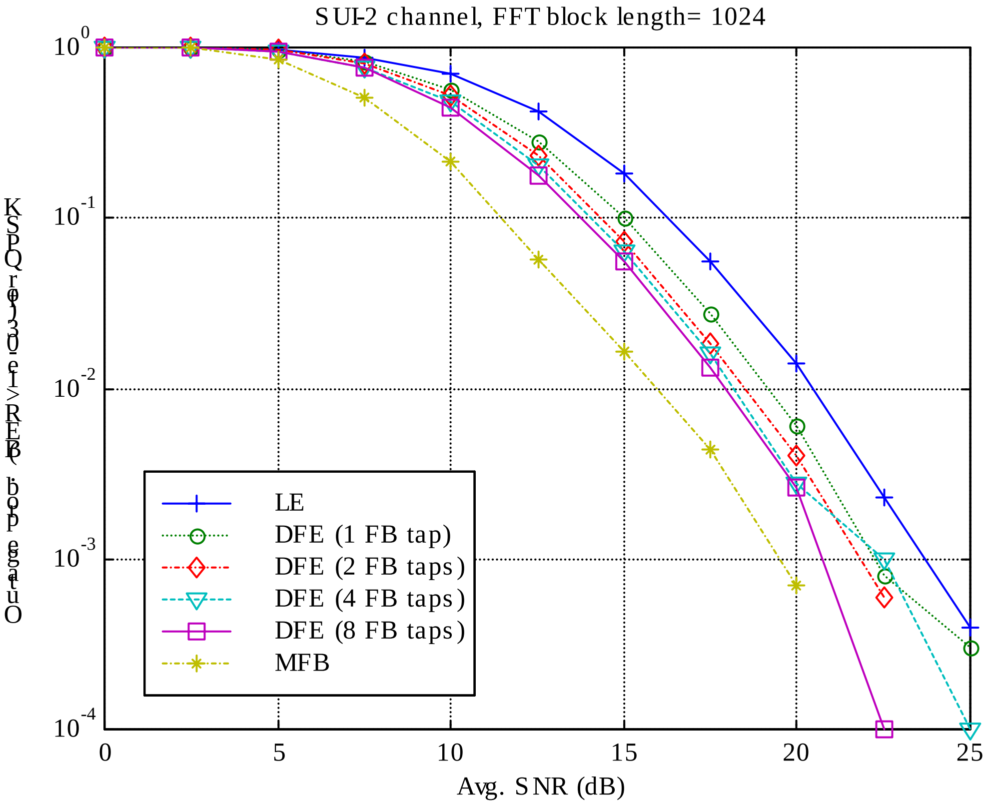
$$\text{Error } e_m = z_m - a_m. \quad (\text{Minimize MSE} = \mathrm{E}(|e_m|^2).)$$

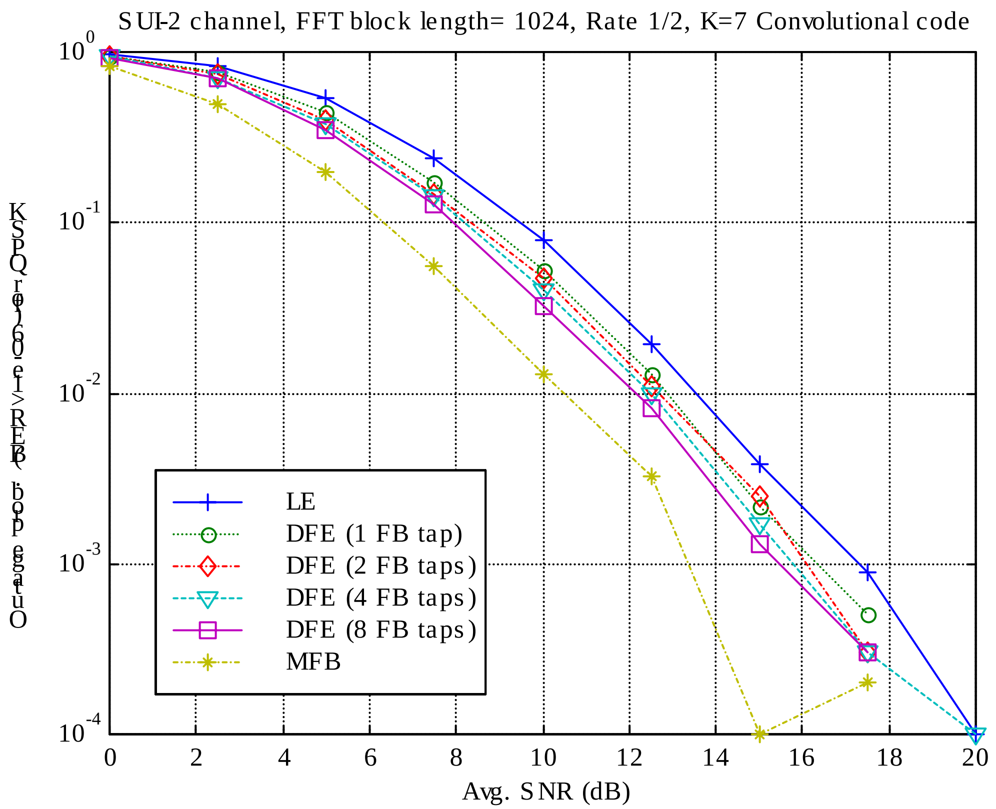

SUI-5 channel, FFT block length= 1024
Outage prob. (BER > 1e-3) for QPSK
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
Avg. SNR (dB)
LE
DFE (1 FB tap)
DFE (2 FB taps)
DFE (4 FB taps)
DFE (8 FB taps)
MFB


SUI-5 channel, FFT block length= 1024, Rate 1/2, K=7 Convolutional code
Outage prob. (BER>1e-06) for QPSK
Avg. SNR (dB)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
LE
DFE (1 FB tap)
DFE (2 FB taps)
DFE (4 FB taps)
DFE (8 FB taps)
MFB


SUI-5a channel, FFT block length= 1024
Outage Prob. (BER>1e-03) for 64QAM
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
15
20
25
30
35
40
Avg. SNR (dB)
LE
DFE (1 FB tap)
DFE (2 FB taps)
DFE (4 FB taps)
DFE (8 FB taps)
MFB


SUI-5a channel, FFT block length= 1024, Rate 3/4, K=7 Convolutional Code
Outage prob. (BER>1e-06) for 64QAM
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
15
20
25
30
35
40
Avg. SNR (dB)
LE
DFE (1 FB tap)
DFE (2 FB taps)
DFE (4 FB taps)
DFE (8 FB taps)
MFB


SUI-2 channel, FFT block length= 1024
Outage prob (BER>1e-03), QPSK
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
Avg. SNR (dB)
LE
DFE (1 FB tap)
DFE (2 FB taps)
DFE (4 FB taps)
DFE (8 FB taps)
MFB


SUI-2 channel, FFT block length= 1024, Rate 1/2, K=7 Convolutional code
Outage prob. (BER > 1e-06) for QPSK
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
10
12
14
16
18
20
Avg. SNR (dB)
LE
DFE (1 FB tap)
DFE (2 FB taps)
DFE (4 FB taps)
DFE (8 FB taps)
MFB

Conclusions

- 1 feedback tap is simple to provide, and is nearly as effective as 2,..8 feedback taps.
- The use of 1 feedback tap gives SNR gain of 1-4 dB over linear equalization. DFE with 1 feedback tap outperforms OFDM by a few dB.
- DFE error propagation?:
  - Moderate for 1 feedback tap
  - If channel has sparse multipath, and therefore the single feedback tap has a large delay, fed-back decision errors will be separated in time by this delay, and can be effectively dealt with by coding.

Latest Update (preliminary)

For uncoded QPSK and 64QAM for SUI2 and SUI5, and with 1 feedback tap

- The BER with actual decision feedback is only 1.2 to 2 times the BER assuming correct feedback.
- The corresponding SNR penalty is less than 1 dB at any range of SNR.

Effect of the number of training blocks on SC-FDE performance

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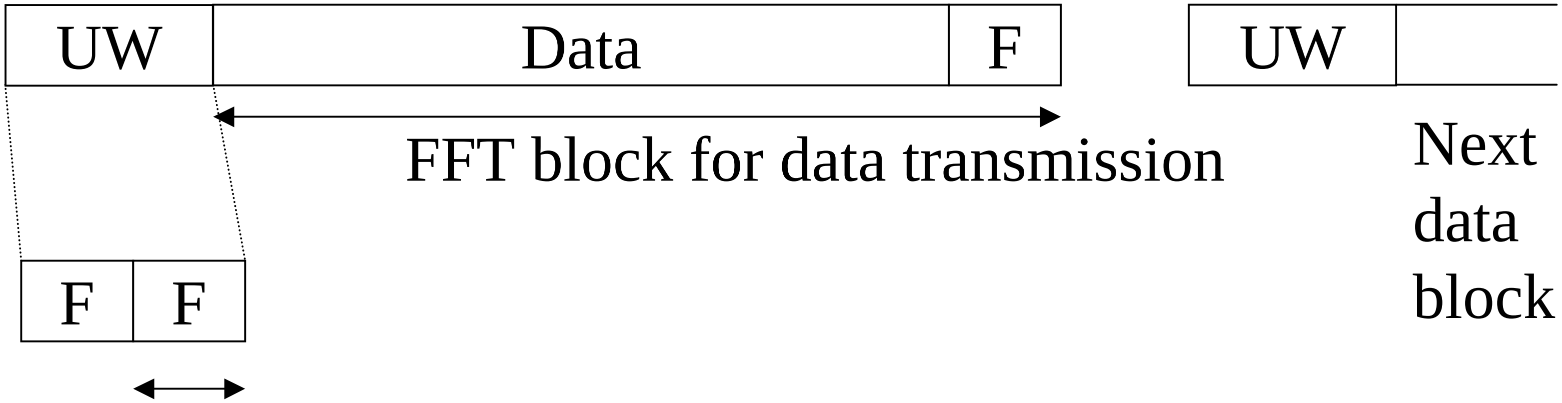
Framing, Showing Training Block



UW

Data

F

UW

FFT block for data transmission

Next
data
block

F

F

F = Frank or other sequence
used as a training block

UW = unique word for training, sync, and cyclic prefix

Frank Training Sequence

Desirable properties:

- Perfect periodic autocorrelation (e.g. 0,0,..0,1,0,0…0,1,0,0…)
  - Corresponding frequency response is flat
- Constant envelope, polyphase signal with small phase alphabet.

e.g. Frank sequence of length 64: 8 phase sequence.

(0.707 + 0.707j), (0.000 + 1.000j), (-0.707 + 0.707j),…

(-1.000 + 0.000j), (-0.707 - 0.707j),…

Ref: R.L Frank and S.A. Zadoff, “Phase Shift Pulse Codes With Good Periodic Correlation Properties”, IRE Trans. Info. Theory, Oct. 1962, pp. 381-382.

Another Training Sequence: Modified PN

Pn sequence of length N
+ j(1 1 1….(length N)…1)/√N

(1, -1, -1, -1, 1, ….)+j(1,1,1,…)/√63

Ref. A. Milewski, "Periodic Sequences with Optimal Properties for Channel Estimation and Fast Start-Up Equalization", IBM J. Res. And Dev., Sept., 1983, pp. 426-431.

Parameter Adaptation for Frequency Domain DFE (for N>1 Training Blocks)

For N ($N \ge 2$) training blocks of length M, with received samples $\{r_m^{(n)};\, m = 0,1,..M-1;\;\; n = 1,2,..N\}$, and known training symbols $\{a_m^{(n)};\;\; m = 0,1,..M-1;\;\; n = 1,2,..N\}$:

$$W_\ell = \frac{\sum\limits_{n=1}^{N} R_\ell^{(n)*} A_\ell^{(n)} [1 + \sum\limits_{k \in F_B} f_k^* \exp(-j\,\frac{2\pi\ell k}{M})]}{\sum\limits_{n=1}^{N} \left| R_\ell^{(n)} \right|^2}, \qquad \ell = 0,1,2,..M-1,\;\; F_B = \{k_1,...k_B\}$$

Parameter Adaptation for Frequency Domain DFE (for *N*>1 Training Blocks) (cont.)

$\mathbf{f} = -\mathbf{V}^{-\mathbf{1}}\mathbf{v}$, where $f_0 = 1$,

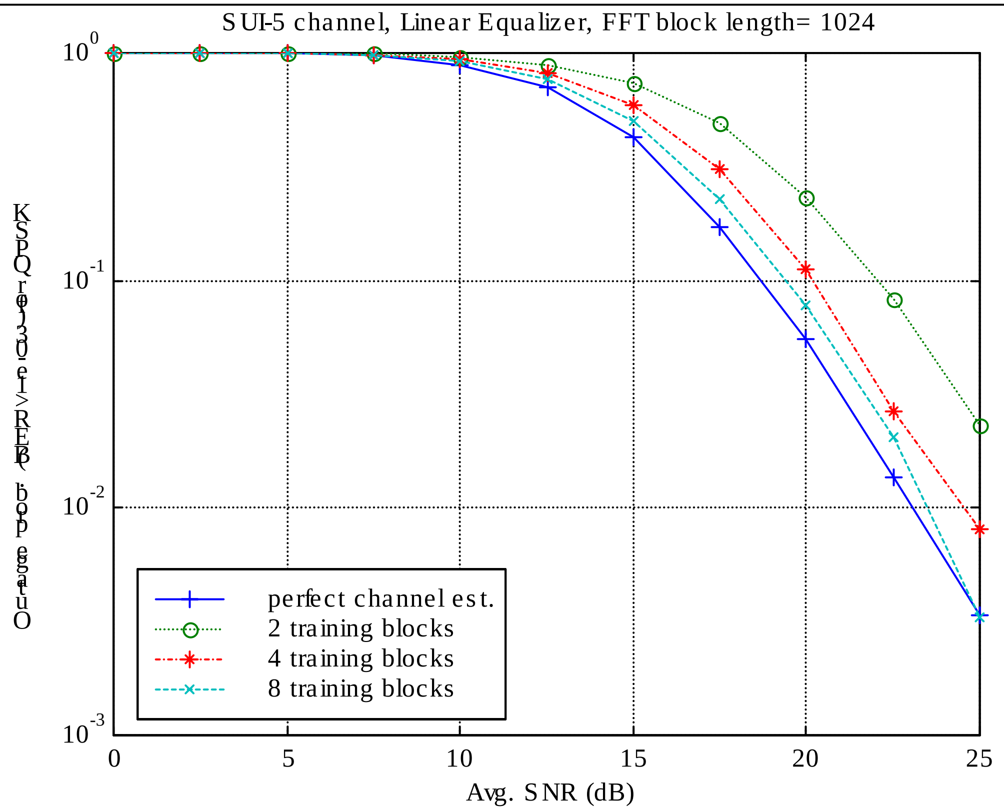
$$\mathbf{V} = \begin{bmatrix} v_0 & v^*_{k_1-k_2} & \cdot & v^*_{k_1-k_B} \\ v_{k_1-k_2} & v_0 & v^*_{k_2-k_3} & \cdot \\ \cdot & & & \\ v_{k_1-k_B} & & & v_0 \end{bmatrix}, \qquad \mathbf{f} = \begin{bmatrix} f_{k_1} \\ f_{k_2} \\ \cdot \\ f_{k_B} \end{bmatrix}, \qquad \mathbf{v} = \begin{bmatrix} v_{k_1} \\ v_{k_2} \\ \cdot \\ v_{k_B} \end{bmatrix}$$

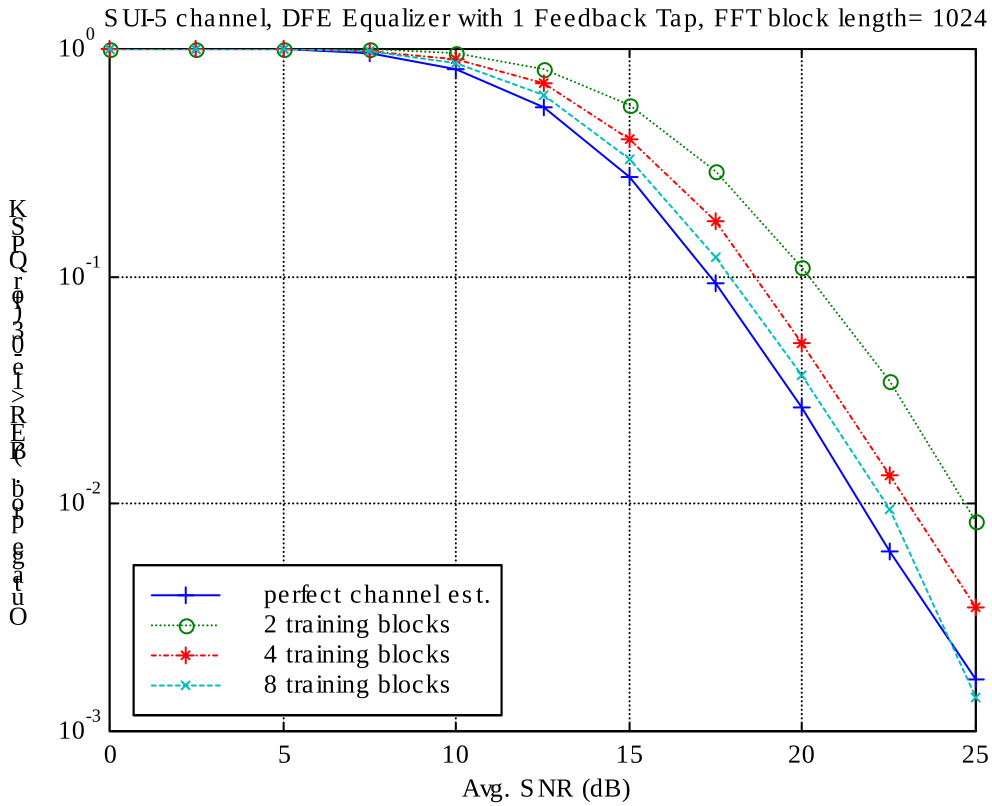
and $v_k = \frac{1}{M}\sum_{\ell=0}^{M-1}\left[\sum_{n=1}^{N}\left|A_\ell^{(n)}\right|^2 - \frac{\left|\sum_{n=1}^{N} R_\ell^{(n)*}A_\ell^{(n)}\right|^2}{\sum_{n=1}^{N}\left|R_\ell^{(n)}\right|^2}\right]\exp(-j\frac{2\pi\ell k}{M}) \qquad k \in F_B = \{k_1, k_2, \ldots k_B\}$

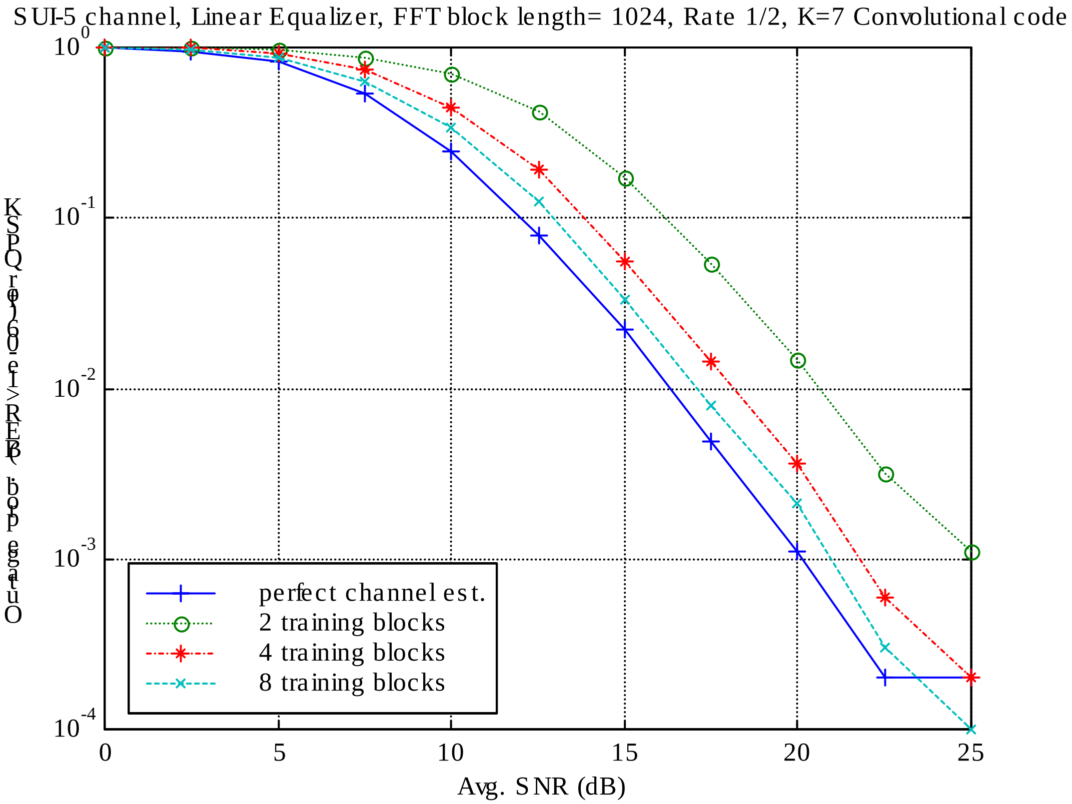
where

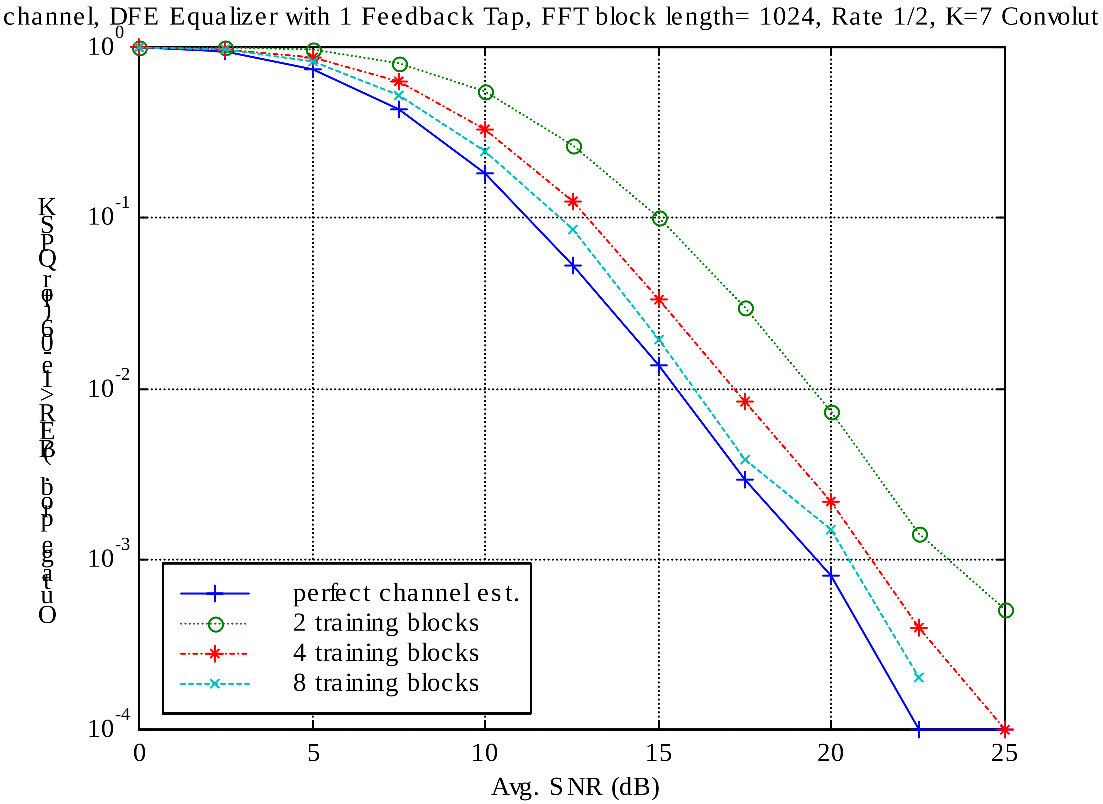
$R_\ell^{(n)} = \sum_{m=0}^{M-1} r_m^{(n)}\exp(-j\frac{2\pi\ell m}{M})$ and $A_\ell^{(n)} = \sum_{m=0}^{M-1} a_m^{(n)}\exp(-j\frac{2\pi\ell m}{M})$

Simulation Results for QPSK

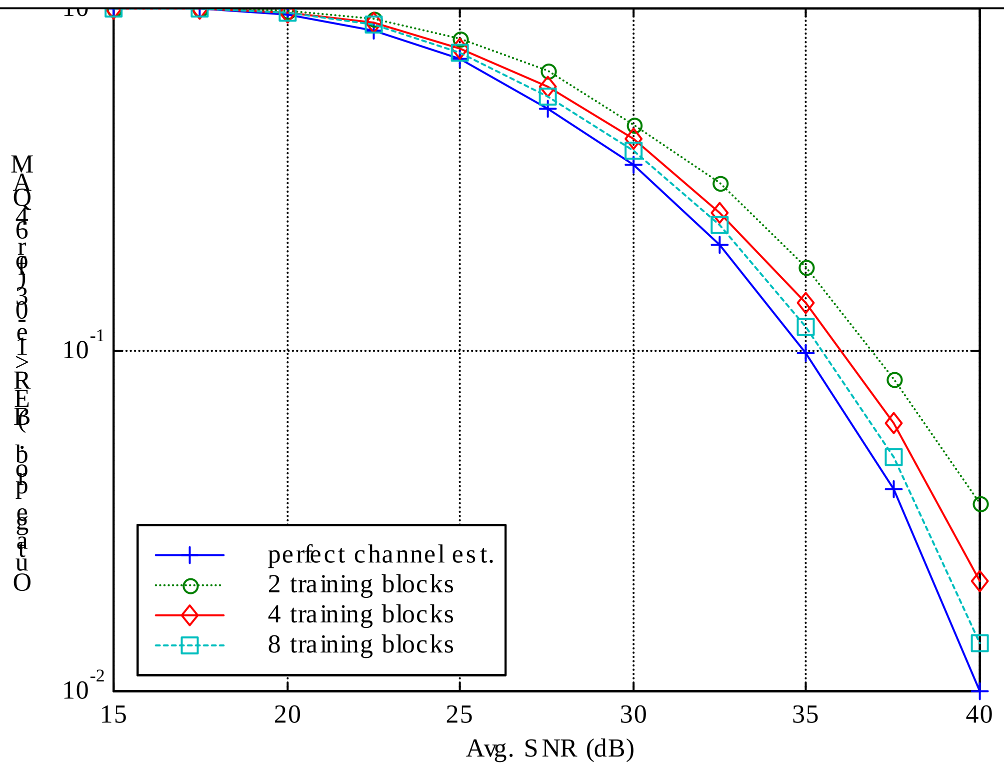


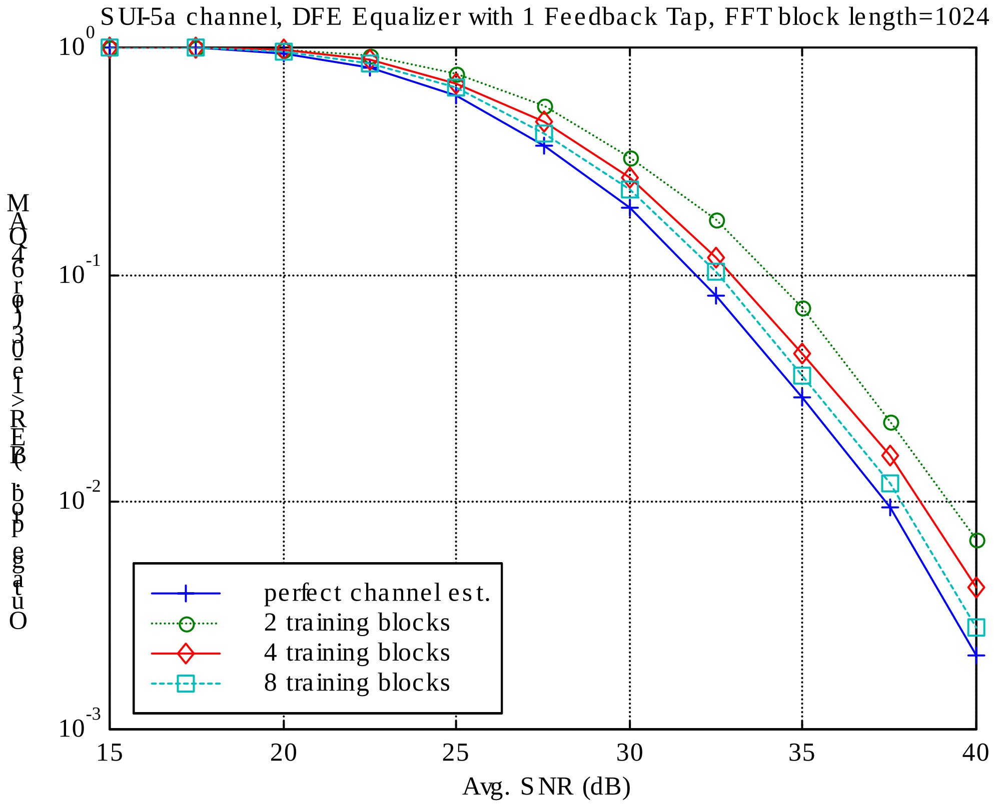

SUI-5 channel, DFE Equalizer with 1 Feedback Tap, FFT block length= 1024
Outage prob. (BER>1e-3) for QPSK
10^0
10^{-1}
10^{-2}
10^{-3}
0
5
10
15
20
25
Avg. SNR (dB)
perfect channel est.
2 training blocks
4 training blocks
8 training blocks

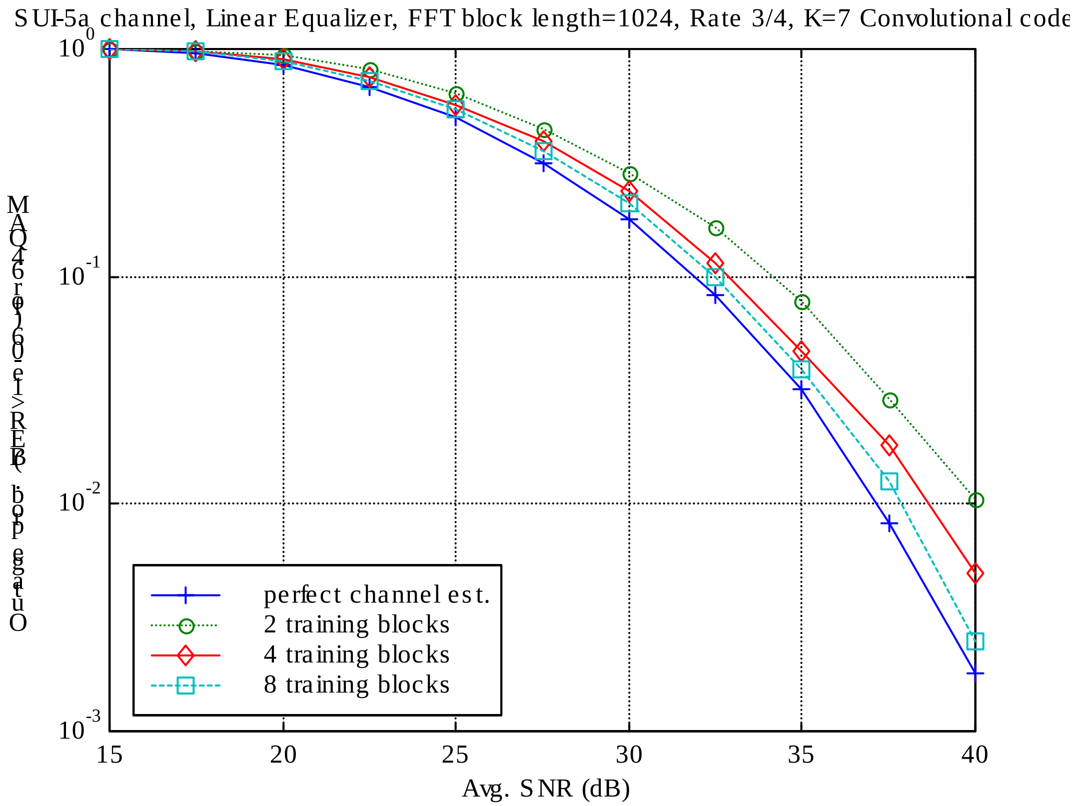

SUI-5 channel, Linear Equalizer, FFT block length= 1024, Rate 1/2, K=7 Convolutional code
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
Avg. SNR (dB)
perfect channel est.
2 training blocks
4 training blocks
8 training blocks

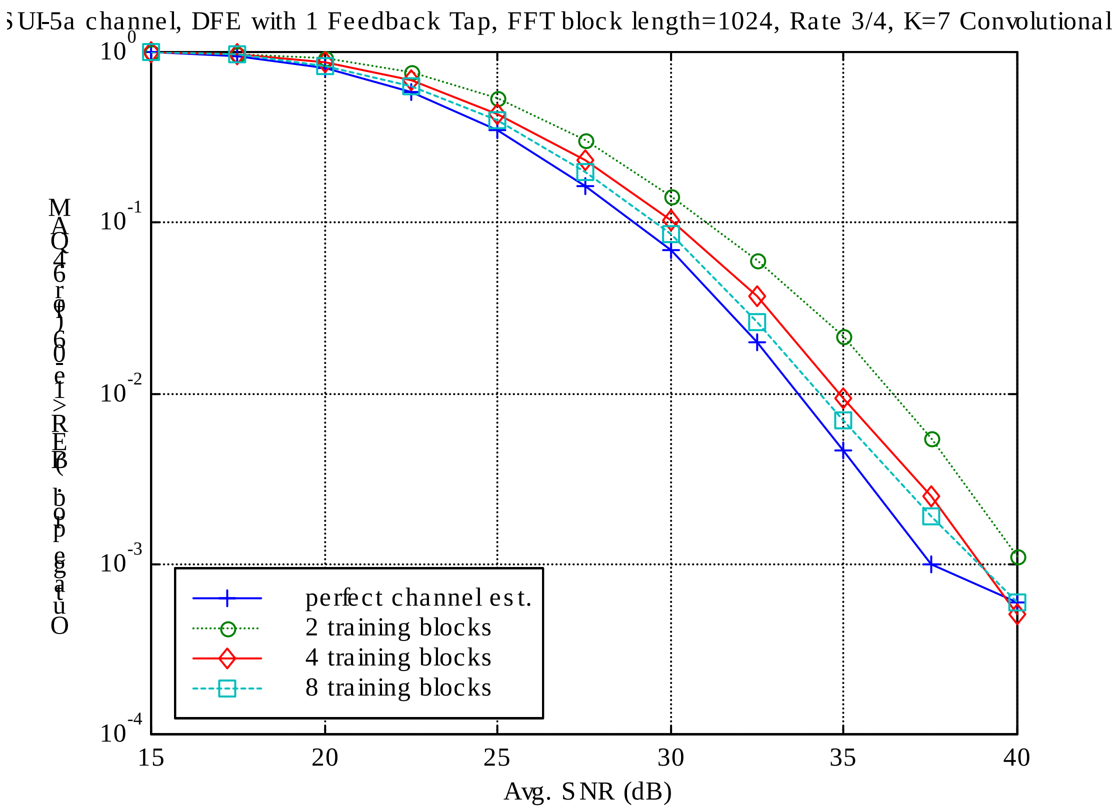

channel, DFE Equalizer with 1 Feedback Tap, FFT block length= 1024, Rate 1/2, K=7 Convolut
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
5
10
15
20
25
Avg. SNR (dB)
perfect channel est.
2 training blocks
4 training blocks
8 training blocks

Simulation Results for 64QAM




SUI-5a channel, DFE Equalizer with 1 Feedback Tap, FFT block length=1024
Outage prob. (BER>1e-03) for 64QAM
10^{0}
10^{-1}
10^{-2}
10^{-3}
15
20
25
30
35
40
Avg. SNR (dB)
perfect channel est.
2 training blocks
4 training blocks
8 training blocks


SUI-5a channel, Linear Equalizer, FFT block length=1024, Rate 3/4, K=7 Convolutional code
Outage Prob. (BER>1e-06) for 64QAM
10^{0}
10^{-1}
10^{-2}
10^{-3}
15
20
25
30
35
40
Avg. SNR (dB)
perfect channel est.
2 training blocks
4 training blocks
8 training blocks


SUI-5a channel, DFE with 1 Feedback Tap, FFT block length=1024, Rate 3/4, K=7 Convolutional
Outage prob. (BER > 1e-006) 16QAM
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
15
20
25
30
35
40
Avg. SNR (dB)
perfect channel est.
2 training blocks
4 training blocks
8 training blocks

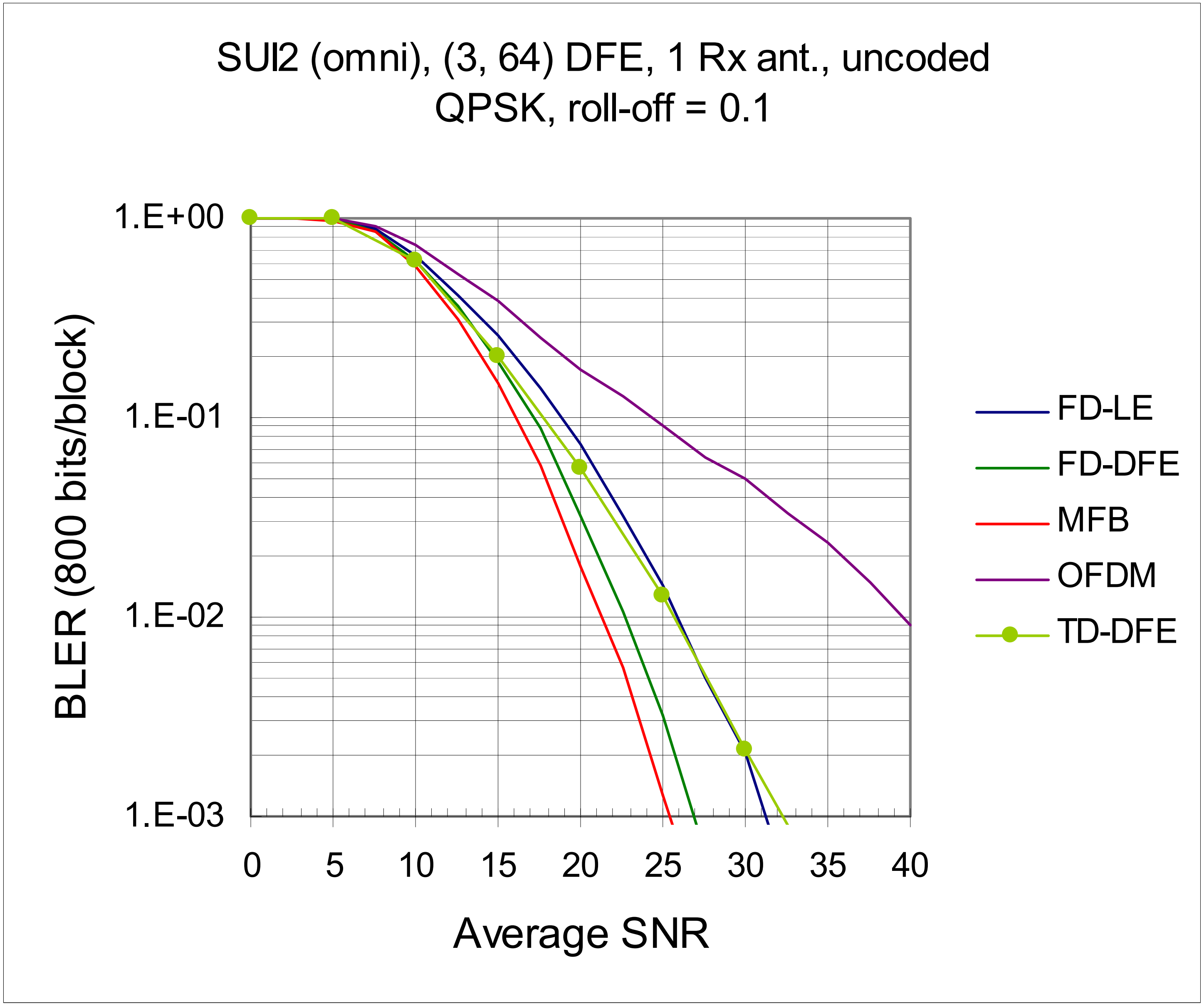
Conclusions

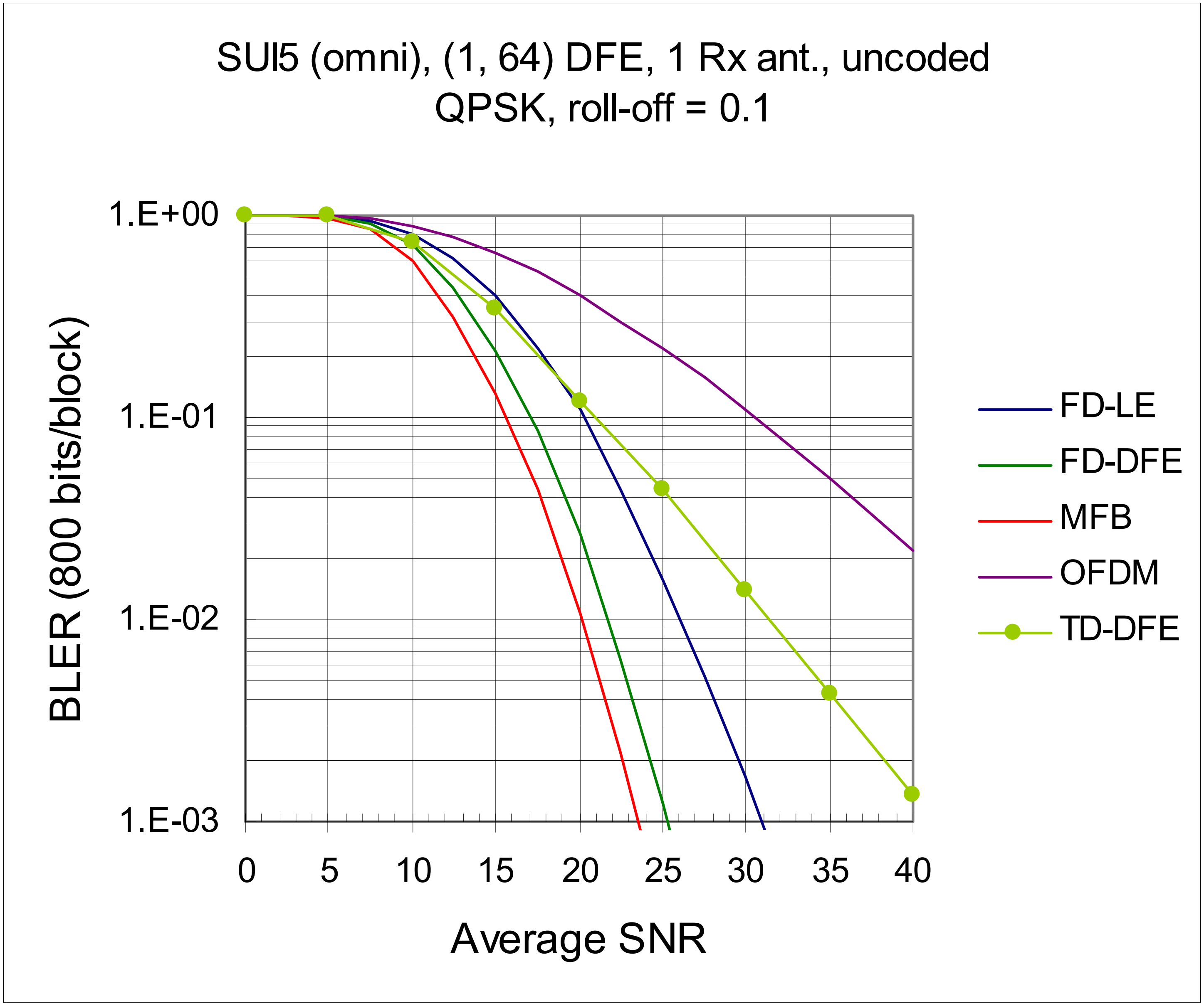
- Relative to perfect knowledge of the channel (training block length ~ max. delay spread):
    - 2-block training degrades about 3 dB for 64QAM, up to 4 dB for QPSK.
    - 4-block training degrades 1 to 1.5 dB.
    - 8-block training degrades 0.5 to 1 dB.
- Since each training block is a fraction of the length of a FFT data block, complete training can be accomplished within one FFT block, or, for distributed updating, within 4 to 8 FFT blocks.
- Frank or modified pn sequences are suitable for training.
    - See also D.C. Chu, “Polyphase Codes With Good Periodic Correlation Properties”, IEEE Trans. Info. Theory, July, 1982, pp. 531-532.

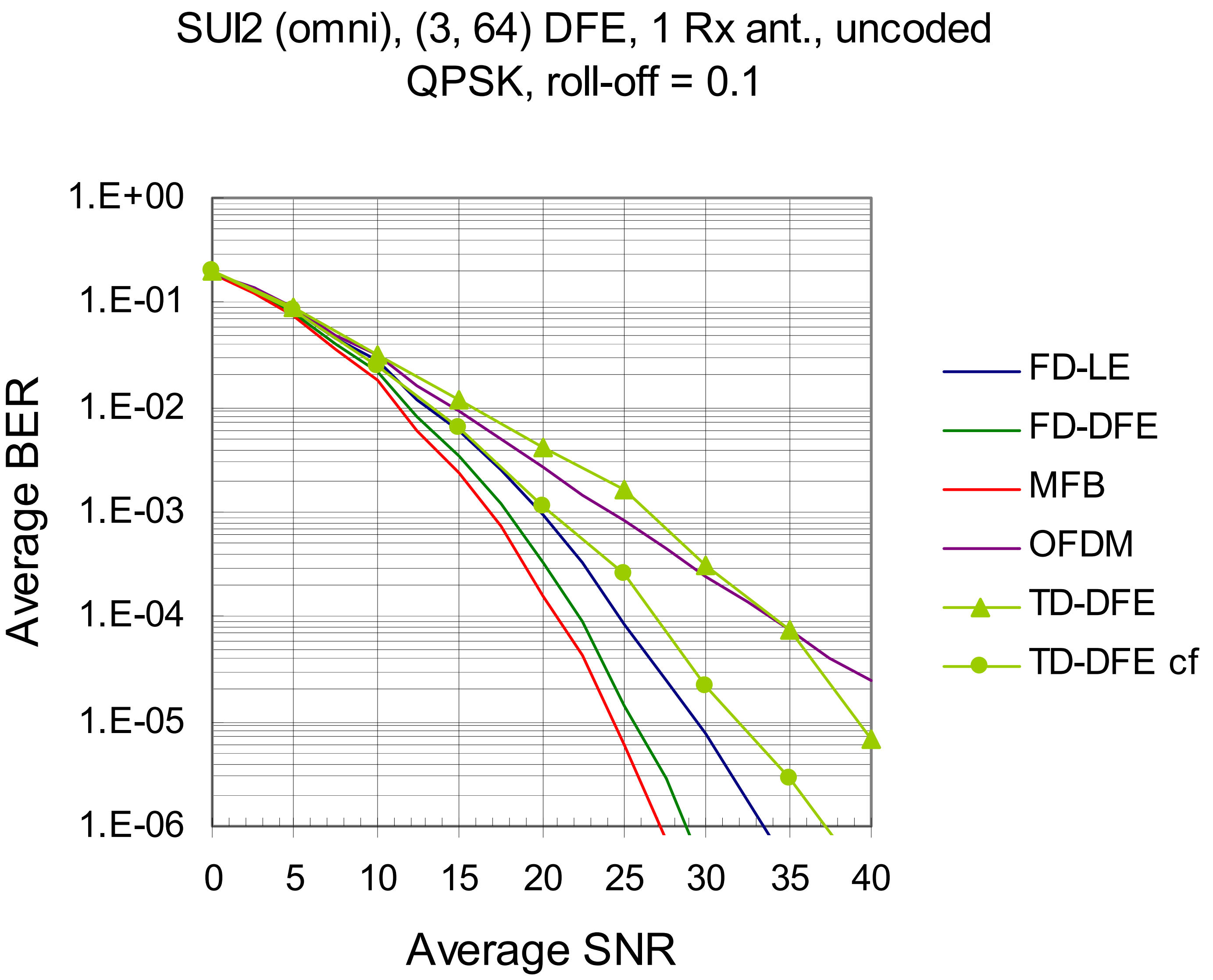
Low-Complexity TD-DFE

Emphasis

- Leverage existing receiver design
- Short time-to-market
- Cope with less severe channels
- Low-complexity structure, fast training


SUI2 (omni), (3, 64) DFE, 1 Rx ant., uncoded
QPSK, roll-off = 0.1
BLER (800 bits/block)
1.E+00
1.E-01
1.E-02
1.E-03
0
5
10
15
20
25
30
35
40
Average SNR
FD-LE
FD-DFE
MFB
OFDM
TD-DFE


SUI5 (omni), (1, 64) DFE, 1 Rx ant., uncoded
QPSK, roll-off = 0.1
BLER (800 bits/block)
1.E+00
1.E-01
1.E-02
1.E-03
0
5
10
15
20
25
30
35
40
Average SNR
FD-LE
FD-DFE
MFB
OFDM
TD-DFE


SUI2 (omni), (3, 64) DFE, 1 Rx ant., uncoded
QPSK, roll-off = 0.1
Average BER
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
5
10
15
20
25
30
35
40
Average SNR
FD-LE
FD-DFE
MFB
OFDM
TD-DFE
TD-DFE cf

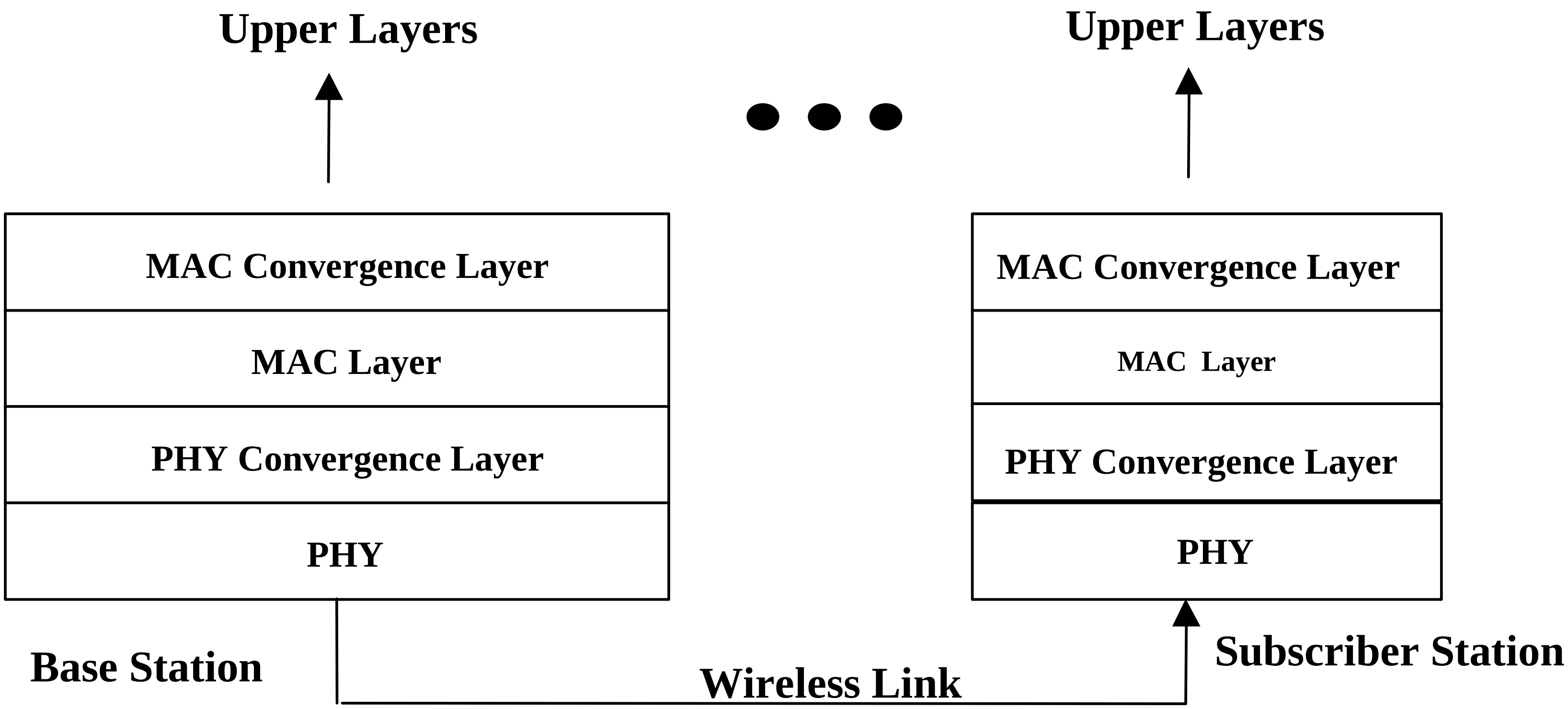
Overall Summary

- For 64QAM with high rate code:
  - OFDM outperforms FD-LE by 1 dB
  - FD-DFE with 1 feedback tap outperforms OFDM by a few dB
- 4 training blocks is sufficient

Other considerations:

  - Backoff penalty
  - Synchronization

The proposed PHY Layer with upper layers protocol stack



Upper Layers

Upper Layers

MAC Convergence Layer

MAC Layer

PHY Convergence Layer

PHY

MAC Convergence Layer

MAC Layer

PHY Convergence Layer

PHY

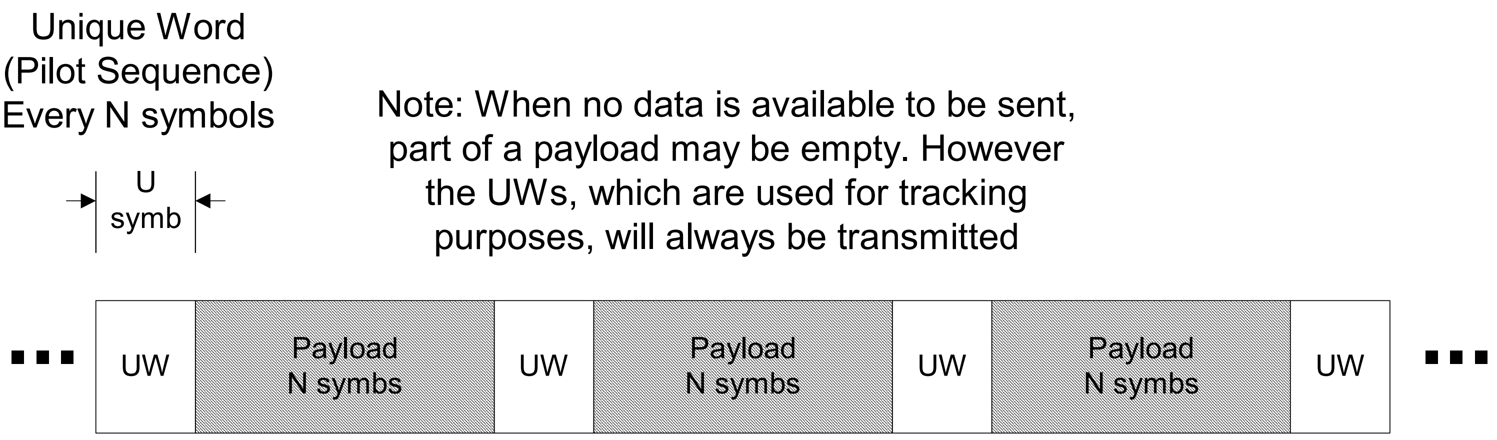
Base Station

Wireless Link

Subscriber Station

PHY Layer Framing

- Continuous transmission Format:

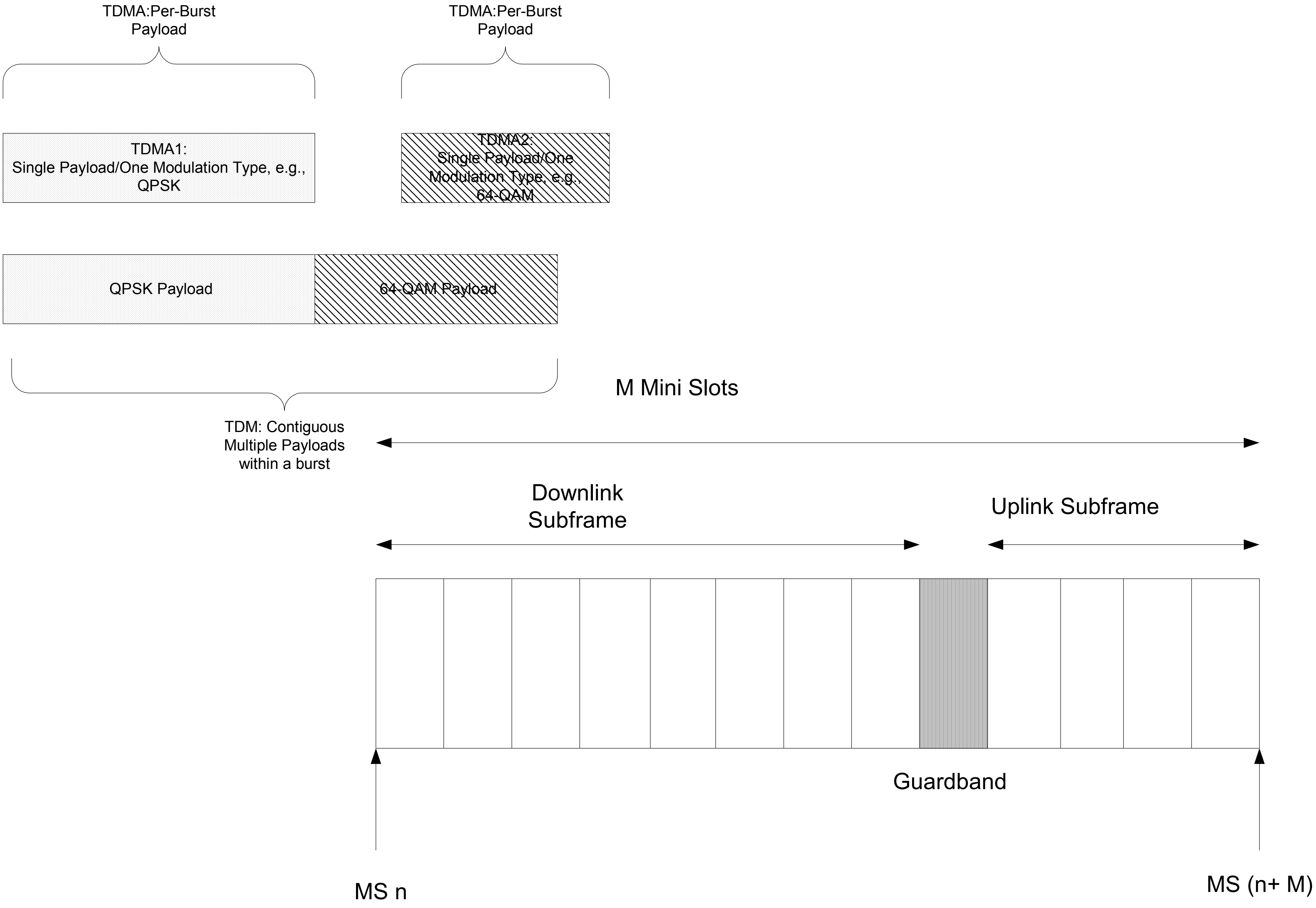


Unique Word
(Pilot Sequence)
Every N symbols

Note: When no data is available to be sent, part of a payload may be empty. However the UWs, which are used for tracking purposes, will always be transmitted

The UW may be used as cyclic prefixes by a FDE, and/ or as Pilot symbols. When used as cyclic prefixes, the UWs should at least be as long as the maximum **delay spread** of a channel. When used as pilot symbols, the UWs may assist in the estimation of emodulation parameters, such as equalizer channel coefficients, carrier phase and frequency offsets, symbol timing, and FFT window timing. They may also assist in initial acquisition of a channel.

Burst transmissions Frame Format



TDMA:Per-Burst Payload

TDMA:Per-Burst Payload

TDMA1:
Single Payload/One Modulation Type, e.g., QPSK

TDMA2:
Single Payload/One Modulation Type, e.g., 64-QAM

QPSK Payload

64-QAM Payload

TDM: Contiguous Multiple Payloads within a burst

M Mini Slots

Downlink Subframe

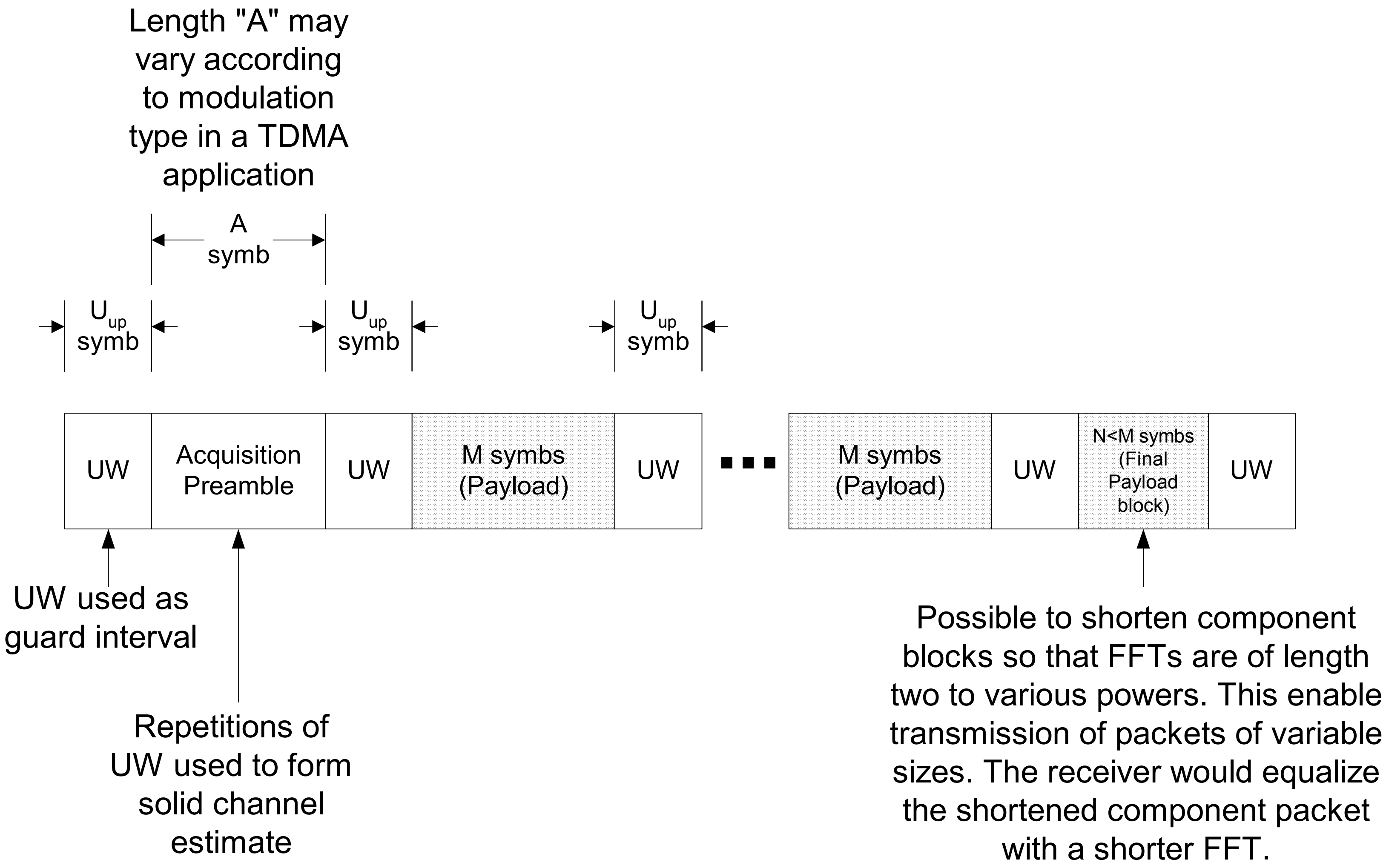
Uplink Subframe

Guardband

MS n

MS (n+ M)

Framing Structure for Burst TDMA Transmission.



Length "A" may vary according to modulation type in a TDMA application

A symb

U_{up} symb

U_{up} symb

U_{up} symb

UW

Acquisition Preamble

UW

M symbs (Payload)

UW

▪ ▪ ▪

M symbs (Payload)

UW

N<M symbs (Final Payload block)

UW

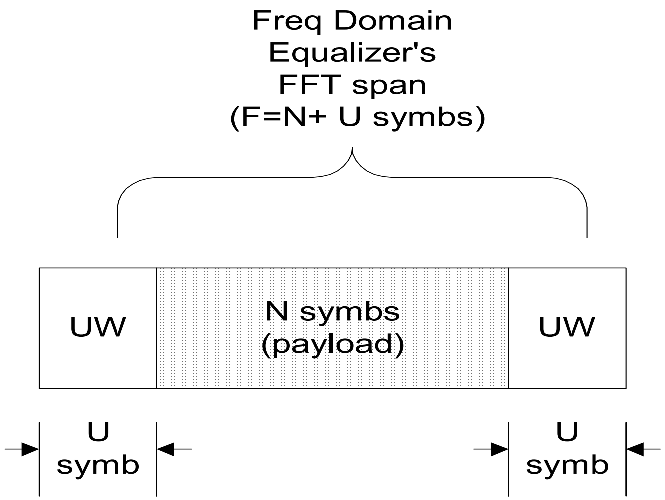
UW used as guard interval

Repetitions of UW used to form solid channel estimate

Possible to shorten component blocks so that FFTs are of length two to various powers. This enable transmission of packets of variable sizes. The receiver would equalize the shortened component packet with a shorter FFT.

Unique Word (U Symb) and Computation of FFT

Length, U (symbols)	PN Generator Polynomial (Binary, with 100101 <-> $x^5 + x^2 + 1$)
15	10011
31	100101
63	1000011
127	10000011
255	100011101



Freq Domain
Equalizer's
FFT span
(F=N+ U symbs)

UW

N symbs
(payload)

UW

U
symb

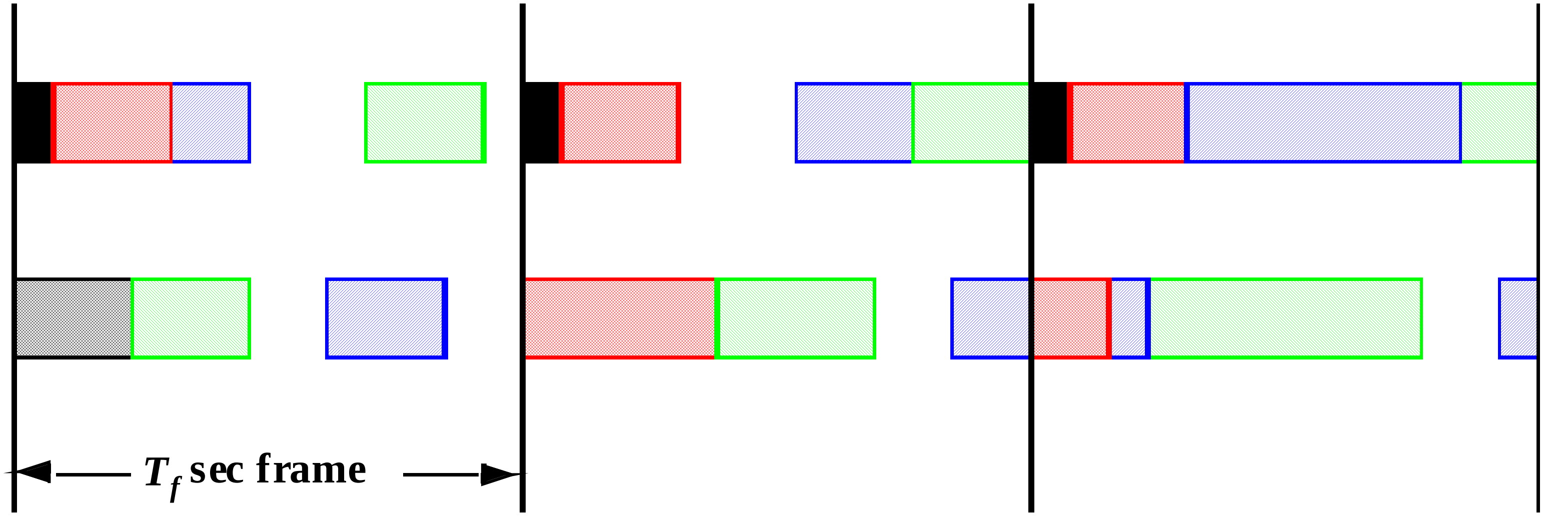
U
symb

Unique Words
Collectively Act
Like "Cyclic Prefixes"
(so that FFT wraps as it
does with OFDM
processing)

Burst Acquisition

- Acquisition can be done in either the time domain or frequency domain.
- Frame with a known acquisition sequence, with optional UW prefix heads in upstream burst.
- A second UW follows the acquisition sequence.
- After passing the first UW, the time domain method solves a linear filter equation for the channel response.
- Time Domain method can be realized by the LMS algorithm, or correlation techniques, among others.
- Frequency method is very similar to OFDM initial channel estimation technique.
- An iterative procedure can be used which mixes the time domain and frequency domain approaches.

MAC and PHY Interface Layers



■ **Broadcast**

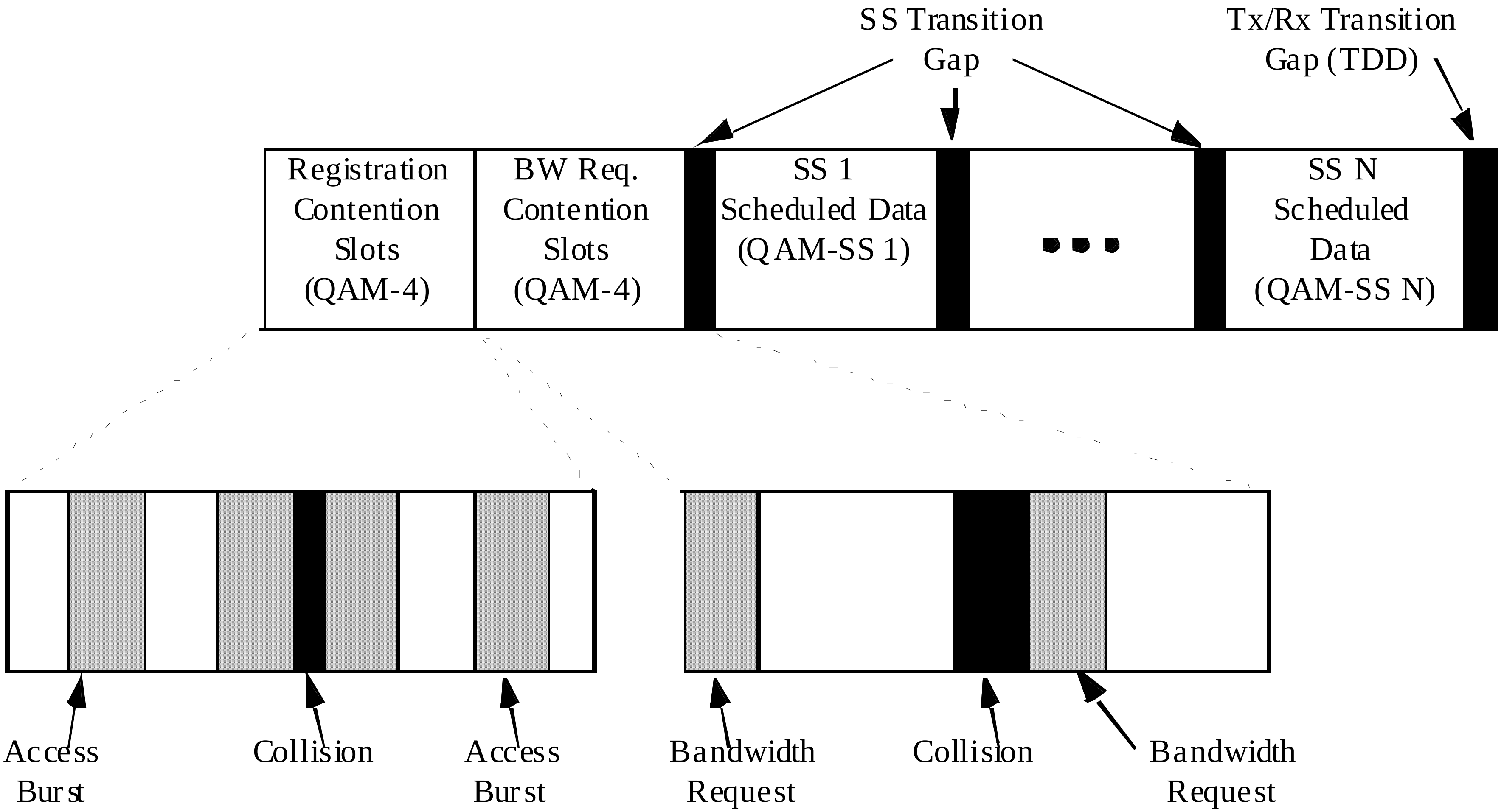
🟥 **Full Duplex Capable User**

🟦 **Half Duplex User #1**

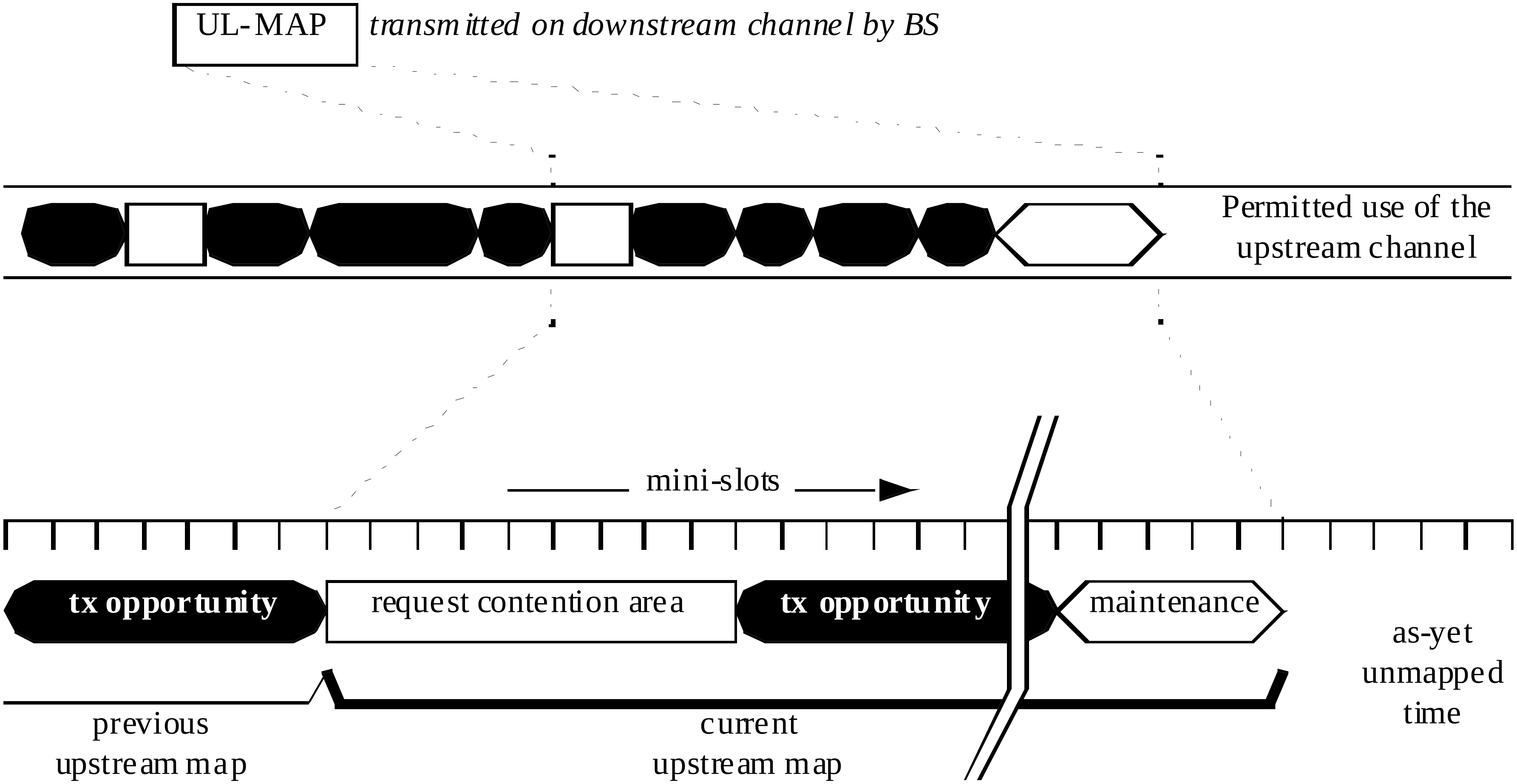
🟩 **Half Duplex User #2**

An Example of Burst FDD bandwidth Allocation

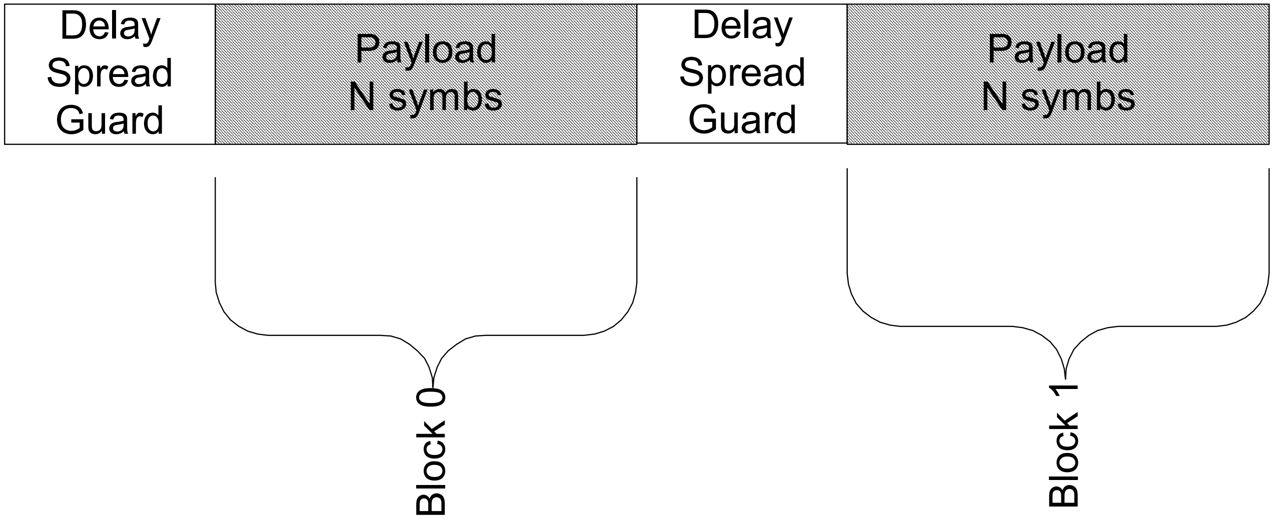
Uplink Burst Subframe Structure



Uplink Burst Profile Modes



Implementation of Alamouti Transmit Diversity Technique (for FD-DFE)



Block Signaling in Frequency Domain

Block Signaling in the Frequency Domain

	Block 0	Block 1
Transmit Antenna 1	$S_0\left(e^{j\omega}\right)$	$S_1\left(e^{j\omega}\right)$
Transmit Antenna 2	$-S_1^*\left(e^{j\omega}\right)$	$S_0^*\left(e^{j\omega}\right)$

Combiner Equations

$$\begin{aligned} C_0\left(e^{j\omega}\right) &= H_0^*\left(e^{j\omega}\right)R_0\left(e^{j\omega}\right)+H_1\left(e^{j\omega}\right)R_1^*\left(e^{j\omega}\right) \\ C_1\left(e^{j\omega}\right) &= -H_1\left(e^{j\omega}\right)R_0^*\left(e^{j\omega}\right)+H_0^*\left(e^{j\omega}\right)R_1\left(e^{j\omega}\right) \end{aligned}$$

Equalize Combiner Result Each with

$$\mathrm{E}\left(\mathrm{e}^{j\omega}\right)=\frac{\mathrm{F}^*\left(\mathrm{e}^{-j\omega}\right)}{\mathrm{D}\left(\mathrm{e}^{j\omega}\right)+\sigma^2}$$

where

$$D\left(\mathrm{e}^{j\omega}\right)=\left|\mathrm{H}_0\left(\mathrm{e}^{j\omega}\right)\right|^2+\left|\mathrm{H}_1\left(\mathrm{e}^{j\omega}\right)\right|^2$$

and

$F\left(e^{j\omega}\right)$ subtracts out components that the temporal feedback equalizer deals with.

(See Falconer & Ariyavsitakul, Ottawa tutorial)

Time Domain Multiplexing & Channel Estimation for Alamouti Algorithm

Time Domain Multiplexing Used to Realize Freq Interpretation:

	Block 0	Block 1
Transmit Antenna 1	$s_0(t)$	$s_1(t)$
Transmit Antenna 2	$-s_1^*(-t)$	$s_0^*(-t)$

(Note: Second Antenna’s results are time reversed)

Similar technique can be applied to OFDM using Block Signaling in Freq Domain.

Channel Estimation using Pilots

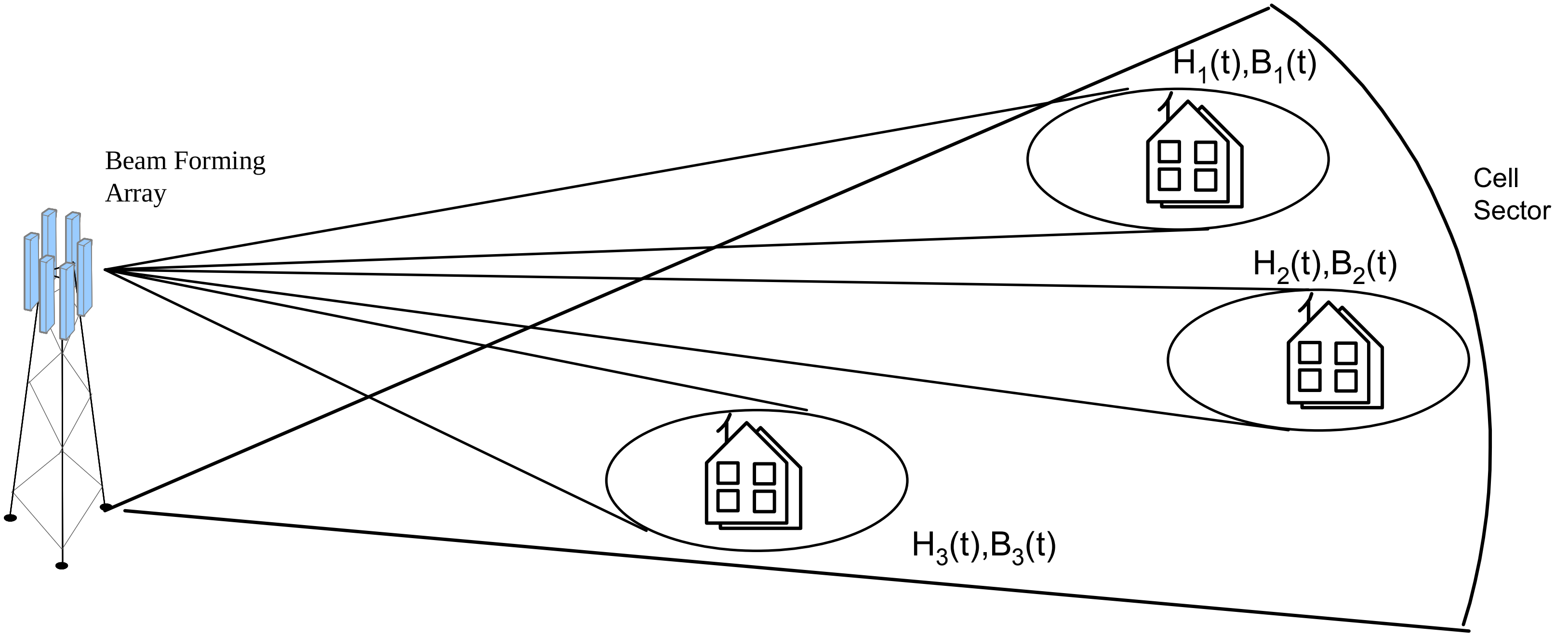
(Take FFT over pilot symbols---see Falconer Contribution on channel estimation)

Use equations:

$$\hat{H}_0(e^{j\omega}) = \frac{S_{pilot}^*(e^{j\omega})R_0(e^{j\omega})+S_{pilot}(e^{j\omega})R_1(e^{j\omega})}{2\left|S_{pilot}(e^{j\omega})\right|^2}$$

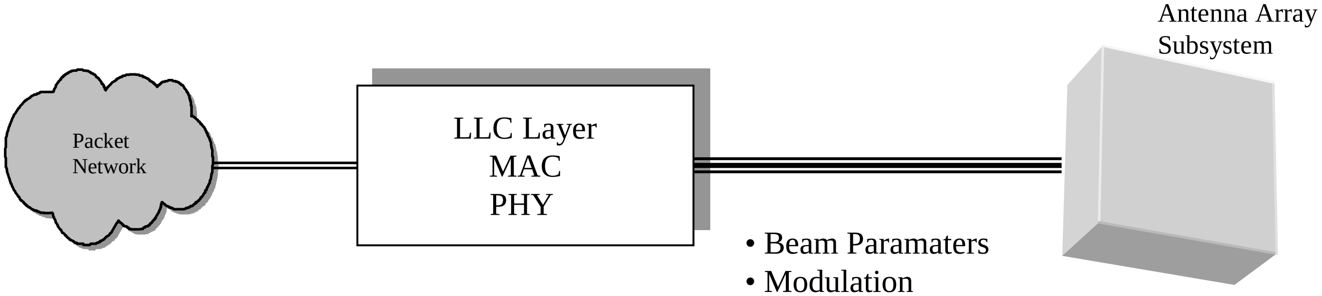
$$\hat{H}_1(e^{j\omega}) = \frac{-S_{pilot}^*(e^{j\omega})R_0(e^{j\omega})+S_{pilot}(e^{j\omega})R_1(e^{j\omega})}{2\left|S_{pilot}(e^{j\omega})\right|^2}$$

MAC/ PHY Framing Considerations for Adaptive Antennas



A Sector of a Base Station Communication with 3 Separate Subscribers

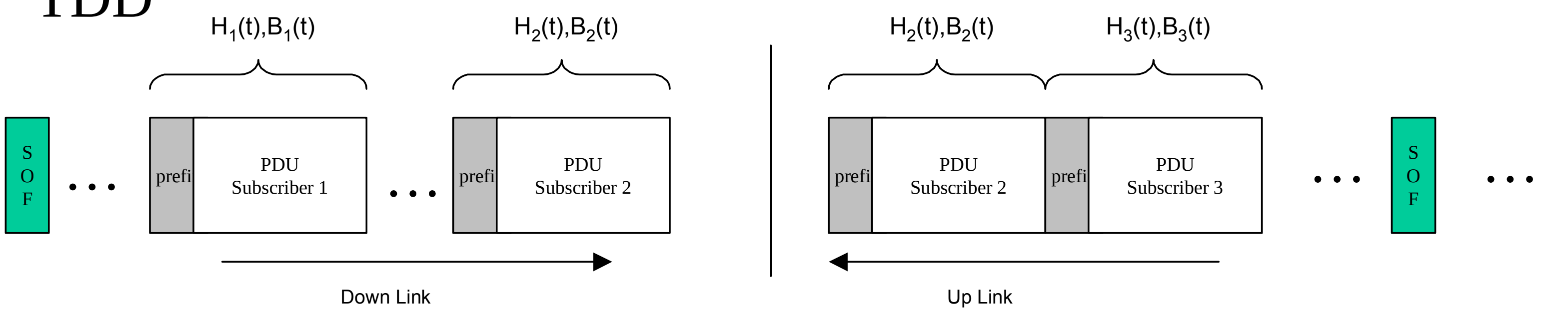
Beam Forming Information



- Beam Paramaters
- Modulation
- FEC
- Length (burst duration)
- Timing

Beam forming Concept for TDD and FDD Cases.

TDD



$H_1(t),B_1(t)$ $H_2(t),B_2(t)$ $H_2(t),B_2(t)$ $H_3(t),B_3(t)$

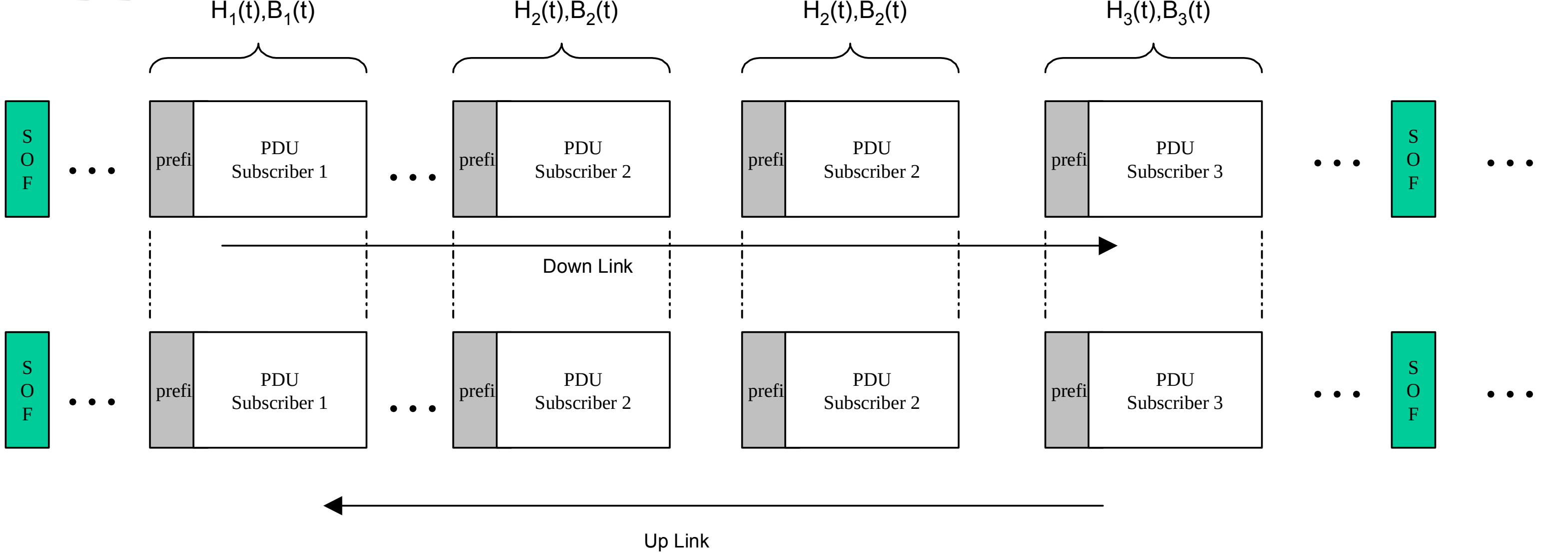
S O F • • • prefi PDU Subscriber 1 • • • prefi PDU Subscriber 2 | prefi PDU Subscriber 2 prefi PDU Subscriber 3 • • • S O F • • •

Down Link

Up Link

TX/RX Boundary

FDD



$H_1(t),B_1(t)$ $H_2(t),B_2(t)$ $H_2(t),B_2(t)$ $H_3(t),B_3(t)$

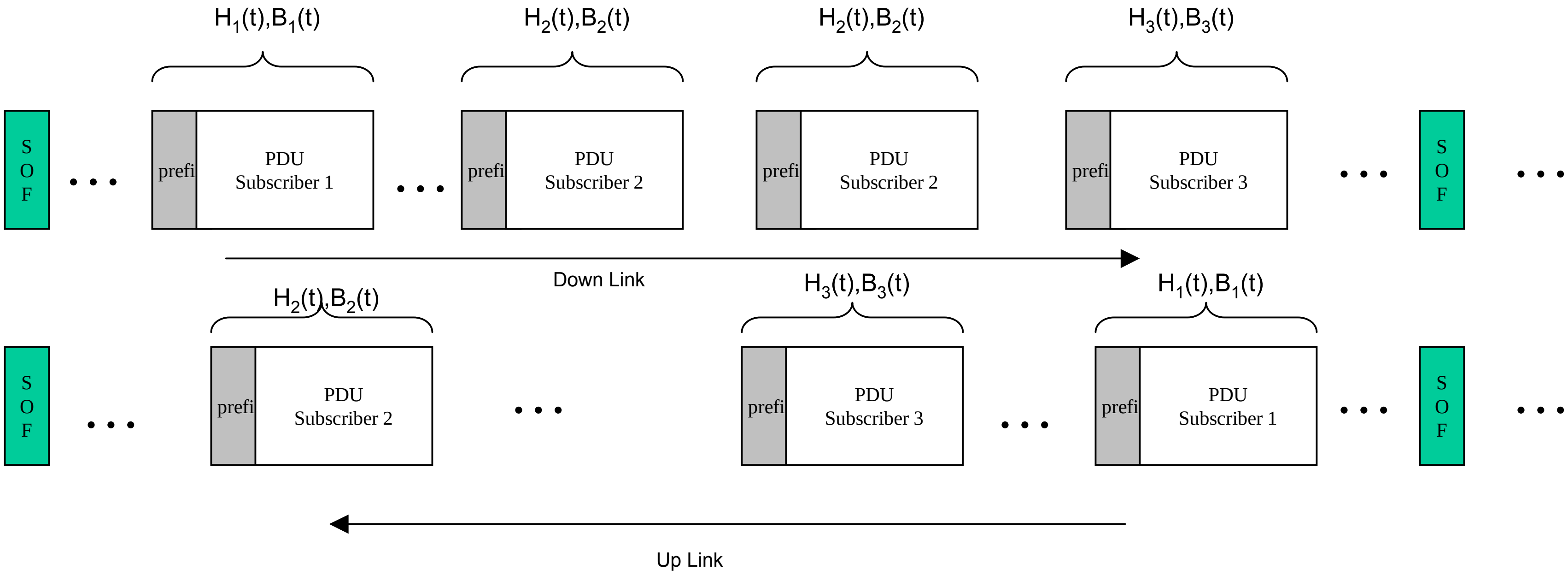
S O F • • • prefi PDU Subscriber 1 • • • prefi PDU Subscriber 2 prefi PDU Subscriber 2 prefi PDU Subscriber 3 • • • S O F • • •

Down Link

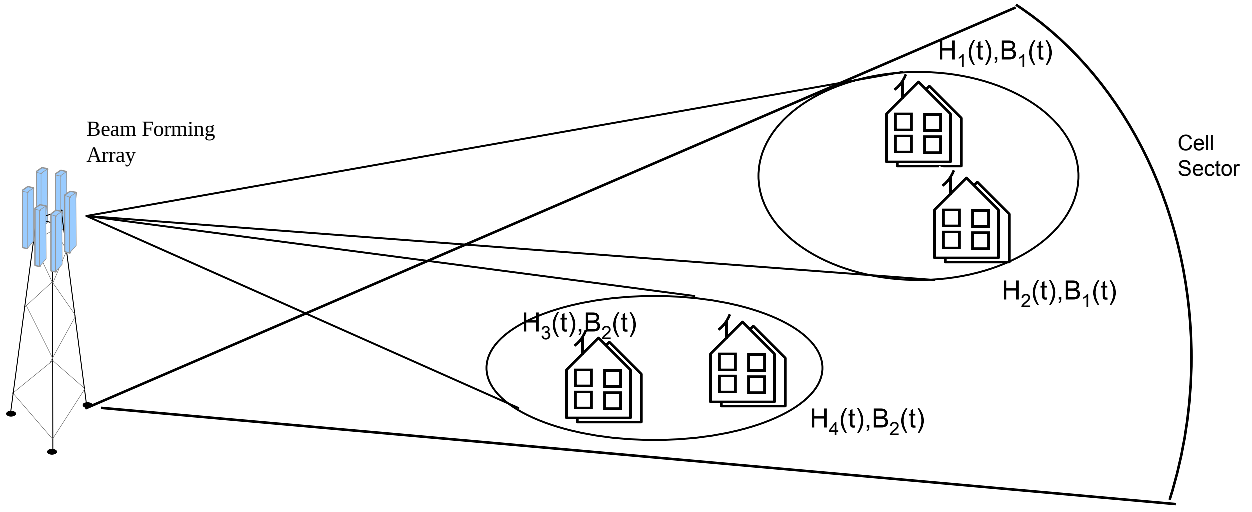
S O F • • • prefi PDU Subscriber 1 • • • prefi PDU Subscriber 2 prefi PDU Subscriber 2 prefi PDU Subscriber 3 • • • S O F • • •

Up Link

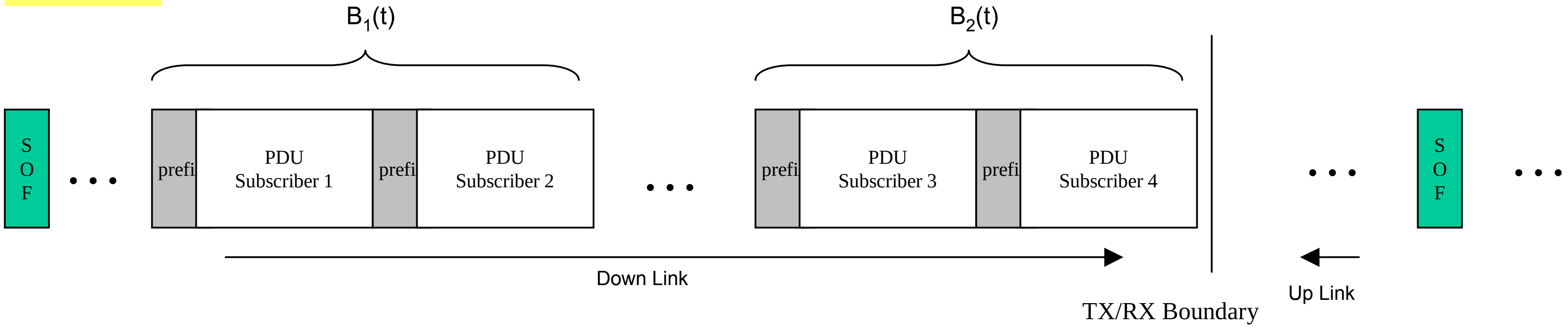
FDD with Independent beam forming



Spatial Concatenation



TDD


$B_1(t)$

$B_2(t)$

S
O
F

• • •

prefi

PDU
Subscriber 1

prefi

PDU
Subscriber 2

• • •

prefi

PDU
Subscriber 3

prefi

PDU
Subscriber 4

• • •

S
O
F

• • •

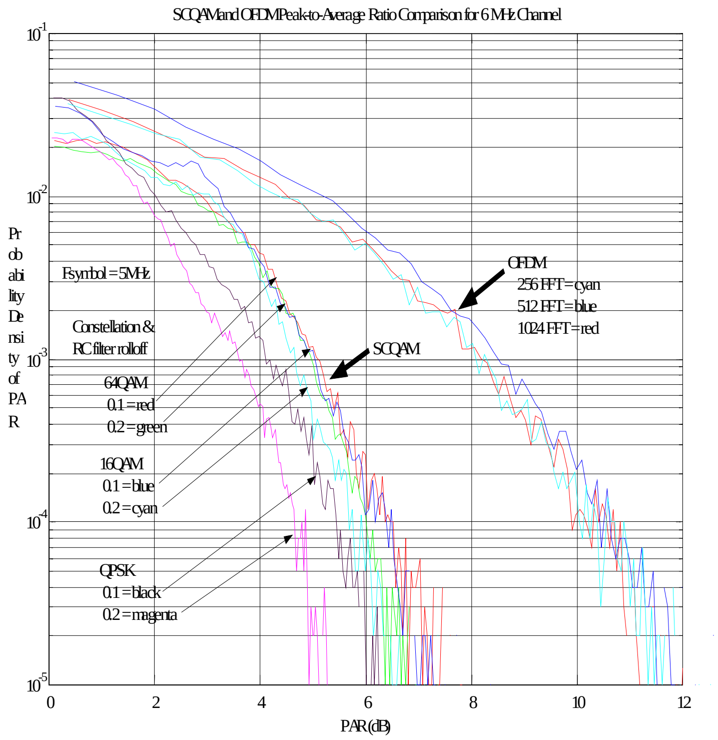
Down Link

TX/RX Boundary

Up Link

RF System Requirements: Amplifier Linearity

- Peak-to-average well known problem in OFDM-like systems
- Compliance with FCC Mask (FCC Regulations, 47CFR21.908, for MMDS transmitters in the 2.5 GHz band).



Peak to Average Ratio

The following table provides representative PAR (peak to average ratio) values for the simulated waveforms:

OFDM	**64 point FFT**	**256 point FFT**	**512 point FFT**
QPSK	13.3	12.0	11.9
16QAM	13.3	12.0	12.0
64QAM	13.4	12.3	12.5

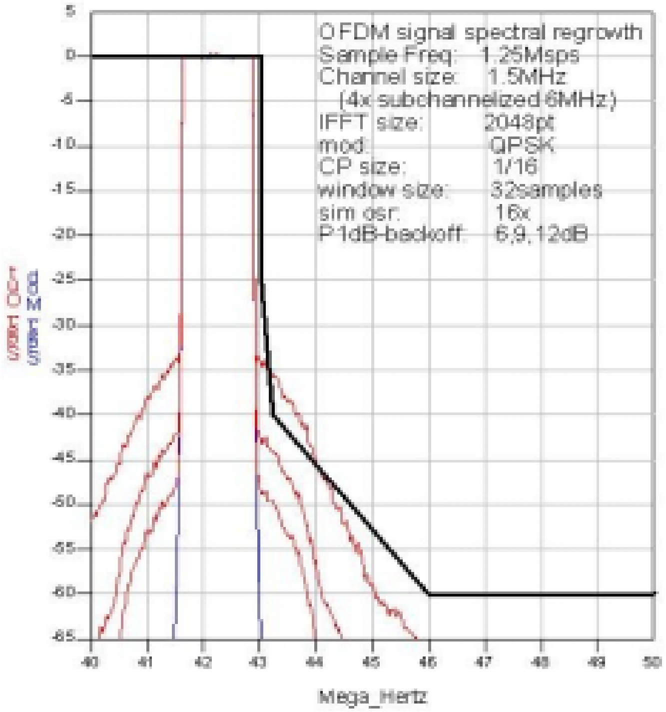
*Number of actual carriers is 75% of indicated in column headers.

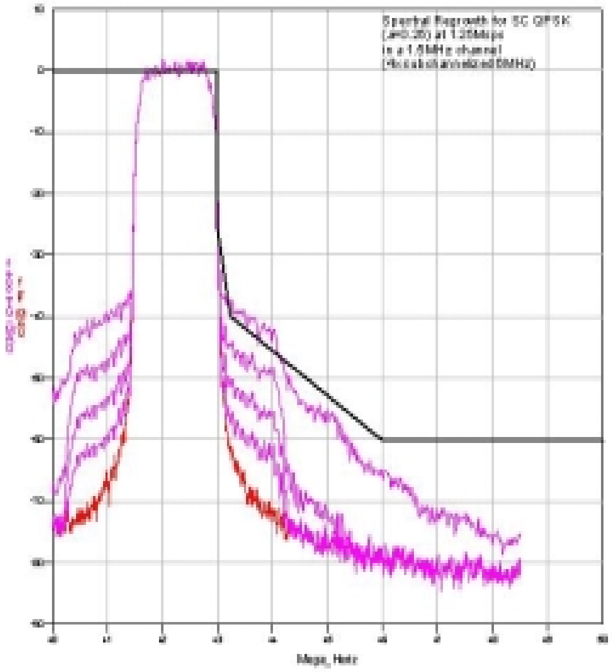
Single Carrier	**PAR**
QPSK	7.5
PI/4 DQPSK	7.0
OQPSK	4.8
16QAM	9.4
64QAM	10.5

*RRC Alpha of 0.25.

Spectral Regrowth Simulations: 1.5 MHz

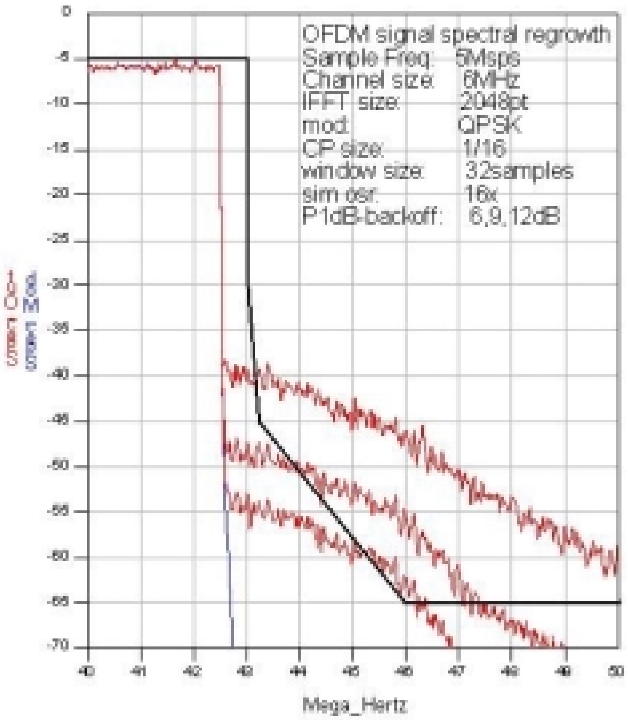
- Upstream Channels will be narrow
- Simulation of sub-channelized band, with offset to band edge
  - SC requires 3 – 6 dB
  - OFDM requires 6 – 9 dB





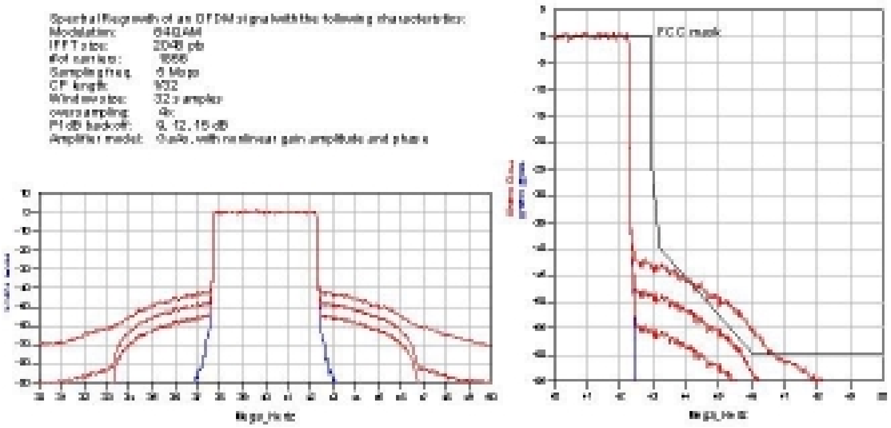
Spectral Regrowth Simulations: 6 MHz

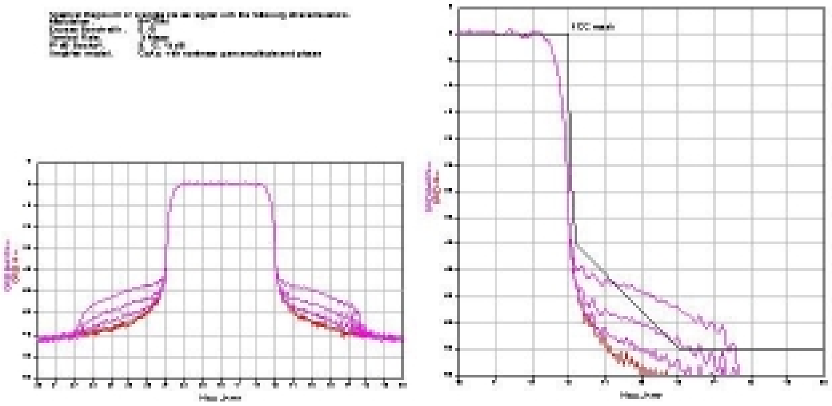
- Downstream channels are wide band
- Simulation of sub-channelized band, with offset to band edge
    - SC requires 9 - 12 dB
    - OFDM requires 12 - 15 dB



Spectral Regrowth Simulations: 6 MHz

- Both SC and OFDM require similar backoff

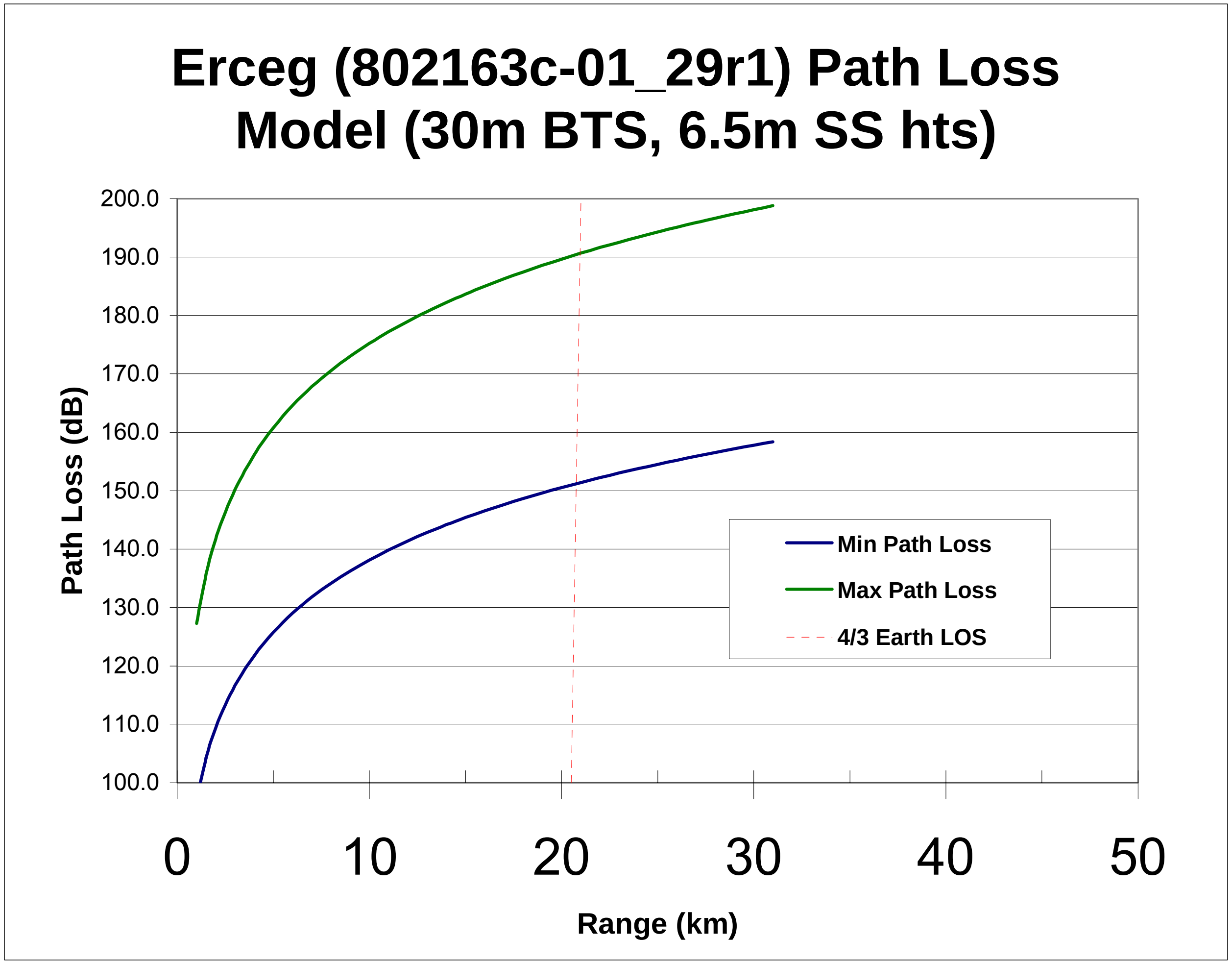




Frequency Bands and Channel Bandwidth

Frequency Bands	Channel Bandwidth Options	Reference
a) 2.15- 2.162 GHz,	2 to 6 MHz downstream,	FCC 47 CFR 21.901 (MDS)
2.50- 2.690 GHz	200 kHz to 6 MHz upstream	FCC 47 CFR 74.902 (ITFS, MMDS)
		Industry Canada SRSP-302.5 (Fixed Services operating in the 2500 to 2686 MHz band)
b) 3.5 GHz	1.75- 7 MHz downstream,	EN 301 021,
	250 KHz to 7 MHz upstream	CEPT/ERC Rec. 14-03 E, CEPT/ERC Rec. 12-08 E, Others (TBD)
c) 10.5 GHz	3.5, 5 and 7 MHz	EN 301 021, CEPT/ERC Rec. 12-05 E

Path Loss Results



Link Budget Results

Table 4-2: Channel Model Section as per Erceg's Contribution 802.16.3c-29r1

Parameter	Category		
	C	B	A
	Flat, few trees	Inter mediate	Hilly, heavy trees
a	3.6	4	4.6
b	0.005	0.0065	0.0075
c	20	17.1	12.6
Channel frequency	2.5	GHz	
Wavelength	0.12	m	
receive antenna height h=	6.5	m	
(hb is the height of the base station in m) hb=	80	m	
γ =(a –b hb +c /hb) γ =	3.45	3.69375	4.1575
A =20 log10 (4 π d0 /λ)(λ being the wavelength in m)	80.40057		
s=	9.4		
PL =A + 10 γ log10 (d/d0) + DPl + DPh ± s for d >d0,			
4/3 Earth Line of Sight =	46.6	km	

Typical Link Budget results for Single Carrier and OFDM for 64 QAM (1.5 and 6 MHz width)

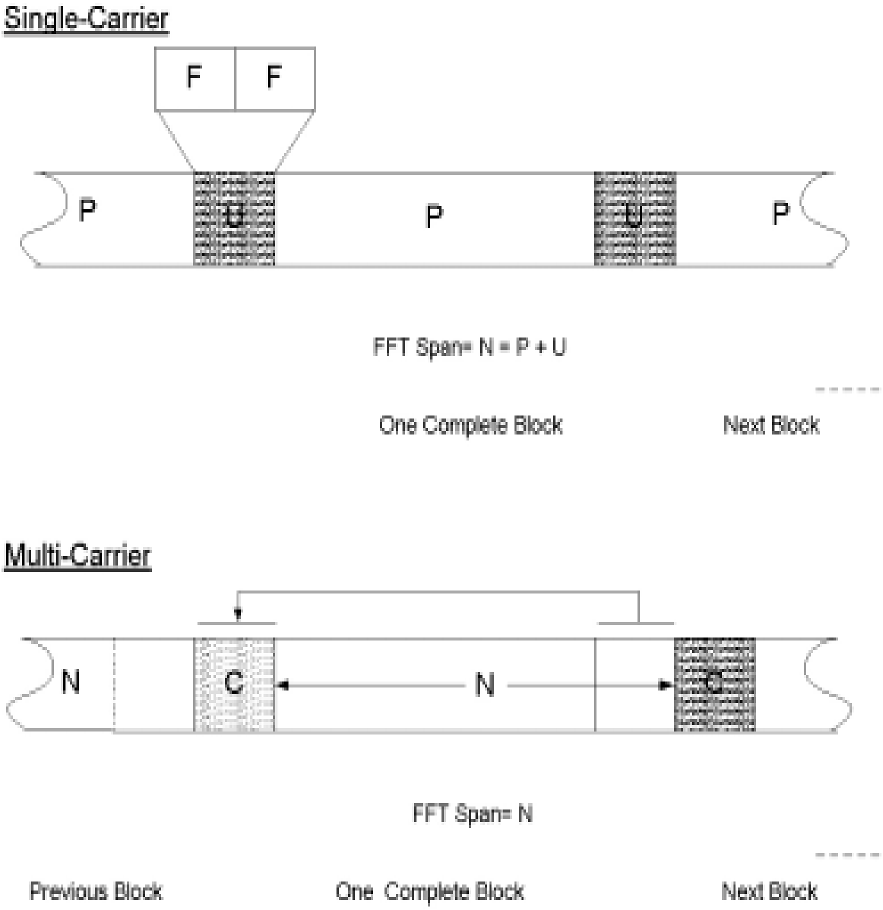
	Single Carrier		512 Carriers		Single Carrier		512 Carriers	
Bandwidth	**1.5**	MHz	**1.5**	MHz	**6.0**	MHz	**6**	MHz
Modulation type / Target SNR	**64 QAM**	25 dB	**OFDM**	25 dB	**64 QAM**	25 dB	**OFDM**	25 dB
Downstream								
EIRP (BTS)	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w
Antenna Gain	3.0 dB		3.0 dB		3.0 dB		3.0 dB	
Back off	12.0 dB		14.0 dB		12.0 dB		14.0 dB	
Nominal 1 dB compression point	52.0 dBm	**158 w**	54.0 dBm	**251 w**	52.0 dBm	**158 w**	54.0 dBm	**251 w**
Normalized Price	**1.0**		**1.3**		**1.0**		**1.3**	
Path distance for targeted SNR	**6.5 km**		**6.5 km**		**4.5 km**		**4.5 km**	
Associated Path Loss (from 802.16.3c-29r1)	-139.8 dB		-139.8 dB		-133.3 dB		-133.3 dB	
Receive Antenna gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Power at Input to Receiver	-82.8 dBm		-82.8 dBm		-76.3 dBm		-76.3 dBm	
Receiver Noise Figure	5.0 dB		5.0 dB		5.0 dB		5.0 dB	
Equivalent Noise Power in channel BW	-107.2 dBm		-107.2 dBm		-101.2 dBm		-101.2 dBm	
SNR, Calculated	**24.4 dB**		**24.4 dB**		**24.9 dB**		**24.9 dB**	
Upstream								
EIRP (SS)	34.0 dBm	3 w	34.0 dBm	3 w	40.0 dBm	10 w	40.0 dBm	10 w
Antenna Gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Back off	6.0 dB		14.0 dB		6.0 dB		14.0 dB	
Nominal 1 dB compression point	26.0 dBm	**0.40 w**	34.0 dBm	**3 w**	32.0 dBm	**2 w**	40.0 dBm	**10 w**
Normalized Price	**1.0**		**4.0**		**1.0**		**4.0**	
Path distance for targeted SNR	**2.5 km**		**2.5 km**		**2.5 km**		**2.5 km**	
Associated Path Loss (from 802.16.3c-29)	-122.8 dB		-122.8 dB		-122.8 dB		-122.8 dB	
Receive Antenna gain	6.0 dB		6.0 dB		6.0 dB		6.0 dB	
Power at Input to Receiver	-82.8 dBm		-82.8 dBm		-76.8 dBm		-76.8 dBm	
Receiver Noise Figure	4.0 dB		4.0 dB		4.0 dB		4.0 dB	
Equivalent Noise Power in channel BW	-108.2 dBm		-108.2 dBm		-102.2 dBm		-102.2 dBm	
SNR, Calculated	**25.5 dB**		**25.5 dB**		**25.5 dB**		**25.5 dB**	

Typical Link Budget results for Single Carrier and OFDM for QPSK (1.5 and 6 MHz width)

	Single Carrier		512 Carriers		Single Carrier		512 Carriers	
Bandwidth	**1.5**	MHz	**1.5**	MHz	**6.0**	MHz	**6**	MHz
Modulation type / Target SNR	**QPSK**	10 dB	**OFDM**	10 dB	**QPSK**	10 dB	**OFDM**	10 dB
Downstream								
EIRP (BTS)	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w	43.0 dBm	20 w
Antenna Gain	3.0 dB		3.0 dB		3.0 dB		3.0 dB	
Back off	12.0 dB		14.0 dB		11.0 dB		14.0 dB	
Nominal 1 dB compression point	52.0 dBm	**158 w**	54.0 dBm	**251 w**	51.0 dBm	**126 w**	54.0 dBm	**251 w**
Normalized Price	**1.0**		**1.3**		**1.0**		**1.3**	
Path distance for targeted SNR	**14.5 km**		**14.5 km**		**10.5 km**		**10.5 km**	
Associated Path Loss (from 802.16.3c-29r1)	-154.2 dB		-154.2 dB		-148.4 dB		-148.4 dB	
Receive Antenna gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Power at Input to Receiver	-97.2 dBm		-97.2 dBm		-91.4 dBm		-91.4 dBm	
Receiver Noise Figure	5.0 dB		5.0 dB		5.0 dB		5.0 dB	
Equivalent Noise Power in channel BW	-107.2 dBm		-107.2 dBm		-101.2 dBm		-101.2 dBm	
SNR, Calculated	**10.0 dB**		**10.0 dB**		**9.8 dB**		**9.8 dB**	
Upstream								
EIRP (SS)	34.0 dBm	3 w	34.0 dBm	3 w	40.0 dBm	10 w	40.0 dBm	10 w
Antenna Gain	14.0 dB		14.0 dB		14.0 dB		14.0 dB	
Back off	6.0 dB		14.0 dB		11.0 dB		14.0 dB	
Nominal 1 dB compression point	26.0 dBm	**0.40 w**	34.0 dBm	**3 w**	37.0 dBm	**5 w**	40.0 dBm	**10 w**
Normalized Price	**1.0**		**4.0**		**1.0**		**4.0**	
Path distance for targeted SNR	**6.0 km**		**6.0 km**		**6.0 km**		**6.0 km**	
Associated Path Loss (from 802.16.3c-29)	-138.4 dB		-138.4 dB		-138.4 dB		-138.4 dB	
Receive Antenna gain	6.0 dB		6.0 dB		6.0 dB		6.0 dB	
Power at Input to Receiver	-98.4 dBm		-98.4 dBm		-92.4 dBm		-92.4 dBm	
Receiver Noise Figure	4.0 dB		4.0 dB		4.0 dB		4.0 dB	
Equivalent Noise Power in channel BW	-108.2 dBm		-108.2 dBm		-102.2 dBm		-102.2 dBm	
SNR, Calculated	**9.8 dB**		**9.8 dB**		**9.8 dB**		**9.8 dB**	

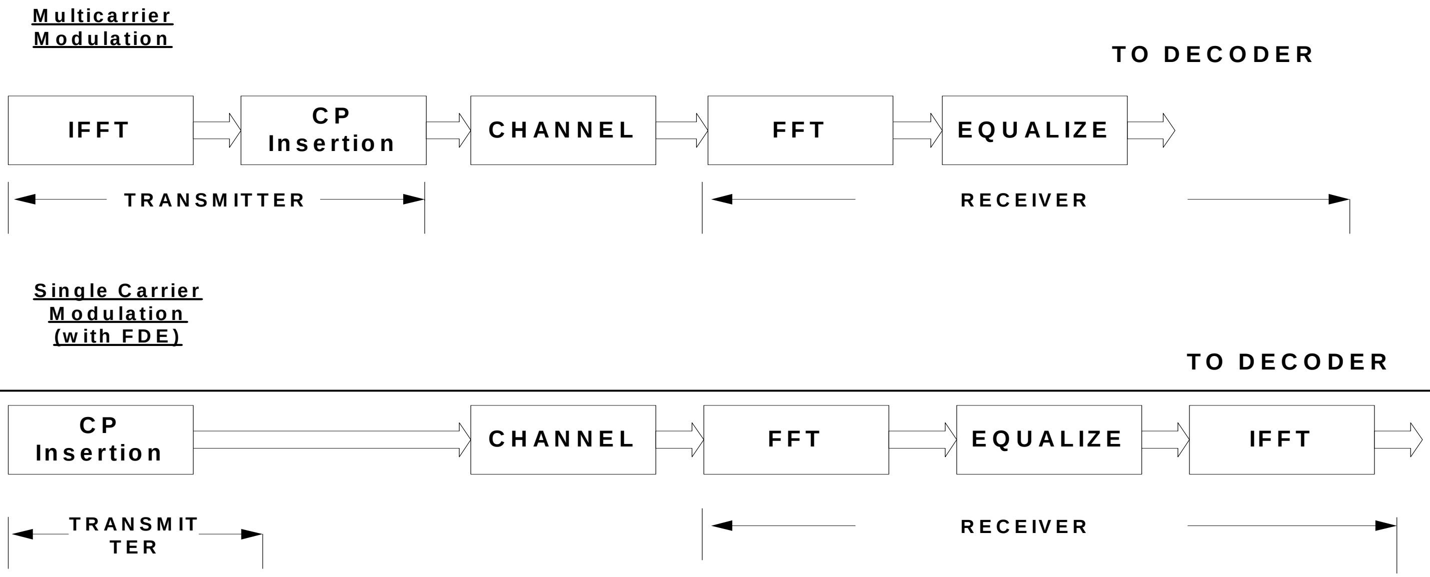
Highlights of Unified SC-OFDM PHY Structure

- Both SC, MC versions of proposal are based on a unifying “block” structure
- Resulting PHY is transparent to higher protocol layers
- DOCSIS-like MAC operates over *both* SC,MC frames
- Support for FDD and TDD



Highlights of Unified SC-OFDM PHY Structure (contd…)

- SC, OFDM Solutions have equivalent complexity
- Both solutions based on “Frequency Domain” Signal Processing
- Same hardware programmed to handle both



Multicarrier Modulation

IFFT → CP Insertion → CHANNEL → FFT → EQUALIZE → TO DECODER

TRANSMITTER

RECEIVER

Single Carrier Modulation (with FDE)

CP Insertion → CHANNEL → FFT → EQUALIZE → IFFT → TO DECODER

TRANSMITTER

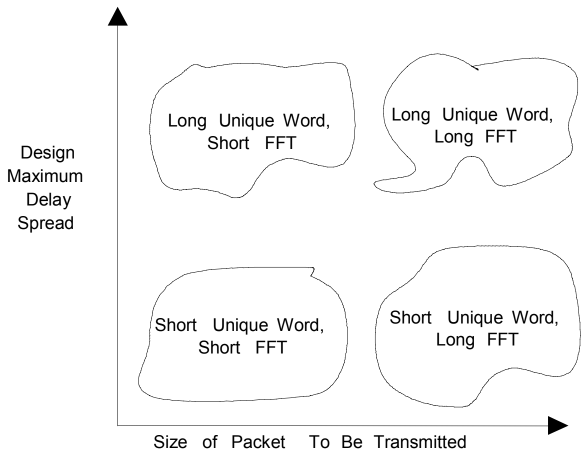
RECEIVER

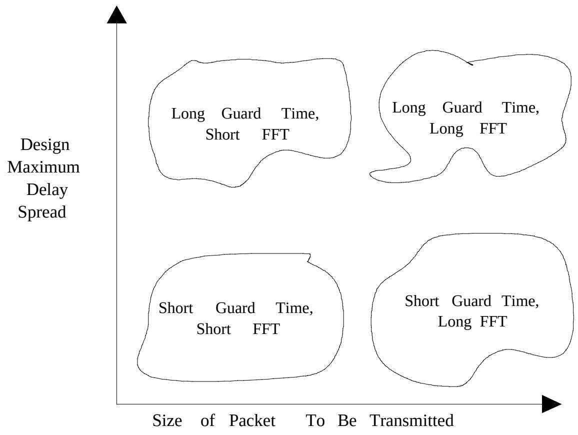
Highlights of Unified SC-OFDM PHY Structure (contd…)

- Design of SC, OFDM PHY based on *Channel* and *Traffic* models available for MMDS BWA
- System parameters in various operating modes chosen to enhance efficiency
- Simple enough to enable **quick roll-out**

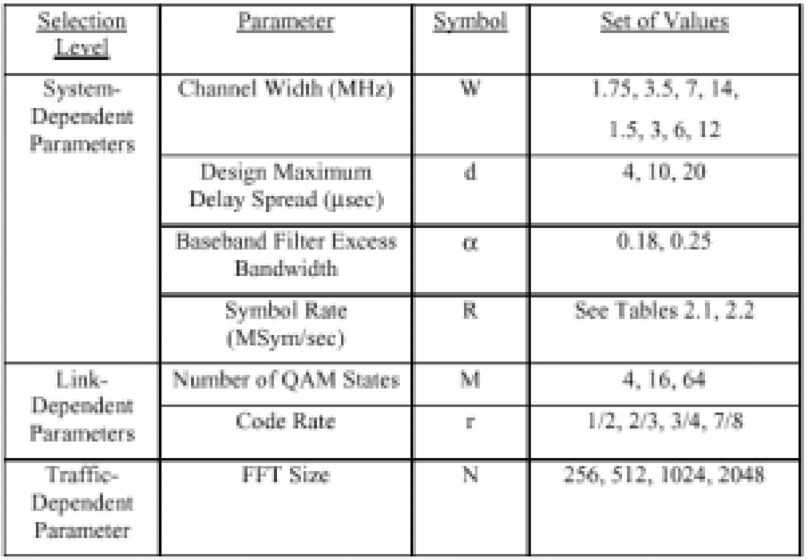
Supported Single, Multi-Carrier Modes

- Choice of system parameters in three hierarchical selection levels





Single Carrier Parameters



Selection Level	Parameter	Symbol	Set of Values
System-Dependent Parameters	Channel Width (MHz)	W	1.75, 3.5, 7, 14, 1.5, 3, 6, 12
	Design Maximum Delay Spread (µsec)	d	4, 10, 20
	Baseband Filter Excess Bandwidth	α	0.18, 0.25
	Symbol Rate (MSym/sec)	R	See Tables 2.1, 2.2
Link-Dependent Parameters	Number of QAM States	M	4, 16, 64
	Code Rate	r	1/2, 2/3, 3/4, 7/8
Traffic-Dependent Parameter	FFT Size	N	256, 512, 1024, 2048

Table 3.2. Parameters and Values Defining Operating Modes for SC Systems

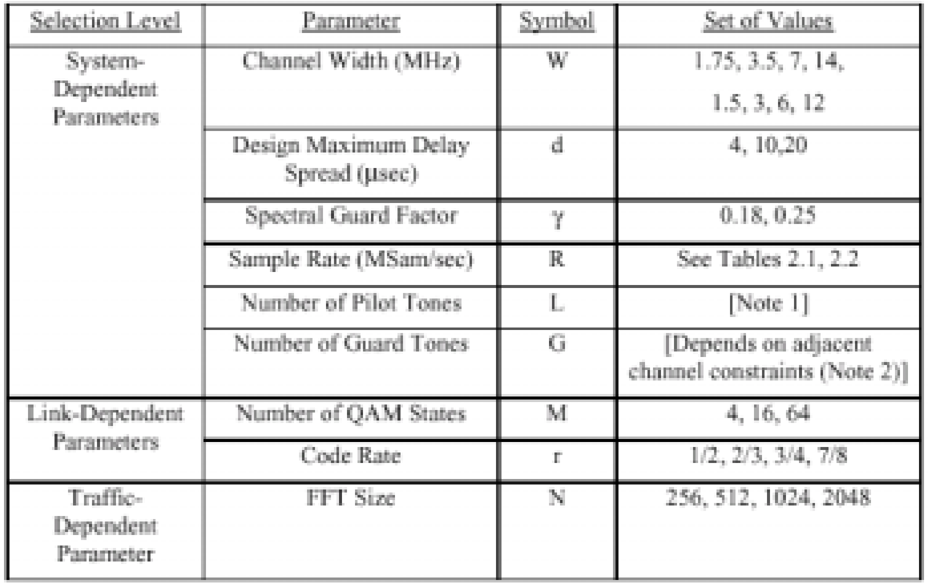
Dependent Parameter	Symbol	Formula	Note
Number of Symbols in Unique Word	U	2 • R • d	
Number of Symbols in Training Sequence	F	U / 2	2.
Number of Payload Symbols Per Block	P	N - U	
Frequency Spacing of Available Channel Estimates Measurable In One Block	e	W / F	3.
Block Period	B	N / R	4.

Table 3.3 Guidelines For Subsidiary Parameters in SC Systems

FFT Size N	Symbol Rate R (MSym/sec)	Block Period (microseconds)
256	1.25	204.800
	1.5	170.667
	2.5	102.400
	3	85.333
	5	51.200
	6	42.667
	10	25.600
	12	21.333
512	1.25	409.600
	1.5	341.333
	2.5	204.800
	3	170.667
	5	102.400
	6	85.333
	10	51.200
	12	42.667
1024	1.25	819.200
	1.5	682.667
	2.5	409.600
	3	341.333
	5	204.800
	6	170.667
	10	102.400
	12	85.333
2048	1.25	1638.400
	1.5	1365.333
	2.5	819.200
	3	682.667
	5	409.600
	6	341.333
	10	204.800
	12	170.667

Table 3.4 **Block Duration in SC Mode**

Multi Carrier Parameters



Selection Level	Parameter	Symbol	Set of Values
System-Dependent Parameters	Channel Width (MHz)	W	1.75, 3.5, 7, 14, 1.5, 3, 6, 12
	Design Maximum Delay Spread (µsec)	d	4, 10,20
	Spectral Guard Factor	γ	0.18, 0.25
	Sample Rate (MSam/sec)	R	See Tables 2.1, 2.2
	Number of Pilot Tones	L	[Note 1]
	Number of Guard Tones	G	[Depends on adjacent channel constraints (Note 2)]
Link-Dependent Parameters	Number of QAM States	M	4, 16, 64
	Code Rate	r	1/2, 2/3, 3/4, 7/8
Traffic-Dependent Parameter	FFT Size	N	256, 512, 1024, 2048

Table 3.5 Parameters and Values Defining Operating Modes for MC Systems

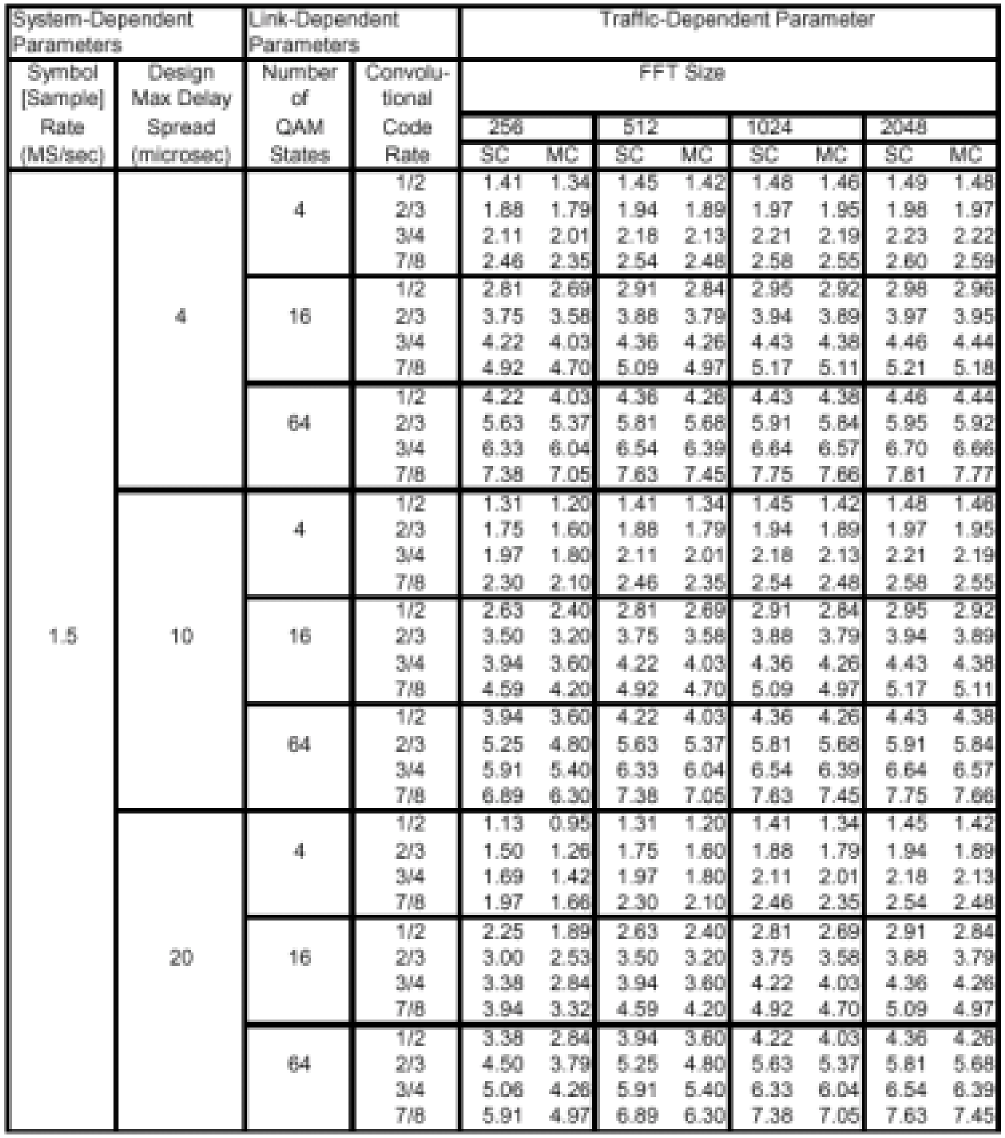
Dependent Parameter	Symbol	Formula	Note
Number of Samples in Cyclic Prefix+Postfix	C	2 • R • d	2.
Number of Payload Subcarriers	P	N - G - L	
Frequency Spacing of Available Channel Estimates Measurable In One Block	e	W / L	
OFDM Symbol Period	S	(N + C - w) / R	
OFDM Subcarrier Spacing	s	R / N	3.

Table 3.6 Guidelines for Subsidiary Parameters In MC Systems

FFT Size N	Sample Rate R (MSam/sec)	Subcarrier Spacing (Hz)
256	1.25	4882.813
	1.5	5859.375
	2.5	9765.625
	3	11718.750
	5	19531.250
	6	23437.500
	10	39062.500
	12	46875.000
512	1.25	2441.406
	1.5	2929.688
	2.5	4882.813
	3	5859.375
	5	9765.625
	6	11718.750
	10	19531.250
	12	23437.500
1024	1.25	1220.703
	1.5	1464.844
	2.5	2441.406
	3	2929.688
	5	4882.813
	6	5859.375
	10	9765.625
	12	11718.750
2048	1.25	610.352
	1.5	732.422
	2.5	1220.703
	3	1464.844
	5	2441.406
	6	2929.688
	10	4882.813
	12	5859.375

Table 3.7 Subcarrier Spacing in MC Mode

Performance for SC and MC (1.75 MHz)



System-Dependent Parameters		Link-Dependent Parameters		Traffic-Dependent Parameter							
Symbol [Sample] Rate (MS/sec)	Design Max Delay Spread (microsec)	Number of QAM States	Convolutional Code Rate	FFT Size							
				256		512		1024		2048	
				SC	MC	SC	MC	SC	MC	SC	MC
1.5	4	4	1/2	1.41	1.34	1.45	1.42	1.48	1.46	1.49	1.48
			2/3	1.88	1.79	1.94	1.89	1.97	1.95	1.98	1.97
			3/4	2.11	2.01	2.18	2.13	2.21	2.19	2.23	2.22
			7/8	2.46	2.35	2.54	2.48	2.58	2.55	2.60	2.59
		16	1/2	2.81	2.69	2.91	2.84	2.95	2.92	2.98	2.96
			2/3	3.75	3.58	3.88	3.79	3.94	3.89	3.97	3.95
			3/4	4.22	4.03	4.36	4.26	4.43	4.38	4.46	4.44
			7/8	4.92	4.70	5.09	4.97	5.17	5.11	5.21	5.18
		64	1/2	4.22	4.03	4.36	4.26	4.43	4.38	4.46	4.44
			2/3	5.63	5.37	5.81	5.68	5.91	5.84	5.95	5.92
			3/4	6.33	6.04	6.54	6.39	6.64	6.57	6.70	6.66
			7/8	7.38	7.05	7.63	7.45	7.75	7.66	7.81	7.77
	10	4	1/2	1.31	1.20	1.41	1.34	1.45	1.42	1.48	1.46
			2/3	1.75	1.60	1.88	1.79	1.94	1.89	1.97	1.95
			3/4	1.97	1.80	2.11	2.01	2.18	2.13	2.21	2.19
			7/8	2.30	2.10	2.46	2.35	2.54	2.48	2.58	2.55
		16	1/2	2.63	2.40	2.81	2.69	2.91	2.84	2.95	2.92
			2/3	3.50	3.20	3.75	3.58	3.88	3.79	3.94	3.89
			3/4	3.94	3.60	4.22	4.03	4.36	4.26	4.43	4.38
			7/8	4.59	4.20	4.92	4.70	5.09	4.97	5.17	5.11
		64	1/2	3.94	3.60	4.22	4.03	4.36	4.26	4.43	4.38
			2/3	5.25	4.80	5.63	5.37	5.81	5.68	5.91	5.84
			3/4	5.91	5.40	6.33	6.04	6.54	6.39	6.64	6.57
			7/8	6.89	6.30	7.38	7.05	7.63	7.45	7.75	7.66
	20	4	1/2	1.13	0.95	1.31	1.20	1.41	1.34	1.45	1.42
			2/3	1.50	1.26	1.75	1.60	1.88	1.79	1.94	1.89
			3/4	1.69	1.42	1.97	1.80	2.11	2.01	2.18	2.13
			7/8	1.97	1.66	2.30	2.10	2.46	2.35	2.54	2.48
		16	1/2	2.25	1.89	2.63	2.40	2.81	2.69	2.91	2.84
			2/3	3.00	2.53	3.50	3.20	3.75	3.58	3.88	3.79
			3/4	3.38	2.84	3.94	3.60	4.22	4.03	4.36	4.26
			7/8	3.94	3.32	4.59	4.20	4.92	4.70	5.09	4.97
		64	1/2	3.38	2.84	3.94	3.60	4.22	4.03	4.36	4.26
			2/3	4.50	3.79	5.25	4.80	5.63	5.37	5.81	5.68
			3/4	5.06	4.26	5.91	5.40	6.33	6.04	6.54	6.39
			7/8	5.91	4.97	6.89	6.30	7.38	7.05	7.63	7.45

Table 6.1 Throughput for Various Modes in 1.75 MHz Channel

Main Features and Benefits of the Proposal

- **Mature and well-proven technology**
- **Supports BOTH SC and OFDM**
- **Adaptive Modulation and Coding**
- **Flexible Asymmetry (Agnostic to Duplexing schemes)**
- **Scalability**
- **Advanced Coding Schemes / Reduced System Delay**
- **An easy migration path to diversity receiver and multiple-input/multiple-output (MIMO)**
- **Full compatibility with the 802.16**

Summary and Conclusions

Commonalities between SC-FDE and OFDM:

- Framing Structure
- Adaptive Modulation and Coding (AMC)
- Antenna Diversity
- Severe Multipath Mitigation (NLOS)
- 802.16 MAC/PHY Interface
- Multiple Access (TDM, TDMA) and Duplexing (TDD, FDD, H-FDD) schemes

Compliance with the Evaluation Criteria

Criteria	Response
1) Meets system requirements	
How well does the proposed PHY protocol meet the requirements described in the current version of the 802.16.3 Functional Requirements Document (FRD)?	Meets all FRD 802.16.3-00/02r4 "MUST" and Recommended Requirements
FRD Compliance Table examples	
M23: Multi-rate support	Yes-via adaptive modulation and coding
M32:Support for TDD and/or FDD duplexing scheme	Yes. Also support H-FDD
Support for optional repeater function	Yes
M35:Support for 1.75 to 7 MHz for ETSI mask, 1.5 to 25 Mhz for other masks.	Yes, full compliance for ETSI, data supplied to support FCC masks up to 12 MHz
M24: ..specifications SHALL NOT preclude the ability of the radio link to be engineered for different link availability based on the preference of the system operator	Yes – allowing both SC-FDE or OFDM as different modes based on the preference of the system operators.
2) Channel and System Efficiency	
Gross bit rate at PHY to MAC interface for each mode	
Modulation scheme	Adaptible between BPSK and 64QAM
Gross Transmission bit rate	Adaptible between ~1 Mbps and 60 Mbps depending on channel mask and modulation format
Sensitivity and 5 dB SNR and PER=10e-2 for 400 Byte packet	Yes. See link budgets
Channel Efficiency; %(capacity-overhead/capacity)	Optimized by adaptive modulation and coding (see sections 3.6 and 3.7). Overheads - UW are adaptively selected to enhance channel characteristics.
Spectral Efficiency Bits/second/Hz	Maximum Spectral Efficiency is controlled by the modulation format and coding rate. Adaptive Coding and Modulation allows ranging from 1 to 6 bits per symbol in all channel bandwidth proposed for the system.

3) Simplicity of Realization	
SS cost optimization	Minimum cost of RF circuitry due to reduced back off required for upstream. The tag price SS unit including RF and BB modules is well below $200. RF cost can be optimized using a direct conversion (ZIF) method.
BS cost optimization	Minimum cost of RF circuitry due to reduced back off required for downstream.
Installation cost	Minimal.
4) Spectrum Resource Flexibility	
Flexibility in use of the frequency band	All channel plans supported. Powerful framing mechanism to support FDD or TDD duplexing schemes
Channel rate flexibility	Adaptive modulation and coding used to adjust for channel quality.
5) System Robustness to Channel Fading, Interference and Radio Impairments	
Small and large scale fading	SC-FDE methods were intensively tested and simulated for the SUI-1 to 6 multipath channels. Ideal FD-DFE performs universally better than OFDM by up to 3 dB. Large scale propagation loss are treated via Antenna diversity, adaptive coding and modulation
Co-channel and adjacent channel interference	Co-channel and adjacent channel leakage are minimized by reduced linearity requirements of single-carrier modulation
Degradation due to phase noise, linearity, etc	Single carrier modulation systems have lower linearity and phase noise requirements than OFDM schemes
6) Support of Adaptive antenna techniques	
Support Tx delayed diversity and Rx diversity	Yes, as shown in simulation scenarios and in Subsection 3.10
Simple migration path to MIMO and Space\Time Coding	Yes, as shown in simulation scenarios and in Subsection 3.10

6) Support of Adaptive antenna techniques	
Support Tx delayed diversity and Rx diversity	Yes, as shown in simulation scenarios and in Subsection 3.10
Simple migration path to MIMO and Space\Time Coding	Yes, as shown in simulation scenarios and in Subsection 3.10
7) Compatibility with existing relevant standards and regulations	
Relevant FCC standard	Fits spectral mask requirements of 47CFR21.907
Relevant ETSI standards	Channelization supports CEPT/ERC Rec. 14-03 E and Rec. 12-08E in 3.5GHz and 12-05E at 10.5 GHz.
Consistent with IEEE802.16MAC and IEEE802.16.1 PHY. Consistent with many SC current deployments	Fits many features of IEEE802.16.1 air interface: i.e.,Duplexing modes, burst operation in D/L, modulation formats etc. This overlap is essential for the 10.5 GHz bands.

Bottom Line

Let’s work Together for a workable Standard