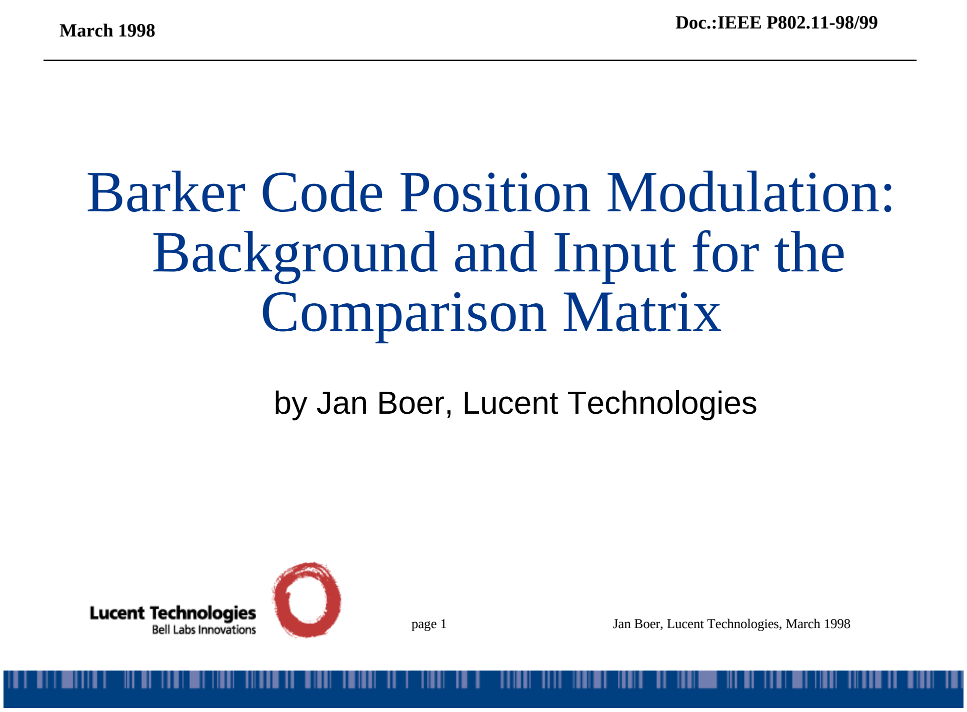
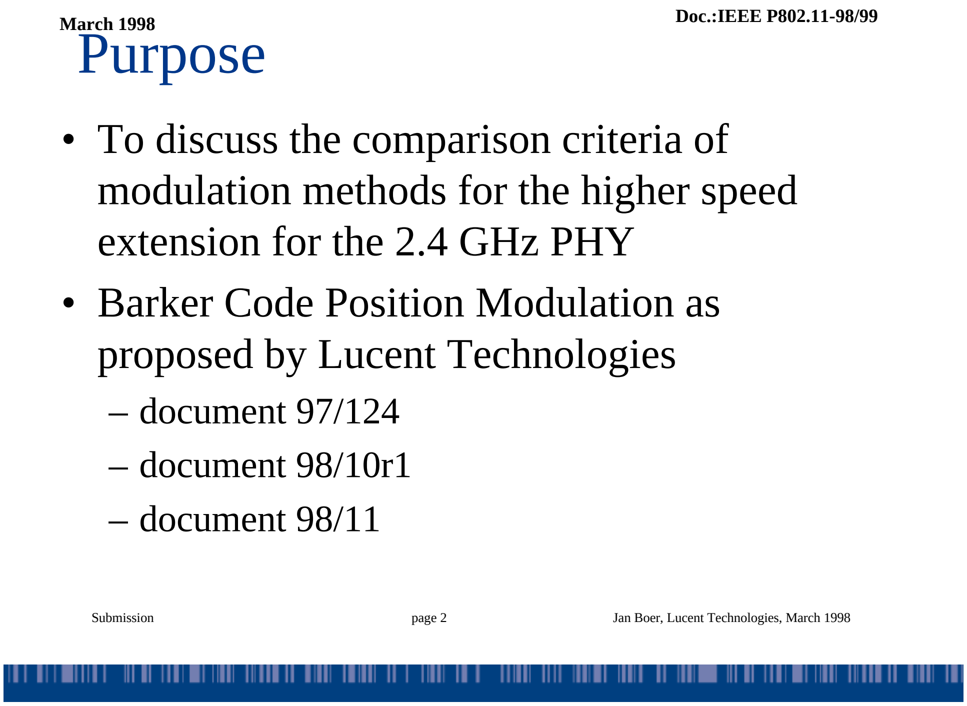


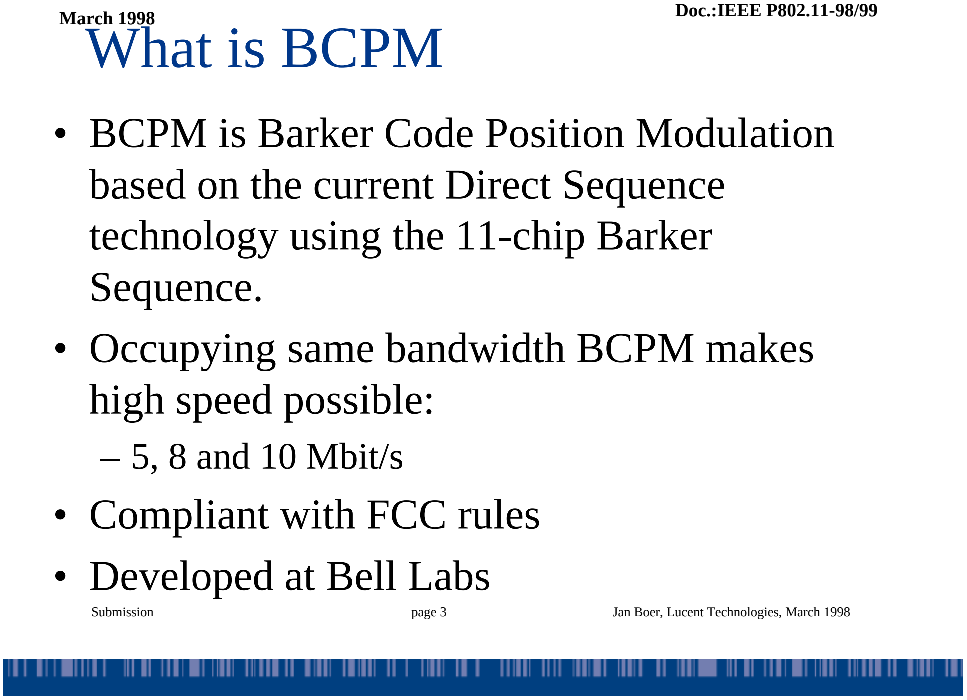
Barker Code Position Modulation: Background and Input for the Comparison Matrix

by Jan Boer, Lucent Technologies



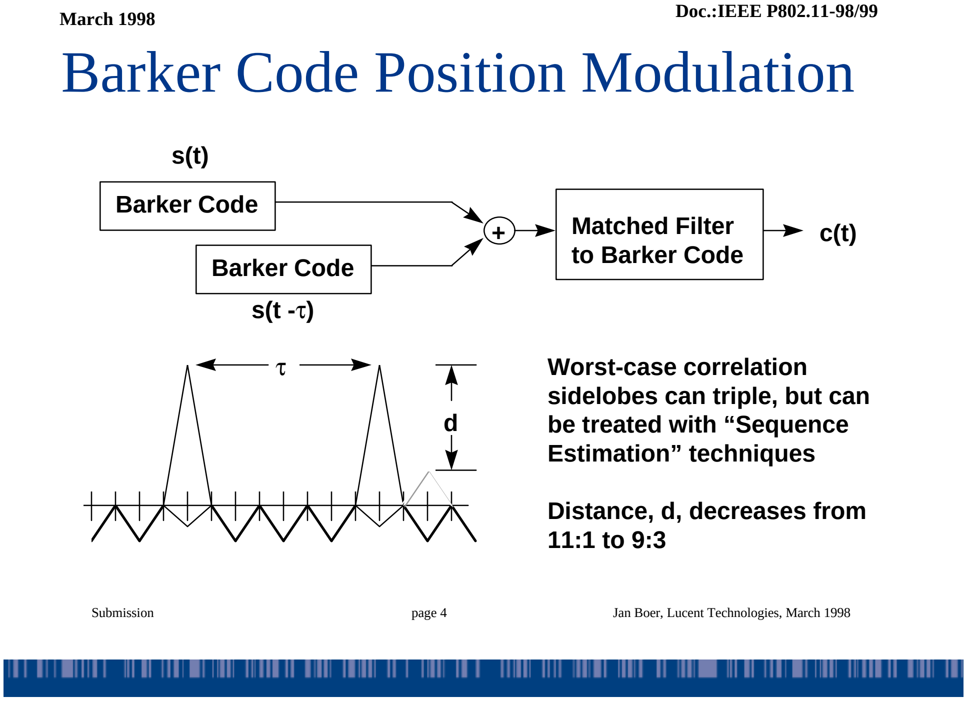
Purpose

- To discuss the comparison criteria of modulation methods for the higher speed extension for the 2.4 GHz PHY
- Barker Code Position Modulation as proposed by Lucent Technologies
  - document 97/124
  - document 98/10r1
  - document 98/11



What is BCPM

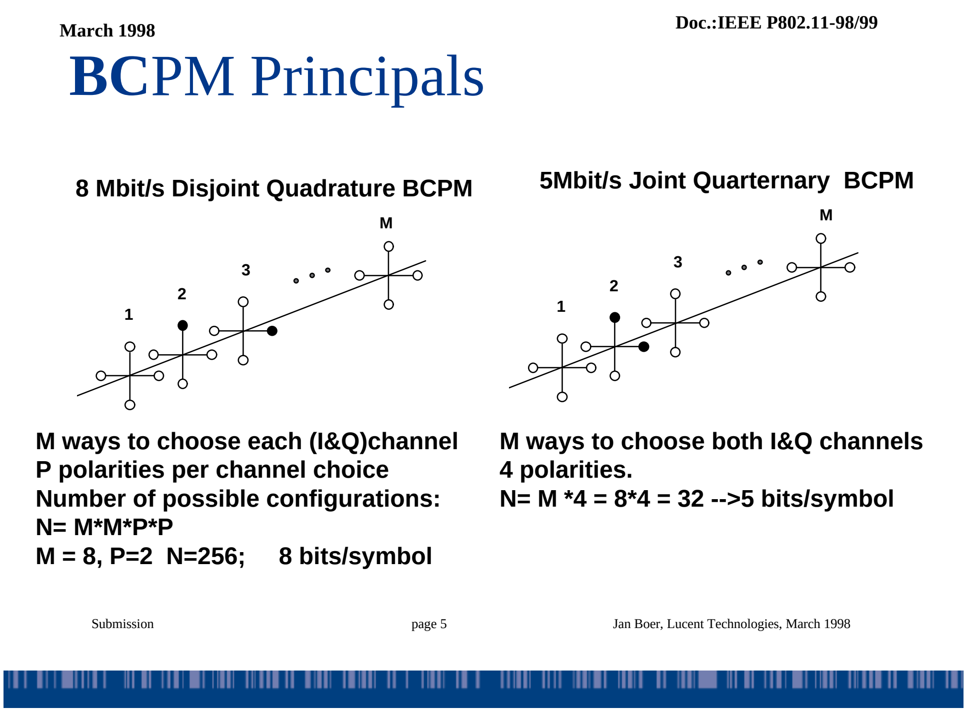
- BCPM is Barker Code Position Modulation based on the current Direct Sequence technology using the 11-chip Barker Sequence.
- Occupying same bandwidth BCPM makes high speed possible:
  - 5, 8 and 10 Mbit/s
- Compliant with FCC rules
- Developed at Bell Labs



Barker Code Position Modulation

Worst-case correlation sidelobes can triple, but can be treated with "Sequence Estimation" techniques

Distance, d, decreases from 11:1 to 9:3



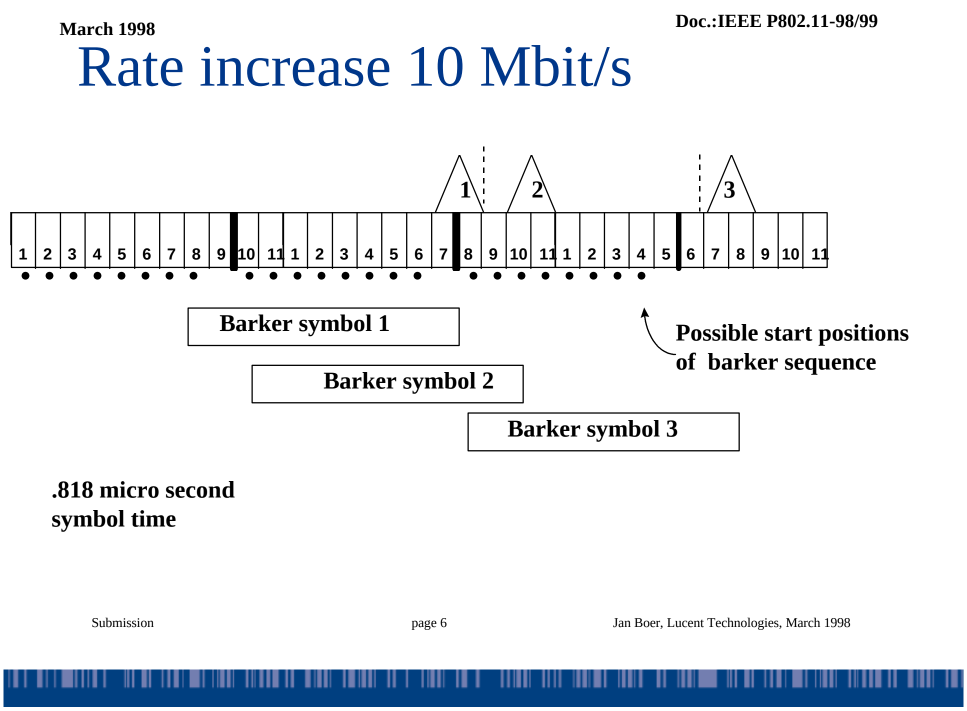
BCPM Principals

8 Mbit/s Disjoint Quadrature BCPM

5Mbit/s Joint Quarternary BCPM

M ways to choose each (I&Q)channel
P polarities per channel choice
Number of possible configurations:
N= M*M*P*P
M = 8, P=2 N=256; 8 bits/symbol

M ways to choose both I&Q channels
4 polarities.
N= M *4 = 8*4 = 32 -->5 bits/symbol



Rate increase 10 Mbit/s

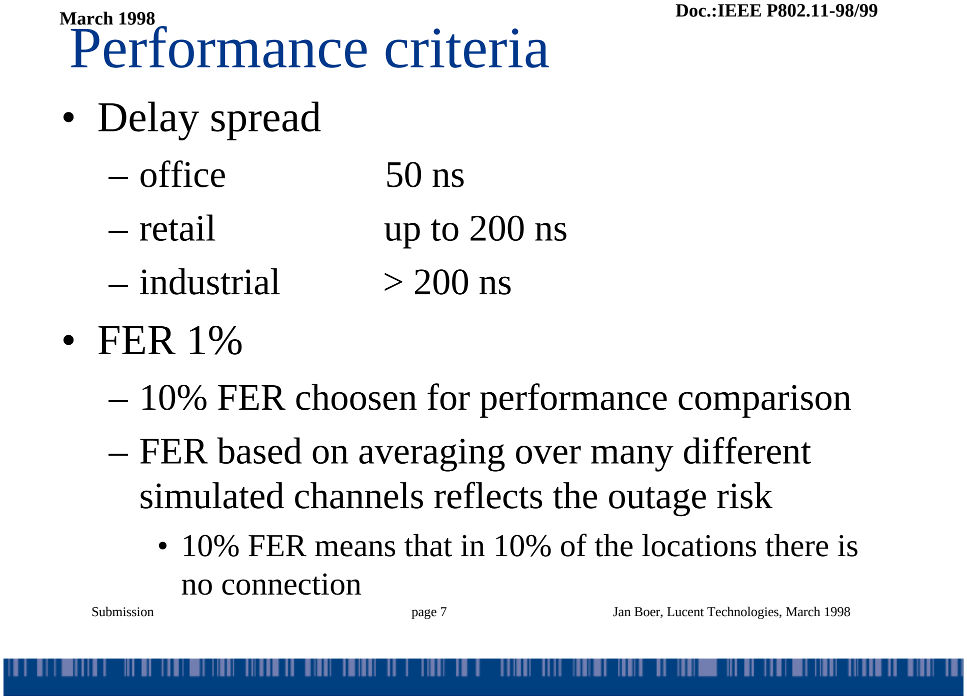
Barker symbol 1

Barker symbol 2

Barker symbol 3

Possible start positions of barker sequence

.818 micro second symbol time

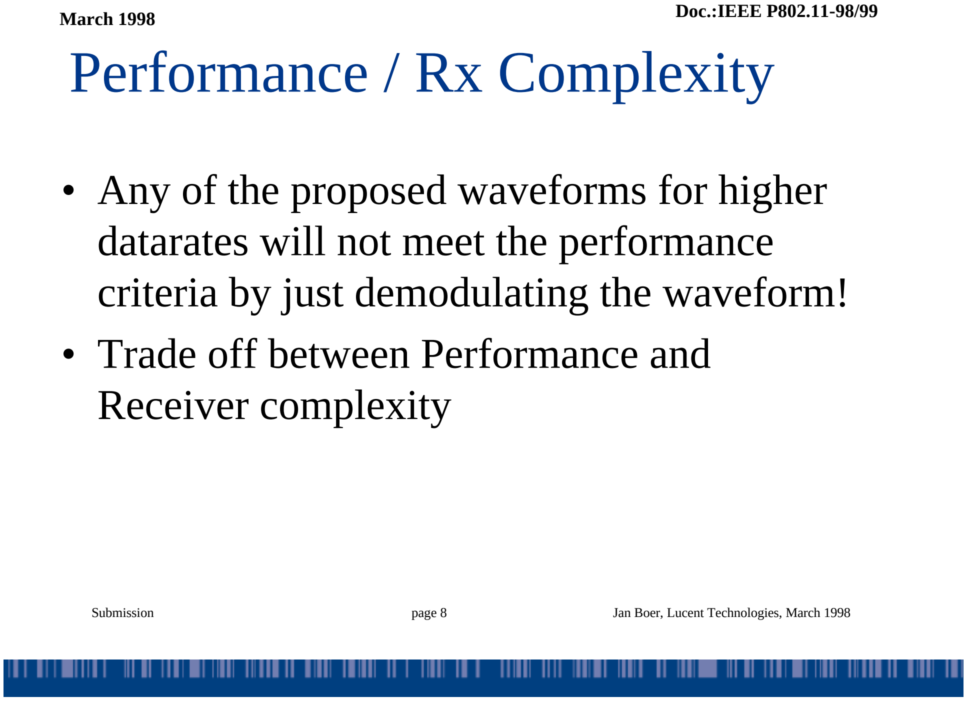


Performance criteria

- Delay spread

– office	50 ns
– retail	up to 200 ns
– industrial	> 200 ns

- FER 1%
  - 10% FER choosen for performance comparison
  - FER based on averaging over many different simulated channels reflects the outage risk
    - 10% FER means that in 10% of the locations there is no connection



Performance / Rx Complexity

- Any of the proposed waveforms for higher datarates will not meet the performance criteria by just demodulating the waveform!
- Trade off between Performance and Receiver complexity

Improved Receiver Structures

- Matched Filter Techniques
- Equalizers
- MLSE

Equalizers

- Theoretical well understood structure
- Regarded to be a solution for all waveforms
- Noise enhancement
- Implementation issues to be solved:
  - complexity to deal with high delayspread
  - training and tracking
  - timing
  - stability

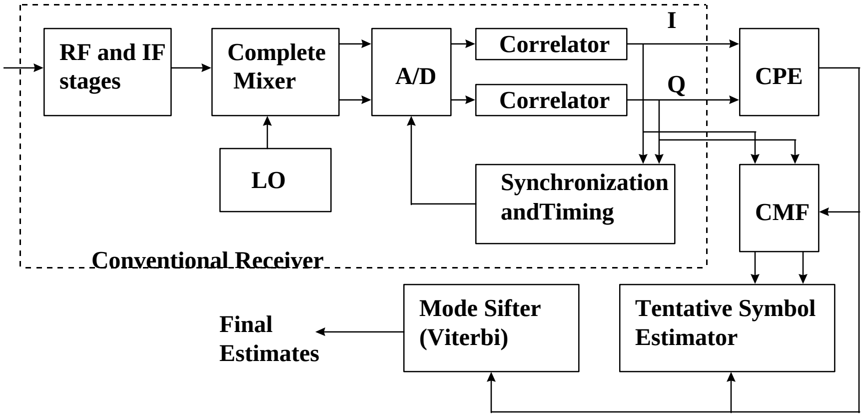
MLSE receivers

- Theoretically well understood
- Optimum performance
- Regarded as very complex
- but….

BCPM and MLSE

- BCPM makes a simple MLSE stucture possible
  - due to the very good autocorrelation properties of the 11-bit Barker Code
- 'Full blown' MLSE structure can be split in 3 simple blocks:
  - Channel Matched Filter
  - Tentative Symbol Estimator
  - Mode Sifter (Trellis stucture)

Receiver Structure



RF and IF stages

Complete Mixer

LO

A/D

Correlator

Correlator

I

Q

Synchronization andTiming

Conventional Receiver

CPE

CMF

Mode Sifter (Viterbi)

Tentative Symbol Estimator

Final Estimates

CPE channel parameter estimator
CMF channel matched filter

Receiver structure development

- C-code simulation program
  - simulations with distortion
    - channels (delayspread)
    - noise, LO offset, timing drift etc.
  - quantization effects
  - training effects
  - complexity vs performance trade-offs

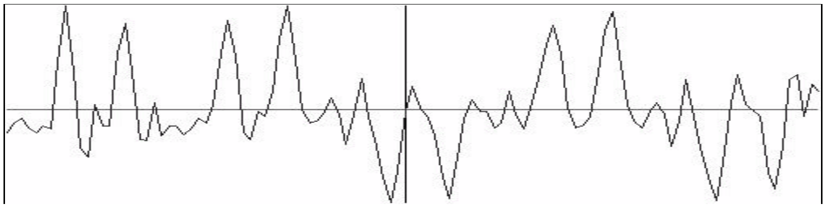
Receiver structure development cont’

- Implementation in SPW
  - – C-code algorithms translated in SPW blocks
  - – bit-true simulations
  - – performance verification
- SPW --> VHDL --> synthesis --> gate count estimates (in progress)

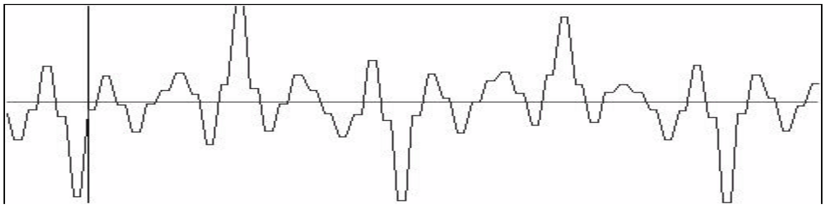
Receiver Functions: Channel Matched Filter

- – Concentrate all energy
- – Gives optimal sample timing
- – Estimation of the channel parameters needed
  - many well-known methods
  - can be achieved during training
    - – on preamble

Example of CMF function



Two ray channel, no MF

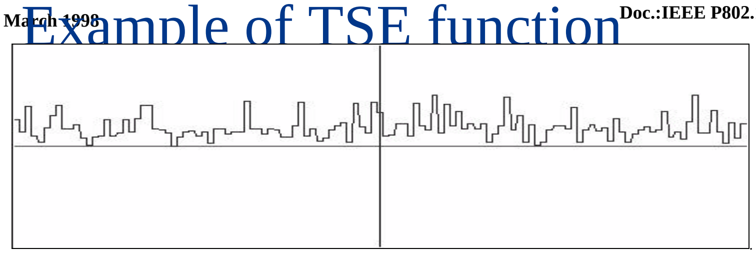


Same as above, but with MF. It can be seen that the peak is very distinct again, and also the energy has doubled, since both peaks are used, rather then only one as would be the case with a normal choose largest approach

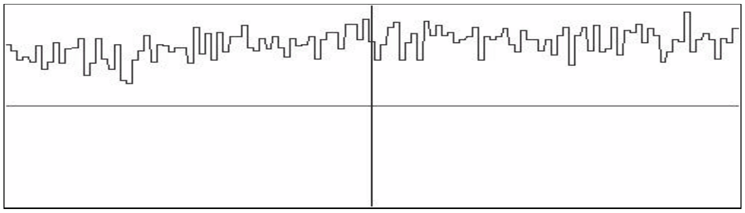
Receiver Functions: Tentative Symbol Estimator

- With knowledge of channel TSE removes cross rail interference for all possible symbols (actually 256, in essense 64 because polarity is not contributing to complexity)
- Due to autocorrelation properties of Barker sidelobes can initially be ignored (mode sifter can take care)
- Estimates N most likely symbols (N=4)

Example of TSE function



Two ray (4 samples, equal size, 90 degrees). The TSE margin when the compensation is off.



Same as above, but now with the compensation on. The scale is the same.

The margin signal shows the difference between the largest result and the next largest result out of the evaluation of the 256 possible combinations. Margin is a measure of the detection margin. If margin gets close to zero, this means that the detection margin gets close to zero.

Receiver Functions: Mode Sifter

- Reduced state trellis structure sifting the tentatively retained modes (maxima of TSE)
- Calculates path metric taking ISI and sidelobs into account
- Trellis path determines final estimate
  - path depth of 4 is sufficient

Receiver structure cont’

- Complexity can be traded for performance
  - moderate complexity
    - CMF+TSE+MS
      - complexity of separate blocks can also be traded
      - e.g. length CMF and depth MS
  - low complexity
    - CMF only

Receiver structure cont’

- Implementation complexity
  - RF/IF complexity comparable to low rate PHY
    - same LO, same bandwidth, …..
  - Baseband gate count for moderate complexity receiver about twice low rate PHY
  - NO equalizer

Transceiver complexity

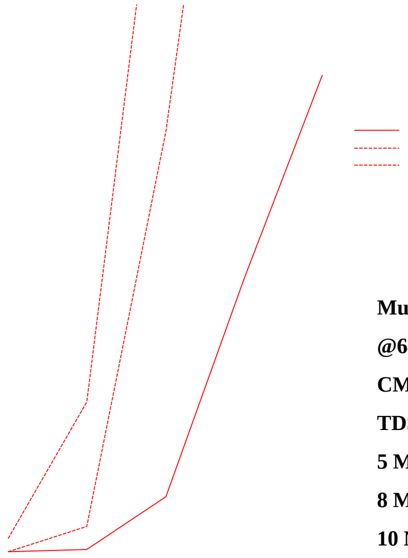
- Transceiver board has the same complexity as the low rate 802.11 DSSS PHY
  - Only the baseband processor has twice the number of gates, but:
  - Physical size is the same (pin limited rather than gate limited)
- PCMCIA formfactor
  - Transmit current: about same as low rate phy
  - Receive current: about same as low rate phy (apply well designed power management)

Receiver structure cont’

- Implementation
  - Diversity implementation
    - If DSSS preamble is used same antenna diversity as low rate PHY
    - BCPM is not dependent on long preamble
      - A short preamble (75 microseconds) is proposed
    - Multipath diversity inherent to BCPM.
      - performance dependent on receiver implementation

Immunity to multipath and noise

- Performance simulations are done with the receiver implementation in C-code
- All points in the performance graphs are simulated over 1000 randomly generated channels according to the adopted channel model (with noise up to 5000).



Multipath without noise

@64 bytes

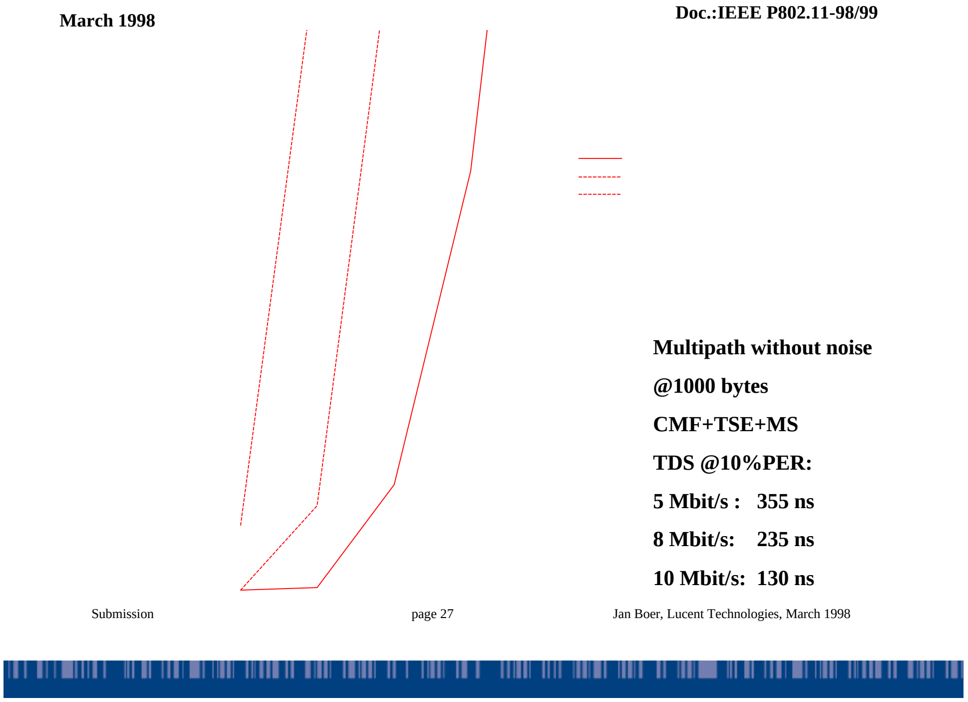
CMF+TSE+MS

TDS @10%PER:

5 Mbit/s : 400 ns

8 Mbit/s: 265 ns

10 Mbit/s: 220 ns



Multipath without noise

@1000 bytes

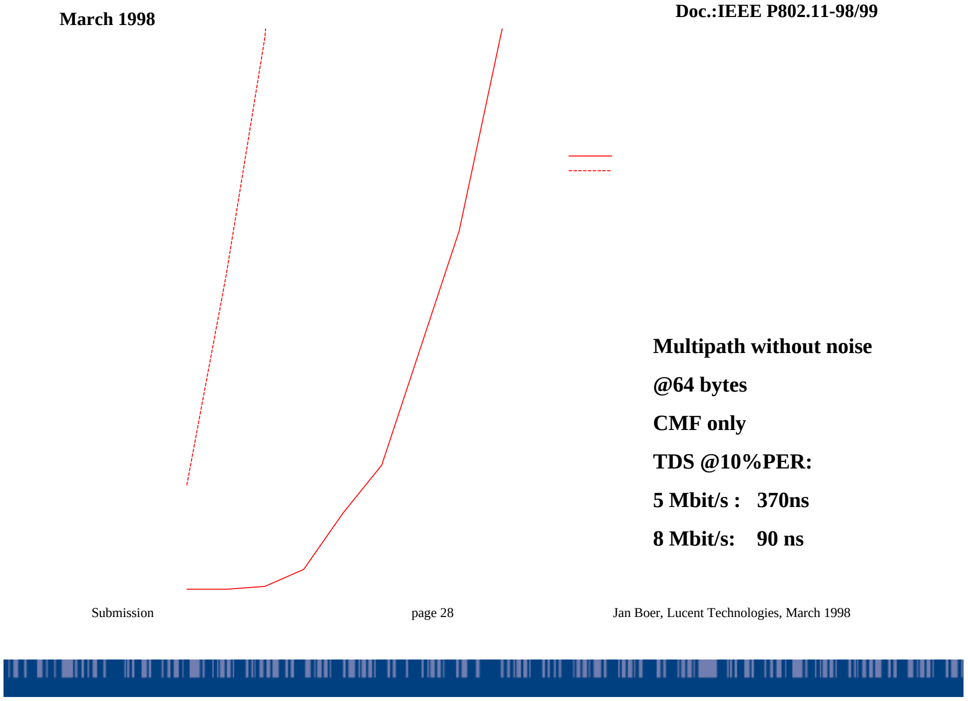
CMF+TSE+MS

TDS @10%PER:

5 Mbit/s : 355 ns

8 Mbit/s: 235 ns

10 Mbit/s: 130 ns



Multipath without noise

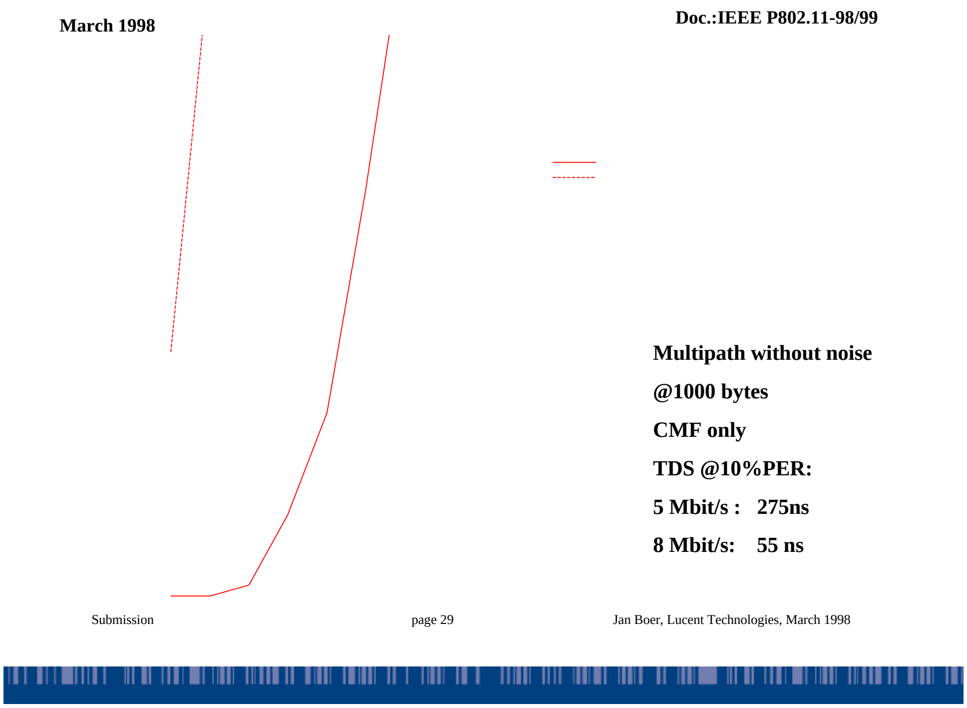
@64 bytes

CMF only

TDS @10%PER:

5 Mbit/s : 370ns

8 Mbit/s: 90 ns



Multipath without noise

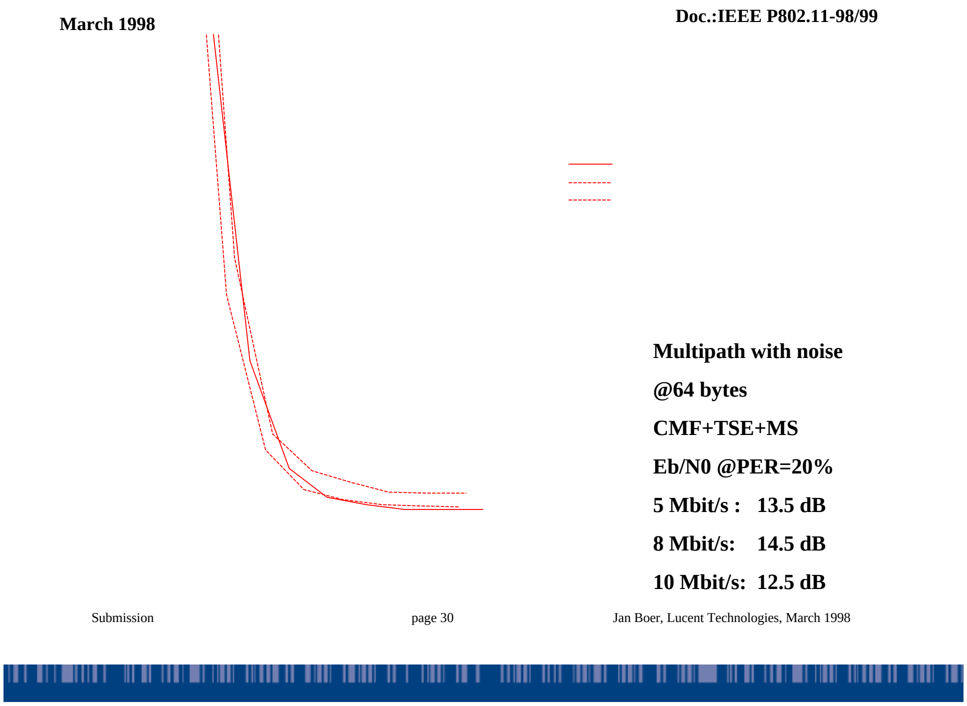
@1000 bytes

CMF only

TDS @10%PER:

5 Mbit/s : 275ns

8 Mbit/s: 55 ns



Multipath with noise

@64 bytes

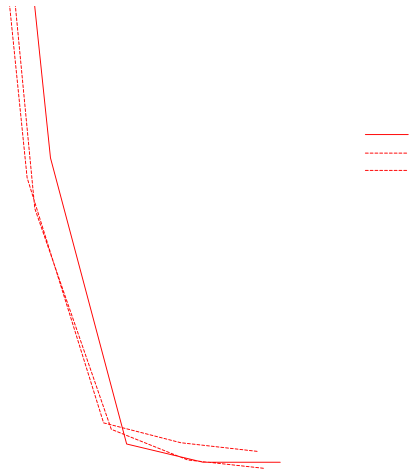
CMF+TSE+MS

Eb/N0 @PER=20%

5 Mbit/s : 13.5 dB

8 Mbit/s: 14.5 dB

10 Mbit/s: 12.5 dB



Multipath with noise

@1000 bytes

CMF+TSE+MS

Eb/N0 @PER=20%

5 Mbit/s : 16.5 dB

8 Mbit/s: 14.5 dB

10 Mbit/s: 14.0 dB

Multipath with noise

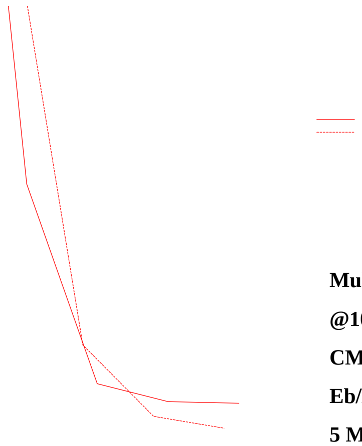
@64 bytes

CMFonly

Eb/N0 @PER=20%

5 Mbit/s: 15 dB

8 Mbit/s: 19 dB



Multipath with noise

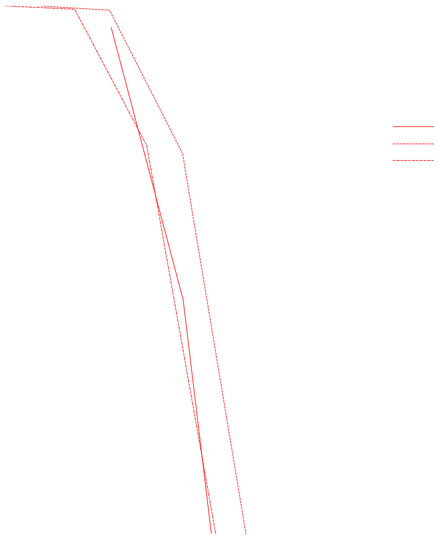
@1000 bytes

CMFonly

Eb/N0 @PER=20%

5 Mbit/s: 19 dB

8 Mbit/s: 20 dB



Thermal noise only

@64 bytes

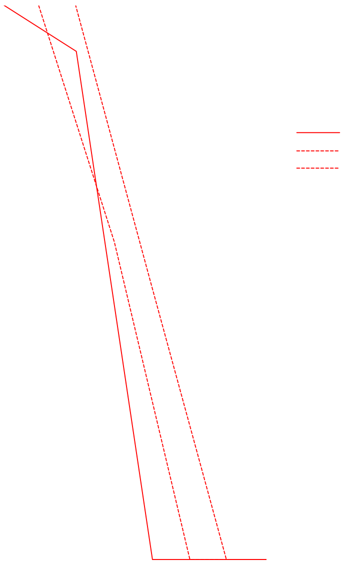
CMF+TSE+MS

Eb/N0 @PER=10%

5 Mbit/s : 5 dB

8 Mbit/s: 5.5 dB

10 Mbit/s: 4.5 dB



Thermal noise only

@1000 bytes

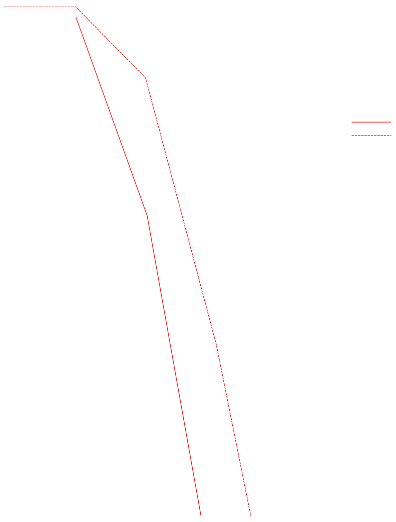
CMF+TSE+MS

Eb/N0 @PER=10%

5 Mbit/s : 6 dB

8 Mbit/s: 7 dB

10 Mbit/s: 6.5 dB



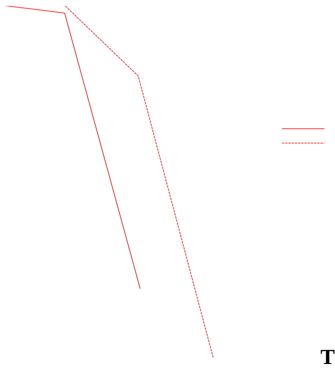
Thermal noise only

@64 bytes CMFonly

Eb/N0 @PER=10%

5 Mbit/s: 5 dB

8 Mbit/s: 6.5 dB



Thermal noise only

@1000 bytes CMFonly

Eb/N0 @PER=10%

5 Mbit/s: 7 dB

8 Mbit/s: 8.5 dB

Immunity to multipath and noise overview

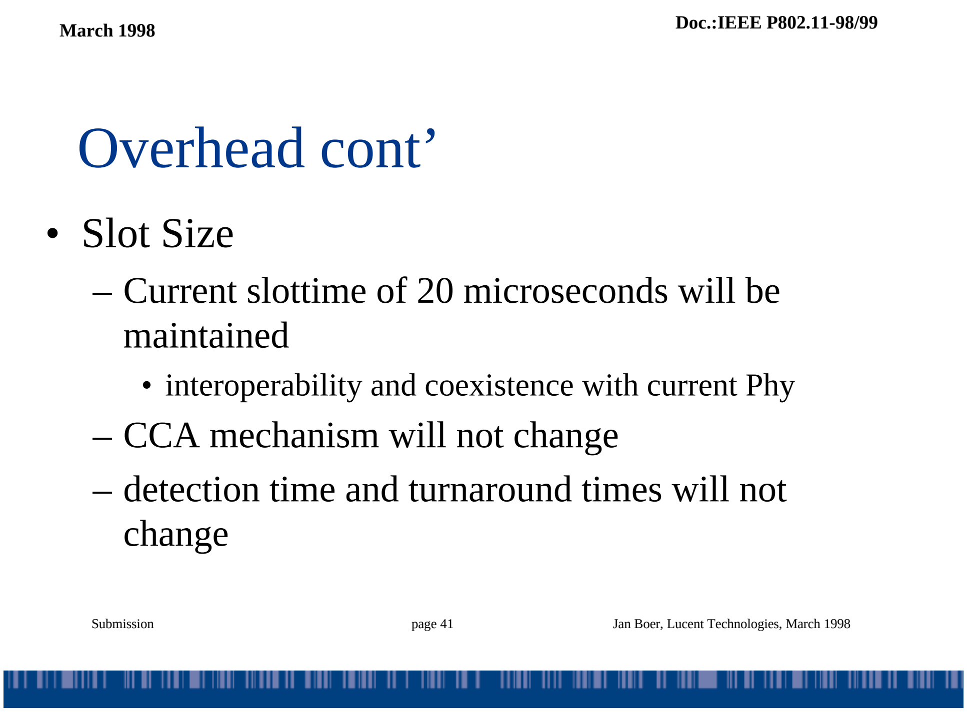
Bitrate	Packetlength	Multipath without noise TDS @ PER=10%	Multipath with noise Eb/N0 @ PER=20%	Termal noise Eb/N0 @ PER=10%
5 TSE+MS	64 1000	400 355	13.5 16.5	5 6
5 CMF only	64 1000	370 275	15 19	5 7
8 TSE+MS	64 1000	265 235	14.5 14.5	5.5 7
8 CMF only	64 1000	90 55	19 20	7 8.5
10 TSE+MS	64 1000	220 130	12.5 14.0	4.5 6.5

Immunity to multipath and noise
cont'

- Center frequency accuracy
  - 25 ppm
  - relatively easy acquisition and tracking of LO offset
  - no noticeable performance degradation if implemented

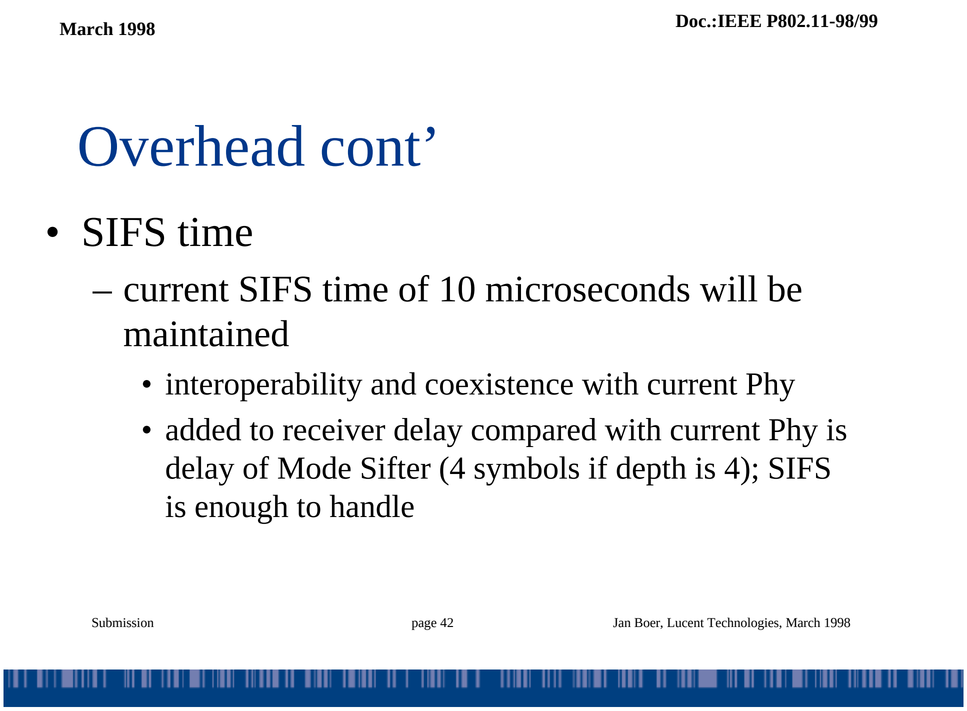
Overhead

- Preamble Length
  - Current DSSS Preamble is proposed for full interoperability and coexistence with current Phy
  - Optional Short Preamble and Header (77 micros) is proposed for higher rates
    - provides coexistence of low rate Phy with High Rate Phy using short preamble
    - provides interoperability of Phy using short preamble with Phy using long preamble by recognizing and 'falling back' to long preamble



Overhead cont’

- Slot Size
  - Current slottime of 20 microseconds will be maintained
    - interoperability and coexistence with current Phy
  - CCA mechanism will not change
  - detection time and turnaround times will not change



Overhead cont’

- SIFS time
  - current SIFS time of 10 microseconds will be maintained
    - interoperability and coexistence with current Phy
    - added to receiver delay compared with current Phy is delay of Mode Sifter (4 symbols if depth is 4); SIFS is enough to handle

Spectral efficiency

- Power spectrum is not changed compared to the current PHY
- The same channelization scheme is employed

Range

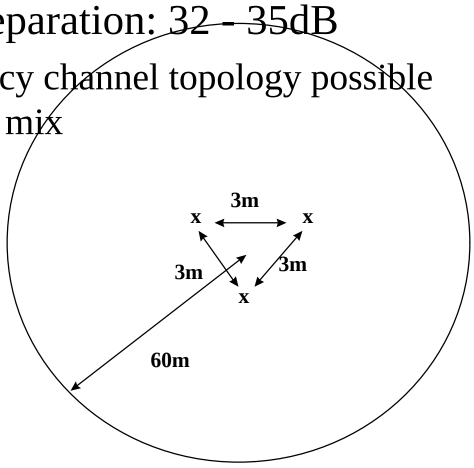
- range
  - transmit power
    - 50 mW (17 dBm) Tx power
  - min receive level (Rx sensitivity)
    - \- 89dBm (SNR 15.8 dB @ BER 10-5)
    - @ noise factor and implementation loss 9dB
  - link budget 106dB - 40dB isotropic loss --> 66 dB
  - 66 dB --> 2000 meter free space (theoretical !)

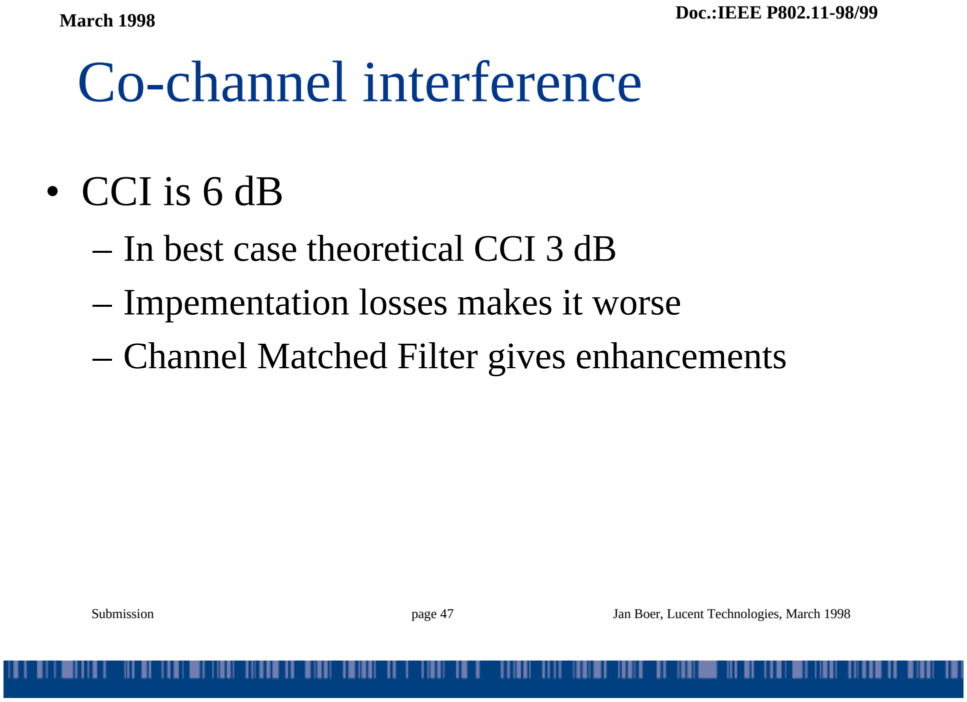
Cell planning and ACI

- 3 frequency channels where same frequency of different cells share
- ACI must be such that a 3 channel solution is possible
  - interfered devices will fall back in rate
  - system throughput more essential than the ACI figure

Adjacent channel interference

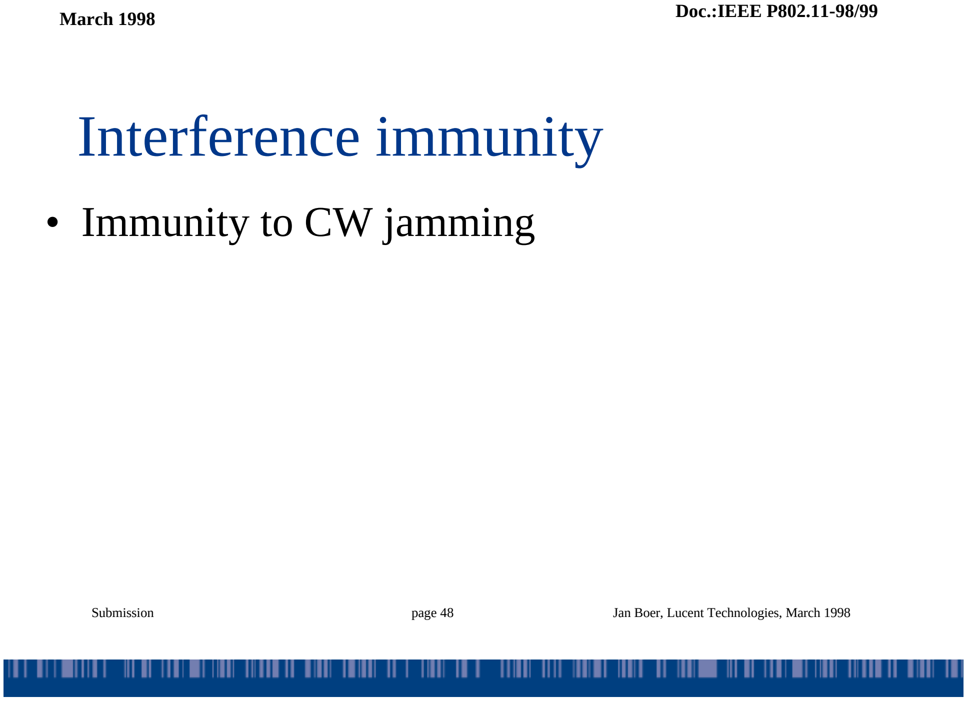
- ACI @ 30 MHz separation: 32 - 35dB
  - makes a 3 frequency channel topology possible at certain distance mix
  - 3 * throughput





Co-channel interference

- CCI is 6 dB
  - In best case theoretical CCI 3 dB
  - Impementation losses makes it worse
  - Channel Matched Filter gives enhancements

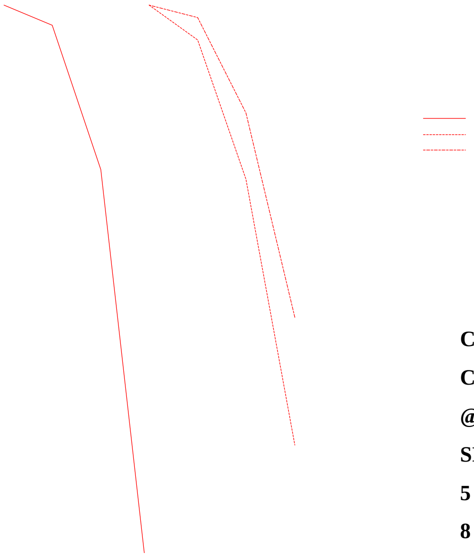


Interference immunity

- Immunity to CW jamming

March 1998

Doc.:IEEE P802.11-98/99



CW jamming

CMF+TSE+MS

@64 bytes

SIR @PER=10%

5 Mbit/s: -5.5 dB

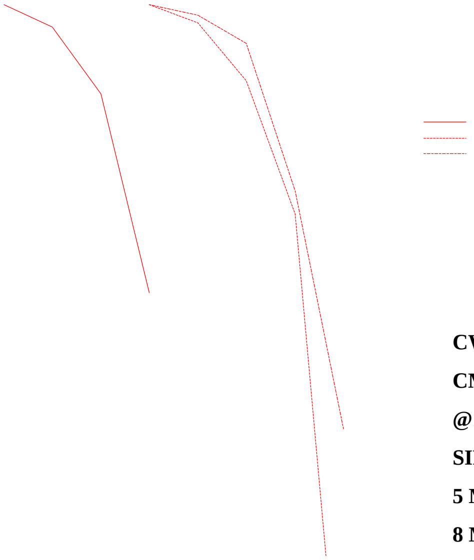
8 Mbit/s: -2.5 dB

10 Mbit/s: -2 dB

Submission page 49 Jan Boer, Lucent Technologies, March 1998

March 1998

Doc.:IEEE P802.11-98/99



CW jamming

CMF+TSE+MS

@1000 Bytes

SIR @PER=10%

5 Mbit/s: -5 dB

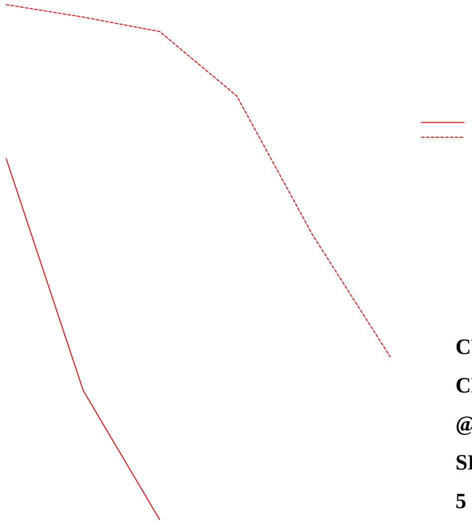
8 Mbit/s: -2 dB

10 Mbit/s: -1.5 dB

Submission page 50 Jan Boer, Lucent Technologies, March 1998

March 1998

Doc.:IEEE P802.11-98/99



CW jamming

CMF only

@64 bytes

SIR @PER=10%

5 Mbit/s: -4.5 dB

8 Mbit/s: -0.5 dB

Submission page 51 Jan Boer, Lucent Technologies, March 1998

March 1998

Doc.:IEEE P802.11-98/99

CW jamming

CMF only

@1000 bytes

SIR @PER=10%

5 Mbit/s: -2.7 dB

8 Mbit/s: 1 dB

Submission page 52 Jan Boer, Lucent Technologies, March 1998

Interference Immunity CW jamming overview

Bitrate	Packetlength	CW Jamming SIR @ PER=10%
5 TSE+MS	64	-5.5 dB
	1000	-5 dB
5 CMF only	64	-4.5 dB
	1000	-2.7 dB
8 TSE+MS	64	-2.5 dB
	1000	-2 dB
8 CMF only	64	-0.5 dB
	1000	1 dB
10 TSE+MS	64	-2 dB
	1000	-1.5 dB

Critical points

- Extreme sensitivity to phase noise
  - no issue, same as DQPSK
- DC power consumption
  - about the same as low rate Phy’s
- Complexity
  - addressed, only baseband processing about twice current Phy
- Dependence on antenna diversity/directivity
  - not more critical than low rate Phy
  - multipath diversity

Critical points cont'

- RF PA backoff
  - 1 and 2 Mbit/s Phy needs 4 dB backoff
  - higher speed adds 3 dB
- BCPM needs more backoff then other waveforms, however at the BCPM receiver with MLSE stucture, especially in environment with high delay spread this is gained back.

Intellectual Property

- US patent 5,596,601 Bar-David
  - Method and apparatus for spread spectrum code pulse position modulation
- Lucent contact:

Lucent Technologies
Bruce Tuch
PO Box 755
3430 AT Nieuwegein, The Netherlands
tel: +31 30 6097527, fax: +31 30 6097556

–

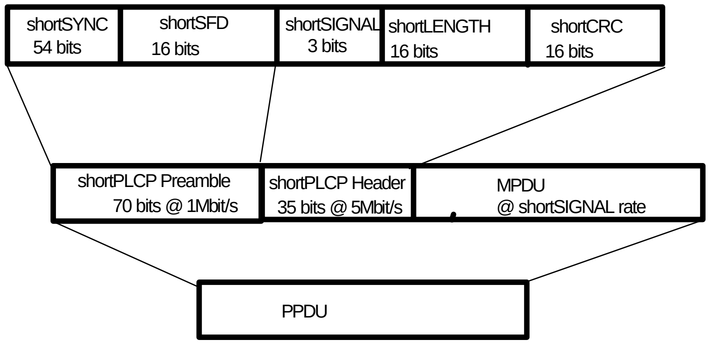
Interoperability / Coexistence

- With long 802.11 header BCPM is fully coexistence and interoperable (can fall back to 1 and 2 Mbit/s), making use of multi-rate capabilities of current standard
- With 20 micros slottime also with a short header coexistence and/or interoperability is maintained

---

Interoperability / Coexistence cont’

short PPDU frame format



ShortSYNC: 54 scrambled all zero’s **used for receiver synchronization:**

e.g 30 micros for CCA @ 20 micro slottime with or without antenn diversity

shortSFD: bit reverse of original SFD

Interoperability / Coexistence cont’

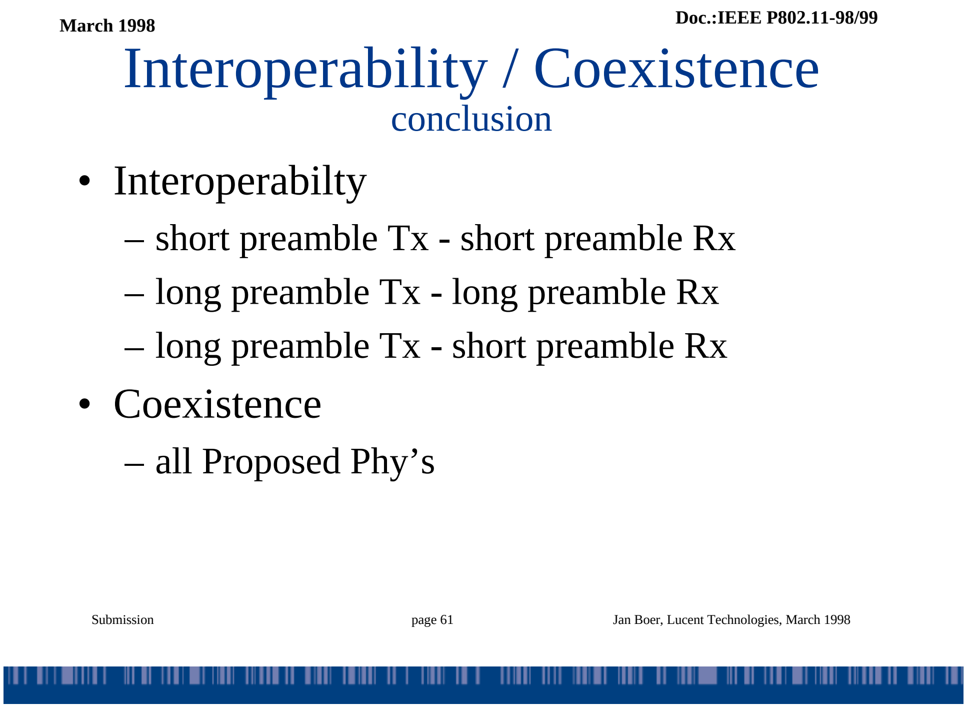
scenario

- PHY capable to handle optional short preamble
  - Defers for PHY with short preamble
    - common slottime, CCA
  - Receives Phy with short peamble
  - Defers for PHY with long preamble
    - common SIFS, slottime, CCA, 1Mbit/s DSSS preamble
  - Receives Phy with long preamble
    - recognize long preamble on
      - preamble content (all scrambled ones)
      - missing shortSFD within time window
    - switches to reception of long preamble
    - ACK with long preamble

Interoperability / Coexistence cont’

scenario

- PHY capable to handle long preamble only
    - low rate PHY, high rate PHY without optional short preamble capability
  - Defers for PHY with long preamble according to currrent standard
  - Receives Phy with long peamble according to current standard
- Coexistent with short preamble PHY
  - Defers for PHY with short preamble
    - common SIFS, slottime, CCA, 1Mbit/s DSSS preamble
    - does not recognize SFD
    - defers until energy or carrier drops (length field is not recognized)
      - this might have impact on network slot sync
      - if network performance because of heavy mix drops below a certain threshold all Phy’s might switch to a long preamble



Interoperability / Coexistence

conclusion

- Interoperabilty
  - short preamble Tx - short preamble Rx
  - long preamble Tx - long preamble Rx
  - long preamble Tx - short preamble Rx
- Coexistence
  - all Proposed Phy's