Multipath Delay-Spread Tolerance

John H. Cafarella
MICRILOR, Inc.

Outline of Symbol-Based Approach

- Probability of Symbol Error Conditioned On:
  - Data Pattern of Symbol
  - Data Pattern of Neighboring Symbols
  - Code Channel Used
  - Multipath Impulse Response
  - Noise Samples for Symbols Involved
- Use Simulation to Generate Test Statistics
- Evaluate Error Probabilities Analytically

WHY?

- Dimensionality
  - 4 symbols: 10^6 (5 bit/symbol)
  - 10 Significant Paths: 10^{20} (100 levels each)
  - 48 Code Channels
  - 64 Noise Samples: 10^{128} (100 levels each)
- Do Not Handle Noise By Simulation
- Dimensionality Still Large (~Avogadro's #)

Generating a Test Statistic

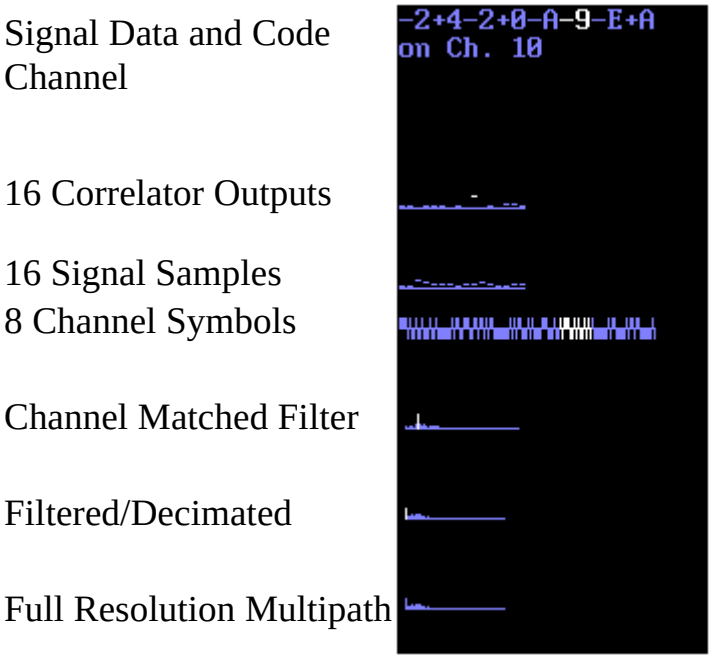
- Generate Sample Multipath Profile
  - Path delay spacing T_s (minimum of 2 per T_{RMS})
  - Path delay span 10 times T_{RMS}
  - Exponential distribution of σ^2 with delay
  - Rayleigh amplitude, uniform phase per path
- Convolve with Rx Chip-Pulse Response
- Select Largest Path for Demodulation

Generating a Test Statistic (cont.)

- Decimate to One Sample per Chip
- Generate Signal
  - Select code channel
  - Generate 4 or 8 symbols of 5-bit data
- Convolve Signal and Chan. Impulse Resp.
- Select 16 Samples for Symbol 3 or 6
- Compute 16 Correlator-Output Magnitudes

Statistical Averaging

- Generate Sample Correlator Statistic
- Evaluate P_E vs. SNR
- Average Results for 4K or 8K Randomizations (typical)

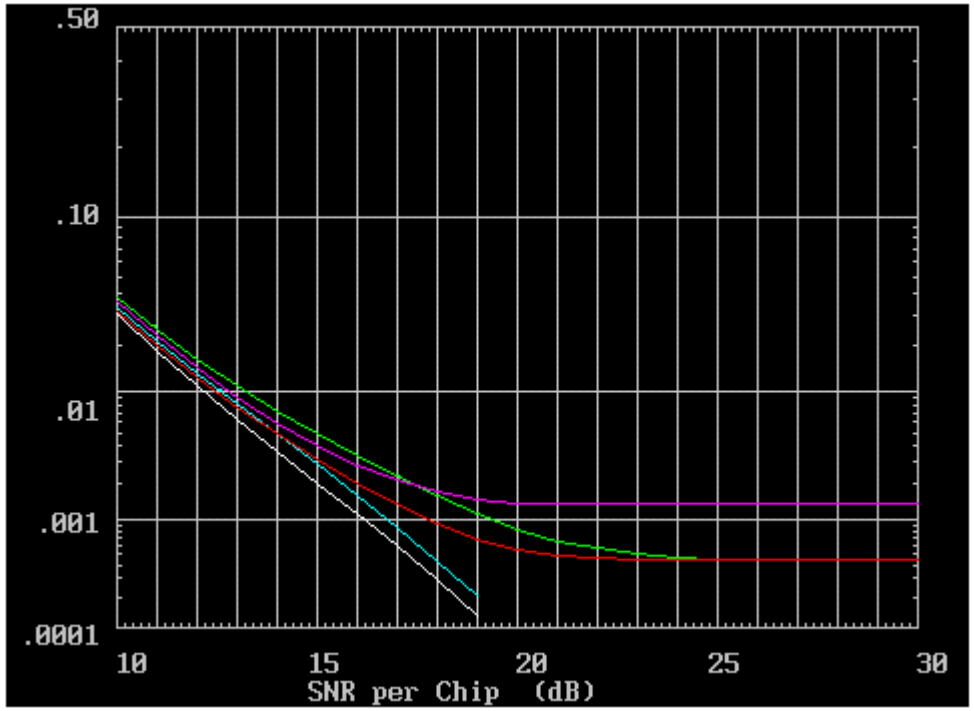


Probability of Symbol Error

- Union Bound
  - Sum of binary-orthogonal error probabilities
  - Correct output vs. 15 incorrect outputs
- Binary Probability of Error
  - Compare correlator magnitudes
  - Probability that one Rice variate exceeds another
  - Procedure given in (D98/118R)

Example Run

- $T_s/T_c=1$
- $T_{RMS}=5T_c$ (~150ns)
- 10^3 Randomizations per Curve
- Irreducible Errors
  - 1 high
  - 2 none
  - 2 ~ average

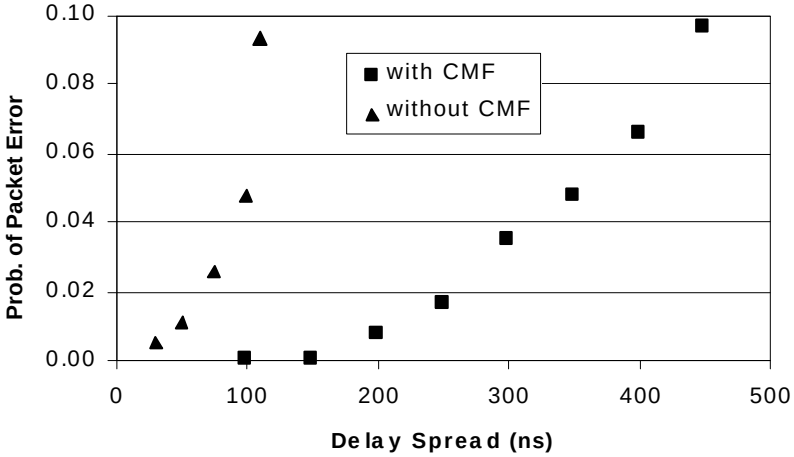


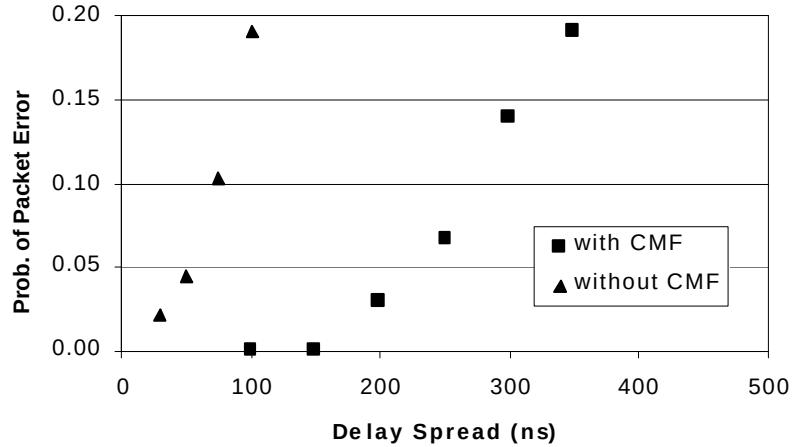
Estimation of Packet Failure Probability from Symbol Error Probability

- $P_{SE}=P_N(SNR,Data,T_{RMS})+P_I(Data,T_{RMS})$
  - P_I = asymptotic symbol error probability
  - Thermal errors $P_N \approx P_{SE}-P_I$
- Thermal Symbol Errors Uncorrelated
- Irreducible Errors Correlated within Packet
  - P_M is probability of “bad” multipath condition
  - $P_{E|M}$ is conditional probability of symbol error
  - $P_I=P_M \bullet P_{E|M}$

Estimation of $P_{E|M}$

- 2 of 16 Members of a Coset Likely to Cause Errors in "Bad" Multipath (D97/120)
-
- Each Coset has 1/8 $P_{E|M}$ (original assumption)
-
- One of Four Cosets (in code channel) has 1/8 $P_{E|M}$





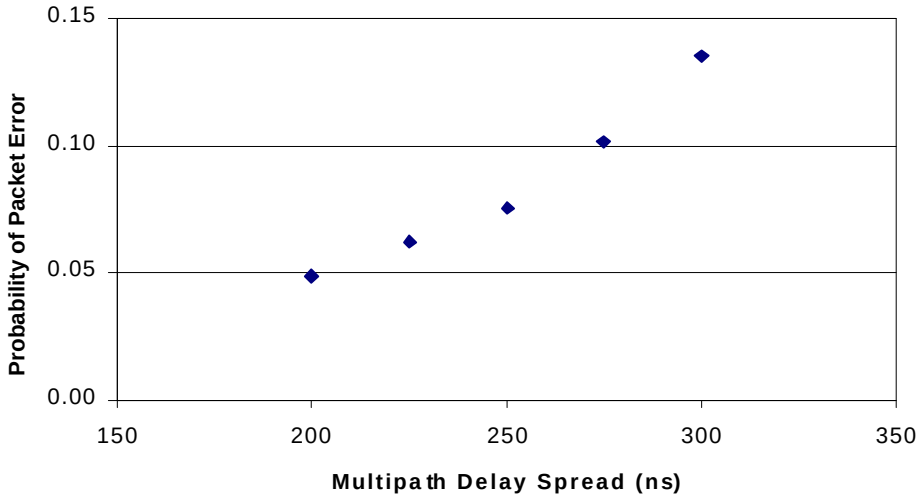
What is $P_{E|M}$ Really?

- Run Full-Packet Simulation
  - 64 Bytes Random Data
  - One Multipath Randomization per Frame
  - No Thermal Noise
- Determine Packet Error Probability
- Accumulate Symbol Error Statistics
  - Estimate $P_{E|M}$

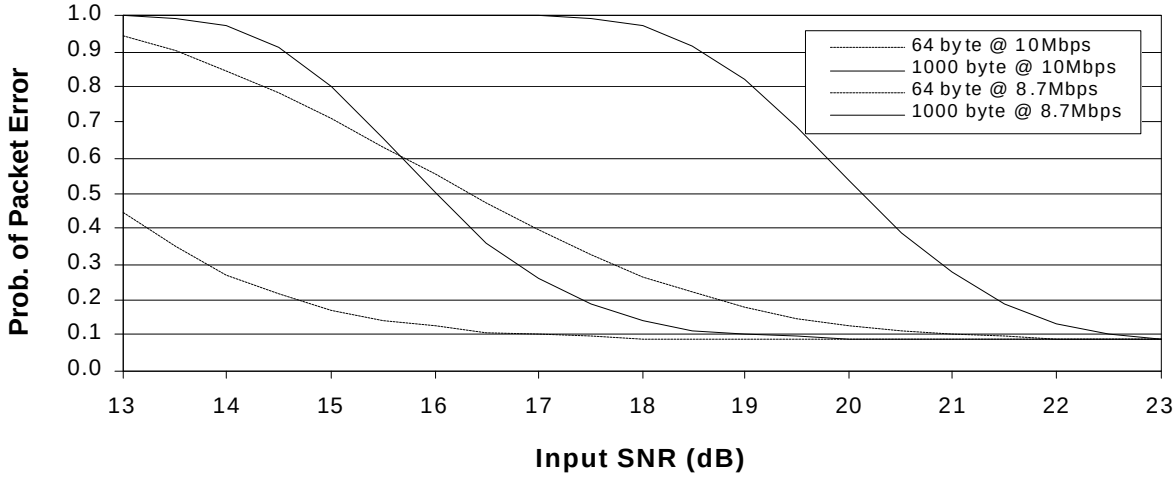
Packet Error Results

- 4096 Multipath Profiles per T_{RMS}
- PER 10% @ 275 ns
-
-
- Use $P_{E|M} = \frac{1}{8} \bullet \frac{1}{4}$
- Only 1 of 4 Cosets Hurt by Specific Multipath Profile

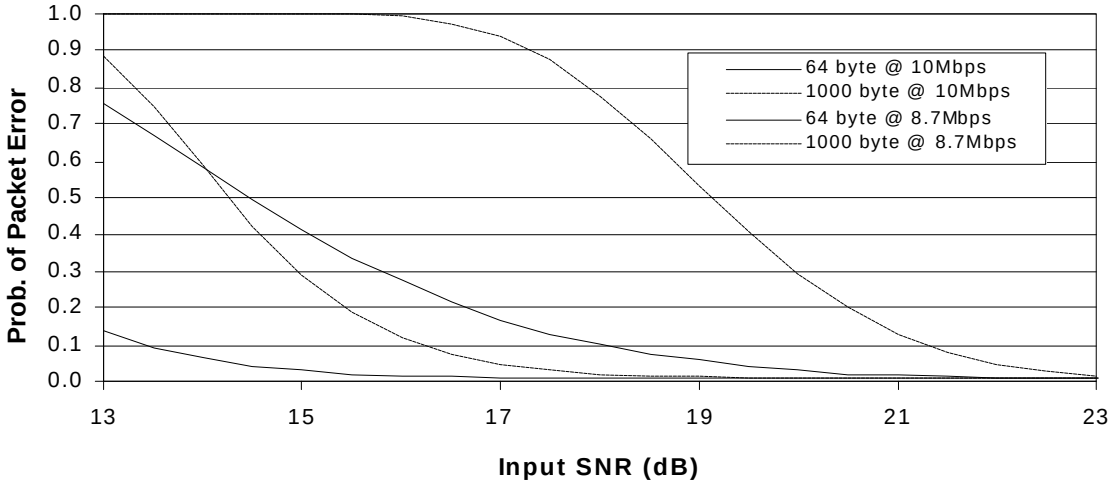
T_{RMS}	PktErr	P_{PE}	$P_{E\|M}$
200	198	0.0483	0.0223
225	254	0.0620	0.0265
250	309	0.0754	0.0248
275	414	0.1011	0.0283
300	553	0.1350	0.0323

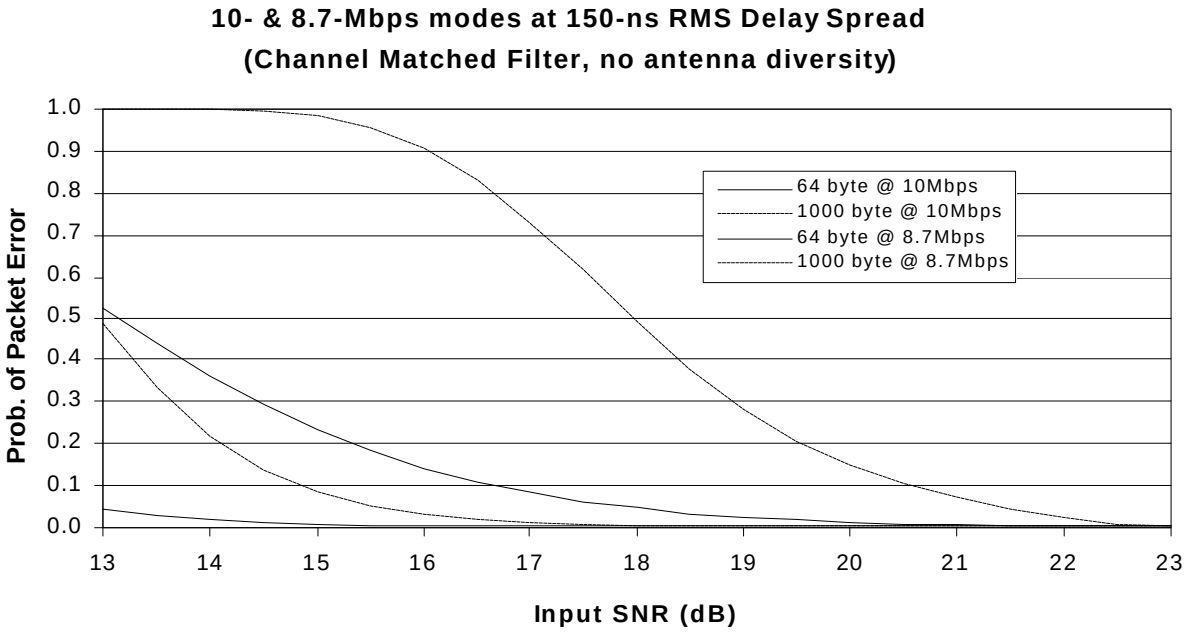


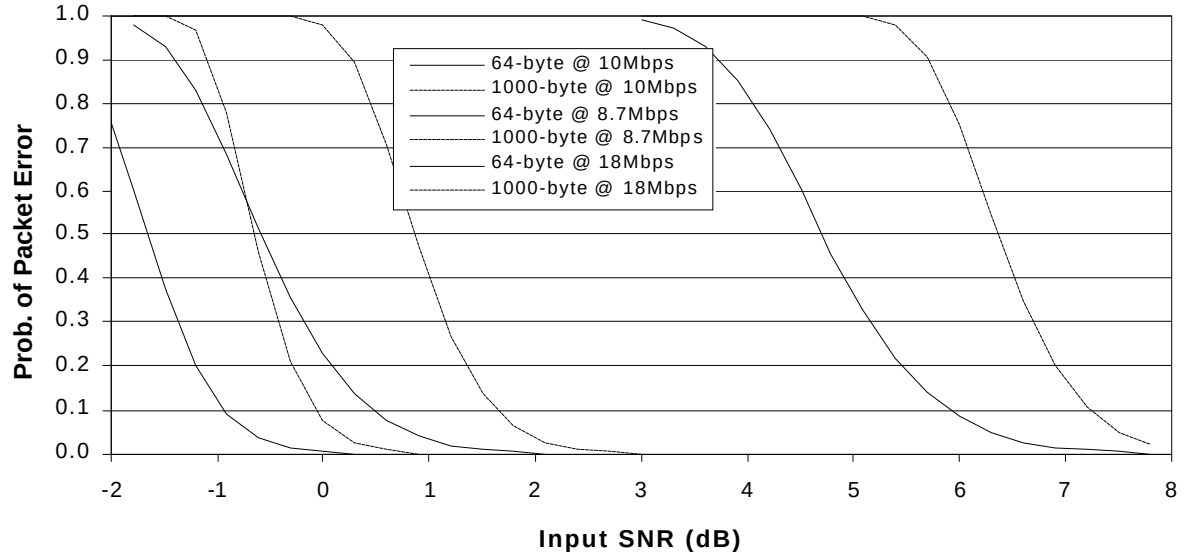
10- & 8.7-Mbps modes at 275-ns RMS Delay Spread
(8-tap Channel Matched Filter, no antenna diversity)



10- & 8.7-Mbps modes at 200-ns RMS Delay Spread
(8-tap Channel Matched Filter, no antenna diversity)




10- & 8.7-Mbps modes at 150-ns RMS Delay Spread
(Channel Matched Filter, no antenna diversity)
Prob. of Packet Error
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
13
14
15
16
17
18
19
20
21
22
23
Input SNR (dB)
64 byte @ 10Mbps
1000 byte @ 10Mbps
64 byte @ 8.7Mbps
1000 byte @ 8.7Mbps


8.7-, 10- & 18-Mbps Rate Gaussian-Channel
Prob. of Packet Error
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
3
4
5
6
7
8
Input SNR (dB)
64-byte @ 10Mbps
1000-byte @ 10Mbps
64-byte @ 8.7Mbps
1000-byte @ 8.7Mbps
64-byte @ 18Mbps
1000-byte @ 18Mbps