The Design of the Soft Decoder of the Interleaved Convolutional Code Used in IEEE 802.11a

Victor W. Cheng and Chia-Hui Lin *

Department of Computer Science and Information Engineering,
Graduate Institute of Communication Engineering,
National Chi Nan University

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Outline

- Abstract.
- System model
- The design of the soft-decision decoding
- Simulation result

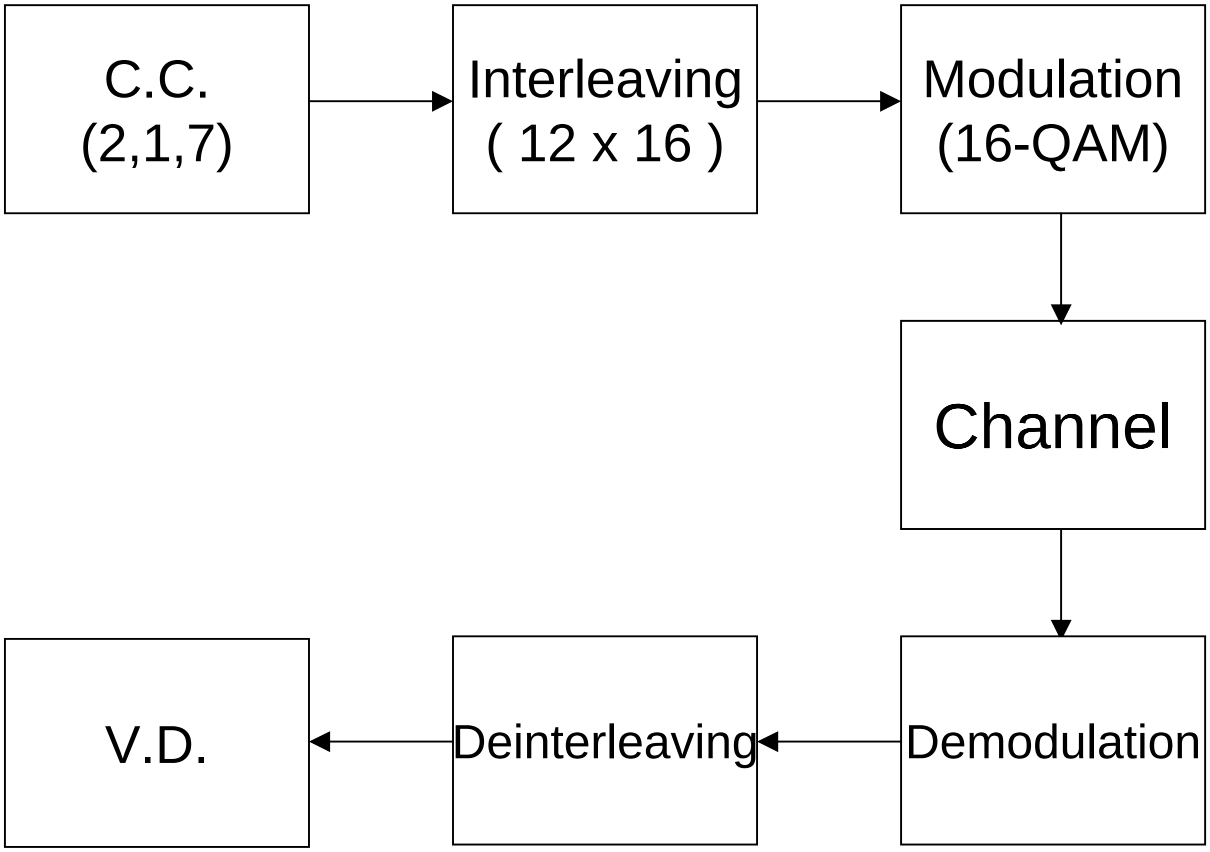
Abstract

- IEEE 802.11a incorporates high QAM to achieve a high data rate.
- A (2,1,7) convolutional code is used, and convolutional codes with higher rates are derived from it by employing “puncturing”.
- Soft-decision decoding instead of hard-decision decoding.
- The effects of block interleaving is also examined.

IEEE 802.11a Spec.

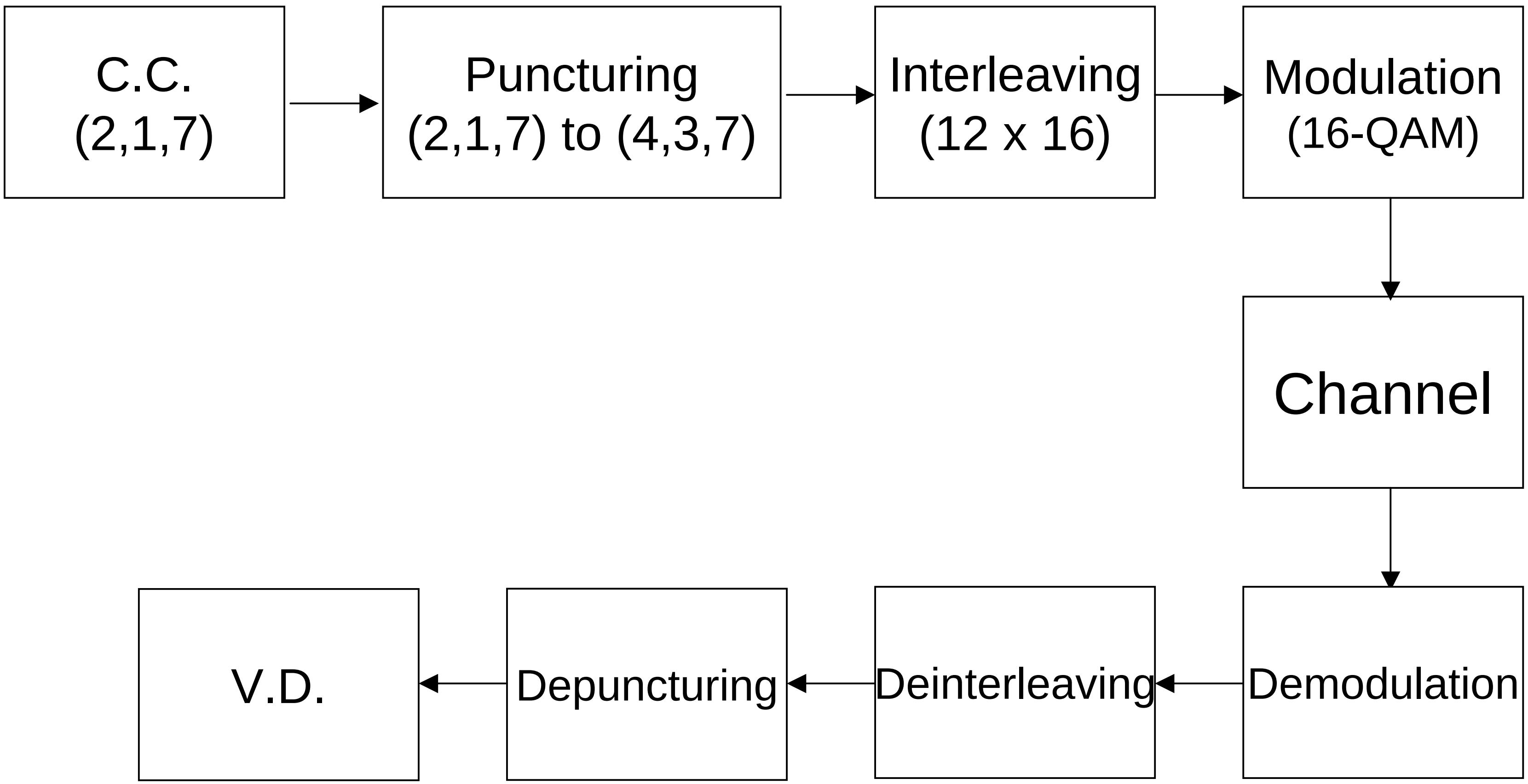
Data rate (Mbits/s)	Modulation	Coding rate (R)	Coded bits per OFDM symbol	Data bits per OFDM symbol	Block Interleaver
24	16-QAM	1 / 2	192	96	12 x 16
36	16-QAM	3 / 4	192	144	12 x 16
48	64-QAM	2 / 3	288	192	18 x 16
54	64-QAM	3 / 4	288	216	18 x 16

Data Rate 24Mbits/s



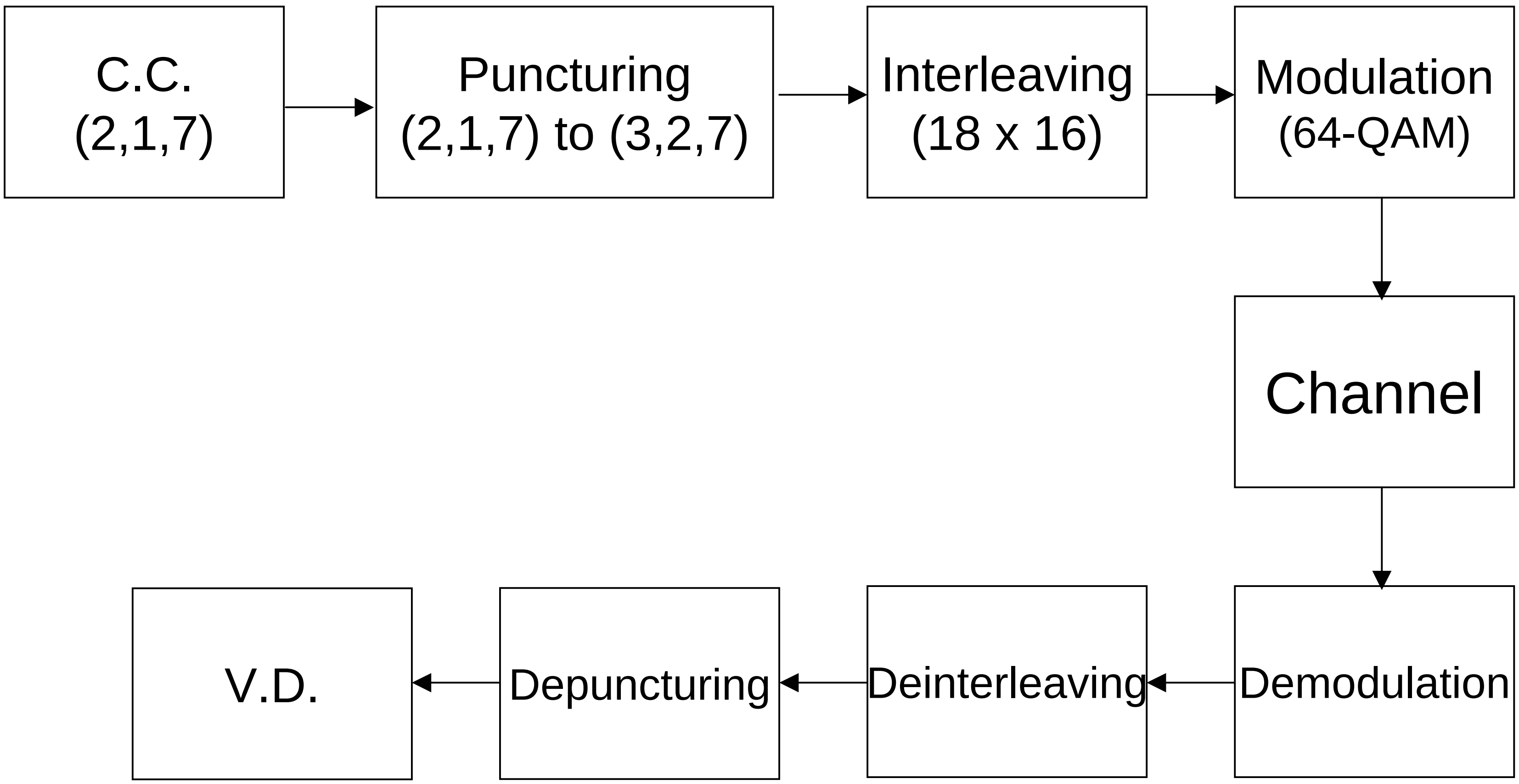
- C.C. : Convolutional Code
- V.D. : Viterbi Decoder

Data Rate 36Mbits/s



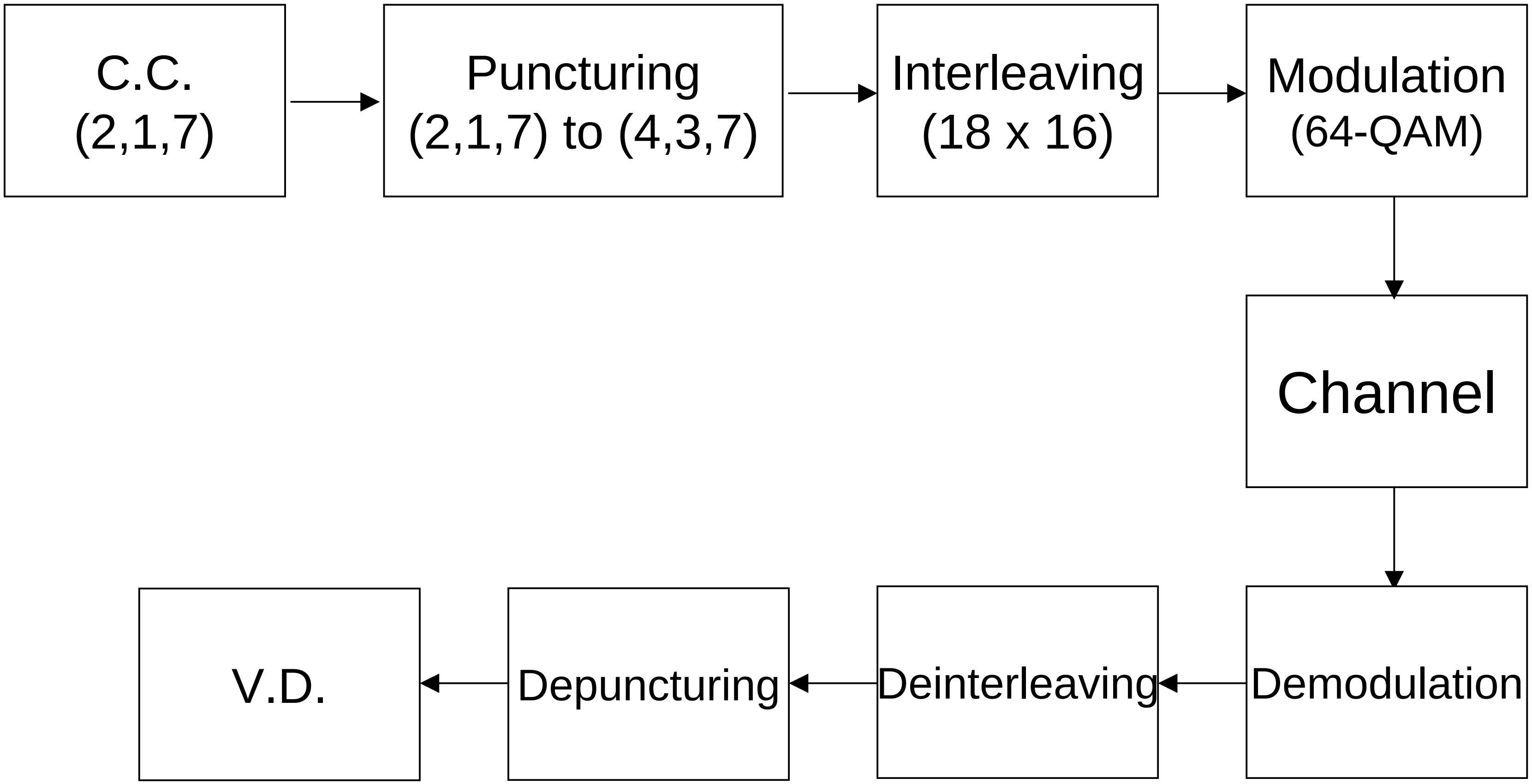
- C.C. : Convolutional Code
- V.D. : Viterbi Decoder

Data Rate 48Mbits/s



- C.C. : Convolutional Code
- V.D. : Viterbi Decoder

Data Rate 54Mbits/s

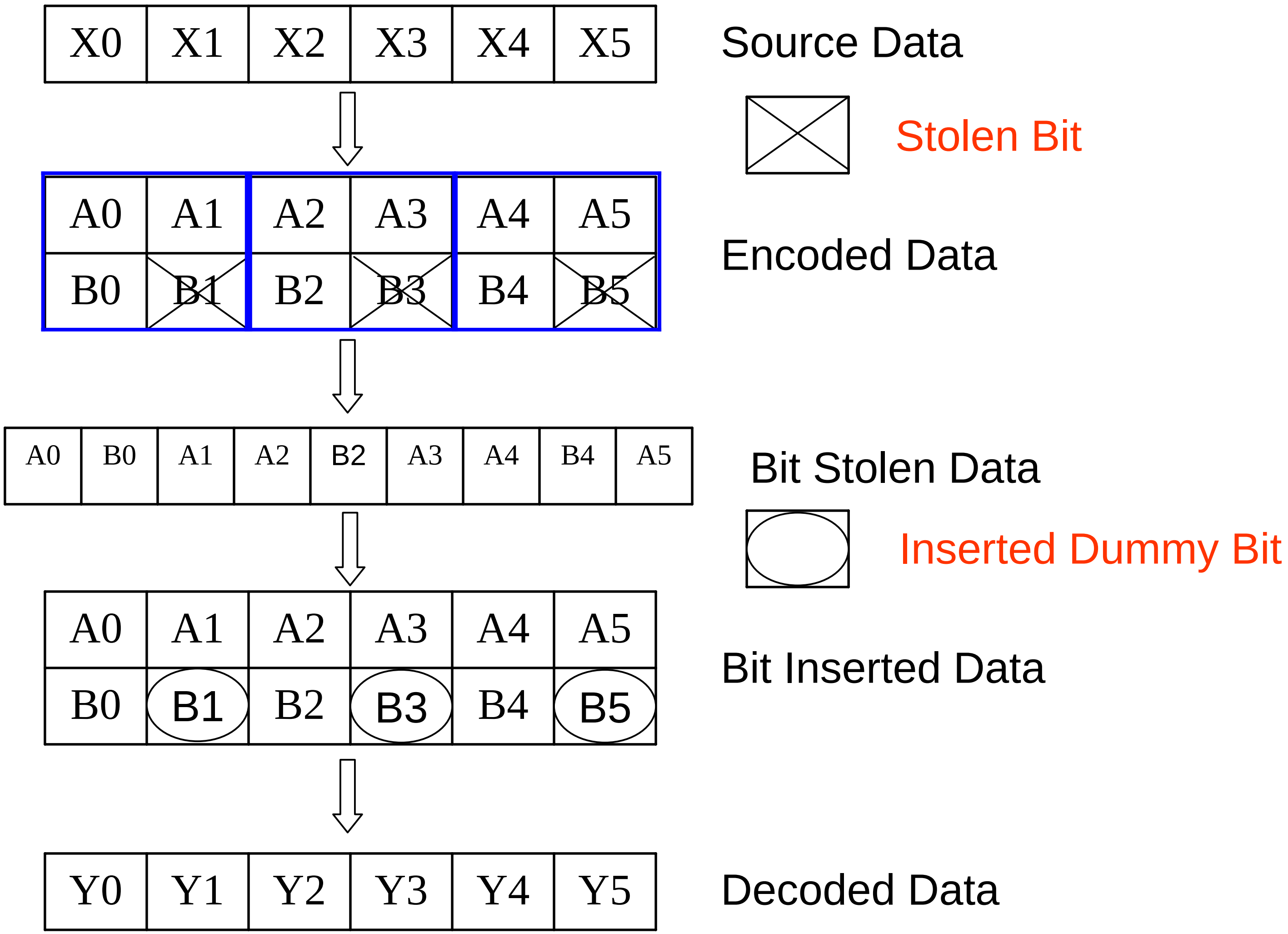


- C.C. : Convolutional Code
- V.D. : Viterbi Decoder

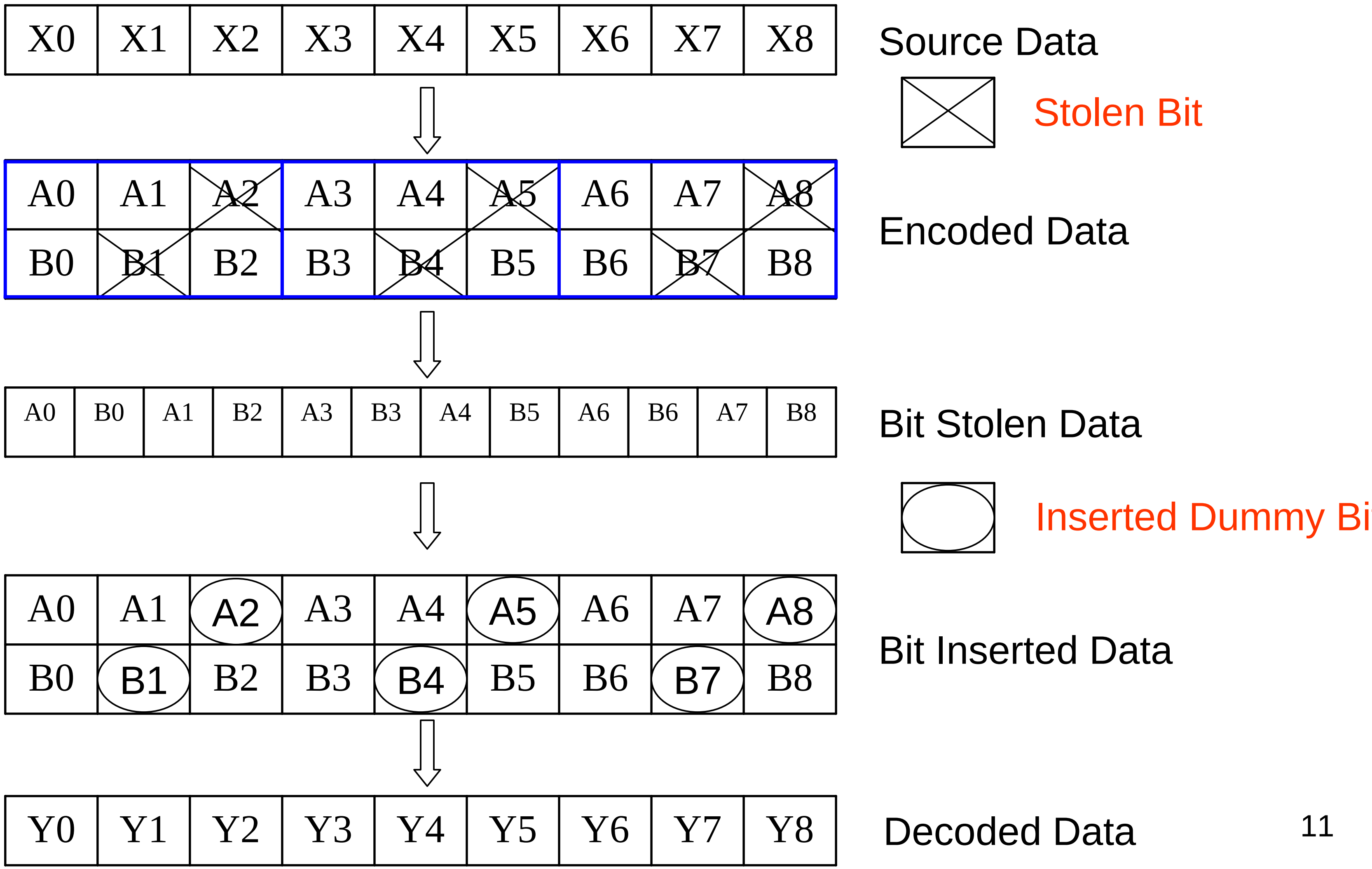
(2,1,7) Convolutional Code

- (2,1,7) Convolutional Code,
  Constraint Length = 7
- Generators:133,171 in Octal
- Free Distance $d_{free} = 10$

Punctured (3,2,7) Convolutional Code



Punctured (4,3,7) Convolutional Code



Interleaving in IEEE 802.11a

- A two-step interleaving is designed.
  1. Mapping adjacent coded bits onto non-adjacent coded bits.
  2. Swapping the coded bits alternately onto less significant bits (LSB) and more significant bits (MSB) of the QAM constellation.

12 by 16 Block Interleaver (16QAM)

C0	C17	C2	C19	C4	C21	C6	C23	C8	C25	C10	C27	C12	C29	C14	C31
C16	C1	C18	C3	C20	C5	C22	C7	C24	C9	C26	C11	C28	C13	C30	C15
C32	C49	C34	C51	C36	C53	C38	C55	C40	C57	C42	C59	C44	C61	C46	C63
C48	C33	C50	C35	C52	C37	C54	C39	C56	C41	C58	C43	C60	C45	C62	C47
C64	C81	C66	C83	C68	C85	C70	C87	C72	C89	C74	C91	C76	C93	C78	C95
C80	C65	C82	C67	C84	C69	C86	C71	C88	C73	C90	C75	C92	C77	C94	C79
C96	C113	C98	C115	C100	C117	C102	C119	C104	C121	C106	C123	C108	C125	C110	C127
C112	C97	C114	C99	C116	C101	C118	C103	C120	C105	C122	C107	C124	C109	C126	C111
C128	C145	C130	C147	C132	C149	C134	C151	C136	C153	C138	C155	C140	C157	C142	C159
C144	C129	C146	C131	C148	C133	C150	C135	C152	C137	C154	C139	C156	C141	C158	C143
C160	C177	C162	C179	C164	C181	C166	C183	C168	C185	C170	C187	C172	C189	C174	C191
C176	C161	C178	C163	C180	C165	C182	C167	C184	C169	C186	C171	C188	C173	C190	C175

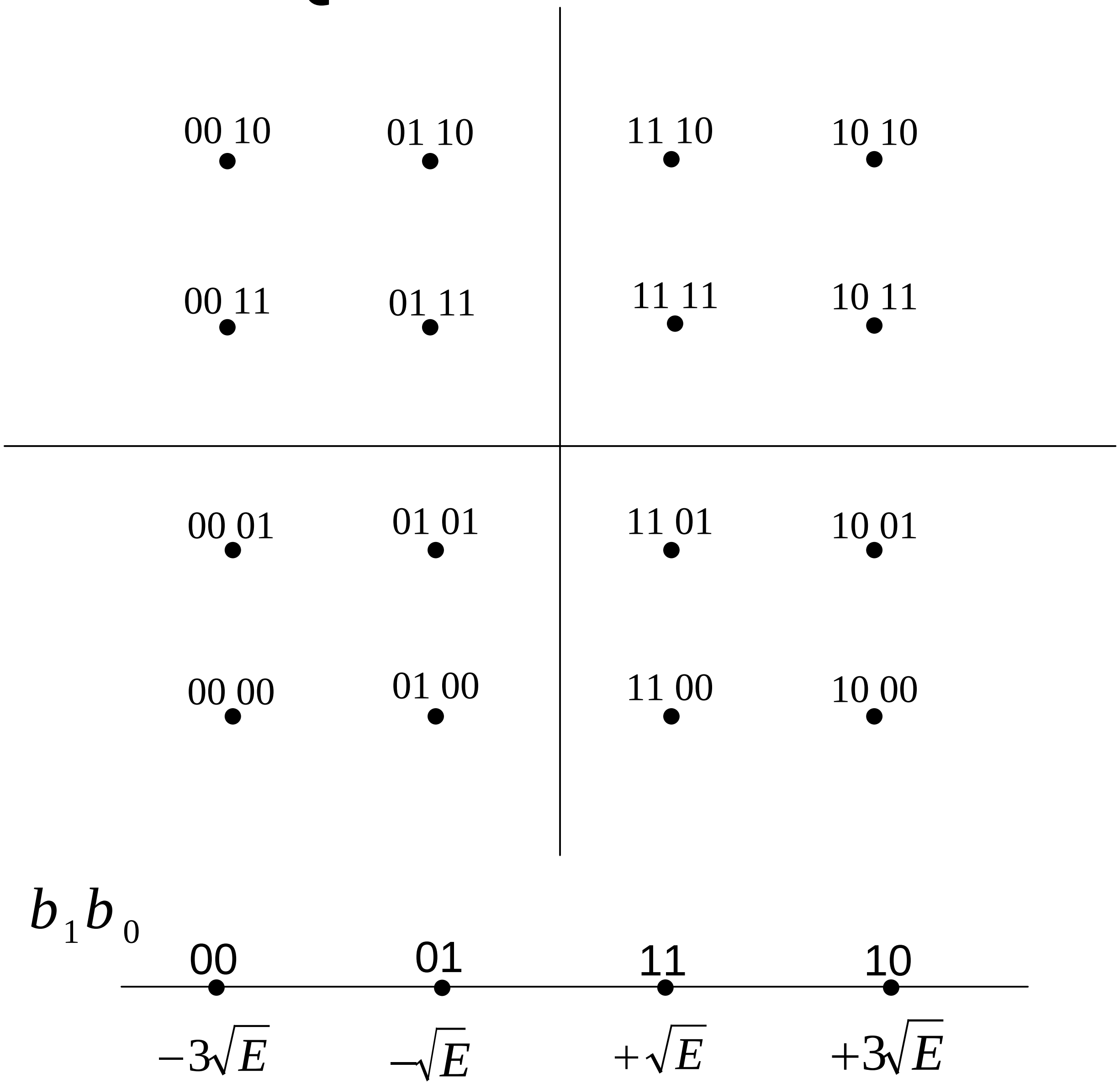
18 by 16 Block Interleaver (64QAM)

001	034	049	004	037	022	007	040	025	010	043	028	013	046	031	016
017	002	035	020	005	038	023	008	041	026	011	044	029	014	047	032
033	018	003	036	021	006	039	024	009	042	027	012	045	030	015	048
049	082	067	052	085	070	055	088	073	058	091	076	061	094	079	064
065	050	083	068	053	086	071	056	089	074	059	092	077	062	095	080
081	066	051	084	069	054	087	072	057	090	075	060	093	078	063	096
097	130	115	100	133	118	103	136	121	106	139	124	109	142	127	112
113	098	131	116	101	134	119	104	137	122	107	140	125	110	143	128
129	114	099	132	117	102	135	120	105	138	123	108	141	126	111	144
145	178	163	148	181	166	151	184	169	154	187	172	157	190	175	160
161	145	179	164	149	182	167	152	185	170	155	188	173	158	191	176
177	162	147	180	165	150	183	168	153	186	171	156	189	174	159	192
193	226	211	196	229	214	199	232	217	202	235	220	205	238	223	208
209	194	227	212	197	230	215	200	233	218	203	236	221	206	239	224
225	210	195	228	213	198	231	216	201	234	219	204	237	222	207	240
241	274	259	244	277	262	247	280	265	250	283	268	253	286	271	256
257	242	275	260	245	278	263	248	281	266	251	284	269	254	287	272
273	258	243	276	261	246	279	264	249	282	267	252	285	270	255	288

Soft-decision decoding

- In IEEE 802.11a, the hard-decision decoding is used because of the employment of high QAM and interleaving.
- The soft-decision decoding usually performs better than the hard-decision decoding.
- In this study, a soft-decision decoder is proposed by determining the bit log-likelihood (soft matric) of each coded bit of the convolutional code.

16-QAM Constellation



Optimum Decision Rule for 16QAM(AWGN)

b_0 : *The less significan t bit*

$$
\begin{cases}
\Lambda\left(r \mid b_0 = 0\right) = \log\left[e^{\frac{-\left(r+3\sqrt{\frac{2E}{N0}}\right)^2}{2}} + e^{\frac{-\left(r-3\sqrt{\frac{2E}{N0}}\right)^2}{2}} \right] \\
\Lambda\left(r \mid b_0 = 1\right) = \log\left[e^{\frac{-\left(r+\sqrt{\frac{2E}{N0}}\right)^2}{2}} + e^{\frac{-\left(r-\sqrt{\frac{2E}{N0}}\right)^2}{2}} \right]
\end{cases}
$$

Optimum Decision Rule for 16QAM(AWGN)

$b_1 : The \quad more \quad significan\,t \quad bit$

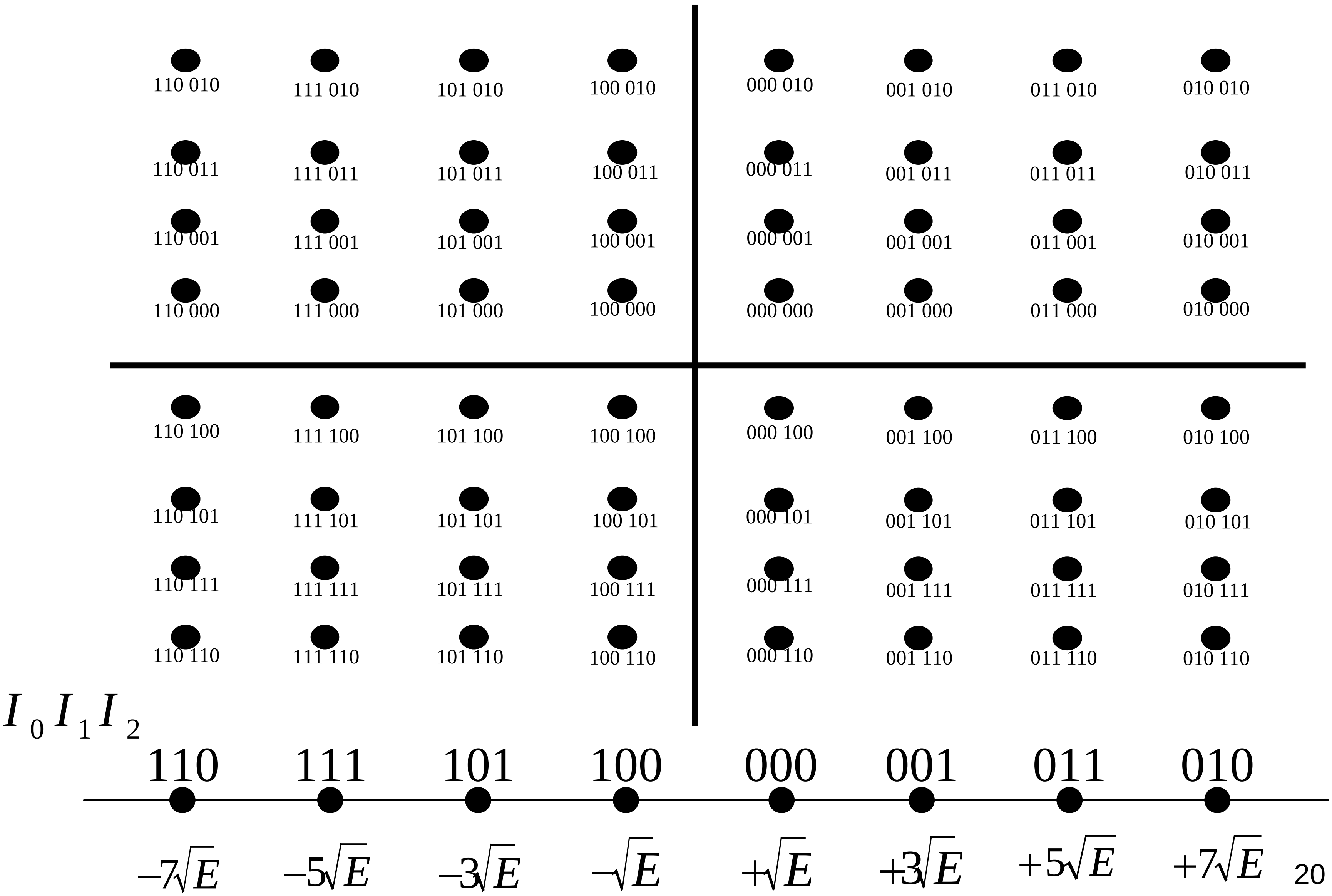
$$
\begin{cases}
\Lambda\left(r \mid b_1 = 0\right) = \log\left[e^{\frac{-\left(r+3\sqrt{\frac{2E}{N0}}\right)^2}{2}} + e^{\frac{-\left(r+\sqrt{\frac{2E}{N0}}\right)^2}{2}} \right] \\
\Lambda\left(r \mid b_1 = 1\right) = \log\left[e^{\frac{-\left(r-3\sqrt{\frac{2E}{N0}}\right)^2}{2}} + e^{\frac{-\left(r-\sqrt{\frac{2E}{N0}}\right)^2}{2}} \right]
\end{cases}
$$

Sub-optimum dual-max Decision Rule for 16QAM

$$\begin{cases} \Lambda\left(r \middle| b_0 = 0\right) \approx \max\left\{3\sqrt{\frac{2E}{N_0}}r - \frac{9E}{2N_0} \;,\; -3\sqrt{\frac{2E}{N_0}}r - \frac{9E}{2N_0}\right\} \\ \Lambda\left(r \middle| b_0 = 1\right) \approx \max\left\{\sqrt{\frac{2E}{N_0}}r - \frac{E}{2N_0} \;,\; -\sqrt{\frac{2E}{N_0}}r - \frac{E}{2N_0}\right\} \end{cases}$$

$$\begin{cases} \Lambda\left(r \middle| b_1 = 0\right) \approx \max\left\{-3\sqrt{\frac{2E}{N_0}}r - \frac{9E}{2N_0} \;,\; -\sqrt{\frac{2E}{N_0}}r - \frac{E}{2N_0}\right\} \\ \Lambda\left(r \middle| b_1 = 1\right) \approx \max\left\{3\sqrt{\frac{2E}{N_0}}r - \frac{9E}{2N_0} \;,\; \sqrt{\frac{2E}{N_0}}r - \frac{E}{2N_0}\right\} \end{cases}$$

64-QAM Constellation



Optimum Decision Rule for 64QAM(AWGN)

$$\begin{cases} \Lambda(r|I_0=0)=\log(e^{-(r-\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-3\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-5\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-7\sqrt{\frac{2E}{N_0}})^2/2}) \\ \Lambda(r|I_0=1)=\log(e^{-(r+\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+3\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+5\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+7\sqrt{\frac{2E}{N_0}})^2/2}) \end{cases}$$

$$\begin{cases} \Lambda(r|I_1=0)=\log(e^{-(r+3\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-3\sqrt{\frac{2E}{N_0}})^2/2}) \\ \Lambda(r|I_1=1)=\log(e^{-(r+7\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+5\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-5\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-7\sqrt{\frac{2E}{N_0}})^2/2}) \end{cases}$$

$$\begin{cases} \Lambda(r|I_2=0)=\log(e^{-(r+7\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+1\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-7\sqrt{\frac{2E}{N_0}})^2/2}) \\ \Lambda(r|I_2=1)=\log(e^{-(r+5\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r+3\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-3\sqrt{\frac{2E}{N_0}})^2/2}+e^{-(r-5\sqrt{\frac{2E}{N_0}})^2/2}) \end{cases}$$

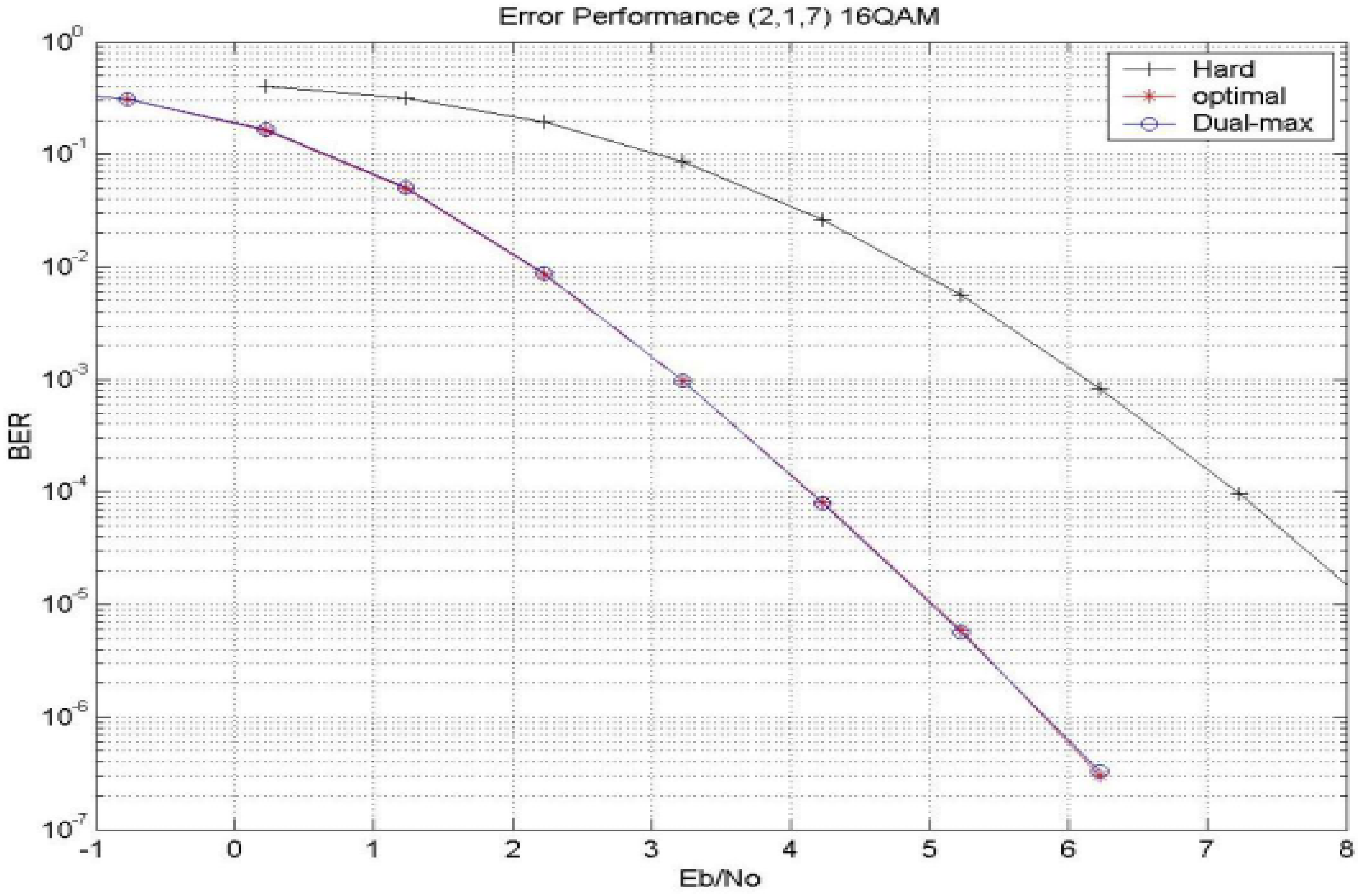
Sub-optimum Dual-max Decision Rule for 64QAM(AWGN)

$$\begin{cases} \Lambda\left(r \middle| I_0=0\right) \approx \max\left(r\sqrt{\frac{2E}{N_0}}-\frac{E}{N_0}, 3r\sqrt{\frac{2E}{N_0}}-9\frac{E}{N_0}, 5r\sqrt{\frac{2E}{N_0}}-25\frac{E}{N_0}, 7r\sqrt{\frac{2E}{N_0}}-49\frac{E}{N_0}\right) \\ \Lambda\left(r \middle| I_0=1\right) \approx \max\left(-r\sqrt{\frac{2E}{N_0}}-\frac{E}{N_0}, -3r\sqrt{\frac{2E}{N_0}}-9\frac{E}{N_0}, -5r\sqrt{\frac{2E}{N_0}}-25\frac{E}{N_0}, -7r\sqrt{\frac{2E}{N_0}}-49\frac{E}{N_0}\right) \end{cases}$$

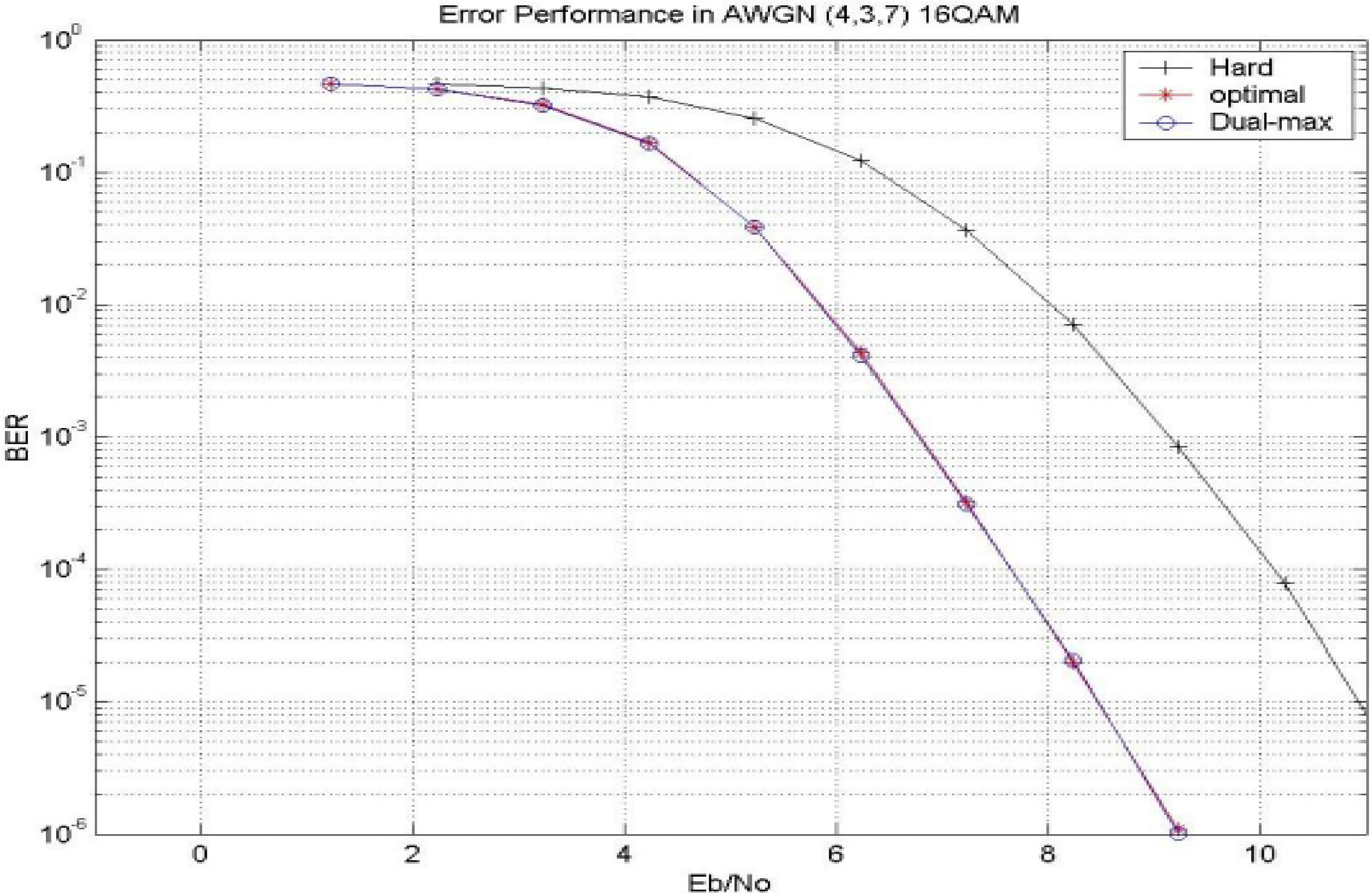
$$\begin{cases} \Lambda\left(r \middle| I_1=0\right) \approx \max\left(-3r\sqrt{\frac{2E}{N_0}}-9\frac{E}{N_0}, -r\sqrt{\frac{2E}{N_0}}-\frac{E}{N_0}, r\sqrt{\frac{2E}{N_0}}-\frac{E}{N_0}, 3r\sqrt{\frac{2E}{N_0}}-9\frac{E}{N_0}\right) \\ \Lambda\left(r \middle| I_1=1\right) \approx \max\left(-7r\sqrt{\frac{2E}{N_0}}-49\frac{E}{N_0}, -5r\sqrt{\frac{2E}{N_0}}-25\frac{E}{N_0}, 5r\sqrt{\frac{2E}{N_0}}-25\frac{E}{N_0}, 7r\sqrt{\frac{2E}{N_0}}-49\frac{E}{N_0}\right) \end{cases}$$

$$\begin{cases} \Lambda\left(r \middle| I_2=0\right) \approx \max\left(-7r\sqrt{\frac{2E}{N_0}}-49\frac{E}{N_0}, -r\sqrt{\frac{2E}{N_0}}-\frac{E}{N_0}, r\sqrt{\frac{2E}{N_0}}-\frac{E}{N_0}, 7r\sqrt{\frac{2E}{N_0}}-49\frac{E}{N_0}\right) \\ \Lambda\left(r \middle| I_2=1\right) \approx \max\left(-5r\sqrt{\frac{2E}{N_0}}-25\frac{E}{N_0}, -3r\sqrt{\frac{2E}{N_0}}-9\frac{E}{N_0}, 3r\sqrt{\frac{2E}{N_0}}-9\frac{E}{N_0}, 5r\sqrt{\frac{2E}{N_0}}-25\frac{E}{N_0}\right) \end{cases}$$

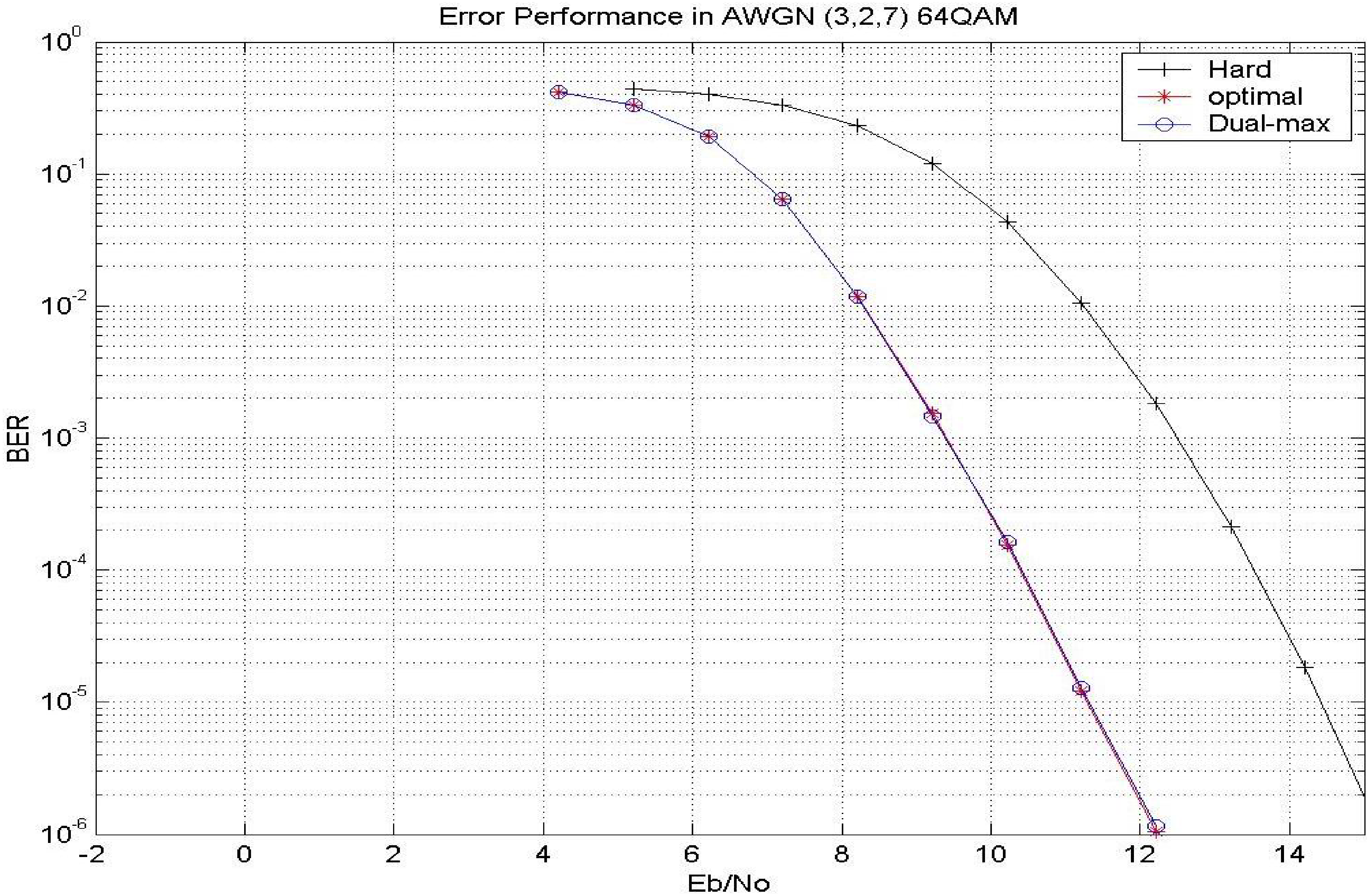
Data rate 24Mbps : CC(2,1,7)+16 QAM



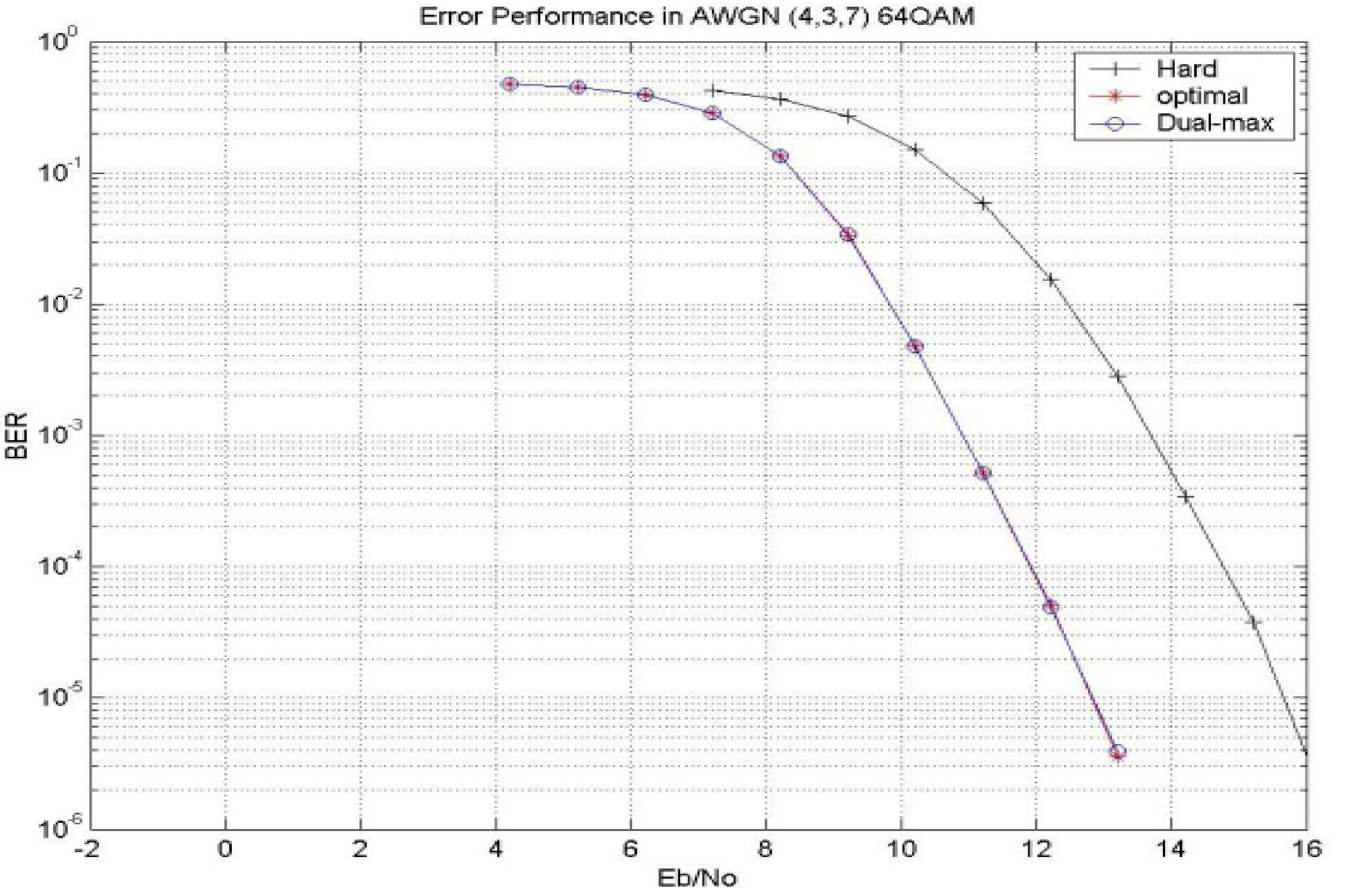
Data rate 36Mbps : CC(4,3,7)+16 QAM



Data rate 48Mbps : CC(3,2,7)+64 QAM



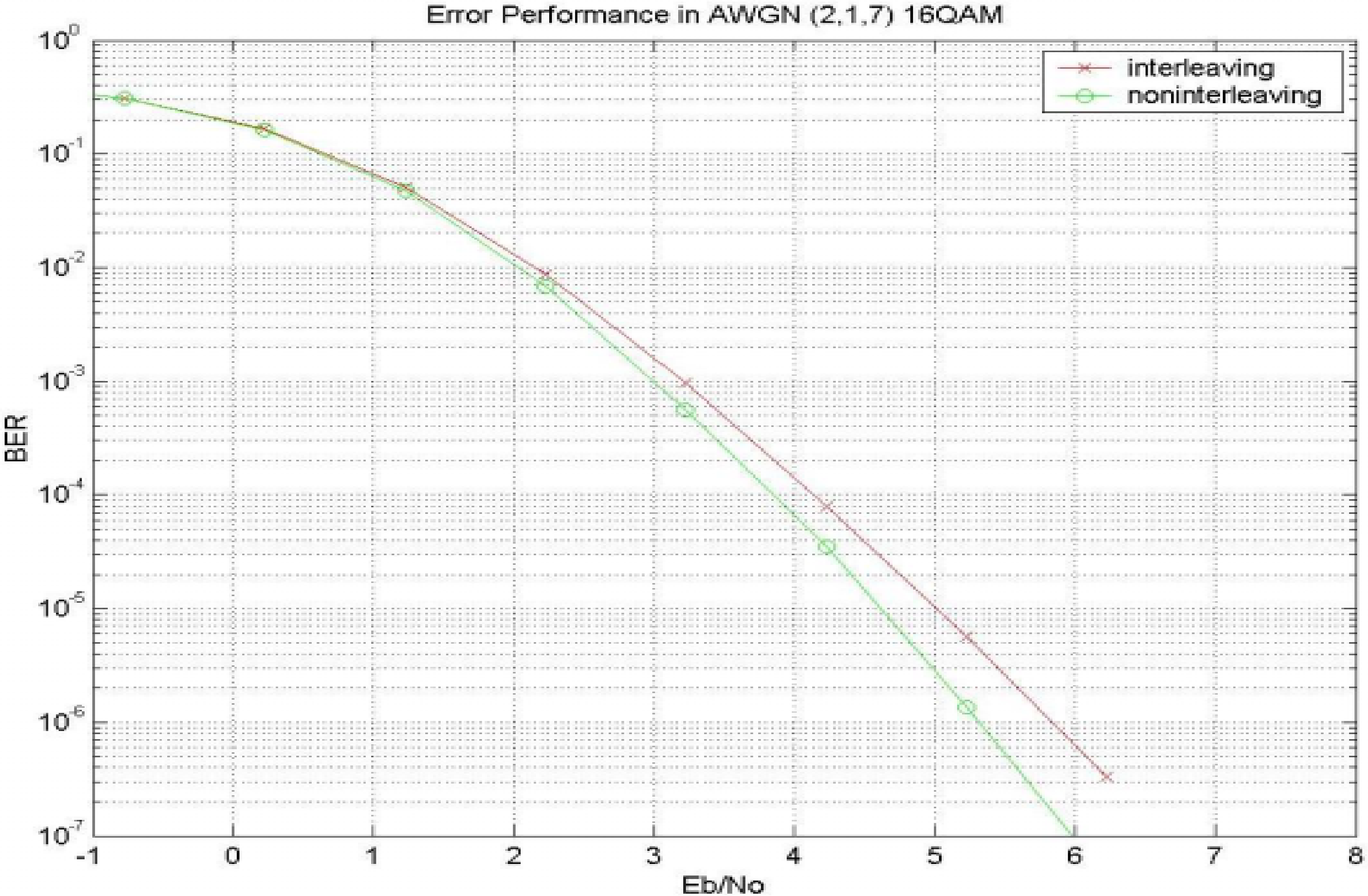
Data rate 54Mbps : CC(4,3,7)+64 QAM



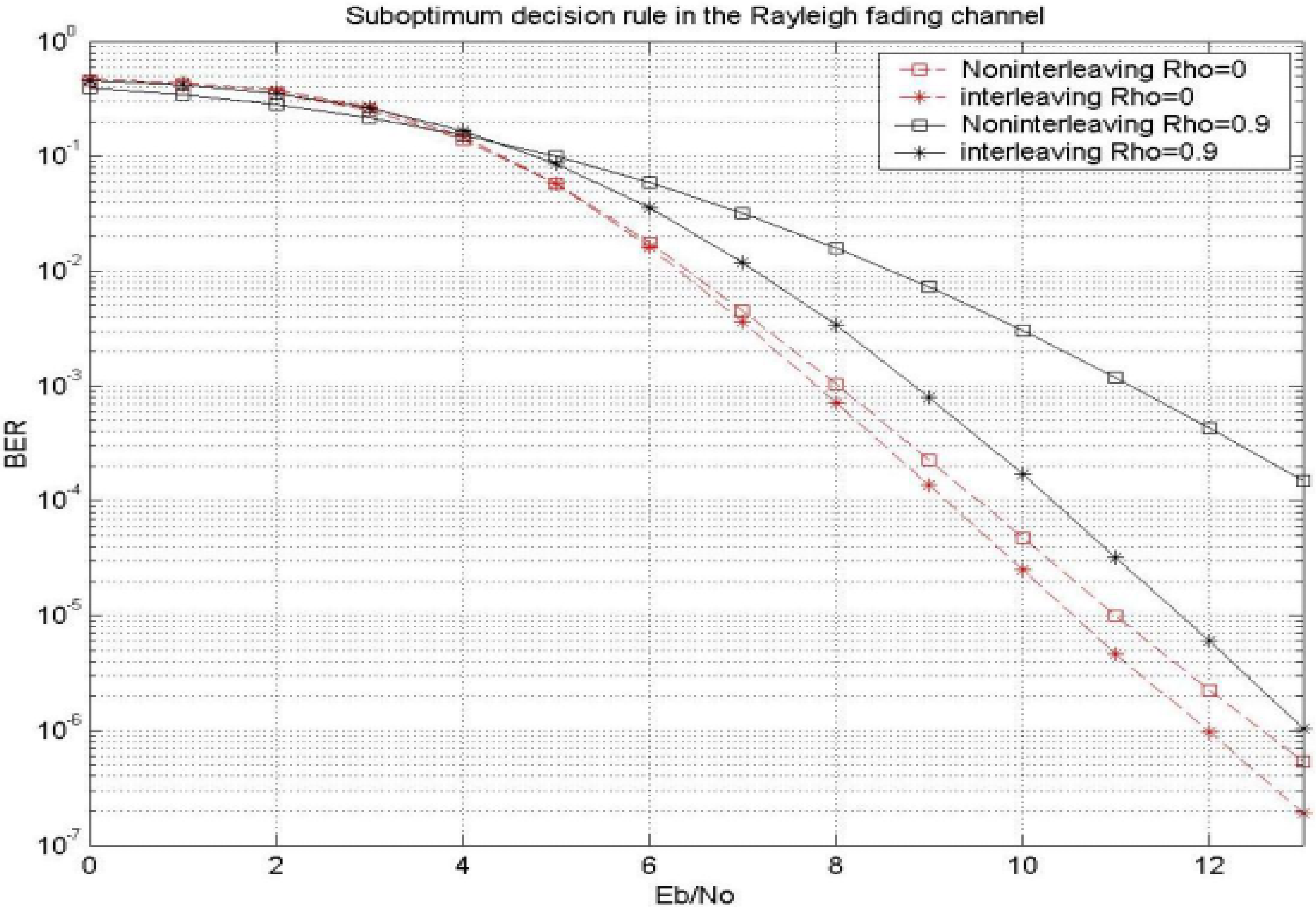
Effects of Interleaving

- Breaking the adjacent coded bits to reduce the risk of bursty errors.
- However, interleaving might hurt the error performance of the (2,1,7) convolutional code when the channel is AWGN. This is because no burty error is observed at the receiver even when the coded bits are not interleaved.
- This might be a special case when the channel is AWGN.
- The help of interleaving becomes significant when channel fading exists.

CC(2,1,7)+16 QAM over AWGN

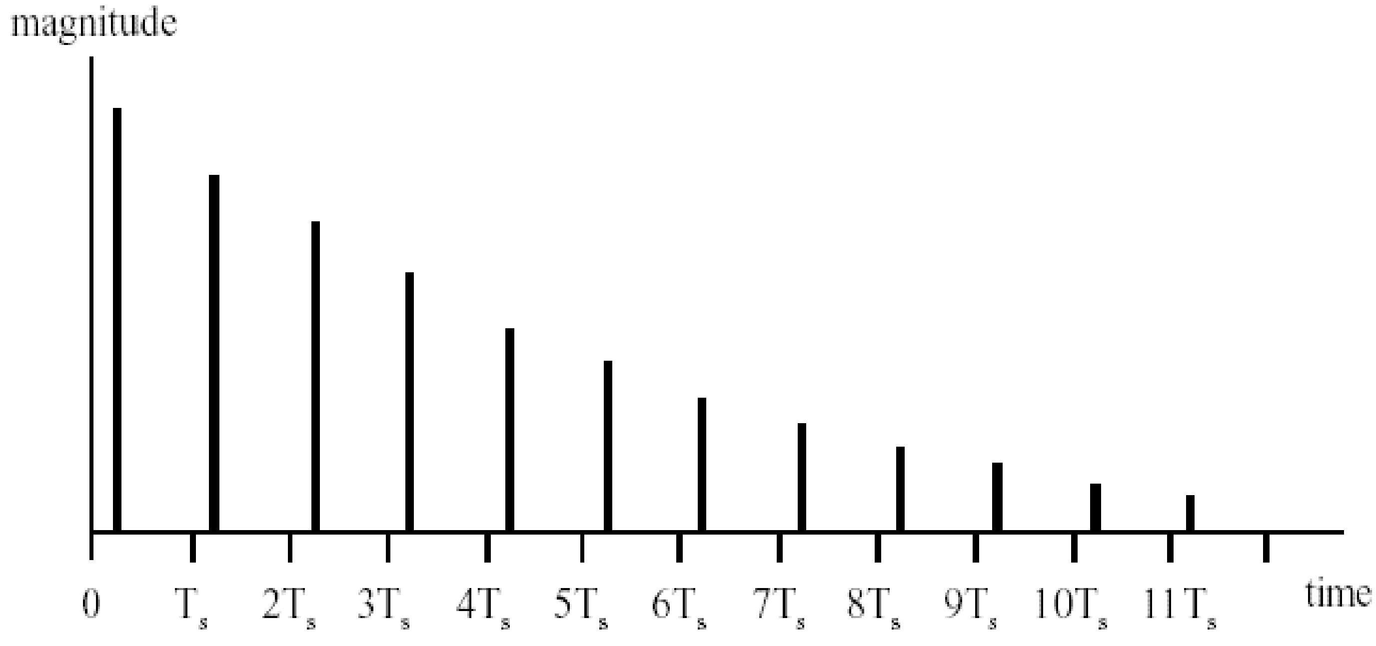


Rayleigh Fading Channel



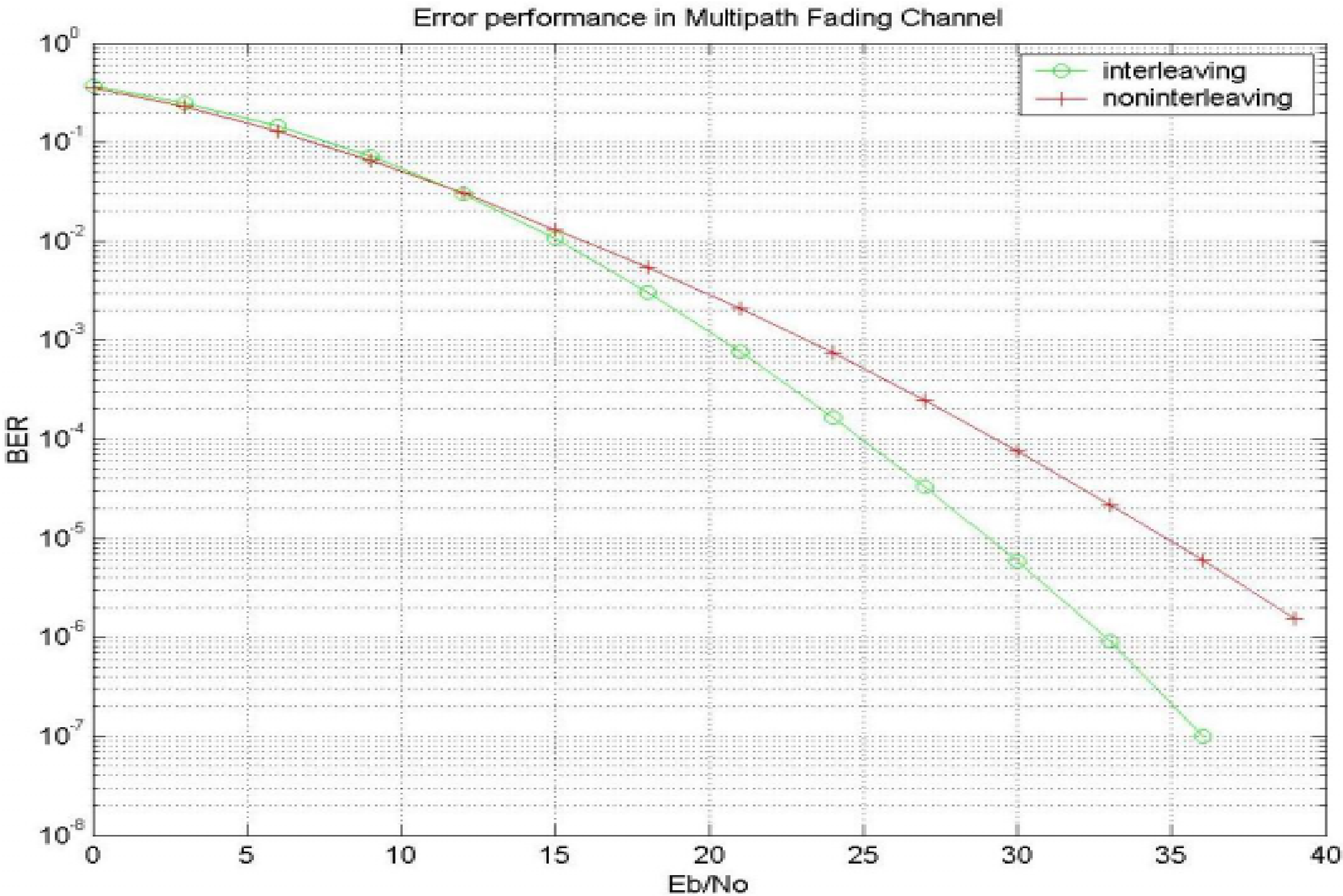
Exponential Delay Power Profile

The multipath fading channel model proposed in IEEE 802.11a.



Power Profile

Multipath Fading Channel



Conclusion

- The soft-decision decoding performs better than the hard-decision decoding designed in IEEE 802.11a.
- The sub-optimal dual-max decision rule that requires less complexity shows no significant difference in error performance over the optimal decision rule.
- The effects of interleaving has been examined under different channel environments.