IEEE P802.11
Wireless LANs

TGb proposal comparison matrix

Date: May, 4, 1998

Author:

Karl Hannestad
Netwave Technologies, Inc.
6663 Owens Drive
Pleasanton, CA 94588
Phone: 510 737-1620
Fax: 510 847-8744
e-Mail: **Error! Bookmark not defined.**

This document is a comparative matrix of the modulation techniques being consideration by the TGb (high data rate 2.4GHz PHY) subgroup. The basis of this matrix is the evaluation criteria described in document "97157r1.doc". Document "9854.doc" describes how this matrix will be used in the selection process.

The proposers have completed this matrix for their individual proposal as well as for any derivative proposals that makes performance, complexity and interoperability trade-offs.

General description:

	Harris	Lucent	MicriLor	Raytheon
Modulation Technique	BMBOK and QMBOK	BCPM	16-ary DBOK 16-ary DBOK with (15,13) R/S FEC 4x4-ary DBOK	Offset Quadrature Bi-Orthogonal (OQBO)
Data Rate(s)	1, 2, 5.5 and 11	5, 8 and optional 10 Mbit/s	10Mbps (primary) 8.7Mbps(drop-down) 18Mbps (spin-up) (optional 5, 4.3 & 9 Mbps 16-Mchip/s modes not presented)	6.875 and 11.0 Mb/s during burst
Sensitivity	-85 dBm @ 11 Mbit/s -88 dBm @ 5.5 Mbit/s	-92 dBm @ 5Mb/s -89 dBm @ 8Mb/s -89 dBm @ 10Mb/s	-88 dBm @10 -90 dBm @8.7 -83 dBm @18 » quoted SNR_{IN} -90dBm Assumes NF=10-dB (Incl. T/R & Div. Sw.)	11.0 Mb/s: Same as Harris Proposal for 11 Mb/s. -85dBm 6.875 Mb/s: ≈1 dB worse than Harris for proposed 5.5 Mb/s rate. –85dBm
Reference submissions	70254, 70867, 71447, 80467B, 80477B,	97/124 98/10r1 98/11 98/99 98/100	Doc 97116.DOC Doc 97117.DOC Doc 97118.DOC Doc 97119.DOC Doc 97120.DOC Doc 97128.PPT Doc 97129.PPT Doc 97130.PPT Doc 97131.PPT Doc 9750.PPT Doc 9752.PPT Doc 9753.PPT Doc 9782.PPT Doc 9783.PPT Doc 98016.DOC Doc 98017.DOC Doc 98018.DOC Doc 98019.DOC	doc:IEEE P 802.11-98/20 98/103r1 98/119 98/177

Receiver structure:

	Harris	Lucent	MicriLor	Raytheon
Receiver structure description	AGC'd IF, single bandwidth	MLSE structure BCPM makes simplification possible; ref doc 98/99	Max-Likelihood for Rayleigh channel; 16 complex correlators for demodulation; correlator-assisted matched filter for acquisition; matched filter for CSMA; non-coherent receiver.	Same as Harris, except a ½ chip delay is added in the I channel A/D output, to compensate for the ½ chip delay inserted in the Q channel at the transmitter. For medium data rate, 16-ary, rather than 8-ary, Walsh correlations are done.
RF/IF complexity relative to current low rate PHYs.	Slight increase to accommodate the AGC vs limiter	Same as low rate Phy's	Identical: Harris PRISM chipset with lower-power-consumption PA (MSK allows saturation)	Same as Harris.
Baseband processing complexity. relative to current low rate PHYs. (Gate Count, MIPS)	the basic 802.11 low rate processor requires 23K gates and the high rate add-on an additional 10K gates.	twice low rate PHY's for moderate complexity receiver, complexity trade off for performance	Similar: baseline chip requires < 35k gates; increased gate count for some features given in relevant sections	Our own independent estimates indicate a gate count of 40 kGates with no Equalization.
Equalizer Complexity and performance impact (if applicable).	40K gates. Will improve delay spread from 30 ns to 100 ns. This is roughly double the gate count.	N/A	Channel Matched Filter: 8-taps; small % increase gates, included in baseline estimate; three-fold increase in delay-spread tolerance.	Same as Harris. Additional Data: Our own independent estimate of equalizer complexity indicates 40 kGates to implement. Performance improvement due to this equalizer is TBD.
Antenna Diversity and performance impact.	Diversity will improve PER by a factor of 2 to 4	Same possibilities as low rate PHY with long PLCP header. Reduces Fading marge with10 dB	Included: Typically offers 1 or 2 dB improvement in SNR in addition to Channel Matched Filter; adds 4 ?s to preamble.	Same as Harris.

Multipath and Noise performance:

	Harris	**Lucent**	**MicriLor**	**Raytheon**
PER vs. multipath rms delay spread (no noise). Delay spread @ 10% PER for 64 and 1000 byte packets.	With no equalizer, 35 ns With Sliding DFE (1FF, 5 FB), 100 ns With Sliding DFE (2FF, 10 FB), 185 ns With Sliding DFE (2FF, 20 FB, 341 ns	5 TSE + MS: 64 byte 400nS 1000 byte 355nS 5 CMF only: 64 byte 370nS 1000 byte 275nS 8 TSE + MS: 64 byte 265nS 1000 byte 235nS 8 CMF only: 64 byte 90nS 1000 byte 50nS 10 TSE + MS: 64 byte 230nS 1000 byte 130nS for graohs see doc 98/99	For 10-Mbps and 8.7 Mbps, and all packet sizes, the delay-spread tolerance is **275 ns**.	Same as Harris for high data rates. Our own, independent simulation of this has been done, using the model given in doc:IEEE P802.11-97/157r1, for the case of 1000 byte packets only, without diversity, without an equalizer and not including the effects of intended acquisition performance. (Figure 1.)This was for the high-data rate mode. The lowest (and only) rms. Multipath delay spread (T_{RMS}) giving a PER of 10% is 31 ns.
PER vs. thermal noise w/ multipath @ 10% PER. Eb/No @ 20% PER for 64 and 1000 byte packets.	With Sliding DFE (2, 5) 18 dB Eb/N0 64 bytes, 24 dB with 1000 bytes	E + MS: 64 byte 13.5dB @ TDS 400ns 1000 byte 16.5dB @ TDS 355ns 5 CMF only: 64 byte 15dB @ TDS 370ns 1000 byte 19dB @ TDS 275ns 8 TSE + MS: 64 byte 14.5dB @ TDS 265ns 1000 byte 14.5dB @ TDS 235ns 8 CMF only: 64 byte 19dB @ TDS 90ns 1000 byte 20dB @ TDS 50ns 10 TSE + MS: 64 byte 12.5dB @ TDS 220ns 1000 byte 14dB @ TDS 120ns for graohs see doc 98/99	<u>275 ns: 20% PER</u> <u>Mbps</u> <u>SNR_{IN}</u> **<u>E_b/N_0</u>** **64 bytes:** **10** 18.7dB **23.7dB** 8.7 14.7dB **21.7dB** **1000 bytes:** **10** 21.4dB **26.4dB** 8.7 17.4dB **22.4dB** (this performance <u>without</u> ant. diversity) <u>150 ns: 10% PER</u> <u>Mbps</u> <u>SNR_{IN}</u> **<u>E_b/N_0</u>** **64 bytes:** **10** 16.7dB **22.7dB** **1000 bytes:** **10** 20.6dB **25.6dB** (this performance <u>without</u> ant. diversity)	Same as Harris for high data rates. Our own, independent simulation of this has been done, using the model given in doc:IEEE802.11-97/157r1, for the case of 1000 byte packets only, without diversity, without an equalizer and not including the effects of intended acquisition performance. (Figure 2.) This was for the high-data rate mode. At the above mentioned T_{RMS} = 31ns, an E_B/N_0 = 17.3 dB gives a PER = 20%

PER vs. thermal noise (no multipath). Eb/No @ 10% PER for 64 and 1000 byte packets.	With or without equalizer, 6.7dB Eb/N0 64bytes, 8.3 dB Eb/N0 1000 bytes	5 TSE + MS: 64 byte 5dB 1000 byte 6dB 5 CMF only: 64 byte 5dB 1000 byte 7dB 8 TSE + MS: 64 byte 5.5dB 1000 byte 7dB 8 CMF only: 64 byte 7dB 1000 byte 8.5dB 10 TSE + MS: 64 byte 4.5dB 1000 byte 6.5dB For graphs see doc 98/99	Mbps SNR_{IN} **E_b/N_0** **64 bytes:** **10** 0.5dB **5.5dB** 8.7 -0.9dB **4.5dB** 10 6.0dB **8.5dB** **1000 bytes:** **10** 1.7dB **6.7dB** 8.7 0.0dB **5.0dB** 18 7.2dB **9.7dB**	Same as Harris for high data rates. Our own, independent simulation of this has been done, using the model given in doc:IEEE802.11-97/157r1, for the case of 1000 byte packets only, without diversity, without an equalizer and not including the effects of intended acquisition performance. (Figure 3.) This was for the high-data rate mode. For this case, an E_B/N_0 = 8.9 dB gives a PER = 10%.

Carrier and Data frequency accuracy:

	Harris	Lucent	MicriLor	Raytheon
Required Carrier frequency accuracy.	+/- 25 PPM	25 ppm = low rate Phy's	**20 ppm** 50 KHz offset Recommend specify @ **10 ppm** to support 16-Mchip/s option.	Same as Harris.
Degradation at worst case carrier frequency offset.	<0.2 dB	Negligible Similar to low rate phy's Easy carrier tracking	**< .2 dB**	Same as Harris.
Data clock frequency accuracy.	+/- 25 PPM	25 ppm	**10 ppm**	Same as Harris.
Degradation at worst case data clock frequency offset.	< 0.5 dB	CMF gives optimal timing Tracking circuits should compensate	**< .7 dB** 1/4-chip timing error.	Same as Harris.

Overhead related parameters:

	Harris	Lucent	MicriLor	Raytheon
Preamble length	192 symbols as per 802.11 DS PHY 52 us for short preamble plus header	Long preamble + header 192 microseconds Short preamble + header 75 microseconds	20uS Preamble +4uS PHY Header	Same as Harris.
Does the preamble length include receive antenna diversity? Yes or no.	Yes for both	Long preamble, same as low rate PHY: yes Short preamble:yes 30 Microseconds (1.5 slottime) reserved	**YES**: Requires additional 4 us of preamble (included in baseline) relative to non-diversity case.	Yes. Same as Harris.
Does the preamble length include equalizer training? Yes or no.	Yes for both	Long preamble: yes Short preamble: yes (24 micros) Note: BCPM does not need an equalizer	**YES**: Channel Matched Filter rather than Equalizer, but adaptation during preamble accounted for.	Yes. Same as Harris.
Slot time.	20us	= low rate phy 20 microseconds	**9uS** 1uS Rx-Tx turnaround plus twice (2 uSCCA detect time times 2 for antenna diversity)	Same as Harris.
CCA mechanism description.	Measure correlated signal energy over 16 us after receiver is reset 4 us for short preamble	= low rate Phy	Matched filter runs for slot time before transmit.	Same as Harris.
Co-Channel signal detection time.	16 us for interoperable preamble or 4 us for short preamble	Energy detect time = current phy 15 micros	Detect on 3 symbols; requires 2 µs processing time; 4 µs allowed to accommodate antenna diversity.	Same as Harris.
RX/TX turnaround time.	2 us	= low rate phy 5 micros.	**1** µs	Same as Harris.
SIFS.	10 us	= low rate phy 10 microsec	2Us @10 & 18 Mbps 9.5 uS @ 8.7 µs 1uS Rx-Tx turn-around plus 1 µs processing time; 7.5µs FEC decoding latency for 8.7-Mbps mode	Same as Harris.

Spectral efficiency, Cell density related parameters:

	Harris	Lucent	MicriLor	Raytheon
Channelization scheme	same as 802.11 now	= low rate phy	**Frequency**: 2 wideband; 1 wide- &1narrowband; 3 narrowband. **Code**: 48 cyclic or 64K random. Legacy Option: 3 frequency chan with 1-/2-Mbps legacy and one 10-/18-Mbps high-rate channel centered middle chan 2 frequency chan with 1-/2-Mbps legacy and 10-/18-Mbps high-rate	6.875 and 11 Mb/s: 25 MHz between channel centers. (Same as Harris.)
Cell planing scheme	same as 802.11 now	= low rate phy 3 independent channels	**2 wideband** Alternate frequency channels in roughly rectangular grid of BSAs. Overlap of BSAs on different frequency channels allowed. Use different code channels within 2x free-speace range. **1 wide-/2 narrowband** Alternate frequency channels in roughly rectangular grid of BSAs. Do not overlap coverage of BSAs on same frequency channel. Use different code channels within 2x free-speace range. **3 narrowband** Same frequency strategy as legacy, except 16-Mchip/s BSAs can exploit different code channels to help spatial re-use. Legacy deployments using 3 freq chan can overlay a high rate chan as part of migration plan.	Same as Harris.

Adjacent channel interference rejection.	Needs 8 dB more filter attenuation to meet same ACI rejection as 1 MBps	32-35 dB	**>35 dB**	Same as Harris.
Co-channel interference rejection.	About 8 dB less rejection than 1 MBps or 7 dB SNR.	6dB	Operates with any inteference 2 dB below desired signal.	Same as Harris.
S/J where CW interference gives 10% PER.	8 dB at 11 MBps, 5 dB with 5.5 MBps	5 TSE+MS 64 byte -5.5dB 1000 byte -5dB 5 CMF only 64 byte -4.5dB 1000 byte -2.7dB 8 TSE+MS 64 byte -2.5dB 1000 byte -2dB 8 CMF only 64 byte -0.5dB 1000 byte –1.5dB 10 TSE+MS 64 byte –2dB 1000 byte –1.5dB See graphs doc 98/99	**0 dB**	Same as Harris.
Other interference immunity tests.	WB noise, 7 dB C/N		S/J **??2 dB** for 10% PER against Gaussian interference.	Same as Harris.
Co-Channel signal detection time.	10 us	= low rate phy	**2** µs	Same as Harris.
Total number of channels in 2.4GHz band.	3 non interfering as with present system	= low rate phy FCC: 11 Etsi: 13 MTP: 1	**96 channels total for spatial re-use**	6.875 and 11 Mb/s: 3 channels. (Same as Harris.)
Aggregate throughput.	33 MBps raw aggregate throughput	Dependent on cell topology. e.g. three channels in one cell gives 3 * throughput	Streaming w/ACK Bytes Rate Thruput 64 10 4.3 1000 10 9.2 1000 18 15.6 BSA w/.5Mbs/STA STAs BSA Thru 10 5.00 12 5.87 14 5.48 16 5.09 18 4.70 20 4.33	11 Mb/s: Same as Harris (for 11 Mb/s mode.) 6.857 Mb/s: ≈1.25 times Harris proposal (for 5.5 Mb/s mode) due to higer rate.

Misc. critical performance factors:

	Harris	Lucent	MicriLor	Raytheon
Phase noise sensitivity	works well with 2 degrees RMS, comparable with low rate pPHY	comparable to low rate phy (QPSK)	**N/A** (non-coherent receiver)	6.875 Mb/s and 11 Mb/s: Same as Harris at 11Mb/s.
RF PA backoff	5 dB	7dB	**None** (MSK) (i.e., operates at 1-dB gain compression point and passes FCC out-of-band requirements for ~10 mW PCMCIA transmitter, higher power Tx would require more filtering or some backoff)	During data: Output power 2dB below saturated output power.
DC power consumption	30mA @ 3V without equalizer	Comparable to low rate PHY PCMCIA formfactor and spec. TX < 300mA @ 3V RX < 250A @ 3V	3V @ 400mA (now) 3V @ 300mA (goal)	Save ≈ 0.55 W over Harris approach by using Power Amplifier with 3 dB less saturated output power. Use ≈ 0.15 W more than Harris approach with 16-ary, rather than 8-ary Walsh. Net savings of 0.4 W. If the entire card uses 2 W, this represents a saving of ≈ 20 %.

Interoperability:

	Harris	Lucent	MicriLor	Raytheon
Interoperability / Co-existence strategy with current low rate PHYs	Interoperable via use of existing low rate preamble and header; either DS or FH	Long Preamble: interoperable and coexistent Optional short preamble: low rate phy is coexistent with transmiter using short preamble and high rate receiver recognizes both long and short preamble : interoperable	**CCA Legacy DSSS** Implement "Multi-Signal" CCA (D97_128); requires ? 4k gates. **CCA Legacy FHSS** Implement "Multi-Signal" CCA (D97_128); requires ??3k gates. CCA-only allows high-rate PHY to defer to legacy equipment. **Interoperate with Legacy DSSS** YES; as dual-mode operation of independent PHYs; high-rate PHY defined as separate from Legacy PHY; coordinate via RTS/CTS. **16-Mchip/s modes** Allows 3 freq. channels if preferred to 48-code & 2-freq. scheme.	Same as Harris.
Is the proposal Interoperable at the data level?	Yes	Yes	**YES**: any PHY supporting 802.11 MAC is data-level interoperable via Access Point.	Yes. Same as Harris.
Is the proposal Interoperable at the antenna level?	Yes	yes	**YES**: Requires CCA and demod.; ??8k gates additional circuitry for direct exchange with legacy DSSS.	Yes. Same as Harris.
Performance penalty due to Interoperability / Coexistence.	192 us of overhead vs 52 us without. ~20 % on 1K byte packet 185 us on FH	Long preamble: 192 micro Phy overhead Short preamble: overhead reduces with factor 3	**Modest**. Because high-rate transmission can exploit small clear-channel time intervals, deferring to legacy DSSS using Multi-Signal CCA will give ? the same throughput as requiring the high-rate to employ low-rate-compatible preamble.	Same as Harris.

General Information:

	Harris	Lucent	MicriLor	Raytheon
Has the submission of the required IEEE letter covering IP been made? Yes or No	Yes	yes	YES	yes
Applicable patent numbers	One patent applied for on the high rate chip implementation	US patent 5,596,601 Bar-David	**Not Available** (being issued)	None.
Point of contact	Al Petrick	Bruce Tuch PO Box 755 3430 AT Nieuwegein, The Netherlands tel: +31 30 6097527, fax: +31 30 6097556	Dr. stanley Reible	Mr. Richard Winer; RAYTHEON COMPANY Tel: (978) 470-9510 358 Lowell Street; Andover MA; 01810