IEEE P802.11
Wireless LANs

TGb proposal comparison matrix

Adjusted to show those proposals still in selection process
Adjusted on April 9, 1998

Date: April, 9, 1998

Authors:
William Roberts
American Microsystems, Inc.
1651 Alvin Ricken Drive
Pocatello Idaho 83201
Phone: 208 233 4690 ext. 6514
Fax: 208 234 6760
e-Mail: wroberts@poci.amis.com

Karl Hannestad
Netwave Technologies, Inc.
6663 Owens Drive
Pleasanton, CA 94588
Phone: 510 737-1620
Fax: 510 847-8744
e-Mail: khannest@netwave-wireless.com

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 tradeoffs.

General description:

	Alantro	Harris	Lucent	MicriLor	Raytheon
Modulation Technique	QPSK	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)	1,2,2.75, 5.5, 11, 14 1/3, 16.5, 17.6, 18 1/3, 19.25 Mbps	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	88.9 dB Depends on data rate. As reference look at a receiver N.F. of 10 dB (not very aggressive). Then sensitivity can be calculated from KTB+B.W.+N.F.+SNR. Where KTB is -174 dB, B.W. is 30 Mhz and N.F. is 10dB and SNR is QPSK demodulation- Processing gain. For the primary rate of 11†Mbps we would get -174 dB+74.77dB+10 dB +(13-12.7)=88.9 dB.	-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. 6.875 Mb/s: ≈1 dB worse than Harris for proposed 5.5 Mb/s rate.
Reference submissions	98/24, 98/83, 98/84, 98/85	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 9751.PPT Doc 9752.PPT	doc:IEEE P 802.11-98/20

				Doc 9753.PPT Doc 9782.PPT Doc 9783.PPT Doc 98016.DOC Doc 98017.DOC Doc 98018.DOC Doc 98019.DOC	

Receiver structure:

	Alantro	**Harris**	**Lucent**	**MicriLor**	**Raytheon**
Receiver structure description	Receiver states are as follows: Antenna w/ diversity 1st Down converter IF filter 2nd Down convert (could be quadrature) A/D converter Equalizer/demodulato BCC decoder MAC interface	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.	Similar to low rate DS PHYs Requires slightly lower phase noise on oscillators.	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)	76-97k gates	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 56 kGates with no Equalization. With a simple Equalizer, this would increase to 88 kGates. This includes the logic for 16-ary Walsh generation and correlation.
Equalizer Complexity and performance impact (if applicable).	44-55k gates	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 32 kGates to implement. Performance

					improvement due to this equalizer is TBD.
Antenna Diversity and performance impact.	System performance may be improved by use of multiple antennas, but multiple antennas are not required to meet the PAR requirements.	Diversity will improve PER by a factor of 2 to 4	Same possibilities as low rate PHY with long PLCP header. Reduces Fading marge with 10 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:

	Alantro	**Harris**	**Lucent**	**MicriLor**	**Raytheon**
Graph of PER vs. multipath rms delay spread (no noise). Delay spread @ 10% PER for 64 and 1000 byte packets.	64 byte packets: 550 ns 1000 byte packets: 420 ns (11 Mbps)	With no equalizer, 35 ns With Sliding DFE (1FF, 5 FB), 100 ns With Sliding DFE (2FF, 10 FB), 185 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 **450 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.
Graph of PER vs. thermal noise w/ multipath @ 10% PER. Eb/No @ 20% PER for 64 and 1000 byte packets.	64 byte packets: 10 dB Eb/No 1000 byte packets: 14 dB Eb/No (11 Mbps)	With Sliding DFE (2, 5) 23dB Eb/N0 64 bytes, 27 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	Mbps SNR$_{IN}$ **E_b/N_0** **64 bytes:** **10** 20.8dB **25.8dB** 8.7 17.7dB **22.7dB** **1000 bytes:** **10** 22.7dB **27.7dB** 8.7 19.8dB **24.8dB**	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

			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	(this performance without ant. diversity)	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%
Graph of PER vs. thermal noise (no multipath). Eb/No @ 10% PER for 64 and 1000 byte packets.	64 byte packets: 3.2 dB Eb/No 1000 byte packets: 4.2 dB Eb/No (11 Mbps)	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:

	Alantro	Harris	Lucent	MicriLor	Raytheon
Required Carrier frequency accuracy.	+ 25ppm	+/- 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.	< 1dB	<0.2 dB	Neglegible Simular to low rate phy's Easy carrier tracking	**< .2 dB**	Same as Harris.
Data clock frequency accuracy.	+25ppm	+/- 25 PPM	25 ppm	**10 ppm**	Same as Harris.
Degradation at worst case data clock frequency offset.	< 1 dB	< 0.5 dB	CMF gives optimal timing Tracking circuits should compensate	**< .7 dB** ?1/4-chip timing error.	Same as Harris.

Overhead related parameters:

	Alantro	Harris	Lucent	MicriLor	Raytheon
Preamble length	Two preamble lengths supported. The first preamble length is identical to that of the low rate PHY, which is 2112 symbols or 192 ?s. (I would also propose appending of training sequence after the data rate field if a high data rate frame is to be received. This maintains compatibility with the current system but allows the benefits of the high data rates if they are coexisting) A second, improved performance preamble may be used with a length of 200 - 500 symbols, or 18.2 ?s - 45.5 ?s	192 symbols as per 802.11 DS PHY	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	Yes	Yes	Long preamble, same as low	**YES**: Requires additional 4 us of preamble (included in	Yes. Same as Harris.

diversity? Yes or no.			rate PHY: yes Short preamble:yes 30 Microseconds (1.5 slottime) reserved	baseline) relative to non-diversity case.	
Does the preamble length include equalizer training? Yes or no.	Yes	Yes	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.	20 µs	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.	Energy detect and Baud rate detection	Measure correlated signal energy over 16 us after receiver is reset	= low rate Phy	Matched filter runs for slot time before transmit.	Same as Harris.
Co-Channel signal detection time.	10 µs	16 us	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.	3-6 µs	2 us	= low rate phy 5 micros.	**1** µs	Same as Harris.
SIFS.	9.6 - 16 µs	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:

	Alantro	**Harris**	**Lucent**	**MicriLor**	**Raytheon**
Channelization scheme	Uses the same channelization scheme as the low rate DS PHY. The available bandwidth is divided into 14 overlapping channels of 30 MHz each with 5 MHz spacing. Overlapping channels are not used simultaneously.	same as 802.11 now	= low rate phy	**Frequency**: 2 wideband; 1 wide- &1narrowband; 3 narrowband. **Code**: 48 cyclic or 64K random.	6.875 and 11 Mb/s: 25 MHz between channel centers. (Same as Harris.)
Cell planing scheme	Since three non-overlapping channels of 30 MHz may be selected, a hexagonal tiling of cells may be used such that no two adjacent cells use the same 30 MHz frequency band.	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.	Same as Harris.
Adjacent channel interference rejection.	Analog bandpass filters may be used to effectively get rid of ACI. This is possible due to the large excess bandwidth.	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.	Co-channel interference is greatly reduced due to the use of a constant PN generator that modulates the output of the BCC. In addition CCI is reduced by	About 8 dB less rejection than 1 MBps.	6dB	Operates with any inteference 2 dB below desired signal.	Same as Harris.

	good cell spacing.				
S/J where CW interference gives 10% PER.	TBD	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.	N/A	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†µs	10 us	= low rate phy	**2** µs	Same as Harris.
Total number of channels in 2.4GHz band.	3 non-overlapping channels of 30 Mhz each	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.	The total throughput for a 30 Mhz band is dependent on the preamble used, the data rate, and the length of the packet. The range is as follows: 0.87 Mbps to >16.9 Mbps	33 MBps	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	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.

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Misc. critical performance factors:

	Alantro	**Harris**	**Lucent**	**MicriLor**	**Raytheon**
Phase noise sensitivity	Residual phase noise should be around 3 to 5 degrees. Clearly more phase noise will effect your RX sensitivity.	works well with 2 degrees RMS	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	To meet FCC we usually back the PA off about 6dB from compression	5 dB	7dB	**None** (MSK)	During data: Output power 1 to 2 dB below saturated output power. (See Figures 5 and 6.) During BPSK preamble: Output power 5 dB below saturated output power.
DC power consumption	Just the RF section (no PA) runs about 100mA. The PA can run from 50 to 300mA for a 23dBm output. The digital section (excluding PHY) will take about 150 to 180 mA. PHY chip will vary but I would estimate with an equilizer to be 110†mA. So totals would be 360 to 390†mA in receive and 410 to 690†mA in transmit.	30mA @ 3V without equalizer	Comparabl 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 0.65 W. If the entire card uses 2 W, this represents a saving of ≈ 20 %.

Intellectual Property:

	Alantro	**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	TBD	One patent applied for on the high rate implementation	US patent 5,596,601 Bar-David	**Not Available** (being issued)	None.
Point of contact	Chris Heegard CEO Alantro Comm. Santa Rosa, CA	Al Petrick	Bruce Tuch PO Box 755 3430 AT Nieuwegein, The Netherlands tel: +31 30 6097527, fax: +31	**Dr. stanley Reible**	Mr. Richard Winer; RAYTHEON COMPANY Tel: (978) 470-9510 358 Lowell Street; Andover MA; 01810

	607/521-3060		30 6097556		

Interoperability:

	Alantro	Harris	Lucent	MicriLor	Raytheon
Interoperability / Co-existence strategy with current low rate PHYs	Incorporate low rate PHY demodulation ability within the high speed PHY. Run the network with the low speed PHYís PLCP and shift to high speed for PDU portion of frame. Include a High speed only PLCP for using in high speed networks to avoid overhead of low speed PHY	Interoperable via use of existing low rate preamble and header	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** Demodulation of Legacy DSSS requires ??4k gates (in addition to those needed for CCA) **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	**YES**: any PHY supporting 802.11 MAC is data-level interoperable via Access Point.	Same as Harris.
Is the proposal Interoperable at the antenna level?	Yes	Yes	yes	**YES**: Requires CCA and demod.; ??8k gates additional circuitry for direct exchange with legacy DSSS.	Same as Harris.
Performance penalty due to Interoperability / Coexistence.	None to significant. When configured in the for low rate system there will be a significant penalty due to	192 us of overhead vs about 50 us without. ~20 % on 1K byte packet	Long preamble: 192 micro Phy overhead Short preamble: overhead	**Modest**. Because high-rate transmission can exploit small clear-channel time intervals, deferring to legacy	Same as Harris.

	PLCP overhead. In a high rate system there would be no penalty.		reduces with factor 3	DSSS using Multi-Signal CCA will give ? the same throughput as requiring the high-rate to employ low-rate-compatible preamble.	