IEEE 802.11

WIRELESS ACCESS METHODS AND PHYSICAL LAYER SPECIFICATIONS

Title: FLEXIBLE HIGHER (AND LOWER) MULTIPLE DATA RATE PHY/MAC PROPOSED STANDARD

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ABSTRACT

For the higher data rate Frequency Hopped (FH) Spread Spectrum (SS) committee of IEEE 802.11, we recommend the adoption of conventional offset QPSK (OQPSK) based modulation and coherent demodulation methods. Coherent offset QPSK techniques have a reduced envelope fluctuation, thus the potential of power efficient nonlinear amplification, reduced peak factor (peak envelope to rms envelope ratio), reduced peak radiation simple implementation, and spectral efficient-robust performance in an interference environment.

With OQPSK modems and compatible nonlinearly amplified power and more spectrally efficient **SIMPLER FQPSK** based modems and their extensions to OQAM (offset QAM) systems, references [1-7; 21], a spectral efficiency of up to 3 b/s/Hz could be attained, leading to a data rate of up to 3 Mb/s in the 1 MHz 20 dB attenuated power spectral density as defined in the FCC-15 2.4 GHz authorized bandwidth, currently considered by this committee.

IMPROVED THROUGHPUT-REDUCED MESSAGE DELAY requires a robust BER = f(E_b/N_0) and BER = f(C/I) and delay spread performance. Simple implementation, increased bit rate, robust performance and migration towards higher future rates suggests the adoption of a flexible data rate standard "universal modem/radio" strategy. As initial steps, we recommend the adoption of higher speed FH-SS **"GEAR SHIFT UP"** systems to

1.4 Mb/s 2 Mb/s 3 Mb/s

PHY data rates (all in 1 MHz).

In this contribution, the advantages of these increased data rates are justified and specific recommendations given. A continued investigation of **"GEAR SHIFT DOWN"** from the standardized 1 Mb/s rate FH-SS-GFSK system to 700 kb/s and 500 kb/s is also recommended. Initial study indicates that in adverse propagation and interference conditions reduced bit rate could lead to more robust BER performance and to increased throughput and reduced message delays.

1. FLEXIBLE MULTIPLE RATE MAC AND PHY ADVANTAGES

- Unique Word and or other MAC bits to provide gear shift "UP/DOWN" to several "higher" and "lower" data rates to **INCREASE THROUGHPUT** and **REDUCE MESSAGE DELAY**, references [6] and [21].
- For "adverse" propagation conditions it might be advantageous to reduce the 1 Mb/s standardized GFSK rate to 700 kb/s or 600 kb/s rate and increase throughput [9] and [21].
- Interoperability with standardized 1 Mb/s-GFSK is achieved during initial connection. Gear shift bits to be designed into MAC. To have only one "gear shift" e.g., from 1 Mb/s to 2 Mb/s or multiple gear shifts, e.g., from 1 Mb/s to 1.4 Mb/s, 2 Mb/s, 3 Mb/s, 700 kb/s and 600 kb/s requires only a very few extra bits.

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2. DATA FILE TRANSFER TIME (REDUCTION OF) AND INCREASED THROUGHPUT - WITH MORE ROBUST MODEMS

- The following examples illustrate the advantages of a more **ROBUST**

  $$BER = f(E_b/N_0) \quad \text{or} \quad BER = f(C/I)$$

  performance.
- These examples are based on Reference [21] and K. Feher's informal presentation to the joint MAC/PHY committee on September 23, 1993 in Atlanta.
- Further study is recommended to verify if the assumptions/computations are accurate, real and practical, or academic.

3. EXAMPLE 1: DATA "FILE TRANSFER TIME" 15 TIMES FASTER WITH A 4 dB MORE ROBUST MODEM

- In Gaussian noise, 4 dB difference corresponds to approximately BER = 10^{-3} versus 10^{-6} or to BER = 10^{-2} versus 10^{-4}.
- ASSUME: Operation in "fringe of cell area" adverse propagation interference conditions, e.g., 5% of coverage [21].

  Raw BER; no FEC.

  File length 400 bits to 12,000 bits

  BER = 10^{-1}; 10^{-2}; 10^{-4}; 10^{-5}

  Random error distribution
- COMPARE: "File transfer time" for a given E_b/N_0 and C/I as function of modem and bit rate.

  Is it fair to proceed as follows?

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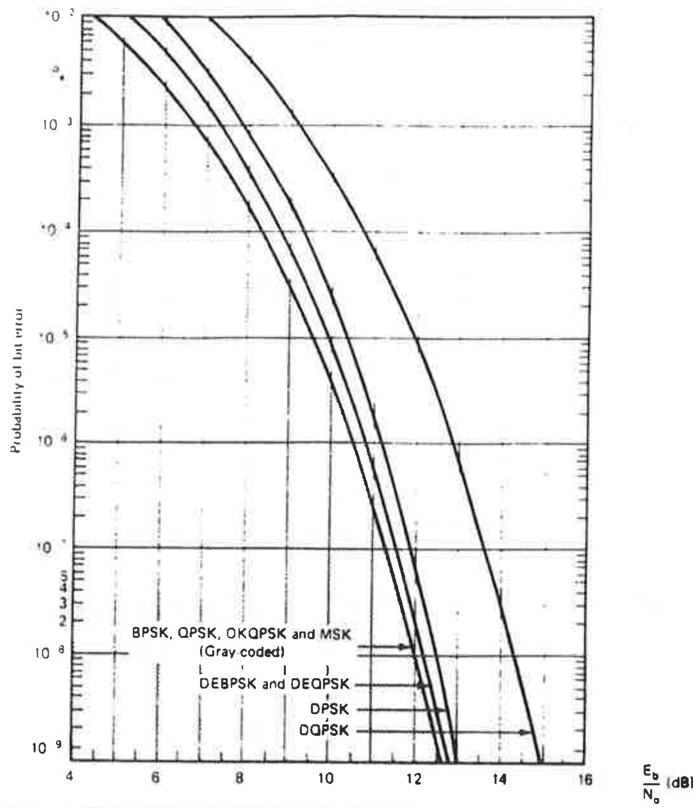
4. LESS ROBUST BY 4 DB COULD LEAD TO A 100 TIMES RETRANSMISSION OR COMPLETE FAIL (INSTEAD OF A SINGLE TRANSMISSION

ACADEMIC OR REAL?

Modem (A)	**Modem (B)**
(less robust)	(more robust by 4 dB)
BER = 10^{-2} (?)	BER = 10^{-4}
On average every file in error ?	Average 1 out of 10 files in error
Complete fail	Almost every file transmission is a "success"
Retransmit time ? Infinity ?	Retransmit 10% only

5. BER = f(E_bN_0) PERFORMANCE OF MODEMS

THEORETICAL BASED ON K. FEHER REF. [13]



6. ANOTHER EXAMPLE ILLUSTRATES THE LARGE ADVANTAGE OF "4 dB" MORE ROBUST SYSTEMS

Modem (A)

(less robust)

BER = 10^{-3} (?)

Retransmit N times N = 15 ?

File transfer time
(normalized)
15 units

Modem (B)

(more robust)

BER = 10^{-7}

Retransmit N = 1 time

File transfer time
1 unit
15 * faster

7. "GEAR SHIFT DOWN" FROM 1 Mb/s - GFSK TO 500 kb/s MIGHT CHANGE A "TOTAL FAILURE" TO "EXCELLENT" PERFORMANCE AT NO COST

WE RECOMMEND STUDYING EXAMPLES AS ILLUSTRATED BELOW

ASSUME 2000 BYTES = 16000 BITS/FRAME

$$\frac{E_b}{N_0} = \frac{C}{N}\frac{BW}{BR}$$

(A)

BW = 1 MHz

f_b = BR = 500 kb/s

$E_b/N_0 = \frac{C}{N} + 3\text{ dB}$

(B)

BW = 1 MHz

f_b = BR = 1 Mb/s

$E_b/N_0 = \frac{C}{N} + 0\text{ dB}$

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8. GFSK AT 500 kb/s "SHIFT-DOWN" FROM 1 Mb/S COULD HAVE ADVANTAGES IN ADVERSE PROPAGATION/SITUATIONS

EXAMPLE FOR STUDY
(not definitive numbers)

		A	B	C
		GFSK at 500 kb/s standard "Gear Down"	GFSK at 1 Mb/s STANDARD	Modem XX "4 dB" improved 1 Mb/s
A GOOD, OPTIMISTIC SCENARIO	E_b/N_0 C/N BER FER	22 dB 19 dB 10^{-7} $1.6 * 10^{-3}$	19 dB 19 dB 10^{-5} $1.6 * 10^{-1}$	19 dB 19 dB 10^{-8} $1.6 * 10^{-4}$
DANGER AREA	E_b/N_0 C/N BER FER	18 dB 15 dB 10^{-4} MARGINAL	15 dB 15 dB 10^{-3} or 10^{-2} FAIL (TOTAL?)	15 dB 15 dB 10^{-5} 0.1

9. REDUCED BIT RATE GFSK OR 4 dB IMPROVED GFSK COMPATIBLE MODEM (AT 1 Mb/s)

- Very significant increase in throughput and reduced data file transfer time.
- FER = Frame Error Rate - illustrated above
  did not take into account additional potential improvement - due to possible increased FM deviation - could lead to 3 dB - 5 dB additional improvement.
- Thus, reduced, e.g., 500 kb/s, bit rate for adverse conditions could be definitively advantageous.

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10. SHORTER FRAMES FOR MAC - IS IT A SOLUTION?

DR. FREDERICK BAUCHOT*, IBM - JULY 1993 DENVER IEEE 802.11/61

$$\text{FER} \triangleq \text{BER} * \text{No. of Bits/Frame}$$

BER	FER One Frame = 2000 Bytes * 8 bits = 16,000 bits IEEE 802.2	FER One Frame = 200 Bytes = 160 bits
10^{-5}	0.16*	0.016*
10^{-4}	1.6 FAIL	0.16
10^{-3}	16 TOTAL FAIL	1.6 FAIL
10^{-2}	TOTAL FAIL	TOTAL FAIL
$3 * 10^{-2}$	TOTAL FAIL	TOTAL FAIL

* "IS-54" Digital Cellular Specification

11. FURTHER STUDY FOR MAC AND PHY

- We recommend in depth study of the above assumptions/calculations.
- Verification of all above tentative results.
- Are the assumptions, model and results accurate?
- If yes, gear "Shift Down" as well as gear "Shift Up" to **SEVERAL RATES** is probably justified.
- MAC/PHY **ISSUES** should be investigated.

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12. FLEXIBLE (MULTIPLE) RATE STANDARDS

- For higher speed (higher than 1 Mb/s) rate, we recommend the following flexible MAC/PHY design concept:
- All connectivity start with standardized FH-SS 1 Mb/s-GFSK

  1 Mb/s-GFSK start
  MAC to include the following higher data rates:

  1.4 Mb/s
  2 Mb/s
  3 Mb/s
  TBD Mb/s

  Lower data rates could include 700 kb/s and 500 kb/s.

13. JUSTIFICATION OF 1.4 Mb/s, 2 Mb/s, 3 Mb/s, ... TBD Mb/s FLEXIBLE (MULTIPLE) RATE STANDARD

- Previous most "ROBUST" proposals are limited to 1.4 Mb/s.
- Robust performance is essential [Silberman, Ref. 22].
- Robust performance as BER = $f_1(E_b/N_0) = f_2(C/I)$ is a must.
- Robust performance in **DELAY SPREAD** essential for higher speed FH-SS systems.
- NLA (nonlinear amplifier) - a practical requirement for standardized PCMCIA card for 1 Watt at 2.4 GHz with present technology. In future linear 16-QAM with 3 b/s/Hz could be practical.

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14. 1.4 Mb/s IS "FASTER" AND HAS REDUCED MESSAGE DELAY AS COMPARED TO 1.5 Mb/s

- Silberman [Wireless-1] [15] and [22]
- N. Chayat, Rothenberg [Lannair] [18] and [20]
- K. Feher [UC Davis & Digcom Consultants] [6] and [21]
- Kato [NTT] [2]
- Demonstrated that the NLA-1 Mb/s to 1.4 Mb/s solutions are about 3 dB to 4 dB more robust than the 1.5 Mb/s and higher rate solutions. Thus reduced message delay - increased throughput.
- Delay spread advantage of 1.4 Mb/s is a further justification to **ADOPT** 1.4 Mb/s as a minimum "higher bit rate" standard (instead of 1.5 Mb/s)

15. COHERENT DEMODULATION IS *MUCH* BETTER THAN NONCOHERENT

- Feher demonstrated in [6] and [13] that the performance of coherently demodulated systems is about 3 dB to 7 dB better than that of noncoherent systems (noise; interference; delay spread).
- Change of bit rate, e.g., from 1.4 Mb/s to 2 Mb/s or even 3 Mb/s in 1 MHz could be achieved simply by changing software/DSP of baseband processor.

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16. ARCHITECTURES TO ACHIEVE FLEXIBLE STANDARD RATES

- Transmit and receive "QUAD" offset based quadrature/coherent structures as described in references [6, 7, 13, 18, 21].
- "Offset" QPSK - OQPSK - extension OQAM essential for nonlinear (NLA) operation; linear operation (16-state) could be required for 3 Mb/s.
- Offset QPSK and offset QAM (OQAM) could achieve 1.4 Mb/s, 2 Mb/s and 3 Mb/s.
- FQPSK family of nonlinearly amplified modems (C-class) is fully compatible with OQPSK [6 to 21].

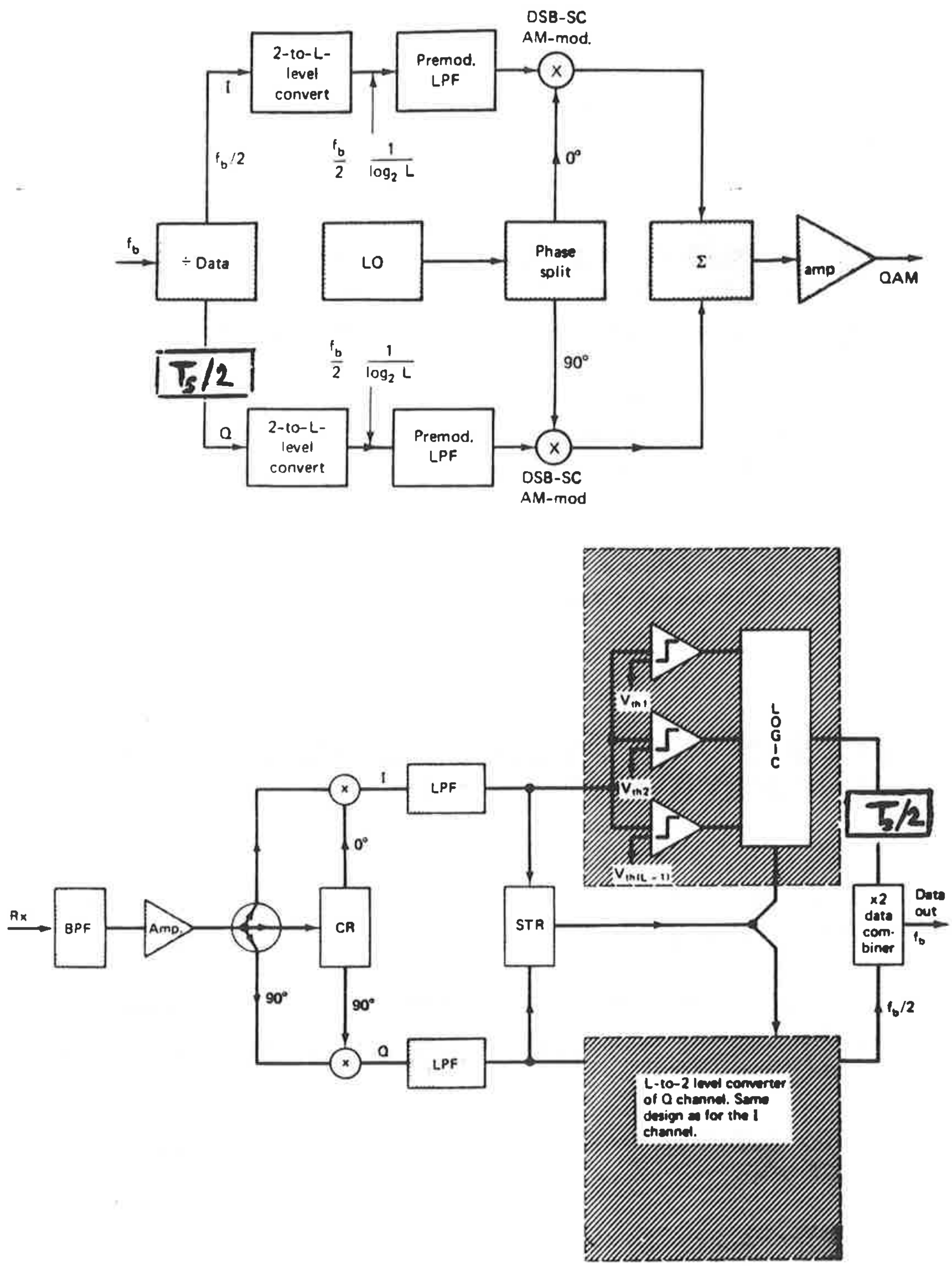

Fig. 1. Flexible bit rate/QUAD modulator/demodulator nonlinearly amplified (NLA) or linear offset OQPSK, constant envelope FQPSK and QAM systems for bit rates in the 1 Mb/s to 3 Mb/s range with BER = 10^{-5} for E_b/N_0 less than 16 dB [References: 1-13; 21].

17. RECOMMENDATIONS FOR FH-SS-MAC/PHY

1. MAC/PHY groups to incorporate flexible (multiple rate) design into standard higher bit rate specification.
2. Higher speed bit rates to include 1.4 Mb/s, 2 Mb/s, 3 Mb/s, and TBD Mb/s. (Exact bit rates to be finalized by Jan. 31, 1994).
3. Lower bit rates to be considered: 500 kb/s, 700 kb/s.
4. Adopt OQPSK and OQAM - coherent modulation format and their compatible FQPSK (as well as any other compatible methods) - as interim modulation structures for higher FH-DS standard.
5. Close proposals for new modulation formats during January - IEEE 802.11 meeting.
6. Proceed with higher data rate standardization details.

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