A COMPARISON BETWEEN COHERENT AND NONCOHERENT MOBILE SYSTEMS IN LARGE DOPPLER SHIFT, DELAY SPREAD AND C/I ENVIRONMENT

KAMIL FEHER
University of California, Davis; Davis, CA 95616
916-752-8127 or 916-752-0583; FAX 916-752-8428

ABSTRACT

The performance and implementation complexity of coherent and of noncoherent QPSK and GMSK modulation/demodulation techniques in a complex mobile satellite systems environment, including large Doppler shift, delay spread and low C/I, are compared. We demonstrate that for large $f_dT_b$ products, where $f_d$ is the Doppler shift and $T_b$ is the bit duration, noncoherent (discriminator detector or differential demodulation) systems have a lower BER floor than their coherent counterparts. For significant delay spreads, e.g., $\tau_{\text{rms}} > 0.4 T_b$ and low C/I coherent systems outperform noncoherent systems. However, the synchronization time of coherent systems is longer than that of noncoherent systems.

Spectral efficiency overall capacity and related hardware complexity issues of these systems are also analyzed. We demonstrate that coherent systems have a simpler overall architecture (IF filter implementation-cost versus carrier recovery) and are more robust in an RF frequency drift environment. Additionally, the prediction tools, computer simulations and analysis of coherent systems is simpler. The threshold or capture effect in low C/I interference environment is critical for noncoherent discriminator based systems.

We conclude with a comparison of hardware architectures of coherent and of noncoherent systems, including recent trends in commercial VLSI technology and direct baseband to RF transmit, RF to baseband (0-IF) receiver implementation strategies.

MODEM/RADIO ARCHITECTURES

In Fig. 1 a Quadrature (QUAD) modulator, nonlinearly amplified (NLA) modulator radio architecture is illustrated. The Baseband Processor (BBP) could implement conventional QPSK [6] $\pi/4$-DQPSK [1, 7] or Gaussian MSK, GMSK functions [6, 8]. In the baseband to RF implementation, a slow Frequency Hopped Spread Spectrum-TDMA application is illustrated. The demodulation could be coherent or differential (discrimination detection) as illustrated in Fig. 2 and Fig. 3, from Ref. [1].

DEFINITIONS

QPSK

$\pi/4$-QPSK

GMSK

F-QPSK

Conventional QPSK [6]

$\pi/4$-shifted QPSK - The standard modulation technique for IS-54-EIA standard [7] as well as for the Japanese digital cellular system.


Feher’s filtered QPSK [5, 6] for nonlinearly amplified systems. This modem/radio [2] doubles the capacity of European GMSK standard cellular/wireless systems.

PERFORMANCE

The $P(e) = f(E_b/N_0)$ performance in a Rayleigh faded channel is illustrated in Fig. 4. Note that the coherent F-QPSK system has a 7dB advantage over the noncoherent GMSK system filtered with $BT_b = 0.5$ [2]. The integrated out-of-band spectrum (ACI = adjacent channel interference), Fig. 5, indicates that F-QPSK is about 50% more spectrally efficient than GMSK. In Fig. 6 and Fig. 7 the performance in large Doppler log($f_D T$) and large delay spread environment is illustrated. Coherent and differential $\pi/4$-QPSK results are presented, based on [9]. These illustrative sample results are
summarized in Table 1, based on Ref. [1]. In this Table, a comparison of coherent-noncoherent GMSK and F-QPSK systems is presented.

REFERENCES


Fig. 1 Transmitter of a BB to RF radio for F-QPSK or GMSK nonlinear amplifier applications (slow frequency hopping-spread spectrum SFH-SS-TDMA) Ref. [1].
Fig. 2 Receiver with one IF stage for Coherent F-QPSK or GMSK systems (TDMA-TDD-SFH-SS) [Ref. 1].

Fig. 3 Differential Demod of a QPSK modem.
Fig. 4 BER of coherent F-QPSK and noncoherent GMSK BT=0.5 (DECT) in Rayleigh fading.

Fig. 5 ACI of F-QPSK and GMSK.  
F-QPSK: Butterworth BPF (4 ord), BiTb=.55  
GMSK: Gaussian BPF (4 ord), BiTb=0.6.

Fig. 6 P(e) vs. fDT of π/4-DQPSK in a frequency-selective fast fading channel.  
f_c=850 MHz, f_s=24 kBaud, α=0.2, C/I=∞ dB.  
(1) τ/T=0.1, C/D=10 dB, (2) τ/T=0.1, C/D=30 dB, (3) τ/T=0.5, C/D=10 dB, (4) τ/T=0.5, C/D=30 dB.

Fig. 7 Error-floors of the fade compensated π/4-QPSK and π/4-DQPSK in a frequency-selective fading channel as functions of C/D for τ=0.1T and 0.4T. The fading rate is assumed to be fDT=3×10⁻³.
Table I Coherent-Noncoherent GMSK and F-OPSK Comparison. Ref. [1].

<table>
<thead>
<tr>
<th>Maximal bit rate and delay spread $\tau_{\text{rms}}$ issues</th>
<th>COHERENT QPSK OR F-QPSK (or GMSK-similar, however worse performance.)</th>
<th>DIFFERENTIAL DQPSK (or DGMSK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{\text{rms}}$ “worst case” 1$\mu$s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\tau_{\text{rms}} = 200$ ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BER $= 10^{-2}$ floor due to $\tau_{\text{rms}}/T_s$</td>
<td>$\tau_{\text{rms}}/T_s = 0.2$</td>
<td>$\tau_{\text{rms}}/T_s = 0.15$</td>
</tr>
<tr>
<td>$P_{(e)} = C/I \text{ degrad}(\text{addit})$ of 1$\text{dB}$ due to $\tau_{\text{rms}}/T$ (4*$\text{more sensit. than for “floor”}$)</td>
<td>$\tau_{\text{rms}}/T_s = 0.075$ QPSK</td>
<td>$\tau_{\text{rms}}/T_s = 0.05$</td>
</tr>
<tr>
<td>Maxim. bit rate $f_b$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $10^{-2}$ Error Floor $1\mu$s[200ns]</td>
<td>600 kb/s [3 Mb/s]</td>
<td>300 kb/s [1.5 Mb/s]</td>
</tr>
<tr>
<td>for 1$\text{db}$ $\tau_{\text{rms}}$ caused degr. $1\mu$s[200ns]</td>
<td>150 kb/s [750 kb/s]</td>
<td>75 kb/s [375 kb/s]</td>
</tr>
<tr>
<td>CAPACITY ISSUES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASED ON C/I $= 3$ dB (CCI advantage)</td>
<td>BER=$10^{-2}$</td>
<td>BER=$10^{-2}$</td>
</tr>
<tr>
<td>150 kb/s [750 kb/s]</td>
<td>C/I-15dB (Rayleigh)</td>
<td>C/I=18dB</td>
</tr>
<tr>
<td>NORMALIZED RELAT. CAPACITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Based on $k = 9$ to $k = 7$ reuse</td>
<td>100%</td>
<td>70% (30% loss)</td>
</tr>
<tr>
<td>Based on WER and throughput</td>
<td>100%</td>
<td>20% (80% loss)</td>
</tr>
<tr>
<td>Spectral efficiency ACI and BPF versus LPF caused</td>
<td>100%</td>
<td>60%</td>
</tr>
<tr>
<td>advantage, i.e., lower noise BW-coherent receiver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(normalized to coherent)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased Bit Rate or Cell Coverage/Adaptive Equalization</td>
<td>Relatively simple/low cost DSP/SW adaptive equalizer could increase rate (coverage)</td>
<td>Very costly if at all feasible adaptive equalization technology (theory not well understood-requires original new research).</td>
</tr>
</tbody>
</table>
Table 1 (continued) Coherent-Noncoherent GMSK and F-OPSK Comparison.

<table>
<thead>
<tr>
<th></th>
<th>COHERENT QPSK</th>
<th>DIFFERENTIAL DQPSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit rate (PHY) change,</td>
<td>Automatic SW (software controlled) in BBP</td>
<td>Very difficult could require change of IF-BPF</td>
</tr>
<tr>
<td>without loss of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>performance (within</td>
<td></td>
<td></td>
</tr>
<tr>
<td>range)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral Efficiency for</td>
<td>F-QPSK = 1.42 b/s/Hz</td>
<td>Approx. 0.7 b/s/Hz depending on BPF complexity</td>
</tr>
<tr>
<td>ACI=-20dB nonlinearly</td>
<td>GMSK = 0.94 b/s/Hz</td>
<td></td>
</tr>
<tr>
<td>amplified radio</td>
<td>BTb = 0.5 and 0.98 b/s/Hz for BTb = 0.3</td>
<td></td>
</tr>
<tr>
<td>Synchronization Time (CR)</td>
<td>50 bits:1000 = 5% (max 100 bits = max 10%)</td>
<td>Potential of 1% to 10% packet/synch time advantage(?). However, could be lost due</td>
</tr>
<tr>
<td>(relative to no CR -</td>
<td>50 bits:10,000 = 0.5%</td>
<td>to BPF transient ringing. Synch. Time advantage could be lost due to DC comp. to</td>
</tr>
<tr>
<td>differential loss of</td>
<td>max 100 bits for CR=max.1%</td>
<td>sat. time requirement.</td>
</tr>
<tr>
<td>frame efficiency for</td>
<td>- a disadvantage. Parallel CR and STR design could eliminate this drawback.</td>
<td></td>
</tr>
<tr>
<td>1000 or 10,000 bit word</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(packet)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold capture effect</td>
<td>No problem</td>
<td>Potential problem in the critical BER = 10^-2 range with discriminator.</td>
</tr>
<tr>
<td>(discriminator-impulse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>noise)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tools (prediction)</td>
<td>Well known.</td>
<td>Much more involved as IF-BPF imperfect; impact of frequency tolerance GMSK BTb =</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3 very difficult.</td>
</tr>
<tr>
<td>RF-oscillator drifts</td>
<td>Simple.</td>
<td>Very costly - potential danger like in DECT.</td>
</tr>
<tr>
<td>include synthesize -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>impact on BER - DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>restoration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional down</td>
<td>Not required.</td>
<td>Very costly, extra stage could be required due to lower IF and BPF problems.</td>
</tr>
<tr>
<td>conversion/filters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrier Recovery</td>
<td>Yes. Simple pilot in band and other Costas ... well-known techniques. No</td>
<td>No need for CR. Advantage</td>
</tr>
<tr>
<td>Requirements</td>
<td>Doppler problem. Low power solution. GSM, ADC other cellular have it.</td>
<td></td>
</tr>
<tr>
<td>DC power-extra for CR</td>
<td>Could be marginally higher for demand alone.</td>
<td>Discriminator power requirement is smaller than coherent. However, DC battery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>power advantage could be lost due to LO or synthesizer-DC compensation requirement.</td>
</tr>
<tr>
<td>IC Chips-Trend</td>
<td>Most manufact. companies developing QUAD (coherent struct.)</td>
<td>Noncoherent discrim. today cheaper however overall radio extra IF, BPF, DC</td>
</tr>
<tr>
<td>Overall Cost/DC</td>
<td></td>
<td>compensation not evident.</td>
</tr>
<tr>
<td>Power estimate</td>
<td>About same as noncoherent receiver (total radio) with new technology.</td>
<td>About same.</td>
</tr>
<tr>
<td>RF Frequency</td>
<td>Same architecture for both RF frequencies</td>
<td>Could require in some applications extra expensive IF stage (space/cost) does not</td>
</tr>
<tr>
<td>900MHz 1.9GHz, 2.4GHz</td>
<td>Flexible bit rate</td>
<td>lead to software driven bit rate change</td>
</tr>
<tr>
<td>Bit Rate Variation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>