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PERFORMANCE ANALYSIS OF QPRS THROUGH A MICROCELLULAR RADIO CHANNEL

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ABSTRACT

This paper investigates the performance of quadrature partial response signaling (QPRS) scheme in a multipath fading channels, with emphasis on microcellular radio channel. The channel is assumed to be Rician fading channel subject to cochannel interference. Perfect synchronization has been assumed. The results are compared with that of the quadrature phase shift keying (QPSK) subject to the same environments. For QPSK a raised-cosine pulse of 0.235 roll-off factor has been used with a corresponding spectral efficiency of 1.62 b/s/Hz. The effect of cell splitting and cell sectorization are also considered. Performance is derived and computed analytically in terms of the bit error probability as a function of the number of time division multiplexing (TDM) users in the digital microcellular radio channel. Results show that the QPRS scheme performs better than the QPSK signaling scheme whenever the transmission is subject to multipath fading and cochannel interference, which is the case for microcellular radio channels.

I. INTRODUCTION

Due to rapid growth in demands for mobile communications available frequency bands are becoming crowded. Suitable choice of efficient digital modulation techniques provides one means of achieving improved spectrum efficiency. One of such techniques is the quadrature partial response signaling (QPRS).

Partial response signaling (PRS) is a practical means of achieving the theoretical maximum symbol rate packing of 2 bits/sec/Hz, for binary transmission, using realizable and tolerant filters. Another unique feature of PRS schemes is that errors can be detected without introducing any redundancy into the original data stream at the transmitter [1-3].

The performance of PRS operating in many channels exhibiting Gaussian noise and other interference environments has been investigated by number of researches [4-8]. However, work is still required to investigate the performance of QPRS in other important channels such as microcellular radio channel where multipath reception can affect the signaling performance. This will be the objective of the present paper.

Microcellular systems are characterized by the small cell size and steel-lamp-level antennas. Such configurations imply a different radio channel model as compared to the one usually assumed in classical cellular systems with large cells and highly elevated antennas.

The paper is organized as follows: Section II describes the system model. Section III provides the system analysis. Section IV provides the results. Section V gives the conclusion.

II. System Model

The model under consideration is shown in Fig. 1. The transmitted signal s(t) is subjected to cochannel interference from the neighbor clusters as well as AWGN n(t).

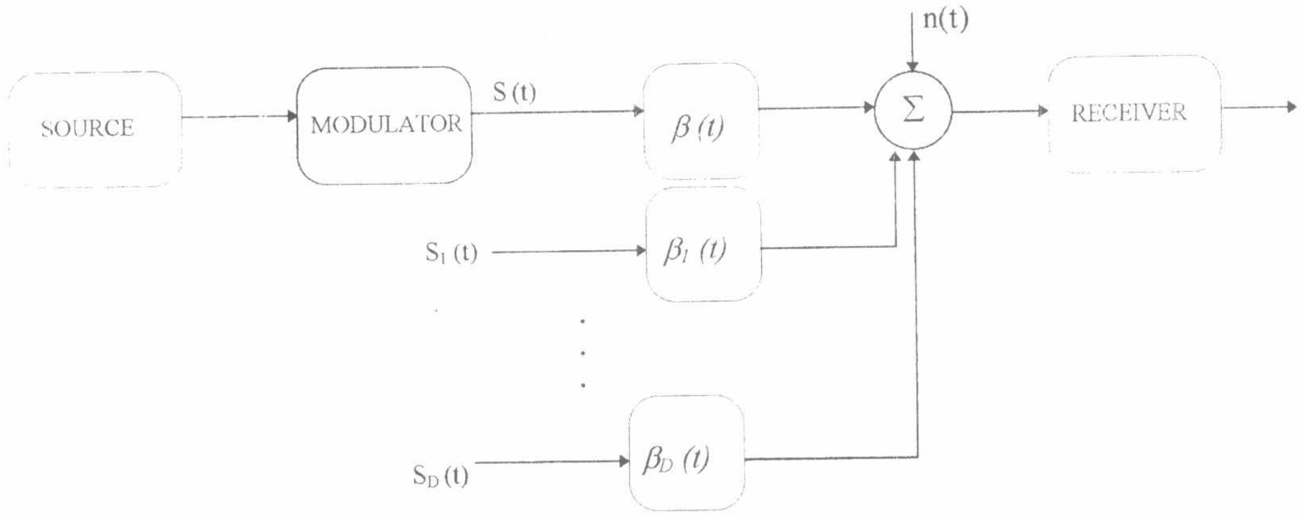


Figure 1. Communication System Model

The low pass channel impulse response $\beta(t)$ is assumed to be a superposition of the dirac delta function $\delta(t)$, corresponding to the specular component, and a zero-mean complex Gaussian process h(t) corresponding to the time dispersive signal component.

$$\beta(t) = \alpha\, \delta(t) + \zeta\, h(t) \tag{1}$$

Where α and ζ are the attenuation of the specular and multipath components respectively. h(t) is assumed to be a wide sense stationary with the following property

$$E[\, h_i(t_1)\, h_j^*(t_2)\,] = \begin{cases} 2\, \eta_j(t_1)\ \delta(t_1 - t_2) & i = j \\ 0 & i \neq j \end{cases} \tag{2}$$

where $\eta_j(t)$ is the multipath intensity profile between the base station and the j[th] mobile receiver. To simplify the analysis, a common rectangular multipath intensity profile defined as

$$\eta_j(t) = \frac{1}{2T_o} \qquad for \quad |t| \leq T_m \tag{3}$$

is assumed, where T_m represents a two sided maximum dispersion and T_o is an arbitrary scaling factor.

III. System Analysis

In QPRS, the in-phase and quadrature components of QPSK are modulated with partial response coders, the resulting signal constellation is a 3x3 rectangular with nine signal states. The transmitted signal is given by

$$S(t) = Re\,[A\, c(t)\, e^{j w o t}\,] = Re\,[A\,(c_c(t) + j\, c_s(t))\ e^{j w o t}\,] \tag{4}$$

where A is the signal amplitude and w_o is the carrier frequency in rad/sec. $c_c(t)$ and $c_s(t)$ are the in-phase and quadrature phase-components of the QPR baseband signal respectively, where

$$c_c(t) = \sum_{-\infty}^{\infty} a_i \, p(t - iT) \quad ; \qquad a_i \in \{-2, o, +2\}$$

$$c_s(t) = \sum_{-\infty}^{\infty} b_i \, p(t - iT) \quad ; \qquad b_i \in \{-2, o, +2\} \tag{5}$$

For duobinary signal transmission the Fourier transform of the pulse signal $p(t)$ has the form

$$P(f) = \begin{cases} \frac{1}{w} exp(\frac{-j\pi f}{2w}) cos(\frac{\pi f}{2w}) & , |f| \leq w \\ 0 & , |f| > w \end{cases} \tag{6}$$

where w is the channel bandwidth. The received signal can be put into the form

$$r(t) = r_1(t) + r_2(t) + r_3(t) \tag{7}$$

with r_1 (t), r_2 (t) and r_3 (t) represent the desired signal, the cochannel interference signal and the channel noise respectively. The desired received signal component $r_1(t)$ is given by

$$r_1(t) = Re\,[\alpha A\, c(t) + \zeta A \int_{-\infty}^{\infty} h(t)\, c(t - \tau)\, d\tau \; e^{jw_o t}] \tag{8}$$

The first term corresponds to the specular component while the second term corresponds to the multipath component. The received cochannel interference signal $r_2(t)$ which represents the interference of D cochannel signals from neighbor clusters is given by

$$r_2(t) = \sum_{l=1}^{D} Re\,[\rho_l\,(\alpha_l A\, c_l(t - \tau_{ol}) + \zeta_l A \int_{-\infty}^{\infty} h(\tau_l)\, c_l(t - \tau_{ol} - \tau_l)\, d\tau_l)\, e^{j(w_o t + \theta_l)}] \tag{9}$$

where ρ_l is the square root of the cochannel interference to desired signal powers ratio, τ_{ol} is the delay of the specular component of the cochannel interference relative to the specular component of the desired signal and θ_l is a random phase of the cochannel interference signal uniformly distributed in the interval $[o, 2\pi]$. Similarly, the lth baseband cochannel interference signal is given by

$$c_l(t) = c_{lc}(t) + j\, c_{ls}(t) \tag{10}$$

where

$$c_{lc}(t) = \sum_{i=-\infty}^{\infty} a_{li}\, p(t - iT) \quad ; \qquad a_{li} \in \{-2, o, +2\}$$

$$c_{ls}(t) = \sum_{i=-\infty}^{\infty} b_{li}\, p(t - iT) \quad ; \qquad b_{li} \in \{-2, o, +2\} \tag{11}$$

The output g_{Im} of the integrate and dump receiver due to the desired signal multipath component over the I channel is a zero mean with conditional variance

$$Var\,[g_{Im}/c] = (\frac{4}{\pi})\, \alpha^2 A^2\, \gamma^2\, T^2 S\, [\,\overline{(a_o^2 + b_o^2)}\,(1 - S + \frac{S^2}{3}) + \overline{(a_1^2 + a_{-1}^2 + b_1^2 + b_{-1}^2)}\,(\frac{S^2}{6})$$
$$+ \overline{(a_o(a_1 + a_{-1}) + b_o(b_1 + b_{-1}))}\,(\frac{S}{2} - \frac{S^2}{3})] \tag{12}$$

where the conditional s over all possible values of the received sequence c. S is the normalized multipath time spread and γ is the ratio of the multipath attenuation coefficient ζ_l to the direct path attenuation coefficient α. a_{-1}, a_o, a_{+1}, and b_{-1}, b_o, b_{+1}, are the values of the QPR baseband signal over the I and Q channel respectively. Taking into consideration the independent nature between the received multipath signals, the output g_{Ics} of the integrate and dump receiver due to the specular component of the cochannel interference over the I channel is a zero mean random variable with variance

$$Var[g_{Ics}] = (\frac{4}{\pi}) A^2 E[\sum_{l=1}^{D} \rho_l^2 \alpha_l^2 \{\cos^2\theta_l (a_{l0}(T+\tau_{ol})-a_{l1}\tau_{ol})^2 + \sin^2\theta_l (b_{l0}(T-\tau_{ol}) - b_{l1}\tau_{ol})^2\}] \quad (13)$$

Taking into account the correlation that exists among successive partial response symbols, we get

$$Var[g_{Ics}] = (\frac{16}{7\pi}) A^2 T^2 \sum_{l=1}^{D} \rho_l^2 \alpha_l^2 \quad (14)$$

This is the form for shadowing (cellular radio) where α_l is a random variable with lognormal distribution However for microcellular radio α_l is unknown constant, i.e. $\alpha_l = \alpha$ for all l. Then

$$Var[g_{Ics}] = (\frac{16}{7\pi}) A^2 T^2 \alpha^2 \sum_{l=1}^{D} \rho_l^2 \quad (15)$$

Defining F_c as the average cochannel interference to desired signal powers ratio, we get

$$Var[g_{Ics}] = (\frac{16}{7\pi}) A^2 T^2 \alpha^2 F_c \quad (16)$$

Similarly, if g_{Icm} denotes the output due to the multipath component of the cochannel interference then for microcellular radio we have

$$Var[g_{Icm}] = (\frac{16}{7\pi}) A^2 T^2 \alpha^2 S \gamma^2 F_c \quad (17)$$

Combining the variances of the cochannel interference specular and multipath components, we get

$$Var[g_{Ic}] = (\frac{16}{7\pi}) A^2 T^2 \alpha^2 F_c (1 + S\gamma^2) \quad (18)$$

Since at the receiving side the channel noise, of zero mean and variance ($N_oT/2$), as well as both the ISI and the cochannel interference components can be approximated by Gaussian random variables, thus the probability of error can be represented by the Q-function integral form [10]. Due to the correlation nature between successive partial response sequences only certain types of transmissions are allowed. For duobinary signal transmission, this condition can be summarized in the following two rules:

1- If a positive (negative) peak is followed by a negative (positive) peak, they must be separated by an odd number of center samples (zeros).
2- If a positive (negative) peak is followed by a positive (negative) peak, they must be separated by an even number of center samples (zeros).

Taking this into consideration when averaging the probability of error over all possible sequence combinations, the average BER will finally be

$$p(\varepsilon)=(\frac{1}{1024})[16Q([\frac{ab}{1+V}]^{1/2})+64Q([\frac{ab}{1+ab\gamma^2[12I_3]+V}]^{1/2})+16Q([\frac{ab}{1+ab\gamma^2[8I_1]+V}]^{1/2})$$
$$8Q([\frac{ab}{1+ab\gamma^2[16I_3]+V}]^{1/2})+128Q([\frac{ab}{1+ab\gamma^2[4I_3]+V}]^{1/2})+24Q([\frac{ab}{1+ab\gamma^2[2(I_1+2I_3)]+V}]^{1/2})$$
$$+160Q([\frac{ab}{1+ab\gamma^2[8I_3]+V}]^{1/2})+96Q([\frac{ab}{1+ab\gamma^2[4(I_1+I_3)]+V}]^{1/2})+48Q([\frac{ab}{1+ab\gamma^2[4I_1]+V}]^{1/2})$$
$$+8Q([\frac{ab}{1+ab\gamma^2[4(I_1+3I_2+3I_3]+V}]^{1/2})+24Q([\frac{ab}{1+ab\gamma^2[4(I_1+I_2+3I_3)]+V}]^{1/2})$$
$$+12Q([\frac{ab}{1+ab\gamma^2[4(4I_1+8I_2+8I_3)]+V}]^{1/2})+Q([\frac{ab}{1+ab\gamma^2[4(I_1+4I_2+4I_3)]+V}]^{1/2})$$
$$+48Q([\frac{ab}{1+ab\gamma^2[4(I_1+I_2+I_3)]+V}]^{1/2})+32Q([\frac{ab}{1+ab\gamma^2[4(2I_1+I_2+I_3)]+V}]^{1/2})$$
$$+24Q([\frac{ab}{1+ab\gamma^2[8(I_1+I_2+I_3)]+V}]^{1/2})+6Q([\frac{ab}{1+ab\gamma^2[4(I_1+2I_2+4I_3)]+V}]^{1/2})$$
$$+96Q([\frac{ab}{1+ab\gamma^2[4(I_1+I_2+2I_3)]+V}]^{1/2})+24Q([\frac{ab}{1+ab\gamma^2[4(I_1+2I_2+3I_3)]+V}]^{1/2}) \quad (19)$$

where "a" denotes the average signal to noise ratio given by

$$a=\frac{\alpha^2 A^2 T}{N_o/2} \quad (20)$$

and $b=(\frac{\pi}{8})^2 a$, $V=(\frac{\pi}{4})^2\frac{a}{7}F_c[1+\gamma^2 s]$ (21)

$$I_1=s-s^2+\frac{s^3}{3}, I_2=s^2(\frac{1}{2}-\frac{s}{3}), I_3=\frac{s^3}{6} \quad (22)$$

IV. Results

Bit error performance results are illustrated in terms of the number of TDM users in digital microcellular radio channel. For comparison purposes the performance of QPR is compared with that of QPSK for the same system environment [4]. For QPSK a raised-cosine pulse of 0.235 roll-off factor has been assumed with a corresponding spectral efficiency of 1.62 b/s/Hz. Also to illustrate the results, we have calculated the average signal-to-cochannel interference ratio ($1/F_c$) , table 1, for hexagonal-shaped cells of cluster sizes k= 3 and 7 and for propagation constant ρ= 3.6. Omnidirectional, 120° and 60° sectorals antennas with 20 dB front-to- back (F/B) powers ratio have been considered. In this calculation, the worst-case cochannel interference has been assumed. Results are shown for a typical measured values of random to specular signal power ratios γ^2 = 0.2 (-7 dB).

Transmission direction	Cluster size	Omnidirectional antenna	120° directional antenna	60° directional antenna
Mobile-to-base transmission	3	7.71413	13.2973	17.7769
	7	15.4225	21.2637	26.0488
Base-to- mobile transmission	3	3.0556	6.0659	7.8268
	7	12.2695	17.0407	20.0510

Table 1. Average signal-to- cochannel interference ratio ($1/F_c$) for propagation constant ρ=3.6 and front-to-back power ratio F/B=20 dB.

Figure 2. QPRS and QPSK performances in microcellular racio for $\gamma^2 = 0.2$, 60° sectoral antenna, and for different clusters sizes.

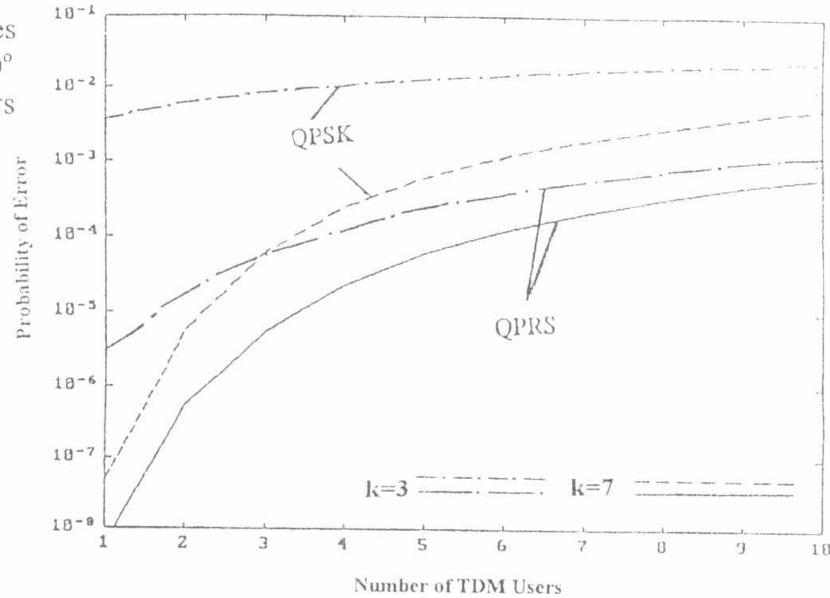


Figure 3. QPRS and QPSK performances in microcellular radio for $\gamma^2 = 0.2$, K=7, and for different cell sectorization.

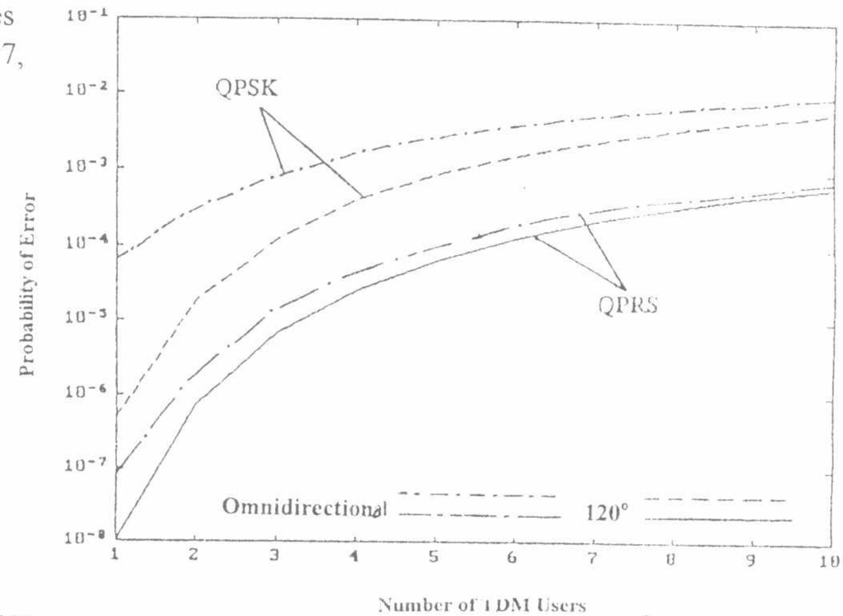


Figure 4. QPRS and QPSK performances in microcellular radio for K=7, 60° sectoral antenna, and for different channel severity.

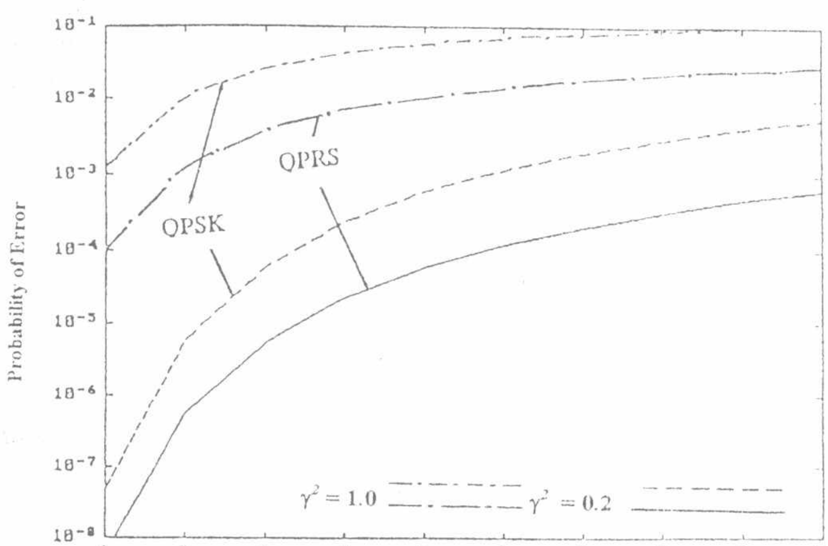


Figure 5. QPRS and QPSK performances in microcellular radio for γ^2 = 1.0, 60° sectoral antenna, and for different clusters sizes.

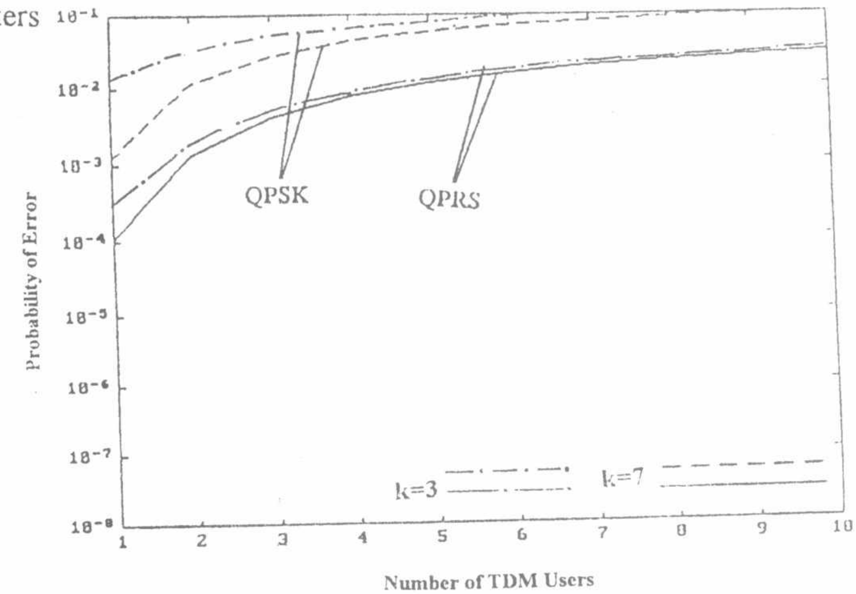
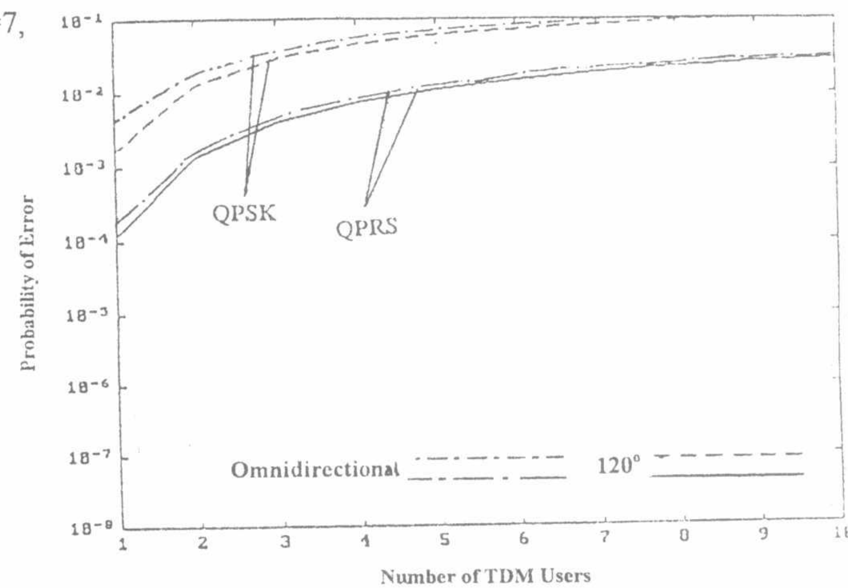


Figure 6. QPRS and QPSK performances in microcellular radio for γ^2 = 1.0, K=7, and for different cell sectorization.



As shown in the given Figures, QPRS outperforms QPSK signaling whenever the transmission is subjected to multipath fading and cochannel interference, which is the case for microcellular radio channels.

Fig. 2 shows how much the performance is affected by changing the cluster size where clusters of sizes 3 and 7 are chosen with all other parameters being fixed. As shown in the Figure, the performance of both schemes is improved by increasing the cluster size.

Fig. 3 shows how much the performance is affected by cell sectorization, results are provided for omnidirectional, and 60° sectoral antennas with all other parameters being fixed. As shown in the Figure, cell sectorization improves the performance of both signaling schemes.

Fig. 4 shows how much the performance is affected as the channel becomes more severe. Results are given for $\gamma^2 = 0.2$ and 1.0 with all other parameters being fixed . As shown in the Figure, the performance of both schemes is highly affected as the channel becomes more severe.

Fig. 5 and Fig 6 show how much the performance is affected by changing the cluster size and the cell sectorization respectively, as the channel becomes more severe ($\gamma^2 = 1.0$). One should notice that as the channel becomes more severe the ISI highly dominates the cochannel interference and therefore cell splitting and sectorization become useless.

Finally, we should also notice that all the previous results are obtained for a noncoded systems. However by employing suitable kind of channel coding as well as interleaving the situation may be changed.

Conclusion

This paper investigates the performance of QPRS in a microcellular radio chann where the channel is subjected to multipath fading and cochannel interference. The obtair results are compared with that of the QPSK subject to the same environments. Res s show that QPRS has better performance compared with QPSK signaling scheme an he performances of both schemes are improved by cell splitting and sectorization. / the channel becomes more severe, the ISI highly dominates the cochannel interferer and therefore cell splitting and sectorization become useless.

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