

## Capacity and Variable Data Rate for Wireless Communications

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### Abstract:

The general trend in wireless technology development is to increase communication capacity for mass market. The propagation problem and limited frequency spectrum still exist. How to achieve the goal of the wireless technology is an important issue. In this work we study the trade off between interference and variable data rate of a typical DPSK link. The objective is to find out what data rate is tolerable for message services under interference. From the study it is realized that interference is the most important issue involved in any multiple access systems. To account for more accurately the relationship between variable data rate and capacity it is also necessary to discuss the quality of service (QOS). This can be either at the link level, i.e. BER or at a higher level such as outage probability. Simulation results showed multipath fading interference has a detrimental effect on single channel data rate. A simple analysis is done to show user capacity, QOS and power management in an uncoordinated multiple access system.

### Introduction:

Wireless technology has been the focus of attention lately. Communication industry combined with digital computer industry will be the foundation of its progress. New wireless technology is supposed to provide personal based services either voice, data, fax, or image in an ubiquitous (tetherless) networks any time and any place. This development includes digital cellular telephone, wireless wide or local area networks, narrow band land mobile radio, and mobile satellite services. The *last mile* of this national information infrastructure (NII) or information highway has to allow user roaming.

Consequently, the *last mile* has to go through either IR or radio wave. Radio wave sharing/multiple access is a very important issue in this effort. Two important issues are involved in shared media. One is the capacity limitation, and the other is interference. If wireless ever reaches mass market, the medium must have enough capacity to accommodate the traffics. Due to shared use of medium there is serious interference problem in the system.

The need to differentiate total capacity and user capacity in an area will be discussed. A total capacity conjecture shows much similarity to Shannon channel capacity with the exception of area interference as an important factor. Interference sources are introduced to show the origination of the problems. Three kinds of interferences are of interests in this work: passive inter modulation (PIM), channel fading, and multiple access interferences. Simulation results showed the trade off limitation between variable data rate and BER in a Rician fading channel. Examples in TDMA/DAMA systems and power control in both GSM and CDMA were described. A simple analysis is presented here to show the nonlinear relationships among User capacity, Power, and QOS.

### Total Capacity Conjecture:

There is a Shannon -Hartley Capacity Theorem for a "Single" Channel.

$$C_S = W \log_2 (1 + S / N)$$

It is possible to transmit at data rate  $R < C_S$  with arbitrary accuracy by using complicated code. Even today people still are searching for new codes.

For a wireless application, it necessary to consider an area, and consider the total capacity

instead of the channel capacity. We need to consider channel Reuse in a Coverage Area (cellular structure perhaps) Let's assume that:

Cell area A:  $\text{km}^2$ .

Active transmitter density in A is  $\rho$  : # /  $\text{km}^2$ .  
The number of channels available: N

Reuse factor of the channel is  $R_U = (\rho A) / N$ .  
High reuse factor R is desirable, but usually  $R_U < 1$ . For a FDMA (current cellular AMPS) system  $R_U = 1 / 7$ . Reuse factor  $R_U$  is really a channel usage measure for a multiple access system. One example is the TDMA cellular (IS-54) where  $R_U = 3 \times (1 / 7)$ .

Assume that there are J transceivers in the Cell. Each transceiver pair involves a data rate  $R_j$ .  
The total Data Rate of the area is  $R_a = \sum_j R_j$   
Total Capacity is related to the  $R_a$ . A total capacity conjecture can be formulated as follows.

There is a total Capacity limit  $C_t$  such that it is possible to "push bits" at total data rate  $R_a < C_t$  with adequate quality (QOS, or BER) using complicated access systems. People are interested in searching them since 1985.

$$C_t = \text{Funct} (NW, S, N, ?)$$

N: Number of channels in area.

W: channel bandwidth.

S: Signal Power.

N: Noise power.

$C_t$  is not  $N \times C_s$ . The Noise is not AWGN. The "?" in  $C_t$  function defined above is the worst kind of factor, "Interference", caused in a multiple access system. This will reduce the total capacity limit for a specific access system.

### Interference Sources:

There are several kinds of interference sources.

Intentional jamming.

RFI from nearby antenna.

Sidelobe radiation from remote transmitter.

Passive inter modulation product (PIM).

Channel Interference (multipath fading).

Multi-access users (FDMA, TDMA, & CDMA).

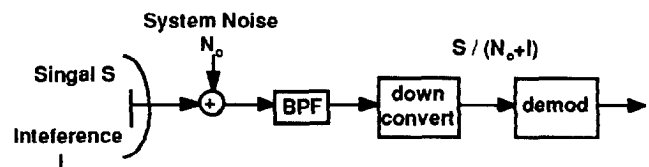
Simulation results of channel interference will be presented here. Simulating multiple access

interface is more difficult because most commercial simulators do not support this kind of study.

PIM is caused by nonlinear processes in current carrying metal-to-metal junctions, micro discharges in voids, etc.. It can also be generated by nearby transmitters and one's own transmitter. Another possibility is from the RF unit of a multi-mode and multi-band receiver (SPEAKEASY) due to the simultaneous active channels. They are in forms of CW or noise.

In frequency division multiple access (FDMA) system inter modulation (IM) is caused by hard limiting transponders. Cochannel interference at the edge of cells may also occurred. In code division multiple access (CDMA) system interference between mobiles is due to offset in chip code synchronization.

A general Communication Receiver in the presence of Interference can be modeled as.



$P_b$  is a function of  $S / (N_o + I)$

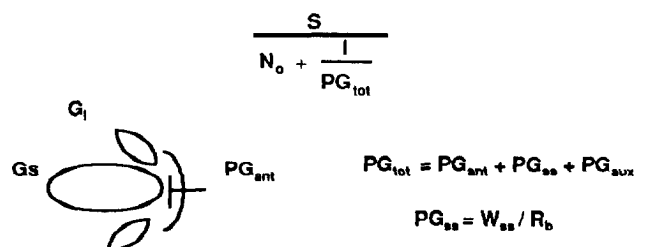
Fig. 1. General Communication Receiver with Interference.

The mitigation techniques used to counter interference are:

Antenna techniques.

Spread spectrum techniques.

Auxiliary suppression techniques.



As you can see that additional gain can reduce the effects of interference.

### Baseband Simulation on Rician Fading Channels:

Here, a link of DPSK modulation and demodulation was examined. There is a cosine pulse shaping with 32 samples/symbol in the signal. The channel has a Rician factor K which is the ratio of direct path energy versus diffused path energy. The diffused path delay is 0.25 of symbol time  $T_s$ . The diffused path bandwidth is 0.01 cycles / symbol. The BER with respect to increasing symbol energy is plotted in Fig. 2.

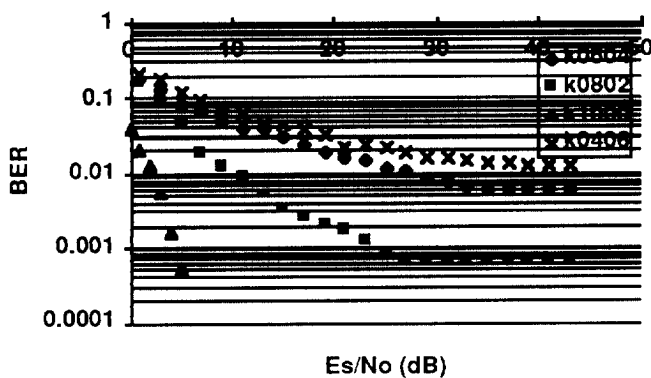


Fig 2. BER of a Rician Channel with different diffuse ratio K.

As can be seen from the results shown in Fig. 2, increase symbol power by slowing down data rate will reach a diminishing return point for different K's. The heavier the interference, the earlier the diminishing return point reached.

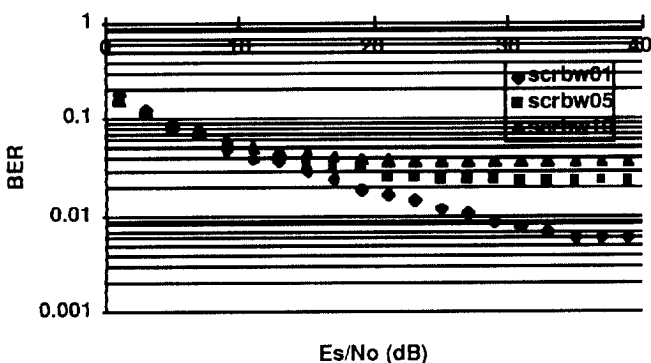


Fig. 3 BER of a Rician Channel with different Scattering Bandwidth.

If we vary instead of the K factor but the scattering bandwidth of the Rician channel. The same diminishing return points exist also as shown in Fig. 3. For wider bandwidth of scattering the saturation points occurred earlier.

It simply says that if the fading channel is bad it is counter productive to slow down the data rate because it will generate more noise to cochannel receivers.

### Variable Data Rate Example:

The existing military UHF FLTSAT system has a new TDMA-Demand Assign Multiple Access (DAMA) standard (MIL-STD 188-183). The system estimates the actual link quality ( $C / N_0$ ) for the assigned time slot in the channel. A ground base signal is usually strong. Therefore, a higher data rate will be used for that time slot burst. An airplane signal may be weak so that a slower rate will be chosen according to,

$$C / N_0 = E_b / N_0 + 10 \log_{10} R_b$$

Depending on the signal strength, it closes the link budget by adjusting "burst rate" in time slot for each channel. This is an example where varying data rate is used to maintain link quality (BER).

### Power Control in GSM:

In European GSM digital cellular system as the mobile moves around within the cell, its transmitter power need to be varied [2]. When it's close to the base station, power levels are set low to reduce the interference to other users. When the mobile is further away, its power level need to increase to overcome the pass loss. A base station (BS) commands the mobiles to a particular power level (2 dB / step, 16 steps). This an example where power control is used to reduce cross channel interference in a wide band base station receiver.

### Power Control for Variable QOS in CDMA:

In Yun's work a scheme to control power for various QOS of multiple substreams were proposed [3]. A statistical multiplexer will collect many substreams. Power assigned to the

substream are negotiated based on the QOS requirements and the total interference in the CDMA multi access system. The substream will be allowed or not allowed to transmit depending on some constraint with power control.

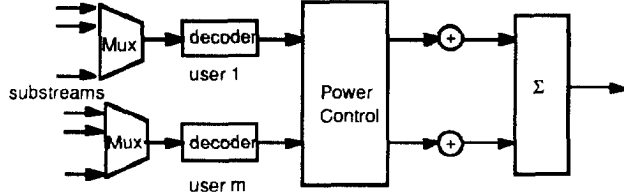


Fig. 4 Statistical Multiplexer and Power Control.

In this study the sum of interference from other user and multiple propagation path are assumed to be AWGN.

- $K = \#$  of substreams.
- $(E_b/N_0)_i =$  QOS required by the substream  $i$ .
- $b_i = 1$  or  $0$  depending on whether allowed or not allowed to transmit in current time slot.
- $x_i =$  power assigned to substream  $i$ .
- $p =$  total power.
- $N =$  processing gain.
- $\sigma_i =$  intercell interference.

The approach is to: Minimize  $p$   
subject to  $Nx_i / (\sigma_i^2 + \sum_{k \neq i} \beta_k x_k) \geq (E_b/N_0)_i$

Specific steps for adding new streams are also suggested. This is an example where variable QOS permit optimal operation of CDMA with appropriate power control.

### Capacity, Interference, and QOS in an Uncoordinated Multiple Access Area:

Assume there is a base station and a terminal separated by distance  $r$  is looking for a "clear channel" to communicate. There are  $N$  channels available, and there are  $\rho$  sources active in the area.

$$R_u = \frac{(\rho A)}{N}$$

Obviously if there are no interference, reuse factor  $R_u$  is one, Because of cochannel interference  $R_u$  is generally less than one. Area user capacity  $C_a$  in this case is really  $\rho A$ .

For the lack of particular details assume that the area is a circle of radius  $r$  centered around base station. Consider the probability that carrier power to noise ratio  $C/I$  falls below threshold  $\Gamma$  on all channels. This is regarded as outage probability  $P_o$ ,

$$P_o = P\{I_{\min} > C/\Gamma\} = P\{C < I_{\min} \cdot \Gamma\}$$

The carrier power received by the base station is,

$$C = V \cdot \alpha \cdot r^{-\gamma}$$

Where  $\alpha$  is the received power at unit distance.  $V$  is the factor counting for channel fading which is a random process. For terrestrial propagation  $\gamma$  is in the range of 3 to 4. The outage probability then becomes,

$$P_o = P\{V \cdot \alpha \cdot r^{-\gamma} < I_{\min} \cdot \Gamma\}$$

$$P_o = P\left\{V < \frac{I_{\min}}{\alpha} \cdot r^\gamma \cdot \Gamma\right\}$$

$$P_o = P\left\{V < \frac{I_{\min}}{\alpha \left(\frac{\pi \rho}{N}\right)^{\gamma/2}} \left[\frac{\pi \rho}{N}\right]^{\gamma/2} \cdot r^\gamma \cdot \Gamma\right\}$$

$$P_o = P\left\{V < \frac{I_{\min}}{\alpha \left(\frac{\pi \rho}{N}\right)^{\gamma/2}} \left[\frac{\pi r^2 \rho}{N}\right]^{\gamma/2} \cdot \Gamma\right\}$$

From our previous derivation, the reuse factor  $R_u$  is,

$$R_u = \frac{\pi r^2 \rho}{N}$$

Let the normalized interference power be  $I'_{\min}$ ,

$$I'_{\min} = \frac{I_{\min}}{\alpha \cdot \left[\frac{\pi \rho}{N}\right]^{\gamma/2}}$$

Therefore, the outage probability becomes,

$$P_o = P\{V < I'_{\min} \cdot R_u \cdot \Gamma\}$$

This outage probability is a combination of two random processes: The fading process  $V$  in the carrier power  $C$  and the cochannel Interference process  $I'_{\min}$ . There are two ways to interpret this result.

If the variation of interference  $I'_{\min}$  is small, it can be considered as a constant  $I_o$ . To achieve a certain small outage probability  $P_o$  it is necessary to choose a small  $r$  so that the  $P_o$  will be within bound. A small  $r$  really means a smaller reuse factor  $R_u$ .

If the fading factor variation of  $V$  is small, it can be considered as a constant  $V_o$ . The outage probability becomes,

$$P_o = P\left\{I'_{\min} > \frac{V_o}{R_u \gamma^{1/2} \cdot \Gamma}\right\}$$

In order to find the outage probability  $P_o$  it is necessary to find out the probability of interference  $I'_{\min}$ . Padgget used Monte Carlo technique to find the CDF of the interference, and compare it with published works [1].

From the above derivation it is possible to say that increasing the reuse factor  $R_u$  will generally increase the interference  $I'_{\min}$  and consequently, deteriorate the outage probability  $P_o$ . Therefore, varying power by adjusting data rate to achieve higher user capacity always has to consider QOS.

### Conclusion:

Our study begin with the following questions:

How is area user capacity related to interference in a multiple access system? What is the trade off between interference and variable data rate? Can variation of data rate increase user capacity? Is BER the appropriate quality of

service (QOS) measurement in a multiple access system? What management methodology can be used to increase user capacity?

Area user capacity has to be associated with QOS in our study. Interference is the major factor in consideration of area user capacity. Variable data rate is a means to control signal power. Too low data rate may induce more self interference. With coordinated power control varying data rate may increase area user capacity. Analytic solutions to these problems are difficult. To evaluate multiple access system higher level measure such as outage probability are more appropriate. Coordinated management for power need to involve variable data rate and variable quality of service (QOS).

The issue related to capacity limitation for the last miles of the NII is very important. The contemporary idea of increased total capacity is to limit the radiated power of the mobile stations. The effective radiation area of a base station is referred to as cells. Decreasing the cells to macro cell (<4 km) of cellular telephone system, micro cell (<1 km) of personal communication system (PCS) / personal communication networks (PCN), or even pico cells in a building is the trend. In our study when cell size is decreased, the interference will increase. The usual idea is to maintain the fixed service at the fixed rate. If lower data rate of service is tolerable, how much interference can you tolerate? How much capacity increase can be realized if variable data rate is allowed?

Searching answers of these issues is still going on.

### Reference:

1. J.E. Padgett, "Capacity Analysis for Unlicensed Wireless Communications", Proceeding of MILCOM94, Oct. 1994.
2. T. Haug, "Overview of GSM: Philosophy and Results", International Journal of Wireless Information Networks, vol. 1, No. 1, 1994.
3. L.C. Yun, "Power Control for Variable QOS on a CDMA Channel", Proceedings of MILCOM94, Oct. 1994.