Optimizing a 3G Cellular Wireless Network using Forward Error Correction

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Abstract—This paper presents Forward Error Control as a technique for controlling errors in packet transmission to guarantee maximum throughput in a 3G cellular wireless network. Packet Error Probability model without Forward Error Control (FEC) depicts the probability of error rate for the existing system. Then the Packet Error Probabilities (PEP) for both systems, that is (with and without Forward Error Control) are simulated and their performance compared.The effect of Signal-to-Interference and Noise Ratio (SINR) on the throughput at fixed channel capacity intervals and the effect of throughput on fixed SINR are also simulated. The results are simulated and shown using the Matlab.

Index Terms— Bit error rate, CDMA, Forward error control, Signal to intereference and noise ratio, Optimisation, Packet error probability.

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1 INTRODUCTION

Mobile cellular communication system is the most rapidly evolving technology in the field of telecommunication[1]. In Nigeria, there has been an extensive demand for mobile services, especially wireless interenet. Reecently, we have witnessed fierce competition by mobile network operators in an attempt to offer efficient quality of service (QoS) delivery to its ever growing subscribers. But given the current infrastructure, these operators face massive challenges/limitations in the course of of design migration which have left them with no other option than to compromise laid down standards. One major reason contributing to these challenges is the static infrastructure/installations largely attributed to poor network planning.Though cellular network operators had 'professed' to have migrated from circuit-switchd mobile technology, such as GSM, known for carrying bursty data traffic to packet switched technique, users were still not satisfied.Heavy traffic load became the order of the day as the network kept witnessing frequent hiccups such as call blocking,busy network lines, delayed traffic, cross talking,voice echoing, etc. These problem created an upsurge that led to the empowering of the Nigerian communication commission (NCC), to appraise and regulate the relative performance of these networks.Today we have witnessed 'frendlier' network operators whose attempt is to please its subscribers through compensations in form of free night calls, free air time credit, etc; rather than a holistic overhaul of their existing infrastructure. The bottom line to this resilience is placing more interest on profit rather than optimization.

From the forgoing, we discover that network operators require robust network planning and deployment techniques to survive in the telecommunication market. In addition, they must adapt regularly to the state-of-art technologies. A welcome development is the recent roll out more 3G services to subscribers. This is as the result of the convergence between mobile telephony and the internet, which has become a common place [2].

2 BASIC CONCEPTS

2.1 Network Optimisation

Prior to installation of base stations, it is first necessary to perform site evaluation measurements to determine an appropriate location for the base stations. This generally consists of transmitting a Continuous Wave (CW) or unmodulated signal from a candidate site and measuring it with receiver such as the one found in a drive test system. Next, initial optimization and verification is performed to take a first-pass look at the Radio Frequency (RF) coverage when the modulated CDMA carrier is turned on. The next step is acceptance-testing phase, after which the network is handed over from the network equipment manufacturer to the wireless service provider and a sign-off process is completed. Once the wireless service provider starts commercial service, ongoing optimization and troubleshooting are continually performed during the life of the network as new cell sites are added for increased capacity or additional geographic coverage. Changes in the propagation paths continually occur, including the addition of new buildings, growth of trees, changing foliage conditions and equipment deterioration. Moreover as traffic increases, CDMA networks need to be re-optimized to account for increased level of interference caused by added traffic.

2.2 Signal to Interference and Noise Ratio (SINR)

Since channels are reused, interference arises from co-channel cells and is reffered to as intercell interference. In addition, system with non-orthogonal channelization (like non-orthogonal CDMA) must deal also with interference within the cell, called intracell interference. Particularly, in orthogo-

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nal channelization, intracell interference also arises when multipath, synchronization errors, and other practical effects compromise the orthogonality. The amount of both intercell and intracell interference experienced by a given user is captured by its SINR, and defined as;

$$\text{SINR} = P_r / N_o B + P_l \qquad (1)$$

Where: P_r is the received signal power, P_l is the received power associated with both intracell and intercell interference, and N_0B is noise power. A larger interference reduces SINR, and therefore increases user BER (Bit Error Rate). Intercell interference can be kept small by separating co-channel cells by large distance. On the other hand, the number of users in the system is maximized by reusing channel as often as possible. So the separation distance between co-channel cells should satisfy maximum channel reuse where intercell interference is kept below the maximum tolerable level for the required data rate and BER[3].

2.3 Forward Error Correction (FEC) in Cellular Network

Forward error control is a module used in wireless communication to correct errors at the receiver end. These errors must have occurred due to interference, noise or various impairments in the medium between transmitter and receiver. As the name implies, this module avoids the retransmission of the corrupted data as it helps in correcting errors at the receiver. FEC is not bandwidth efficient as it adds some amount of data as overhead at the transmitter end, but it is power efficient.

In mathematics, computer science, telecommunication and information theory, error detection and correction has great practical importance in maintaining information (data) integrity across noisy channels and less than-reliable storage media. A channel code is a broadly used term mostly referring to the Forward Error Correction (FEC) code and bit interleaving in communication and storage where the communication media or storage is viewed as a channel [4].The FEC code is used to protect data sent over the channel for storage and retrieval even in the presence of noise (errors). There exist two (2) main forms of channel codes- Convolutional codes and Block codes. Convolutional codes are often used to improve the performance of digital radio, mobile phones, satellites links and blue tooth implementations.Unlike Block encoders, convolutional encoders are not memoryless devices. A Convolutional encoder accepts a fixed number of message symbols and produces a fixed number of code symbols, but its computations depend on the current set of input symbol and on some of the previous input symbols[5].

In wireless, satellite and space communication systems reducing error is important. Wireless medium is quite different from its counterpart using wires and provides several advantages, for example; mobility, better productivity, easy installation facility, scalability and low cost. On the other hand, there are some restrictions and disadvantages of various transmission channels in wireless medium between receiver and transceiver where transmitted signals arrive at the receiver with different power and time delay due to reflection, diffraction and scattering effects [6]. Besides, the BER value of the wireless medium is relatively high. These draw backs sometimes introduce destructive effects on the wireless data transmission performance [7]. As a result, error control is necessary in these applications. During digital data transmission and storage operations, performance criterion is commonly determinedby BER which is simply; the number error bits/ total number of bits. Noise in transmission medium disturbs the signal and causes data corruptions [8]. Relation between signal and noise is described with SNR (Signal-to-noise ratio). Generally, SNR is explained with BER. It means, the less the BER result is, the higher the SNR and the better communication quality [9].

3 SYSTEM MODEL

We aim at optimizing the wireless channel parameters of the existing system to meet with the expected Qos. The reason for the poor quality of service experienced by most cellular network operators could be as a result of lack of proper network optimization and management. Some network operators do not control errors in packet transmission, thus increasing the rate of data corruption in the network, which ultimately multiplies the degree of deterioration.

We propose a model that optimizes the channel parameters and guarantees maximum throughput of transmissions in the system. The wireless channel parameters determine the Bit Transmission Rate B, and the Probability of Packet Error P_e.
We consider the case of Block Codes with Forward Error Correction (FEC). Here, the numbers of bits per packet are encoded into N bits and $N \geq P_{l.}$ Where: P_l is the Packet Length. The ratio $\rho = P_{l.} / N$ is called the Coding Rate, since we regard the throughput in terms of conveyed information, the bit transmission capacity is

$$B_r = \varrho / G d_c \qquad (2)$$

Where; G is the processing Gain
d_e represents the Chip Duration
The collection of N bits is called a Codeword, and there exist a Codeword for each of the 2^L possible bit pattern per packet. In general, the N codeword bits contain redundancy, which enables the possible recovery of the bit pattern of the original encoded packet at the receiver. We assume that up to t errors can be corrected, and that t+1 or more bit transmission errors result in a packet loss. With these assumptions, the probability of packet errors becomes:

$$P_e = \sum_{k=t+1}^{N} \binom{N}{k} [Q(G\gamma)]^k [1 - Q(\sqrt{G\gamma})]^{N-k} \qquad (3)$$

Where: $Q(.)$ is defined as the CDF (Cumulative Density Function) of the zero mean unit variance Gaussian density, i.e.:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-x^2/2} dx \qquad (4)$$

Now, if $\alpha = (t+1)/N$, P_e can be estimated by

$$P_e \cong 2^{N[h(\alpha) + \alpha \log_2(q) + (1-\alpha)\log_2(1-q)]} \qquad (5)$$

Where:

$$q = Q(\sqrt{G\gamma})$$

h=-x $\log_2$ (x) –(1-x) $\log_2$ (1-x), is the Binary Entropy function. To determine t, or α, we use the Gilbert-Varshamov bound [10] [11], which states that for a given coding rate ρ, there exists a block code with error correction capability α, where α satisfies

$$\rho = 1 - h(2\alpha) \tag{6}$$

(5) is the proposed (optimised) packet error probability model. Now, without FEC, the probability of packet error is [12], [5]

$$P_e = 1 - (1 - Q(\sqrt{G\gamma}))^L \tag{7}$$

And it depicts the probability of packet error for the existing system. We shall simulate the Packet Error Probabilities of both systems (with and without FEC) and compare their performance in next section of this paper.
The Uplink throughput of user *i*, normalized by the system bandwidth, in a CDMA network is given as [13]:

$$T_i = \frac{R_i}{W}(1 - f(SIR_i))^L \tag{8}$$

Where:

Ri is the Bit Error Rate (BER) of user *i*
W is the System Bandwidth
L is the Packet Length
f(*SIRi*) is the BER as a function of SIR of user *i*

The function *f*(.) however, depends on the modulation scheme employed.

To assess the performance of the existing system, we compute the system's Packet Error Probability (on the average), by modifying the equal gain diversity equation in [14]. Since traffic intensity is directly proportional to the SINR, we can approximate P_e as:

$$P_e = \frac{1}{2}\left(1 - \sqrt{\frac{\rho}{2+\rho}}\right) \tag{9}$$

Where: ρ is the Traffic Intensity. Thus, substituting traffic intensity of the existing system into (9), we obtain:

$$P_e = \frac{1}{2}\left(1 - \sqrt{\frac{12.75}{2+12.75}}\right) = \frac{1}{2}(1 - 0.9297) = 0.03515 \tag{10}$$

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4 SIMULATION RESULTS AND DISCUSSION

The proposed model is implemented using the Matlab for the computer simulations. The aim is to explore as much as possible, an optimized way of of improving the current methods and operations of the existing system.We implement the proposed model and discuss the results of the simulation.

4.1 Simulation Input

The proposed models were simulated using sample data. Three sets of data were collected, with some of the parameters obtained under ideal conditions. Other parameters were continuously fine-tuned through extensive computer simulation, until we achieved a satisfactory result. Table 1, shows the sample input used for the simulation.

Table 1: Simulation Input Parameters and their Values

Simulation of Packet Error Probability (with and without FEC:	
Total bits (N)	2, 4, 6, 8
SINR (γ)	0.2-2
Processing gain (G)	24
Simulation of Throughput with fixed $\frac{R_i}{W}$:	
Bandwidth (W)	256
Bandwidth rate/channel capacity ($\frac{R_i}{W}$)	[0.1- 1]
SINR	0.5-5
Simulation of Throughput with fixed SINR:	
Bandwidth	256
Bandwidth rate ($\frac{R_i}{W}$)	0.1-1
SINR	[1, 2, 3, 4, 5, 6, 7, 8]

4.1 Discussion of Results

Fig. 1 shows the effect of SINR on Packet Error Probabilty (PEP), with fixed number of bits, for systems without Forward Error Control (FEC). We observed from this (classical) approach that more packet errors occur as the packet size increases. In Fig. 2, the presence of FEC efficiently drops the PEP as N increases, indicating the benefits of transmitting more packet bits at a time (per frame). Hence, the high PEP for systems without FEC causes more transmission errors in the network, compared to systems with FEC. As can be seen, Fig. 1 is far from the realistic values, and proves the notion that the classical approach leads to overestimation of the systems parameters. Also, the same model presents a tighter bound, which ironically turns out to be a good estimation reference for network operators, as network operators always underestimate the system's performance, thus resulting in poor quality of service (Qos) delivery.

In Fig. 3, we study the effect of the SINR on the throughput at fixed channel capacity (R_i/W) intervals. The graph presents a near linear approximation of the throughput after optimum spreading. The linear approximation curve almost reaches T_i=1, at SINR =5, for the BER$\left(f(x)\tfrac{1}{2}e^{-x}\right)$, and can be expressed as:

$$T_I\left\{\begin{array}{l}\dfrac{(1-f(a^*))^L}{a^*}\\ 1,\end{array}\right\}\begin{array}{l}\gamma_i,\gamma_i \le \gamma^*\\ \gamma_i,\gamma_i \ge \gamma^*\end{array}$$

Where: a^* is defined as $\dfrac{W_{\gamma i}}{R_i}$

Through extensive simulations, we observed that in each cell, when a user operates at $\gamma_i = \gamma^*$, other users are most likely to have negligible γ_i 's, i.e., users having $\gamma_i = \gamma^*$ have throughputs of unity, while the rest have negligible T_i 's. Hence the total throughput is roughly the same as the number of base stations.

Fig. 4 states the same result in terms of the spreading gains of user. In each cell, only a single user is allowed to operate at R_i/W = 1, i.e., with no spreading, while others operate at varying degrees of spreading to suppress the interference, but possess negligible total throughput. Also observed is the fact that users transmitting at highest possible rate and achieving a throughput of unity has the highest channel gain to the base station.

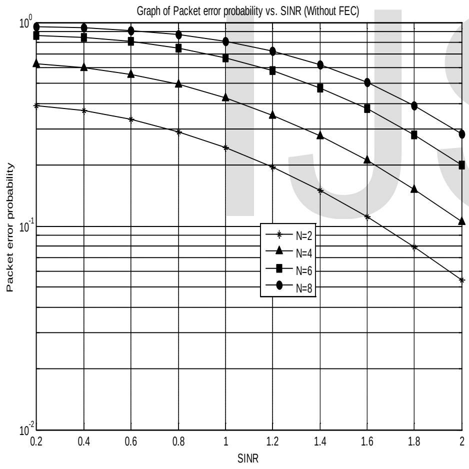

Fig. 1: Graph of Packet Error Probability vs. SINR (without FEC)

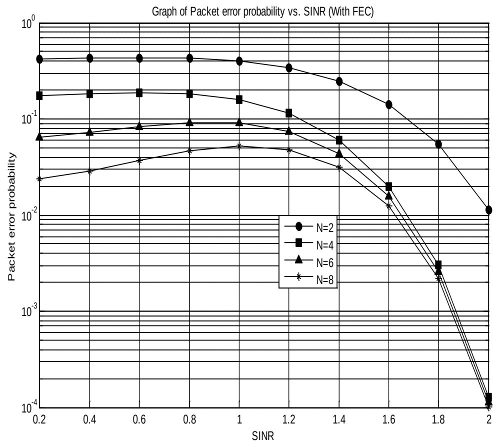

Fig. 2: Graph of Packet Error Probability vs. SINR (with FEC)

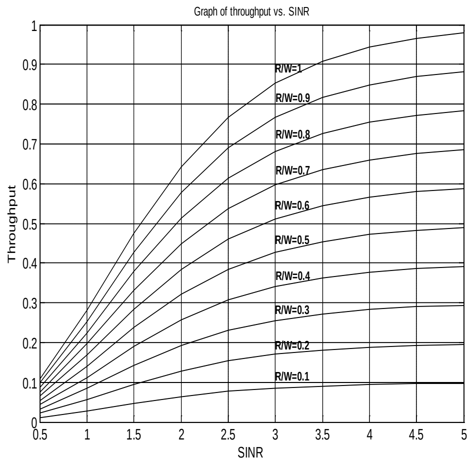

Fig. 3: Graph of Throughput vs. SINR, with fixed R_i/W

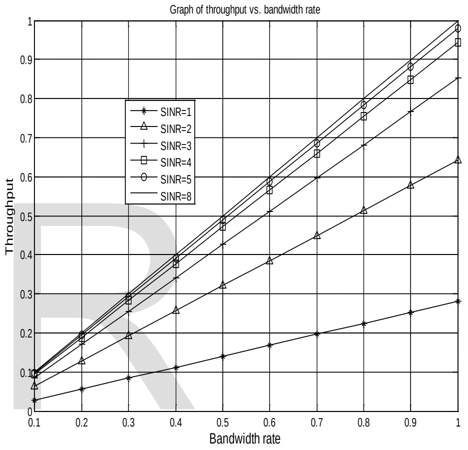

Fig. 4: Graph of Throughput vs. R_i/W, with fixed SINR

5 CONCLUSION

Forward Error Control (FEC) can be used to optimize a 3G cellular wireless network by controlling errors in packet transmission. The result has shown that, the presence of FEC is capable of efficiently dropping the packect error probability as the total number of packet bits increases, indicating the benefit of transmitting more packet bits per frame.

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