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Performance Enhancement in Cellular Network Using Decoding-based Successive Interference Cancellation Technique

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Abstract: Interference if not properly attended to could have negative influence on the air interface performance of any wireless network service. Hence, there is a need to moderate interference in cellular network system. This study is aimed at analysing the performance of decoding-based successive interference cancellation technique. The was done analysing the performance of decoding based successive interference cancellation on uplink High Speed Uplink Packet Access Enhanced Dedicated Physical Data Channel. From the analysis, simulations and results obtained from this study, we have been able to show that this technique would reduce the load of the cell and increase the network capacity of the cellular network provider, thereby improving the quality of service.

Keywords: Cellular Network; Quality of Service; Performance; Interference; Uplink

Introduction

Since the development of mobile telecommunication, the industries have undergone great changes and seen momentous advancements. The mobile telecommunication industries which are involved in wireless networks provision have changed from making marginal military and vehicle-oriented products to delivering mobiles and network components to mass markets [1-5].

According to [6], “to have a better communication link for radio wave, the transmission medium needs to be considered in order to have a better signal from the radio communication network, since the radio wave communication links are influenced by meteorological variables". The attitude and phase scintillations, absorption, scattering of radio wave network signals and other numerous complex mechanisms that occur in the troposphere are caused by the random changes in the surface and vertical refractivity which can cause transmission signals lost and co-channel interference [7-10]. The consequence of interference as a result of refractivity difference in the troposphere is much in the humid climate than in the temperate climate regions due to the occurrence of high intensity humid rainfall [6-7].

Signal interference in wireless networks negatively affects transmission coverage and mobile capacity, limiting overall network performance, especially in the uplink. Unavoidable signal interference is becoming more prevalent in wireless networks with the increasing numbers of active transmitters on the Radio Frequency (RF) spectrum. In wireless network, interference can affect the transmission of the mobile to the cell site (Uplink) as well as the transmission of the cell site to the mobile (Downlink). It is however, to note that the uplink is mostly affected by interference due to the fact that the cell sites have higher levels of power transmission [1, 11].

Interference analysis in wireless network has three main stages:

(i) Detection; which have to do with using metrics that monitor the spectrum activity in frequency and time domain allowing continuous recording of spectrum analysis and spectrogram measurements.

(ii) Identification; having the ability to identify the type of interference signal through demodulation.

(iii) Location; performing directional measurements, recording the geographical coordinates used to triangulate and find the intersection area which represent the geographical location of the interferer [1, 11].

During the initial development of wireless cellular networks, the second generation (2G) cellular wireless networks produce much interference. However, the interference from the third generation (3G) wireless cellular networks is considerably lower than the ones from the 2G networks. Wideband code division multiple access (WCDMA) system; third-generation mobile systems are gradually being deployed in many developing countries like Nigeria in hotspot areas. However, owing to the number of new infrastructures require and the economical situations on ground in some of these countries, it is now that 3G are becoming prevalent, especially in remote villages in these developing countries [1, 2].

In Release 5, High Speed Downlink Packet Access (HSDPA) technology was introduced. This greatly increased downlink transmission rate. In order to meet the rapidly growing demands for data services in the uplink, the 3rd Generation Partnership Project (3GPP) Release 6 introduced High Speed Uplink Packet Access (HSUPA). The technical advancements in HSUPA include fast scheduling, Fast Hybrid Automatic Repeat Request (HARQ), shorter Transmission Time Interval (TTI), and macro diversity combining (MDC).

The benefits of HSUPA were improvement in the uplink capacity, increase in user data rate, and reduction in the transmission delay on the WCDMA network.

HSUPA has the following impacts on the network:

(i) A new control channel that requires more power in the uplink, called Enhanced Dedicated Physical Control Channel (E-DPCCH).

(ii) When the uplink load is limited and there is a large number of User Equipment (UEs). The UEs can upload data only at a guaranteed bit rate (GBR), for example, 64 kbit/s. As compared with R99 channels, E-DPCCH consumes more system resources.

HSUPA Physical Channels is shown in Figure 1.

The Enhanced Dedicated Channel (E-DCH) has a TTI of either 10 ms or 2 ms. It is mapped onto the Enhanced Dedicated Physical Data Channel (E-DPDCH) or E-DPCCH. When the transmission time interval (TTI) is 10 ms, the Enhanced Dedicated Channel (E-DCH) provides better uplink coverage performance but when the TTI is 2 ms, the E-DCH provides higher transmission rates.

The E-DPDCH carries data in the uplink. The spreading factor of the E-DPDCH varies from SF256 to SF2 depending on the data transmission rate.

The E-DPCCH carries control information related to data transmission in the uplink. The control information consists of the E-DCH Transport Format Combination Indicator (E-TFCI), Retransmission Sequence Number (RSN), and happy bit. The SF of the E-DPCCH is fixed to 256.

To implement the hybrid, acknowledge repeat request (HARQ) function, the Enhance HARQ Indicator Channel (E-HICH) is introduced in the downlink. The E-HICH carries retransmission requests from the NodeB. The SF of the E-HICH is fixed to 128.

The downlink Enhanced Access Grant Channels (E-AGCH) and Enhanced Relative Grant Channel (E-RGCH) carry the HSUPA scheduling control information. The E-AGCH is a shared channel, which carries the maximum E-DPDCH to DPCCH power ratio, that is, absolute grants. The SF of the E-AGCH is fixed to 256.

The E-RGCH is a dedicated channel, which is used to indicate relative grants and increase or decrease the maximum E-DPDCH to DPCCH power ratio. The SF of the E-RGCH is fixed to 128 [12, 13].

This study is aimed at analysing the performance of decoding-based successive interference cancellation technique whose functions are as follows:

(i) The Network detects and decodes E-DPDCH signals from HSUPA UEs.

(ii) Network regenerates signals of UEs on their respective E-DPDCHs by using the detection results and channel estimation results.

(iii) The regenerated signals are then removed from the received signals before detection for demodulation.

(iv) The Network processes the signals of another HSUPA UE and the process continues.

Methodology

It is becoming obvious that modern-day wireless network systems are gradually interference restricted. There is an ascending interest in using advanced/unconventional interference mitigation techniques for the improvement of cellular network performance as well as the conventional techniques of mitigating interference as contextual noise [13-17].

According to [13], one of the most important method is successive interference cancellation. Though, successive interference cancellation is not always the best multiple access scheme in wireless network systems, it is specifically open to execution and does accomplish restrictions of the dimensions regions in multiuser systems in many cases [13]. Conventional performance analyses of successive interference cancellation do not consider the spatial distribution of the users.

The transmitters are either presumed to exist at a given location with deterministic path loss and the references within, or presumed subject to centralized power control which to a large extent recompenses for the channel unpredictability [17].

In launching the advanced/unconventional models, spatial distribution of the users, is essentially taken into consideration [13].

Successive Interference Cancellation Model and Metrics

According to [13], if we are considering a situation where all the users transmit with unit power, it is appropriate to introduce the following standard signal-to-interference ratio based single user decoding condition:

Standard Signal-to-Interference Ratio Based Single User Decoding Condition

In an interference-limited network, a particular user at $x \in \Phi$ can be successfully decoded without successive interference cancellation, if only:

$$SIR_x = \frac{h_x \| x \|^{-\alpha}}{\sum_{y \in \Phi} h_x \| y \|^{-\alpha}} \succ \theta$$

(1)

Where SIR_x is the standard signal-to-interference ratio based single user, $h_x \| x \|^{-\alpha}$ is the received signal power from x, $\sum_{y \in \Phi} hy \| y \|^{-\alpha}$ is the aggregate interference from the other active transmitters and θ is the standard signal-to-interference ratio based decoding threshold.

Similarly, in a situation of perfect interference cancellation, once a user is successfully decoded, its signal component can be completely subtracted from the received signal. Assuming the decoding order is always from the stronger users to the weaker users, we obtain the following decoding condition for the case with signal-to-interference ratio [13].

Signal-to-Residual-Interference Ratio-Based Decoding Condition with Successive Interference Cancellation.

With successive interference cancellation, a user x can be decoded if all the users in

$$\tau_c = \left\{ y \in \mathbf{\Phi} : h_x \left\| y \right\|^{-\alpha} \succ h_x \left\| x \right\|^{-\alpha} \right\}$$

are successfully decoded and the signal-to-residual-interference ratio at *x*.

$$SIR_x = \frac{h_x \left\| x \right\|^{-\alpha}}{\sum_{y \in \mathbf{\Phi} \setminus \{x\} \setminus \tau_c} h_y \left\| y \right\|^{-\alpha}} \succ \theta$$

(2)

Consequently, consider the ordering of all nodes in Φ such that $h_{xi} \left\| x_i \right\|^{-\alpha} \succ h_{xj} \left\| x_j \right\|^{-\alpha}, \forall_i \prec j^5$. The number of users that can be successively decoded is N if only:

$$h_{xi} \left\| x_i \right\|^{-\alpha} \succ \theta \sum_{j=i+1}^{\infty} h_{xj} \left\| x_j \right\|^{-\alpha}, \forall_i \leq N$$

and

$$h_{xN+1} \left\| x_{N+1} \right\|^{-\alpha} \leq \theta \sum_{j=N+1}^{\infty} h_{xj} \left\| x_j \right\|^{-\alpha}$$

.

It is noteworthy, according to [13], "that the received power ordering is only presented for analysis purposes. As is not necessary, we do not assume that the received power ordering is known a priori at the receiver".

According to [13], the mean number of users that can be successively decoded; E[N], with respect to different system parameters and the distribution of N in the form:

$$P_k \underset{=}{\Delta} \mathrm{P}\left(N \geq k\right)$$

(3)

Eqn. (3) is known as the probability of successively decoding at least k users at the origin. To make the dependence on the point process clear, occasionally we have to use $P_k(\Phi)$.

Since successive interference cancellation is intrinsically a multiple packet reception (MPR) scheme, we can further define the aggregate sum rate (throughput) to be the total information rate received at the receiver o, because all the users in the system transmit at the same rate log (1 + θ), the sum rate is:

$$R = \mathrm{E}\left[\log(1+\theta)N\right] = l\,\mathrm{og}(1+\theta)\mathrm{E}\left[N\right]$$

(4)

In this study, the evaluation of the gains from decoding-based successive interference cancellation technique would be noticeable when HSUPA 2 ms TTI UEs with continuous data transmission account for a larger proportion of total UEs in a cell or when HSUPA 2 ms TTI UEs with high throughput/sum rate exist in a cell. This would amount to high Uu-interference load.

Discussion of Results

The number of Dedicated Channel (DCH) UE's as compared to UL load of different cells is shown in Figure 2. It is observed from this figure that there is a great gain in DCH UEs Vs Receive Total Wideband Power (RTWP) distribution for high number of users. It can be seen from the above chart showing DCH User number Vs RTWP trend that post RTWP samples have shifted to lower values particularly on cells with DCH UE numbers greater than 60. This is a great achievement as for cells with high user numbers, whose experience was supposedly very poor as a result of high RTWP were greatly improved.

The number of TTIs in which HSUPA users transmit data under different air interface loads in a cell (X=3, 6, 7, 9, 10, 13, 20) is shown in Figure 3. From the figure is it noticed that there is a great improvement between cell loads of 6dB to 10dB range.

The number of HSUPA users with data transmission under different uplink Uu interface loads in a cell (X=3, 6, 7, 9, 10, 13, 20) is shown in Figure 4. The figure reveals the number of HSUPA users with data transmission at different load ranges in the air interface. There was also a great improvement is observed at 6dB to 10dB range, with the system maintaining stability at 13dB range.

The number of times that cell Uu-interface load is between Ydb to Zdb; Ratio of the Actual RTWP in a cell to the Reference RTWP, (X=0~25) is shown in Figure 5.

The figure reveals the uplink load distribution comparison before and after the study. It was observed that the trend is stable with no major gain in the load distribution. This could be attributed to low number of users processed during the course of the study.

Conclusion

From the analysis, simulations and results obtained from this study, we have been able to show that this technique would reduce the load of the cell and increase the network capacity of the cellular network provider, thereby improving the quality of service.

It is therefore recommended that cellular network service providers should adapt this technique in mitigating interference in WCDMA so as to implore and optimize the quality of service generally.

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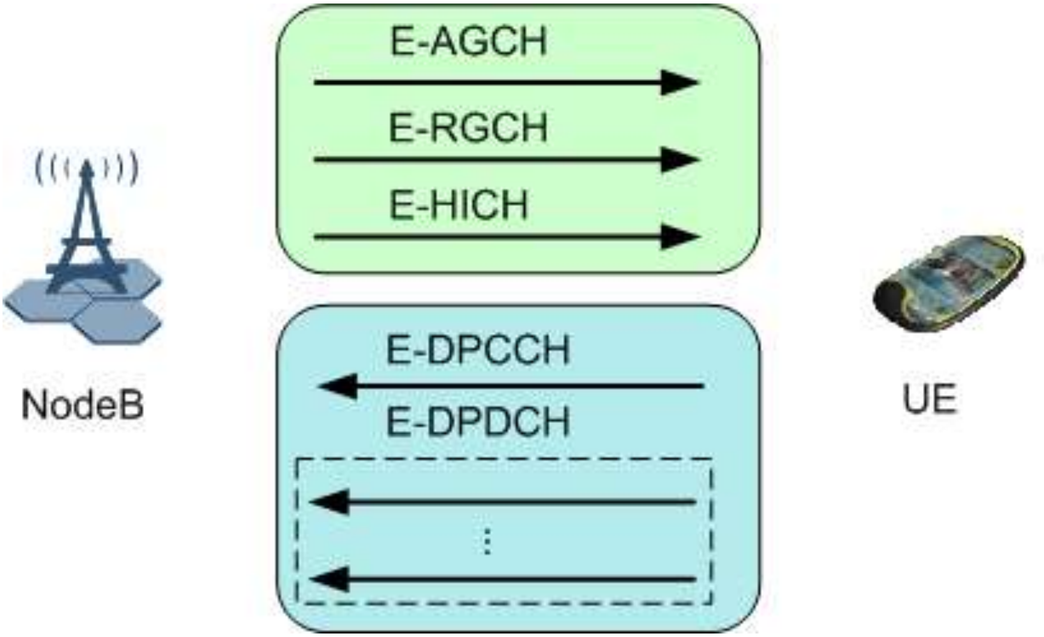

Figure 1: HSUPA Physical Channels

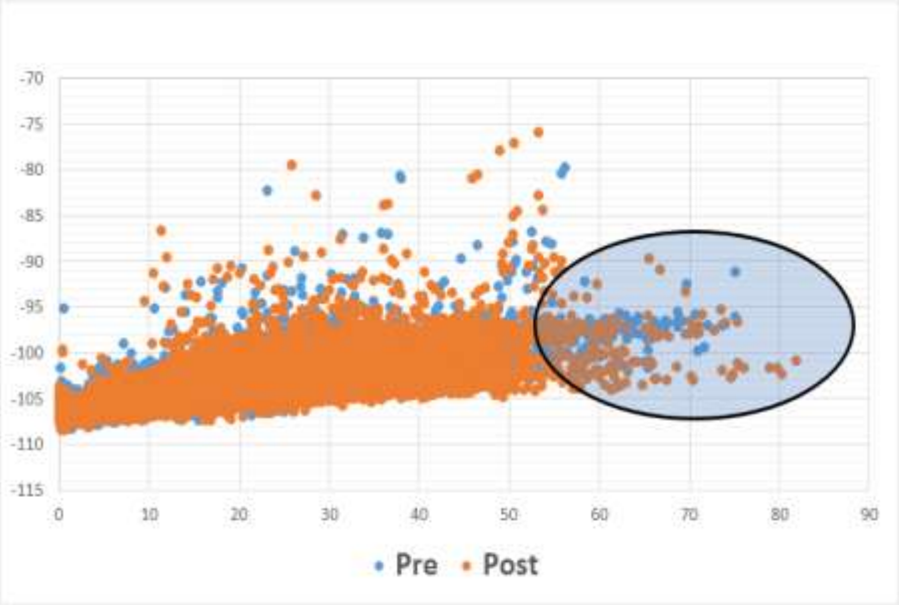

Figure 2: Number of DCH UE's as Compared to UL Load of Different Cells

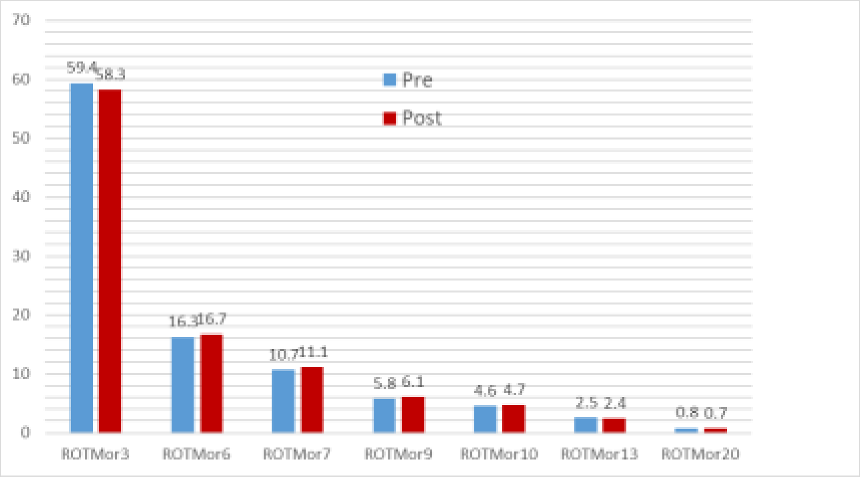

Figure 3: Number of TTIs in which HSUPA Users Transmit Data under Different air Interface Loads in a Cell (X=3, 6, 7, 9, 10, 13, 20)

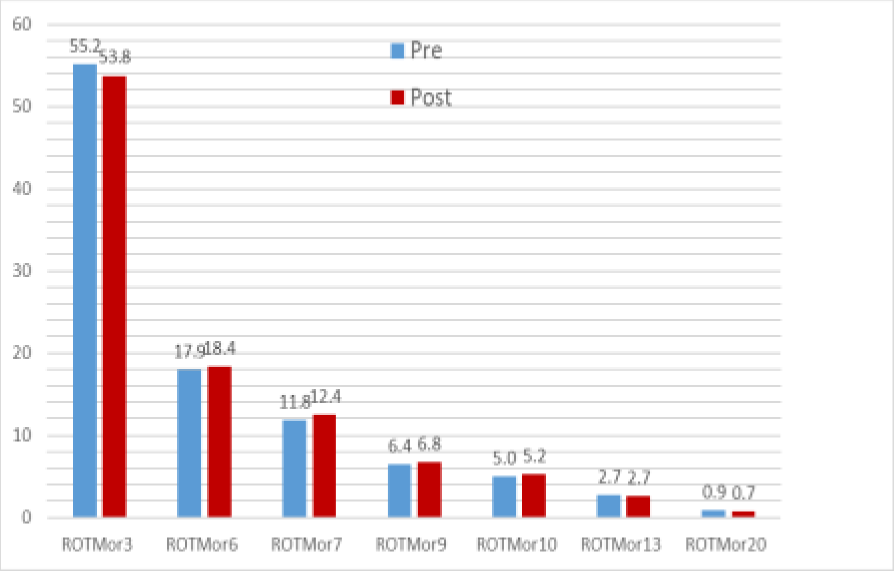

Figure 4: Number of HSUPA Users with Data Transmission under Different Uplink Uu Interface Loads in a Cell (X=3, 6, 7, 9, 10, 13, 20)

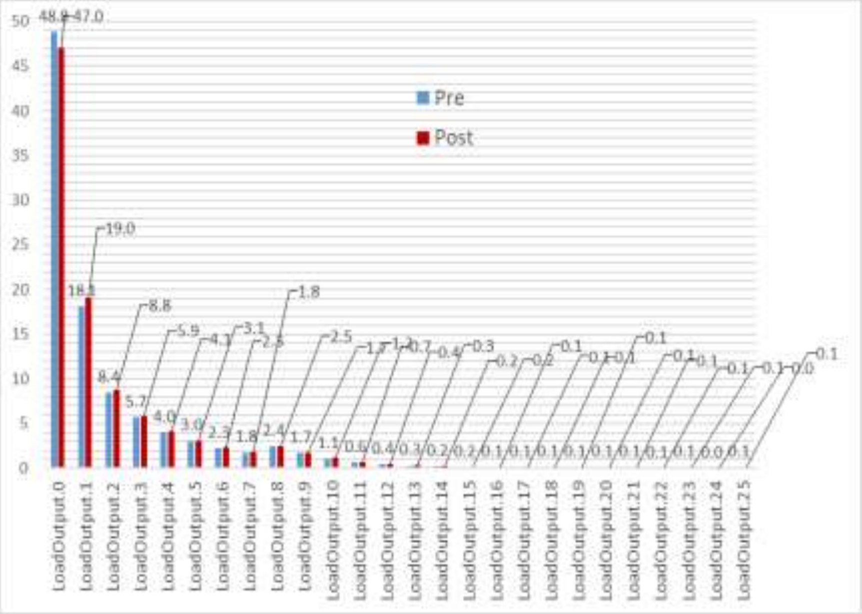

Figure 5: Number of times that Cell Uu-lnterface Load is between Ydb to Zdb; Ratio of the Actual RTWP in a Cell to the Reference RTWP, (X=0~25)