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ADAPTIVE INTERFERENCE MITIGATION TECHNIQUE FOR LTE NETWORKS

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Abstract: Interference mitigation is a big challenging issue in cellular systems and LTE network which is a high data rate and fully ALL-IP network is not an exception. Motivated by this we developed an adaptive scheduling technique as a means of mitigating interference in the uplink of an LTE network to enhance the network performance. In this work, the proposed scheme is implemented in a system level simulator designed for LTE network simulations and the well-known maximum throughput (MT) and blind equal throughput (BET) scheduler were used as benchmark to compare the performance of our proposed scheme. The results obtained showed that there is about 4dB performance gain from our proposed scheme in terms of the achieved rate for the cell in comparison with the benchmark schedulers. Also results obtained showed that the schedulers are impacted by the UE mobility as the achieved rate in a cell decreases with increase in user speed.

Keywords: Adaptive, Interference, Mitigation, Mobility, Scheduler

1. INTRODUCTION

The growing demands for mobile networks to support data applications at high throughput and spectral capacity led to the need to develop orthogonal frequency division multiplexing (OFDM) based fourth generation (4G) networks, including WiMAX and 3GPP Long Term Evolution (LTE). They are targeting a reuse factor of 1 ($n = 1$), which refers to the reuse of the entire spectrum in each cell. However, a frequency reuse factor of 1 causes considerable inter-cell interference (ICI) by signals transmitted at essentially the same frequency from adjacent cells. Due to transmit power limitations in mobile terminals, a constraint on the uplink link budget will require smaller cell sizes than is typically deployed for current second generation (2G) and third generation (3G) cellular systems. This need is driven by the need to meet the high data rate throughput targeted for users not only near the base station, but also for cell edge users. The resulting interference limiting system for n=1 deployments will not achieve the full potential that the LTE standard can support without the implementation of one or more viable interference mitigation and/or cancellation techniques at base stations and mobile terminals. Therefore, effective ICI coordination (ICIC) and spectrum utilization management are important and challenging issues for LTE system design (Himayat et al, 2010). There have been tremendous research efforts on sharing scarce resources in LTE cellular systems, but most researchers have treated only the single cell scenario. Against this back drop, we propose the use of an adaptive scheduling strategy to reduce interference in uplinks to LTE networks. In this work, the eNB in each cell calculates the SINR for its UE and uses information about the level of interference experienced by users to determine how they will be scheduled using their individual determined SINRs. This research work considered the uplink direction which is more challenging than the downlink direction because the uplink power control has to adapt to fluctuations in radio propagation channel conditions such as path loss, shading and rapid fading, while limiting interference.

2. RELATED WORKS

The application of Fractional Frequency Reuse in LTE system has been the subject of much discussion in the communication society. Adaptive partial frequency reuse proposed in (Sun et al, 2015) could improve the efficiency of the communication system. However various transmitting power and positions have been assumed. In another work (Zhan et al, 2016), contention-based FFR was proposed but the algorithm is applicable only for certain conditions. In (Ali et al, 2015), crowd management was proposed in the intellectual transport system. Soft frequency reuse (SFR) was proposed in (AboulHassan et al, 2015, Qian et al, 2015, Huang et al, 2016). However, most of the works did not consider the effect of inter-cell interference. Dynamic allocation of frequency was considered (Rahman et al, 2015; Chung, 2015). However, none of these considered multiple base stations, each with randomly placed users. Since ICI mitigation technology has become one of the major issues in the communication field, many researchers are working on this topic to improve the situation. Therefore, the objective of this research work is to reduce the level of interference experienced in the uplinks of LTE networks thereby improving the quality of service of the users and improving the overall network performance.

3. MATERIALS AND METHOD

A drive test was conducted using the existing mixed mode LTE network of one of the major service providers in the country (MTN Nigeria). The drive test was conducted within the main city of Port Harcourt, River State and its geographic coordinates are 4° 47' 21" North, 7° 21' 55" East. The drive test ran through Rumuokwurusi, Rumudara, Aba-Road, East West Road, Okpolo Road, etc The various key performance indicators such as data quality of reference signal received (RSRQ), reference signal received power (RSRP), latency, data rate, SINR, system capacity, network coverage, handover performance were obtained and analyzed and subsequently the measurement environment was characterized. For the empirical path loss determination for the test area, field experimental data from the drive test were used and the pathloss exponent was found to be n=2.69, while the standard deviation was found to be =6.94. These values were used to derive a propagation path loss model for the test environment which was later used in the simulation.

3.1 LTE Uplink System Level Simulator

The simulation software used in this work is Vienna LTE-A Uplink Link Level Simulator v1.6. The Vienna LTE Simulator was developed by the authors (Zoechmann et al, 2016) as a platform to aid in the alignment of research efforts directed towards achieving the LTE specifications given by the 3GPP workgroup. It serves as a common test base for implementing ideas and checking results of analysis that can be easily reproduced and improved upon. This software package contains link level and system level simulators as separate entities built on the MATLAB platform, and employs Object Oriented Programming (OOP) development techniques. The Vienna LTE simulator was used in this work instead of OPNET, OMNET or NS-3 as it was specifically designed for LTE and LTE-Advanced simulation purposes. Unlike other simulators that can be used to test common network communication protocols and various parameters, the Vienna Simulator is streamlined for LTE-related research purposes only

3.2 SYSTEM ANALYSIS AND MODELLING

The model adopted in this work is interference limited multiple cell OFDMA system with three cells, each cell equipped with a base station (eNB) with N antennas, serving K single-antenna users in the uplink as shown in Figure 3.1. In the system, there are total L=3K users in the network, each user has N_u subcarriers and overall the system has N_T subcarriers, the system bandwidth B (Hz) divided into resource blocks (RBs). The LTE uplink scheduler is located at the base station in LTE (eNB). The minimum transmission unit of an LTE scheduler is known as a resource block (RB). The radio resource available in uplink LTE systems is defined in both the frequency and time domains. In the frequency domain, each RB consists 12 consecutive subcarriers and in the time domain it is composed of a time slot of 0.5ms duration. Each 1ms Transmission Time Interval (TTI) has 2 slots, and a subframe is defined as 10 TTIs. In each TTI, multiple RBs can be assigned to multiple users with different classes. However each resource block can be assigned to a maximum of one user. It is assumed that the scheduler is capable of arbitrarily allocating RBs to all users and that each RB has a bandwidth of $\frac{B}{N}\ (Hz)$.

The "weak" UE_k is served by eNB$_1$ and is allocated the n-th RB and the "interfering" set of users IP_k^1 transmitting over the n-th RB is located in eNB$_2$ and eNB$_3$ neighboring cells . The uplink interference I_k^1 which is the inter-cell interference caused by the set of users "interfering" with the weak UE_k, results in a reduction in the obtained signal-to-interference-plus noise ratio (SINR) at UE_k at its own serving base station. The signal received on eNB1 for UE_k before receive combining is given as:

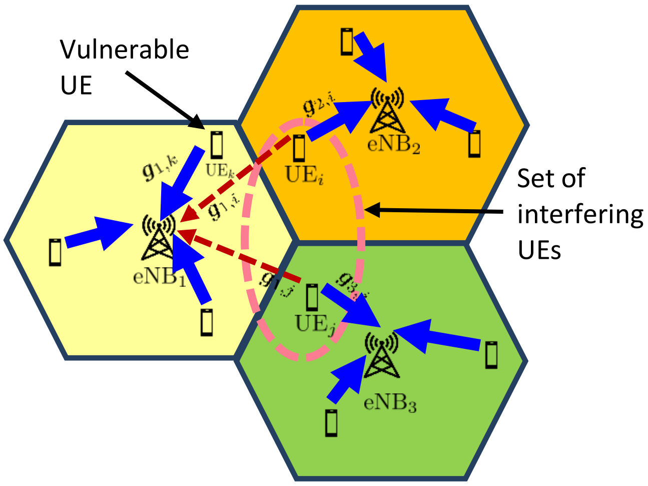

Figure 1: Interference Limited Multiple Cell OFDM System

$$y_{1,k} = P_{1,k}\boldsymbol{g}_{1,k}x_{1,k} + \underbrace{\textstyle\sum_{a\in IP_k^1} P_{1,a}\boldsymbol{g}_{1,a}x_{1,a}\partial_{1,k}}_{\text{Inter-cell interference}} + z_{1,k} \qquad (1)$$

where $p_{1,k}$ is the transmit power of UE_k, $\boldsymbol{g}_{1,k} \in \mathbb{C}^{N\times 1}$ is the channel (including fading and shadowing) between UE and eNB, $\boldsymbol{g}_{1,a}$ denotes the interfering channel between the desired UE and the interfering set, $x_{1,k}$ is the normalized transmit symbol for UE to unit 1 such that $\mathbb{E}\left[\left|x_{1,k}\right|^2\right] = 1$. Inter-cell interference is interference from the set of users interfering in neighboring cells using the same resource block, $\partial_{1,k}$ is a binary variable indicating that users in neighboring cells share the same RB or not, $\partial_{1,k} = 1$ indicates that the user is scheduled with the same RB as our desired user and $\partial_{1,k} = 0$ otherwise. The noise is modeled as a spherically symmetric complex Gaussian distributed as $z_{1,k} \sim \mathcal{CN}(0, \sigma_{1,k}^2)$), where $\sigma_{1,k}^2$ is the noise power. The SINR of UE_k at its serving base station eNB1 is given by

$$\Gamma_{1,k} = \frac{P_{1,k}\boldsymbol{g}_{1,k}}{\sum_{a\in I_k^1} P_{1,a}\boldsymbol{g}_{1,a}\partial_{1,k} + \sigma_{1,k}^2} \qquad (2)$$

3.3 CHANNEL MODEL

Channel model adopted is flat fading Rayleigh channel model with unrelated channels in antenna. The channel vector is given as:

$$\boldsymbol{g}_{x,y} = L_p d^{-\alpha}\widetilde{\boldsymbol{g}_{x,y}} \qquad (3)$$

where L_p is the path loss at the reference distance d_0 $(d_o = 0.1km)$, d is the distance between the transmitter and the receiver, ∝ is the path loss exponent and $\widetilde{\boldsymbol{g}_{x,y}} \in \mathbb{C}^{N\times 1}$ is the small scale(fading) channel vector.

3.4 UPLINK CAPACITY

The uplink capacity of a mixed mode LTE network is given by the well-known Shannon capacity equation. The capacity gain is increasing logarithmically according to Shannon and the capacity is given by:

$$C = BLog_2(1 + SINR) \qquad (4)$$

where B is the bandwidth and SINR is the signal to interference plus noise ratio.

By Shannon's theorem, the bandwidth available with SINR (B) plays an important role in determining the achievable channel capacity between transmitter and receiver.

To specify a range of acceptable performance, let the system specify the values of the maximum and minimum SINRs as $\Gamma_{\max}^{k}$ and $\Gamma_{\min}^{k}$, respectively. At any time t, a serving eNB may use a sub-channel for transmission and to ensure correct decoding of $x_{1,k}$ the condition $\Gamma_{1,k} \geq \Gamma_{\min}$ must be satisfied. From (3.2), the maximum interference attainable at $\Gamma_{\max}$ is given as

$$I_{k,\max}^{1} = \frac{P_{1,k} g_{1,k}}{\Gamma_{\max}^{k}} - \sigma_{1,k}^{2} \qquad (5)$$

Similarly, the minimum interference attainable at $\Gamma_{\min}$ is given as

$$I_{k,\min}^{1} = \frac{P_{1,k} g_{1,k}}{\Gamma_{\min}^{k}} - \sigma_{1,k}^{2} \qquad (6)$$

Therefore, the link rates attainable for the scenarios can be determined using Shannon's potential equation and it is given as

$$C_{1,k} \begin{cases} 0, & \Gamma_{1,k} < \Gamma_{\min}^{k} \\ Log_2\left(1 + \Gamma_{1,k}\right), & \Gamma_{\min}^{k} \leq \Gamma_{1,k} \leq \Gamma_{\max}^{k} \\ Log_2\left(1 + \Gamma_{1,k}^{\max}\right), & \Gamma_{1,k} > \Gamma_{\max}^{k} \end{cases} \qquad (7)$$

3.5 DEVELOPED ADAPTIVE SINR BASED SCHEDULING (ASBS)

In this work an adaptive scheduling has been developed, the scheme developed is known as adaptive SINR based scheduling. The ASBS algorithm is described in the following steps;

1. The maximum and minimum SINR target for the UE are declared as $\Gamma_{\max}^{k}$ and $\Gamma_{\min}^{k}$ and are used to classify the UE link as strong or weak. The scheduler would group the UEs as high priority (UE with weakest SINR), low priority (UE with strongest SINR) and mid-priority.
2. The eNB calculates $\Gamma_{1,k}$ and correlates it with the SINR target, if $\Gamma_{1,k} \geq \Gamma_{\max}^{k}$ the UE is classified as a strongest link and assigned low priority index use a higher order modulation scheme, like 64 QAM.
3. If $\Gamma_{\min}^{k} \leq \Gamma_{1,k} < \Gamma_{\max}^{k}$ UE classified as a strong link and assigned mid-priority index and use a high order modulation scheme such as 16QAM.
4. If $\Gamma_{1,k} < \Gamma_{\min}^{k}$ UE is classified as a weak link and assigned the highest priority index and use a lower order modulation scheme such as QPSK
5. Priority grouping is used by the scheduler as a metric for scheduling. The principle of allocation is to assign RBs from high-priority classes to low-priority classes in chronological order.

It is clear to see that distant UEs (from the serving eNB) will be assigned higher-priority RB, and adjacent UEs, which are shielded from neighboring cell interference, are assigned lower-priority RB. The middle-priority RBs will be assigned to the remaining UEs. At each TTI, the eNB scheduler captures the buffer status report and channel status information from the UEs, and calculates the SINR values. When a new UE enters the cell, an initial allocation is made using the SNR (which can be estimated using RSRP), as no SNR information is available initially. In the following time slots, however, the UE's SINR is used. The mean SINR figures are rapidly employed to eliminate fading effects and prevent MS from rapidly changing priority classes, allowing the system to reach a stable operating point. The pseudocode for the ASBS algorithm is given in Figure 2

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Algorithm:  Adaptative SINR based Scheduling (ASBS)
Input    :  Buffer Status Report, CSI
Output   :  Scheduled UEs
Step 1   :  Access the Buffer Status Report
Step 2   :  Calculate $I_k^1$ and $\Gamma_{1,k}$
            For new UE use SNR
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Step 3  :  If $\Gamma_{1,k} \geq \Gamma^{k}_{\max}$ , classify UE as Strongest, assign lowest priority index,  and use 64 QAM
           If $\Gamma^{k}_{\min} \leq \Gamma_{1,k} < \Gamma^{k}_{\max}$, classify UE as strong, assign mid-priority index, adapt MATP by and use 16 QAM
           If $\Gamma_{1,k} < \Gamma^{k}_{\min}$, classify UE as weakest, assign highest priority index and use QPSK.
Step 4  :  Supply priority grouping metric to the scheduler
Step 5  :  Schedule UE from highest-mid-lowest priority
```

Figure: 2 Pseudo code for the ASBS algorithm

4. SIMULATION MODEL

Table 1: Main Simulation Parameters

Parameter	**Setting**
Cell Layout	3 Cells, 1, Enb
UE per cell K	4
Number of eNB antenna	48
System bandwidth	5 MHz (~25 PRBs)
Duplexing	TDD
Multiple access scheme	SC-FDMA
Frequency reuse factor	1
Cell radius	375m
Max UE power	23dBm
UE speed	5 km/h
Path loss model	$P_L(d_i) = 117.02 + 26.9Log_{10}\left(\frac{d_i}{d_0}\right)$, d is in km
Slow fading	Log-normal shadowing, 8dB standard deviation
UE distribution	Uniform distribution
Traffic environment	Loaded
Channel realizations	1000

5. RESULTS AND ANALYSIS

Figure 3 shows the performance of the developed ASBS algorithm in terms of the rate obtained with respect to different values of the signal-to-noise ratio for 4 users in the cell.

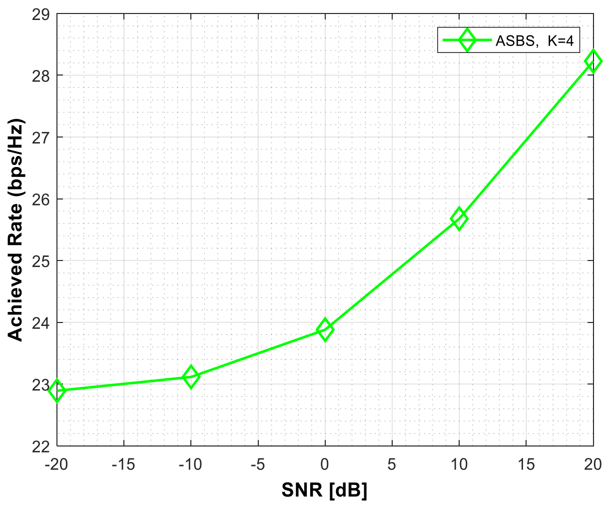

Figure 3: Different SNR. Rate received,K=4

It is observed that the performance of the developed algorithm improves with increase in SNR. ASBS maximizes cell throughput by prioritizing UEs with unfavorable channel conditions and maintaining some level of fairness by providing resources to UEs with better channel conditions, allowing users to vary transmit power based on their locations.

In Figure 4, we show the performance of our developed algorithm with an increased number of users.

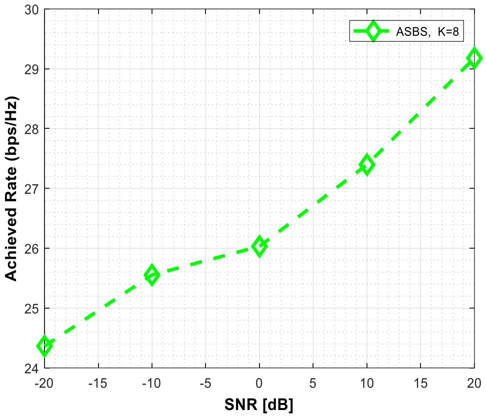

Figure 4: Rate obtained at different SNR, K=8

It can be seen that using the ASBS algorithm increases the rate achievable in systems that have a higher number of users per cell (K = 8), this supports the idea behind the algorithm that fairness allows for more users by adjusting the SINR to accommodate users with poor channel conditions rather than abandon them entirely. Figure 5.3 shows the data rate obtained as a function of SNR for the considered schedulers.

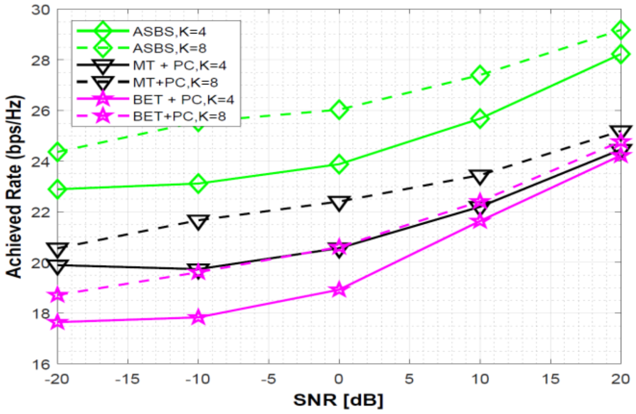

Fig. 5: Rate obtained at different SNR, K=[4, 8]

As shown by the figure and the result of the previous experiment, our proposed ASBS shows better performance than others. It turns out that the rate of performance improvement with respect to SNR for BET and MT is comparable at low SNR but BET achieves a higher rate of improvement at higher SNR. This is due to the fact that by the principle of operation of MTs, high achievable rates are achieved by discriminating users with poor channel conditions, effectively allowing cell edge users at high SNR when the system is interference-limited. In practice this is not desirable. This means, UEs with lower average throughput will be scheduled until they reach or pass the average throughput of other UEs connected to the same eNB. As a result, UEs experiencing poor channel quality are allocated more RBs than UEs with good channel quality to maintain a good fairness result in terms of throughput. BET tries to reach the same rate for all users regardless of their channel status, this leads to poor receivable rates but good cell edge performance at high SNR, due to the fact that users with poor channel conditions is allocated with more radio resources

5.1 IMPACT OF USER MOBILITY

LTE network is developed to perform well under a range of diverse user speeds from about 5km/h to 120km/h. In the simulations, three level of user speeds are chosen to test out the performance of scheduling algorithms about mobility: 5km/h as average human walking speed, 50km/h as maximum urban driving speed and 100km/h as highway driving speed. The achieved rate results under different user speeds for K=4 UEs, evaluated at SNR of 20dB are shown in Figure 4.13. The schedulers performance is affected by UE mobility, achieved rate supplied by each scheduler tends to decrease as the speed of the users increase. This is also a natural result of mobility, because as the speed of a user increases, the harder is it to maintain good channel quality between the user and the eNodeB. For low velocity MT performs better but as the velocity increases BET dominates MT and approaches a minimum UE throughput whereas the latter experiences constant performance degradation. As MT does not consider the channel conditions of the UEs. Performance degradation of BET at higher velocities is little because there are going to be more users behaving as edge users as the user speed increases, and they are allocated more radio resources based on the principle of operation of BET.

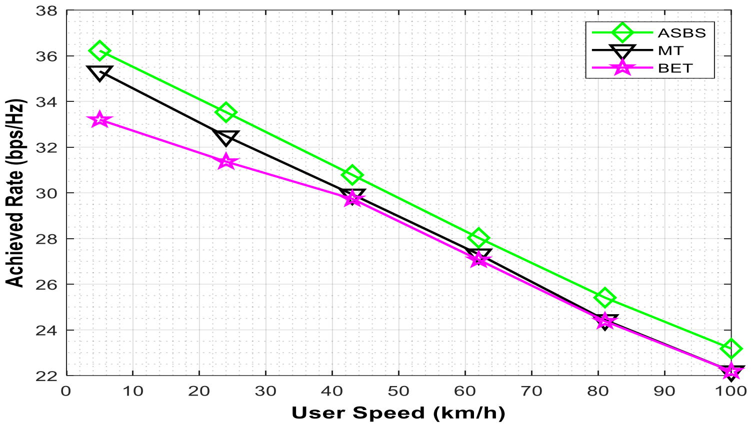

Figure 6: Achieved Rate with Mobility

6. CONCLUSION

This work proposed and implemented an adaptive scheduling scheme to improve the uplink capability of mixed mode LTE networks. A drive test measurement campaign was conducted using a live network, where importance performance metrics that characterize the operating conditions of a network were measured. The experimental test used to study the effects of interference on cell edge users. Empirical characterization of the environment was performed to develop a pathloss model specific to our test bed. Drive test results showed that cell edge users do indeed have severe interference by users in negotiating cells and inspired by this we proposed a means of handling interference using an adaptive scheduling algorithm. For cell edge users we have implemented scheduling scheme which is adaptive with respect to the users' SINR. By giving high priority to cell edge users and high transmit power, our implementation ensures that fairness is given to all users within the cell. The proposed scheme is implemented in a system level simulator designed for LTE network simulation and the well-known maximum throughput (MT) and blind equal throughput (BET) schedulers are used as benchmarks to compare the performance of our proposed scheme. The obtained results showed that our proposed scheme has a performance gain of about 4dB in terms of rate achievable for the cell as compared to the benchmark scheduler.

7. ACKNOWLEDGEMENT

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