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Scheduling in Interference-Limited Environment for LTE-A Systems

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Abstract

Interference limited environment is becoming a significant scenery in wireless network deployment particularly LTE-A systems due to introduction of enhancing technologies and scenariosbeing ensued by 3GPP standardization. Schedulers are being designed to optimize the utility of the scarce resources to be allocated to user equipment (UE) through time and frequency domains, however, the decision of the schedulers are pinned on the channel quality indicators e.g. interference. In this paper we have proposed amethod that would combine the Worst-case Fair Weighted-Fair Queuing (WF^{2}Q) techniqueand Markov-chain to estimate the interference level prior to making final decision for allocation of resource units to UEs in order to enhance the network utility. Our simulation results showed that UE's throughput can be improved with acceptable fairness.

Keywords: *Interference-limited, LTE-Advanced, Markov-chain, WF^{2}Q*

1. Introduction

Interference-limited environment is the case where base stations are located very close to each other. Examples are dense suburban, urban or dense urban with small cells. Typically the cell-edge composite signal level is very high, but the out-of-cell interference level is also very high too, as a result the cell-edge signal to interference plus noise ratio (SINR) is still poor. For interference-limited environment, one can approximate using the formula;

$$SINR = \frac{s}{\alpha + \sum_{l=1} I_l} = \frac{s}{\alpha + I} \tag{1}$$

Where S =received signal level; α is the thermal noise energy which is constant, whilst the total out-of-cell interference from all neighboring base stations measured at distance $a \in \mathbb{R}^d$ is given as: [1]:

$$I(a) = \sum_{x \in \omega} p_x h_x \ell(\|a - x\|) \tag{2}$$

Where $\omega \in \mathbb{R}^d$ represents total numberof transmitting nodes. p_x and h_x are the transmit power and the power fading

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coefficient for node x, and ℓ is the path loss function which depends on the distance $\|a - x\|$ from node x to point a, as interference increases the SINR reduces.

Figure 1 depicts a no dominant server scenario wherein the upper floors of high-rise buildings have line-of-sight (LOS) with many base stations (herein referred to as evolved Node B (eNB)) on the ground. The composite signal levels on the upper floors can be very high, but no server is much better than the others, so the combined SINR from every server is poor because receive signal to power ratio (RSPR) is almost equal from all available eNBs.The scenario described above is unfavorable for realizing efficient resource scheduling because: it encourages immense increase in overhead signaling andrequire the UEs to report their channel experience to their respective serving eNBs for every scheduling time. This situation causes delay, consume more power at UEs' sides and over burden the eNBs. Hence there is need to curb the impact of this factor to achieve better results especially for LTE-A systems. Ideally, acceptable schedulers should take into cognizance the channel condition in order to optimally and efficiently make the allocation decision. Most of the works presented in wireless communication scheduling use different metrics for making final decision. A detail survey of decision criteria for scheduling in wireless network is presented in[2] similar scheduling suggestion for LTE network could be found in the works of [3, 4]. The downsides for the earlier suggestions includes: increase in overhead signaling, the requirement for special power control mechanism for eNBs, above all final scheduling decisions are based on several network parameters which wouldprone the final decision to errors due to approximations. Hence, a new approach that will guarantee higher accuracy and low complexity is much needed to address these problems.

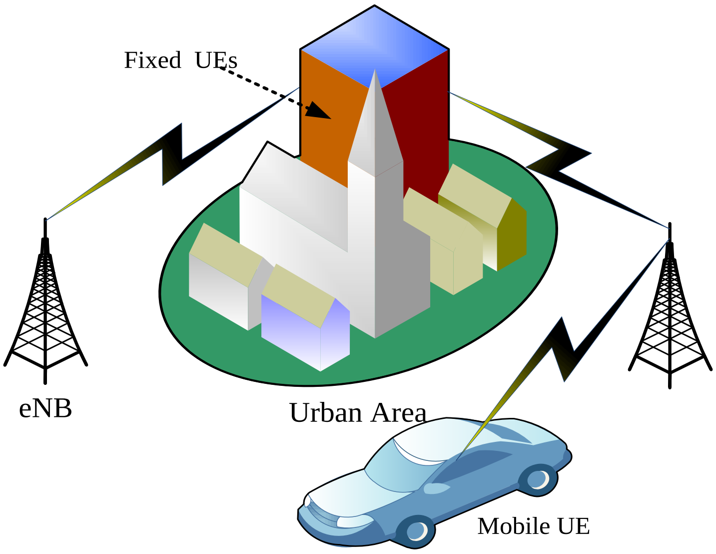

Figure 1. No Dominant Server Scenario for Fixed UEs at High Rise Buildings

In this paper we proposed alternative solution to aforementioned problems, our framework considers a general resource scheduling in wireless network within an interference limited environment (case study LTE-A system). The underlying problem is the estimation of the interference level for each UE during resource scheduling. We applied Markov-chain model to provide a systematic and general approach to obtain interference distribution pattern without necessarily depending on the UE's feedback for every scheduling time. A few initial UEs' channel experience reported to their serving eNB generates good starting points that can be used as the initial parameters; subsequently, the interference level can be estimated with relative accuracy. While we do not rule out approximation errors, the obtained estimates are close to what is obtainable in practical scenario. With the knowledge of interference distribution we adopt the method of WF^{2}Q to impose fairness criteria during resource allocation. Thus, our method has a faster decision processing time, ensure fairness and burst resource utilization.

2. System Model

The resources available for scheduling could be in terms of packet or frame units, time or frequency slots etc., however, resource block (RB) is the basic resource unit in LTE. Also the scheduling rate is well defined for LTE and the most dynamic scheduling rate takes place within every transmission time interval (TTI) which is 1ms [5]. In this paper we consider only the downlink scheduling for LTE-A systems.The downlink channel state information experienced by k^{th} user on n^{th} RB at slot t is given by equation 3 as presented in [6];

$$SINR_{k,n}(\mathrm{t}) = \frac{\mathrm{p}_n^s\, g_{k,n}^s}{\mathrm{p}_n^{\mathrm{int}}\, g_{k,n}^{\mathrm{int}} + \alpha} \tag{3}$$

Where α is the noise, p_n^s and $\mathrm{p}_n^{\mathrm{int}}$ are transmit powers for required and interfering signals respectively, while $g_{k,n}^s$, $g_{k,n}^{\mathrm{int}}$ are gains for require and interfering signals respectively. Equation 3 would make sense $\Leftrightarrow$ $(\mathrm{p}_n^{\mathrm{int}}\, g_{k,n}^{\mathrm{int}} + \alpha) > 0$ to avoid $SINR_{k,n}(\mathrm{t}) \to \infty$. For any UE to successfully utilize a particular RB the $SINR_{k,n}(\mathrm{t}) \geq \beta_{\min}$ where $\beta_{\min}$ is the minimum signal level require for guaranteeing 1% BLER.

The supportable rate for each UE in the presence of interfering signals is defined as[7]:

$$r_k(n) = \log(1 + \lambda_k(n)) \tag{4}$$

Where $\lambda_k(\mathrm{n}) = \dfrac{\mathrm{g}_{k,n}^s(t)}{1/\eta + \sum_{c=1, c\in I}^{C} \mathrm{g}_{k,n}^{\mathrm{int}}(t)}$ with assumption that $p_{k,n}^s \equiv p_{k,n}^{\mathrm{int}}$ and $\eta = \dfrac{p_{k,n}^s}{\alpha}$.

In resource scheduling, optimal throughput and fairness are metrics that can guarantee quality of user experience. In our proposed scheme, we consider using method of Worst-case Fair Weighted Fair Queuing (WF^{2}Q) technique. Our motivation for WF^{2}Q is because it helps to smooth out the variation in service times caused by UEs' resource request that have widely differing weights[8].In our case, the resources are the RBs available for each slot of a downlink subframe. WF^{2}Q also keep track of delay boundby throttling UEs' resource allocation especially for the privileged UEs that have less interference and as wellensure efficient resource allocation among competing UEs at any given time using a predefine priority.

The simulation of WF^{2}Q is characterized by equation 5 as presented in [9] with modification;

$$S_i(k) = \max(F_i(k-1), V(A_i(k)))$$

$$F_i(k) = S_i(k) + \frac{L_i(k)}{w_i} \tag{5}$$

$S_i(\bullet)$ is the virtual start time UE begin to access the network resources, $F_i(\bullet)$ virtual finish time a UE would complete utilizing the network resources, $V(\bullet)$ is virtual time function for service request arrival at the eNB which is a piecewise function of the real time $A_i(\bullet)$,whereas $L_i(\bullet)$ and w_i are the service length and the weighted priority for each service request respectively.

3. Model for Interference Estimation

The principle of operation of interference-limited WF^{2}Q is homogeneous to WF^{2}Q with fluid flow server; however, in our case the interference factor is included as one of metrics for determining the priority for each UE during scheduling. UEs are been categorized according to degree of interference they are experiencing and the supportable rate. The supportable rate can be figured out using equation4whilethe degree of interference is estimated by;

$$\delta_{\text{int},k}(t) = \sum_{i=1}^{K} p_i - \sum_{j=1, j\in I}^{K-1} (1 - |\tau_i|) p_i \tag{6}$$

p_i = the transmitting powers for both desire and interfering signals, $|\tau_i|$ is cardinal number of interferers. Basically, the weighting priority in equation 5is given as; $w_i = r_k \Big/ \sum_{j=1}^{N} r_j$. With our new concept of accounting for interference factor, we modify w_i as;

$$w_i(t) = \delta_{\text{int},k}(t).w_i \tag{7}$$

The new weighting priority given in equation 7will give account of interference for each UE during scheduling. Though,the underlying issue in substituting equation 7into 5is the difference in time caused by the value of $|\tau_i|$ in $\delta_{\text{int},k}(t)$. In clearer say, all metrics in equation 5 are predetermined but $w_i(t)$ is instantaneous; hence, there is need to make it predetermine too to ease updating of equation 5. To address this drawback, we consider the variation of $|\tau_i|$ within a radio frame.

Let X_t be an indicator random variable that indicates whether an UE is active or idle at slot t in a given frame. The index $T = [0,1,\ldots,10)$ is also discrete and represents the time slot. During each frame, UE'sstates can be described as discrete-time stochastic process with a discrete state space $S \in \{0,1\}$, where 0=idle and 1= active states respectively. At the beginning of each radio frame *i.e.*, slot $t = 0$, UE k would be in state $X_{k,t} = u$, then the transition to the next state enters state $X_{k,t+1} = v$ with transition probability $P_{u,v}$. This transition takes place at holding time h_1 . Computing the values of $P_{u,v}$ for each UE for every transition can be challenging,however, the process can be qualified as having Markov property given as[10]:

$$\wp\{\underbrace{\mathrm{X}_{t+1} = \mathrm{j}_t}_{\text{future state}} \mid \underbrace{\mathrm{X}_0 = \mathrm{j}_0, \ldots, \mathrm{X}_{t-1} = \mathrm{j}_{t-1}}_{\text{preceeding states}}, \underbrace{\mathrm{X}_t = \mathrm{j}_t}_{\text{current state}}\} \tag{8}$$

For Markov chain of order d we have:

$$= \wp\{\underbrace{\mathrm{X}_{t+1} = \mathrm{j}_t}_{\text{future state}} \mid \underbrace{\mathrm{X}_{t-d-1} = \mathrm{j}_{t-d-1}, \ldots, \mathrm{X}_t = \mathrm{j}_t}_{\text{Information for } d \text{ precceding states}}\} \tag{9}$$

One-step transition probability of a Markov chain from state space u to v, denoted by $P_{u,v}(\mathrm{t})$, isnow define as;

$$P_{u,v}(t) \square \wp\{\mathrm{X}_{t+r} = v \mid \mathrm{X}_t = u\} \tag{10}$$

Where $r = 0,1,2,3,\ldots$ .Having known the transition matrix (obtainable from equation 10), we can then determine the possible state of the interferers at every instant using the transition probabilities.See example in equation 11. At the end, we would realize a matrix representing the $|\tau_i|$.For example, Let A be the transition matrix of Markov chain and u be probability vector which denotes starting distribution, then the probability that the chain is in state s_n after n steps can be realized as follows;

$$u^{(0)} = u$$

$$u^{(1)} = uA$$

$$u^{(2)} = u^{(1)}A = uA^{(2)}$$

$$u^{(3)} = u^{(2)}A = uA^{(3)}$$

$$\bullet$$

$$\bullet$$

$$\bullet$$

$$u^{(\mathrm{n})} = u^{(\mathrm{n}-1)}A = uA^{(\mathrm{n})} \tag{11}$$

Thus, we can predetermine the states for each RB at any time instant using the initial statevector and transition matrix only.

3.1 Scheduling Models

Scheduling is one of the key functions performed by the MAC layer that helps in guaranteeing and moderating quality of service among network users. In LTE, resource allocation is network controlled; hence the distribution of resource units among UEs is moderated by eNBs [11]. The allocation procedure would have to consider network parameters and UEs' network experience to determine the best algorithm for resource distribution, this is to provide balance resource distribution, however the key challenge is how to balance the tradeoff between fairness and throughput. There are number of established algorithms in literature designed for resource allocation in wireless communication systems such as proportional fair (PF), maximum SINR, generalized processor sharing(GPS), best CQI [2, 12, 13] *etc.*, the performance of these algorithms in LTE with different scenario is important particularly for achieving the stipulated throughput and spectral efficiency. In every scheduling scheme, fairness index and throughput are considered fundamental. Proportional fair, generalized processor sharing and their respective enhanced algorithms are very popular because of efficiency and acceptable fairness they indicate,whereas best CQI and MaxSINRare bandwidth efficient though biased in favour of UEs with good channel experience.

3.2 Simulation Setup

Our test bed comprised of 5 eNBs and 20 UEs. Each UE is configured to experience difference interference level at different times. The rate of change of the interference level is random for all UEs. The simulator is customized and implemented in MATLAB programme. The network layout is as depicted in Figure 1. Figure 2 shows the scheduling pattern.

We considered only downlink subframe with bandwidth of 10MHz, uniform transmit power is assume for all the eNBs whereas the UEs are expected to have variation in received signal strength and data rate due different level of interference being experienced by individual UE. The scheduling is fully dynamic and the overhead especially for the control channel is partly considered.

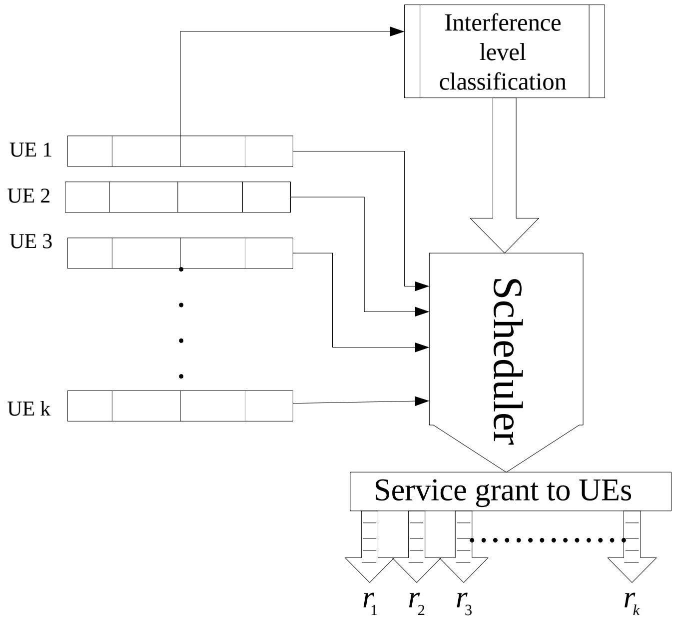

Figure 2. Scheduling Pattern

4. Results

4.1. Throughput Evaluation

We conducted simulations to evaluate the performance of our proposed algorithm, further, for comparison purpose we emulated the performance of three other algorithms namely: General Processor Scheduling (GPS), proportional fair (PF) and MaxSINR. In each case the same network parameters were used for both eNBs and the UEs. The results from each algorithm exhibit different performance as shown in Figure 3.

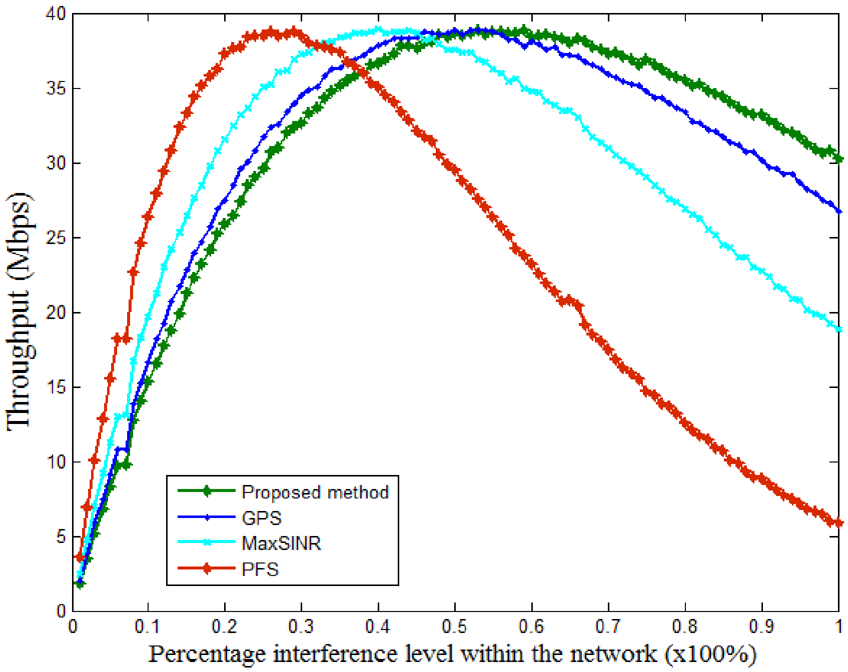

Figure 3. Throughput-vs-percentage Interference Level

It is observed from throughput-vs-interference probability graph that for each algorithm the network'sthroughput continue to increase until it reaches a peak of about 38Mbps, however, the difference in performance becomes obvious as the probability of interference tend to 1.

MaxSINRshowed higher throughput at lower interference level but perform poorly after the peak, this is because the variation of UEs' SINR is apparently small in such a network scenario we considered. During scheduling process the scheduler will try to assign resource units to a few UEs that may have slightly higher SINR leaving many starved thereby encouraging unsolicited grant services (UGS), this algorithm is not only biased but also ineffective in interference limited scenario. PF indicates a fair resource allocation for users and perform better than MaxSINR, However it shows underutilization of network resources too beyond the peak.

GPS and our proposed algorithm show comparable results with GPS performing even better before the peak. Beyond the peak our algorithm outperforms the GPS because it captures the entire interference predicament before allocating resource units. The result of proposed algorithm depicted in Figure 3 also suggests it to be a good choice because it ensures fairness amongUEs and improve the network resource utilization.

4.2. Fairness Evaluation

The goal of resource scheduling in a network is to enhance or maximize the whole utility ofUEs subject to network'scapacity constraints.However, fairness issue is cannot be ignored because there might be a situation where a given scheme is capable of maximizing the network throughput while denying some UEs access to network resources. Jain's fairness index is one of the ways of expressing the fairness criteria in wireless network as demonstrated in the works of [14-16], the Jain'sfairness index is given as [15]:

$$J(u_i) = \frac{\left(\sum_{i=1}^{n} u_i\right)^2}{n\sum_{i=1}^{n} u_i^2} \quad (12)$$

Where u_i is feasible allocation for user i defined as the ratio of measure throughput to fair throughput. Figure 4 depict the the performance of the each algorithm simulated. As demostrated in the figure our proposed algorithm guarantee better fairness compare to others.

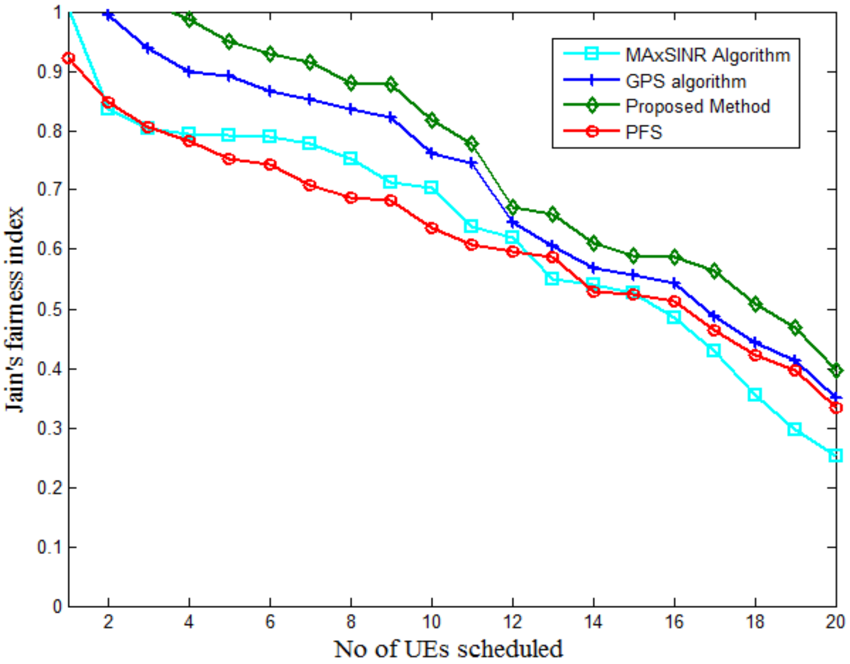

Figure 4. Jain's Fairness Index for Different Algorithms

5. Conclusion

Scheduling in intereference-limted environment like sub urban scenario was herein investigated. UEs are assumed to be capable of estimating their potential inteferers per reource block (RB) and report same to their serving eNBs as soon as they establish connectivity with serving eNB. Through analytical model of such we have showed a new technique to manage the interference effectively. Our method has showed and proved two inportant achievements: UEs interference level can be estimated by eNB using Markov-chain without much feedback from the UEs, this situation reduce the overhead for feedback reporting during channel estimation. Also, the method of WF^2Qintegrated in the proposed scheme makes it possible to conviently serve the UEs with worst-case interference experience while ensuring fairness during resource allocation.We validated our model through simulations and quantitatively evaluate it in an outdoor wireless testbed.Our results has demostrated the gain of proposed model.

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