ADAPTIVE PACKET ERROR RATE TARGET FOR ENERGY EFFICIENT PACKET DELIVERY

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ABSTRACT

Link adaptation mechanisms are viewed as one of the key techniques for increasing the diversity order, robustness and effectiveness of a wireless communication system. Traditional schemes are designed to increase the system capacity and momentary transmission spectral efficiency. In this paper we present a novel algorithm in which we co-design Adaptive Modulation and Coding (AMC), Hybrid ARQ (HARQ) and power control in order to enhance the energy efficient of packet delivery. Our goal is to reduce the overall transmission energy consumption while meeting the QoS constraints of heterogeneous application services. Our analysis reveals how the proposed approach permits to achieve notable energy gain over traditional adaptive mechanism design.

1. INTRODUCTION

Telecommunication has experienced tremendous success causing proliferation and demand for ubiquitous heterogeneous broadband mobile wireless communications. Up to now, innovation has targeted to improve wireless networks coverage and capacity while meeting the QoS for users admitted in the system. Nowadays, the number of mobile subscribers equals more than half the global population. Forecast on telecommunication market assume an increase in subscribers, per subscriber's data rate and, the roll out of additional base stations for next generation mobile networks. The undesired consequence is the growth of wireless network's energy consumption which will cause an increase of the global carbon dioxide (CO_2) emissions and, impose more and more challenging operational cost for operators. Communication energy efficiency represents indeed an alarming bottleneck in the telecommunication growth paradigm.

Recently, increasing maturity of mobile technology in combination with the growing amount of equipment deployed each year has woken up the need of innovating in the field of energy efficient communications. Energy efficient enhancement in wireless communication can be achieved only if improvements are experienced in the whole communication chain for different operational load scenarios. Several investigations are on going on this research area, ranging from energy efficient cooling of base stations, to innovative energy efficient deployment strategies and frequency planning [7] [2] [3].

Information theorists have studied energy-efficient transmission for at least two decades [5] [13]. The work in [5] defines reliable communication under a finite energy constraint in terms of the capacity per unit energy, which is the maximum number of bits that can be transmitted per unit energy. This definition ensures that for any transmission rates below the capacity per unit energy, error probability decreases exponentially with the total energy.

With this paper we investigate how adaptive mechanisms can be exploited to improve the energy efficiency of wireless communications. More precisely, we focus on Adaptive Modulation and Coding (AMC)[6], Hybrid Automatic Repeat Request (HARQ) and power control algorithm, in order to improve the energy efficiency of transmission. Classically, adaptive mechanisms aim at improving wireless packet transmission performance under Quality of Service (QoS) requirements. Most of the time such QoS constraints are imposed in terms of fixed packet error rate target. QoS constraints limit indeed optimization potentials of adaptive mechanisms. Moreover, while users may access to resources with a variety of heterogeneous services such as voice (VoIP), video, gaming, web browsing and others, in adaptive mechanisms, target error rate are typically set to satisfy the packet error rate constraints of the application which has more stringent packet error rate requirement[8].

There have been lot of work in development of efficient HARQ algorithms for wireless channels in last decade. Ebert. et al[10] have proposed combined tuning of transmission power and medium access control. Sun et. al[12] proposed the energy efficient algorithm for HARQ under error constraints by adaptively changing the coding rate for subsequent retransmissions according to channel conditions. The impact of both circuit and transmit power on energy efficiency HARQ Type I has been studied in [11].

In our view, energy efficient correct delivery of packets can be achieved by co-designing AMC, HARQ and power control. The reduction of transmit power of each transmission increases packet error rate(PER), hence increased average number of transmissions for successful packet. However, increased transmit power of each transmission reduces PER of each transmission, thus resulting in reduced average number of transmissions for successful packet delivery. With this paper we propose to adaptively achieve the optimization tradeoff between power, spectral efficiency and delay, by adapting at each transmission attempt of a packet, the risk of unsuccessful packet delivery. QoS constraints of heterogeneous application services are taken into account in terms of residual packet error rate after a pre-fixed number of maximum retransmission attempts. We call the proposed algorithm *Variable PER Adaptation*.

The organization of the paper is as follows. The next section introduces the system model followed by the problem formulation in section 3. Section 4 shows the link level simulation results of the proposed algorithm. Finally, we conclude the paper with the discussion of conclusions and future work in section 5.

2. SYSTEM MODEL

The system under consideration is an OFDM system with frequency-division multiple access (FDMA). Perfect channel state information is assumed at both the receiver and the transmitter, i.e., the channel gain on each chunk due to path loss, shadowing, and multipath fading is assumed to be known. Channel parameters are assumed to be estimated by some other method, which is not specified in this paper. The system does not employ spreading in either time or frequency; each chunk can only be used by one user at any given time. Chunk allocation is performed at the base station and the users are notified of the carriers chosen for them. After the allocation, each user performs power allocation and bit loading across the chunks allocated to it to find the transmission power.

The transmitted symbol x is multiplied by fading channel coefficient H, which is i.i.d rayleigh distribution, and then subsequently added to White Gaussian Noise. We further assume that noise, n is AWGN noise with mean 0 and variance σ_n^2. The received signal vector y is given by,

$$y = Hx + n \tag{1}$$

Hence, we can express SINR as, $\gamma = \frac{|H|^2}{\sigma_n^2}$. The input to variable PER algorithm is this normalized chunk SINR, γ. We assume that all the symbols within a packet undergo the same fading to simplify the design of the algorithm. This assumption assumes that the coherence time of the channel is larger than the packet duration, which is true for slow fading pedestrian cellular environment. The various system parameters are described in table 1

3. PROPOSED ALGORITHM: VARIABLE PER ADAPTATION TO IMPROVE ENERGY EFFICIENCY(EE) OF HARQ

Traditional link adaptation mechanisms are designed to track fast and/slow variation of the transmission context in order to maximize the momentary transmission rate while aiming at meeting quality of service (QoS) constraints such as delivery delay, residual PER (PER_{res}), etc. Indeed, classically, link adaptation and in general adaptive mechanisms targets' are the enhancement of the transmission spectral efficiency, reduction of delivery delay, improvement of transmission reliability and avoidance of catastrophic transmission configurations for which QoS is strongly reduced and communication can drop for a long period. The reason for this is that after a given maximum number of retransmissions, there is a targeted residual PER, PER_{res} which depends on overall service tolerance on residual packet error rate. For the case of cellular systems like LTE, the AMC selection criterion is set to 10% PER Target threshold for 3 maximum retransmissions. The reason for this being that residual packet error rate in this case is simply 10^{-4}, which is adequate enough for most applications like voice, video and data transfer[8]. However, such an approach is inefficient in terms of energy consumption of retransmissions. It should also be noted that different applications require different residual packet error rate [1]. For example, voice/video conferencing applications typically need a residual packet error rate of 1%, whereas streamed video applications can tolerate residual PER as high as 5%. In light of these observations, we believe target packet error rate for different retransmissions can be adaptively optimized along with power control, AMC selection and the number of retransmissions to reduce the system energy consumption while at the same time meeting the application QoS requirements. We explain the algorithm for variable PER adaptation for one chunk for easier understanding of the problem. The main idea is to minimize average total power, P_{avg}^m of all the transmissions subject to certain QoS constraints of the user. The average total power, P_{avg}^m is given by,

$$P_{avg}^m = \sum_{i=1}^{Tr_n} \left\{ P_i^m \prod_{k=0}^{i-1} PER_k^m \right\}, \tag{2}$$

where $PER_0^m = 1$. The above calculation of P_{avg}^m assumes that the errors in multiple retransmissions of a packet are independent of each other and the channel does not change during *all* the retransmissions. Hence, the optimization problem can be formulated as follows:

$$\min_{m, Tr_n, P_i^m} P_{avg}^m \text{ s.t. } 1 \le i \le Tr_n$$

subject to

$$P_i^m \le P_{max}$$

Power Control without chase combining :

$$P_i^m \gamma \ge SINR_i^m$$

Power Control with chase combining :

$$\sum_{j=1}^{i} P_j^m \gamma \ge SINR_i^m$$

Residual PER constraint :

$$PER_{res} \le \prod_{i=1}^{Tr_n} PER_i$$

$$PER_i \ge PER_{i+1} \; \forall i \in [1, Tr_n]$$

QoS requirement :

$$PS^m \ge B \tag{3}$$

This problem formulation is only valid for chase combining[4] in which sender transmits same information (data and parity bits) for each retransmission. The receiver then combines all the packets using maximal ratio combining thus resulting in increased perceived SINR. Also, the second constraint of residual PER indicates that PER target of each subsequent transmission should be at least or higher than the target used by previous transmissions. This constraint ensures that power, P_i calculation in step 7 of the algorithm (described later in the section) is positive. The optimal solution to the problem in equation 3 is non-trivial due to non-convex and discrete nature of the problem. Nevertheless, we can find sub-optimal solution by searching over a PER Target vector space and using some optimizations to reduce the number of iterations required to find the sub-optimal solution. Now, we describe the basic steps of the sub-optimal algorithm, which solves the above problem in sub-optimal way. The algorithm is comprised of the following steps:

Step 1: Choose starting MCS, m such that

$$m = \text{argmin}_k \left\{ B > PS^k \right\}$$

Step 2: We first define a PER Target vector, PER_{tg} over which search is carried out to minimize P_{avg}^m. The example vector that we use in our simulations is $PER_{tg} =$

$[PER_0\, PER_1\, PER_2 \ldots PER_\eta]$. The search to find the right PER_i^m for each transmission based on minimizing equation 2 according to channel and QoS constraints is a permutation problem with $\eta^{Tr_{max}}$ possible solutions (for the case of Tr_{max} maximum number of retransmissions). However, we employ some optimization methods to reduce this search space to speedup the algorithm.

Step 3: Find the $SINR_{tg}^m$ vector that corresponds to PER_{tg} for MCS m. $SINR_{tg}^m$ is the minimum SINR threshold required to achieve packet transmission with packet error rate PER_{tg} for MCS m. After that we delete the entries in PER_{tg} and $SINR_{tg}^m$ vector which cannot meet the SINR threshold requirements. Hence, each entry i of $SINR_{tg}^m$ has to satisfy the following constraint, $SINR_i^m \leq \gamma P_{max}$. This can significantly reduce the dimension of PER_{tg} and $SINR_{tg}^m$ vector.

Step 4: Now, we build the permutation matrix based on the reduced PER_{tg} from previous step. Each row of the permutation matrix describes the sequence of target PER, PER_i^m that should be selected for each of the transmission attempts. The dimension of permutation matrix is $\eta'^{Tr_{max}} X Tr_{max}$, where η' is the new dimension of PER_{tg} computed in step 3.

Step 5: We delete the rows in this permutation matrix which cannot satisfy the residual PER constraint $PER_{res} \leq \prod_{i=1}^{Tr_n} PER_i$. We also discard the rows in above-mentioned permutation matrix for which the following constraint is not satisfied, $PER_i \geq PER_{i+1}\ \forall i \in [1, Tr_n]$. It is possible that PER_{tg} vector matrix is null at the end of this step if channel to the user is not sufficient to satisfy MCS, m computed in step 1. If this is the case, we reduce MCS by 1 and goto first step to restart the algorithm.

Step 6: Now, we compute the average power, P_{avg}^m for all the rows in permutation matrix as given in equation 2. Finally, we select the row in Permutation matrix which minimizes P_{avg}^m. The reason is that after every failed transmission, we intend to use lower PER Target for subsequent re-transmission.

Step 7: Finally, the power, P_i for each transmission, i is computed recursively for chase combining HARQ transmission as,

$$P_1^m = \frac{SINR_1^m}{\gamma}$$

$$P_i^m = \frac{SINR_i^m - \sum_{k=1}^{i-1} SINR_k^m}{\gamma}, \forall i \geq 1$$

The above optimizations actually significantly reduce the search space over which we can minimize P_{avg}^m.

4. SIMULATION RESULTS

In this section, we describe the link level simulation results obtained for the simulation parameters in table 2. Here, it is worth mentioning a note on the size and values chosen for PER target vector, PER_{tg}. The larger is the size of PER target vector, the better is the Energy Efficiency(EE) gains possible from the algorithm, but it comes at the cost of increased complexity and time required to find the sub-optimal solution. However, the smaller size of PER target vector, PER_{tg} can significantly reduce the EE gains possible from the Variable PER adaptation. The proposed PER target vector in table 2 is the right compromise we found from both the EE gain and implementation complexity point of view.

We place a UE randomly in a cell of radius 250m. Figure 1 shows the EE gain Vs UE downlink traffic compared to

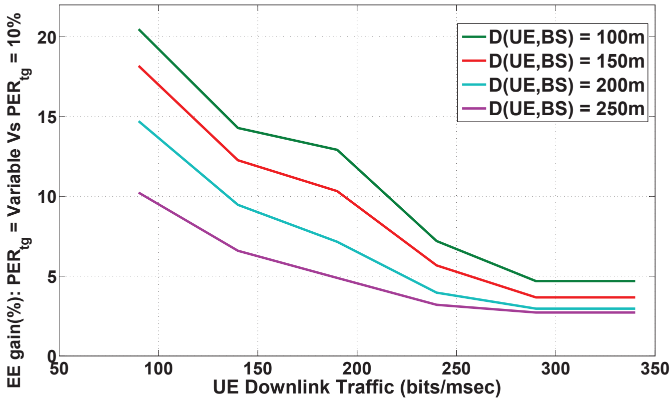

Figure 1: Energy Efficiency gain(%) Vs UE Downlink traffic compared to $PER_{tg} = 10\%$ for Residual PER, $PER_{res} = 0.01$

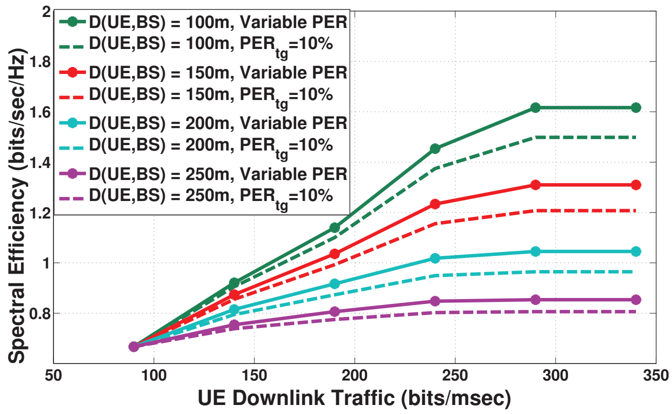

Figure 2: Spectral Efficiency Vs UE Downlink traffic comparison of $PER_{tg} = 10\%$ and Variable PER for Residual PER, $PER_{res} = 0.01$

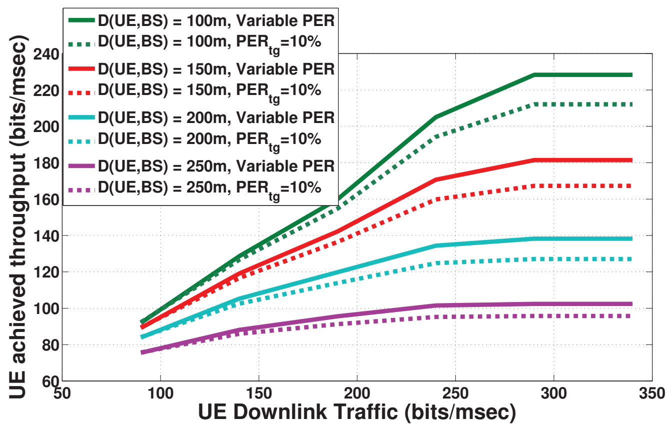

Figure 3: Achieved throughput Vs UE Downlink traffic comparison of $PER_{tg} = 10\%$ and Variable PER for Residual PER, $PER_{res} = 0.01$

Table 1: System Parameters

Modulation and Coding Scheme (MCS) index	m
Distance of UE to BS	$D(UE,BS)$
Maximum no of allowed transmissions	Tr_{max}
Power per chunk for i^{th} transmission using MCS m	P_i^m
Target PER for transmission i for MCS m	PER_i^m
Residual PER after all the re-transmissions	PER_{res}
Number of transmissions	$1 \leq Tr_n \leq Tr_{max}$
Packet size of user to transmit	B
Average power of all the transmissions for MCS m	P_{avg}^m
SINR threshold for transmission i to achieve PER Target PER_i for MCS m	$SINR_i^m$
Packet size corresponding to MCS m	PS^m
Maximum Power allowed on each chunk	P_{max}
Discrete values of PER target vector search space for optimization	PER_{tg}
Size of PER_{tg} vector	η
Average power consumption of all the transmissions	P_w

fixed $PER_{tg} = 10\%$. The EE gain plotted in figure 1 is given by,

$$\text{EE gain} = \frac{P_w(PER_{tg} = 10\%) - P_w(PER_{tg} = Variable)}{P_w(PER_{tg} = 10\%)} \tag{4}$$

We plot the results of EE gain Vs UE downlink traffic for users with varying distance from BS.

We can see from the figure that the UE closer to the BS gains much more in terms of EE than the UE farther away from BS. It should also be noted that there is lot more EE gain for low-load scenarios than high-load scenarios. The reason for this behavior is that whenever there is better channel compared to the spectral efficiency requirement of the user based on downlink traffic, we have more degrees of freedom to optimize the target packet error rate. Hence, the UEs which have better momentarily channel are more suited to gain from the variable PER adaptation. The EE gain for low load scenarios especially for UEs closer to the base-station can be as high as 20%. The EE for high load scenarios is very little due to the fact that high data rate requirement from the application limits the degree of freedom available to the algorithm to reduce power consumption.

We plot the spectral efficiency comparison of proposed variable PER scheme compared to fixed 10% PER in figure 2. We note from this figure that while variable PER performs slightly better in terms of spectral efficiency, but the two schemes operate essentially on the same MCS most of the time as spectral efficiency is computed directly from MCS used in the simulation using table 3. This means that even though variable PER selects the same MCS as that which is required to satisfy $PER_{tg} = 10\%$, it adaptively adjusts the PER_{tg} of each transmission to improve EE of overall successful transmission of a packet.

Table 2: Simulation Parameters

UE distance from BS, $D(UE,BS)$	$\{100,150,200,250\}$m
Channel	Rayleigh Fading Channel
Traffic model	Constant bit-rate
Distance-dependent path loss	$L = 128.7 + 37.6\log 10(R)$, R in km [9]
Maximum no of allowed transmissions	4
Residual PER, PER_{res}	$\{0.01, 0.05\}$
Packet size of user to transmit/TTI, B	{90, 140, 190, 240, 290, 340}
Packet size corresponding to each MCS	See table 3
Maximum Power allowed on each chunk, P_{max}	0.8 Watt
Size of PER_{tg} vector over which optimization is performed, η	11
PER Target vector, PER_{tg}	{0.01, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5}

Table 3: Packet Size and Spectral Efficiency for MCS

MCS mode	Modulation	Coding	Spectral Efficiency (bits/sec/Hz)	Packet Size (bits)
1	QPSK	1/3	2/3	96
2	QPSK	1/2	1	144
3	QPSK	2/3	4/3	192
4	16-QAM	1/3	4/3	192
5	QPSK	3/4	3/2	216
6	16-QAM	1/2	2	288
7	64-QAM	1/3	2	288
8	16-QAM	2/3	8/3	384
9	16-QAM	3/4	3	432
10	64-QAM	1/2	3	432
11	64-QAM	2/3	4	576
12	64-QAM	3/4	9/2	648

We also plot the achieved throughput in figure 3 for fixed PER Target of 10% and variable PER scheme. The two schemes achieve almost same throughput, while variable PER performs slightly better in terms of throughput performance, especially at high load scenarios. The reason for this behaviour is that variable PER algorithm is more spectral and energy efficient compared to fixed $PER_{tg} = 10\%$. The main explanation of this result is that especially in channel instances when the channel does not suppport the minimum MCS required due to the traffic requirement of the user(QoS constraint in equation 2), the variable PER can select higher MCS(than the one selected by fixed PER target=10%) with higher target PER($> 10\%$).

We finally plot the EE gain Vs UE downlink traffic varying the $PER_{res} = 0.01$ and $PER_{res} = 0.05$ in figure 4. We can see clearly that Variable PER performs slightly better for higher Residual PER, $PER_{res} = 0.05$ compared to $PER_{res} =$

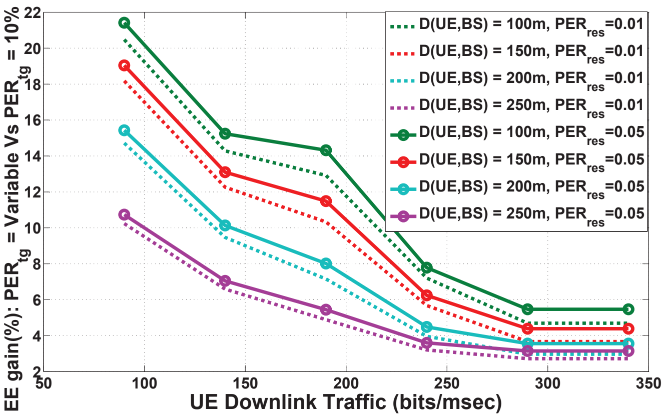

Figure 4: Energy Efficiency gain Vs UE downlink traffic comparison for $PER_{res} = 0.01$ and $PER_{res} = 0.05$

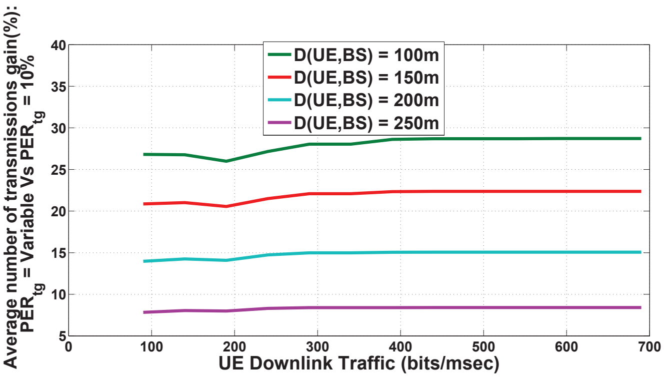

Figure 5: Average number of retransmissions gain(%) Vs UE downlink traffic for $PER_{res} = 0.05$

0.01 as higher residual PER allows for more flexible adaptation of PER for each transmission.

We also plot the gain in average number of retransmissions Vs UE downlink traffic for the two schemes in figure 5. The variable PER adaptation increases the average number of retransmissions especially for users with high spectral efficiency, hence increases the delay of packets in the system. But, this delay is acceptable as long as its below the tolerance level desired by the application.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we propose to adapt the PER Target of each transmission along with power control and AMC selection to reduce the average power consumption of single link. We show that UEs with good link conditions are poised to gain more from variable PER algorithm as this allows more degrees of freedom for adaptation of algorithm parameters. The variable PER algorithm improves the EE of system at the expense of increased *average* number of retransmissions and this obviously increases the average delay experienced by the application. Hence, variable PER algorithm exploits the tradeoff between delay and energy consumption. The next step of this work is to extend the algorithm to design multi-user scheduling approaches which exploit such tradeoff between delay and energy.

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