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Energy-aware Link Adaptation Technique for Massive MIMO Antenna Systems

Isabona Joseph and Ojuh. O. Divine
[1]*Department of Physics, Federal University Lokoja, Kogi State*
[2]*Department of Physical Sciences, Benson Idahosa University, Benin City, Edo State*

Abstract
Power consumption control and energy efficiency maximization with robust data transmission rates in Gigabits, are the most essential factors driving toward the evolution of future fifth generation cellular communication standards. One of the fundamental antenna deployment techniques to meet these performance targets is the use of large scale multiple antenna systems called Massive MIMO (M-MIMO). Previous works focused on the enhancement of energy of narrowband system with a single carrier, which uses one or few antennas at the transmitter and receiver via energy-aware link adaptation technique In this is work, energy-aware link adaptation technique is studied in a single- cell downlink M-MIMO antenna systems, under a broader range of influencing system service quality parameters: frame packet lengths, varying traffic loads in terms of number active users and error rate targets. Simulation and analysis of the achievable throughput and absolute energy efficiency have been presented under the aforementioned influencing system parameters. The results show that longer packets are more energy efficient than shorter packets. This is as a result of less payload data overheads with long packet lengths. Furthermore, the simulation results are presented to reveal how energy efficiency performance degrade with increasing number of users, owing to pilot pollution and higher power consumption. Our findings can act as guidelines to designing energy proficient wireless network setup.
Keywords: *Massive MIMO, Power efficiency, Energy efficiency, packet length, bit error rate.*

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Nomenclatures

N_t	Number of transmission antennas
Nr	Number of receiving antennas
K	Number of users
Kc	Boltzmann constant
T_K	Throughput
T,max	Maximum achievable throughput
T	Achievable throughput
Ta	Absolute temperature
P_0	overhead power consumption
P_{TX}	Transmit power
P_{max}	Maximum Transmit power
P_S	Stand-by mode power
P_{BB}	Baseband power
N_{TRX}	Number of transceiver
ZF	Zero forcing

Greek Symbols

σ	Gaussian noise.
σ_{MS}	Losses incurred by main supply
σ_{DC}	Losses incurred by direct current supply
σ_{cool}	Losses incurred by cooling supply
σ_{feed}	Losses incurred by feeder supply
η_{PA}	Power efficiency

Abbreviations

AEE	Absolute Energy Efficiency
BS	Base Station
BER	Bit Error Rate
HSPA	High Speed Packet Data Access
MIMO	Multiple Input Multiple Output
OFDM	Orthogonal Frequency Duplex Multiplexing
PER	Packet Error Rate

I. Introduction

The growth of wireless communication technology has been very remarkable in the last few years. This growth have been boosted with an ever-increasing demand by subscribers for both portable and medium sized multi-purpose devices such as smart phones, iPod, iPad, tablets, palmtops and laptops[1][2]. To sustain the growth, the telecommunication industry and their network operators have been rolling out different multimedia personal communication standards such as high speed packet access (HSPA) and Long Term Evolution (LTE) systems which support robust network reliability and high data transmission rates. As the different mobile broad communication standards are being rolled out to address the higher data throughput capacity demands by subscribers, the power. consumption by the mobile station devices and their base stations infrastructure is also increasing. It is revealed in [3-5] that radio network interfaces, comprising cellular communications, Wi-Fi, etc., consume above 50% of entire system energy budget. Thus, high energy efficiency consumption is becoming more central issue for power driven mobile communications systems. This has in turn drawn amassed attention recently from the telecom operators and the research community. Today, we have a number of international research projects devoted to handling energy-efficient wireless communications problems. Some of them includes the EARTH [6] and OPERANet [7]. For example, the main drive behind the EARTH project is to tackle the global environmental energy challenges by finding out different effective mechanisms that will significantly reduce energy wastage in mobile communication cellular networks, whilst providing uncompromised service quality and user experience.

In [8-14], the array and multiplexing gain of MIMO scheme have been explored to enhance energy efficiency in sensor networks. However, direct practical utilization of M-MIMO to sensor nodes is unrealistic owing to their constrained physical dimension. Moreover, Wireless sensor networks are very low-power networks where energy consumption is off less concern as compared to that of cellular networks with high percentage of energy consumption**.** A MIMO based resource allocation policy to maximise energy efficiency for OFDM Systems under the condition of Statistical QoS Requirement is proposed in [15]. Their results pointed out that the energy efficiency that can be achieved via the resource allocation policy approach is large delay bound limited. A link adaptation Smart MIMO based control is proposed in [16], for throughput optimisation and energy consumption minimization in WLANs with OFDM Radio interface. Similar MIMO based adaptive approach was also adopted in [17], however, the authors only focused on power amplifier, leaving other energy sources with radio frequency components.

Particularly, it has been shown in [18], that without circuit power consumption consideration, a huge energy efficiency can be accomplished when the number of antennas is increase to infinity, (i.e. $Nt \rightarrow \infty$), which is unrealistic. Some key recent works in [3][4] [19 – 21], concentrated plainly on the enhancement of energy efficiency of wireless link. Specifically, a link adaptation problem was formulated by the authors in [13], using single antenna based quadrature amplitude modulation (QAM) technique for energy minimization. Their work was later extended in [14], for MIMO link adaptation problem. However, the authors only focused on a narrowband system with a single carrier, which uses one or few antennas at the transmitter and receiver.

In this is work, energy-aware link adaptation technique is studied in a large scale multiple antenna systems called Massive MIMO (M-MIMO), under a broader range of parameter settings: frame packet lengths, varying traffic loads and error rate targets. Our goal is to investigate the amount of energy consumption that can be conserved in a single cell downlink M-MIMO systems during data transmission by tuning the above highlighted systems parameters.

II. System Model

Notation: We employed bold letters to indicate matrices (vectors). The superscripts H represent conjugate-transpose; the mathematical operators, tr (**.**) and E [**.**] denote trace and statistical expectation of a matrix, respectively.

A downlink M-MIMO system model is considered where a base station is equipped with Nt number of transmission antennas to serve *K* users, as illustrated in Fig. 1. First, we assume that channel is fast fading channel. Let the *k*-th M-MIMO channel matrix be denoted as $\mathbf{H}_k \in C^{N_t x N_r}$ where *k* = 1, 2,..., *K* and the noise vector be denoted as $\boldsymbol{n} \sim \mathcal{CN}(0,\sigma^2\mathbf{I})$, with **I and** $\mathcal{CN}(0,\sigma^2)$**,** being the identity matrix and complex Gaussian noise, respectively. The received vector, can be expressed as:

$$\mathbf{y} = \mathbf{HW}\; x + \mathbf{n} \tag{1}$$

where

$\mathbf{H} = \left[h_1^T \;, h_{2_2}^T ,..., \; h_k^T\right]^T$ = downlink channel matrix,

$\mathbf{W} = [w_1, w_2, ..., w_k]^T$ = precoding matrix, and

$[x_1, x_2, ..., x_k]^T$ = transmit signal vector

Now, assume that the transmitter is power constrained, then $E[(xx^H)] = P_{TX}$, where P_{TX} is the total transmit antenna power. The mean signal-to-noise (SNR) available at the receiver can be given as $SNR = \frac{P_{TX}}{\sigma^2}$.

Accordingly, the received baseband signal at the *k*-th user equipment (UE) terminal receiving with Nr antennas can be expressed as:

$$\mathbf{y}_k = p_k \mathbf{h}_k \mathbf{w}_k x_k + \sum_{i=1, i\neq k}^{k} p_i \mathbf{h}_i \mathbf{w}_k x_k + n \tag{2}$$

where $p_k \mathbf{h}_k \mathbf{w}_k x_k$ and $\sum_{i=1, i\neq k}^{k} p_i \mathbf{h}_i \mathbf{w}_k x_k$ are the desired signal and interference signal respectively.

The Two basic linear precoding methods that often applied in cancelling the user interference in downlink M-MIMO systems are Zero forcing (ZF) and Match filtering (MF). The choice for this work is ZF. This is due to higher multiplexing gain over MF [3][4]. The ZF precoding design is given by:

$$\mathbf{V}_{ZF} = \left(\mathbf{H}\;\;\mathbf{H}^T\right)^{-1}\mathbf{H}^T \tag{3}$$

The normalised form of Eq. (2) is given by:

$$\mathbf{W} = \left[\mathbf{w}_1, \mathbf{w}_2, ..., \;\mathbf{w}_{\mathbf{K}}\right] \tag{4}$$

$$\mathbf{w}_K = \mathbf{v}_k \big/ \left\|\mathbf{v}_k\right\| \tag{5}$$

By computing the $\mathbf{V}_{ZF}$ into the signal model, the SINR at the *k*-th user becomes [3]:

$$SINR_k = \frac{p_k}{tr\left(\left(\mathbf{H}\;\;\mathbf{H}^T\right)^{-1}\right)} \tag{6}$$

Thus, the achievable throughput, T_k and the achievable sum throughput, T for user K can be obtained from the $SINR_k$ model to give:

$$T_k = \log_2\left(1 + SINR_{,k}\right) \tag{7}$$

$$T = \sum_{k=1}^{N_t} T_k \tag{8}$$

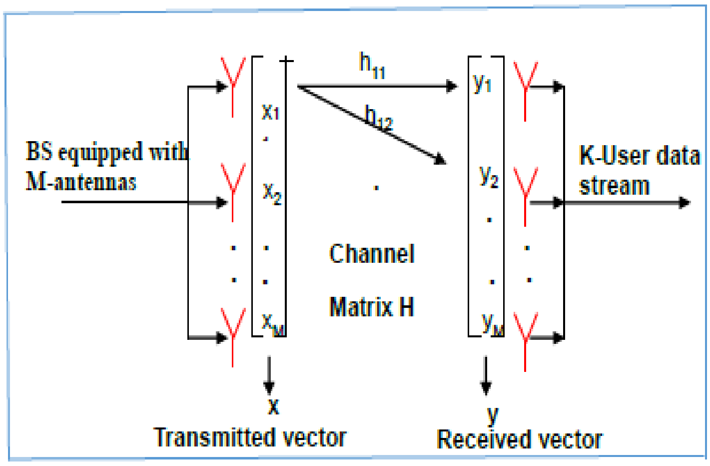

Fig. 1: Downlink M-MIMO System Model

2.2. Power model

The power consumption for energy analysis is comprised of two main parts: fixed and dynamic. Whereas the fixed part account for baseline power consumption at the BS, the second part caters for RF transmission power consumption. The combined power consumption is given by [3] [13], 24]:

$$P_{BS} = N_{TRX}\left[\frac{P_{TX}/\eta_{PA}\left(1-\sigma_{feed}\right)+P_{RF}+P_{BB}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{cool})}\right] \tag{9}$$

Where σ_{MS}, σ_{DC}, σ_{MS}, σ_{cool}, and σ_{feed} symbolize losses incurred by main supply, DC-DC power supply, cooling and the feeder, respectively. P_{TX}, P_{BB} and P_{RF} denote the antenna transmission power, baseband power and the radio frequency power, respectively. N_{TRX} and η_{PA} denote the number of transceiver and power efficiency of the amplifier, respectively. It was further shown in [25-27], that the BS power consumption or supply can be well approximated by linear function of the transmission power:

$$P_{supply} = \left\{\begin{matrix} Po + mP_{TX} & \text{if } 0<P_{TX}\leq P_{max} \\ P_s & < \ \text{if } P_{TX}=0 \end{matrix}\right\} \tag{10}$$

where m indicates load of trajectory and it measures the load dependence of the BS transmitter. P_{TX} and P_{max} denote the transmit power and the maximum transmit power of the BS. P_s account for when the BS is not transmitting or in stand-by mode. In this work, the parametised model as expressed in equation (10) is employed for energy analysis.

2.3. Absolute Energy Efficiency

An important metric for evaluating the energy efficiency of wireless communication systems is the Absolute Energy Efficiency (AEE). Besides power consumption, this metric also captures the throughput, reliability and absolute temperature constraints. The absolute temperature constraints account for carbon emission footprint [28], [29]. It is given by [3]:

$$AEE = 10\log_{10}\left(\frac{\text{Power} / \text{Bit Rate}}{(K_c T_a \ln 2)}\right) \tag{11}$$

where K_c and T_a denote the Boltzmann constant in J/K and absolute temperature in kelvin respectively. The smaller the value of AEE, the better of the achieved energy efficiency. Given the achievable throughput formula:

$$\text{Throughput} = (1-BER)^L \text{ Bit Rate}, \quad .$$

we have:

$$\text{Bit Rate} = \frac{(1-BER)^L}{\text{Throughput}} \tag{12}$$

With the Bit Rate expression in eq. (12), eq. (11) can be rewritten as:

$$AEE = 1og_{10}\left(\frac{\text{Power}\ (1 - BER)^{L}}{\text{Throughput}\ \ \left(K_{c} T_{a} \ln 2\right)}\right) \tag{13}$$

where BER represents the bit error rate and it is related to packet error rate (PER) by $PER = 1 - (1 - BER)^{L}$, such that $1 - PER = (1 - BER)^{L}$ = success probability. L is the packet length in bits. Thus, $1 - PER = (1 - BER)^{L}$ account data reliability.

Accordingly, our next goal is to determine the amount of energy that can be conserved while transmitting packet data of L in bits in the downlink M-MIMO channel, subject to the BER and transmit power constraint, via simulation. This is the same as minimizing of the total energy consumption for every successfully transmitted. Specifically, the aim is to:

$$\begin{aligned}
&\text{Minimise} \quad : AEE\ (BER, P_T, T) \\
&\text{Subject to} \quad : (1 - PER) = (1 - BER)^{L} \\
&T \geq T_{\max} \\
&P_{TX} \leq P_{TX,\max}
\end{aligned}$$

where *T and* $T_{,max}$ are the achievable throughput and maximum achievable sum throughput (see equation 7), P_{TX} *and* $P_{TX,\ max}$ are the transmit power and maximum transmit power of the BS.

III. Results and analysis

In this section, power consumption and energy efficiency simulation results and their analysis are presented and discussed. All simulations were performed using Matlab 2013a. During simulation, the throughput and energy efficiency performances were examined in terms of MIMO antenna number, BER threshold, packet length and number of active user equipment (UEs). 170W, 34W and 2.4 were taken as values for P_o, P_{TX} and m [3] [26], [27], during simulation.

3.1. The Effect of packet length on AEE at different BER targets

Figs. 2 to 5 show the performance of AEE across varying packet lengths and BER values. As the packet length increases, also the AEE improves (see Fig. 4).This implies that energy consumption is minimize when the number of packets success transmission amid the transmitter and the receiver increases, which can only occur at lower BER values. On the other hand, the reverse is the case with energy efficiency when the BER increases, as shown in 5. This is because, at high BER, the retransmission of packet increases, thus progressively consuming more energy. This also shows that longer packets are more energy efficient and at lower BER.

The need to use reasonable packet length with low bit error to enhance the AEE performance is clearly seen in the plot. For example, the energy efficiency with 0.001 BER channel condition performs better than with 0.002 and 0.003 channel conditions. This result agrees with the findings in [3], that shorter packet lengths favour channels that are more error-prone.

3.2. The Effect of packet lengths on AEE at different UE numbers

The effect of packet length variation on AEE at different number of users, i.e. k users is plotted in Figs. 6 to 9. With k users = 10, the AEE decreases from 208.7 to 207.5 when the packet length, L is increased from 100 to 2100. With k users = 30, the AEE decreases 210.1 to 208.5 when the packet length is increased from 100 to 2100. With k users = 50, the AEE decreases from 210.9 to 208.6 when the packet length is increased from 100 to 2100. As earlier mentioned, the smaller the value of AEE, the better of the achieved energy efficiency. Therefore, it is clear that the energy efficiency improves with increasing packet lengths; the improvement can be attributed to lesser payload data overheads with longer packet lengths. However, it is also seen from the graphs that the AEE performance degrade with increasing number of users from 10 to 50. An increasing user numbers connotes a rise in the number of UE terminals, which in turn leads to pilot pollution/signal power saturation at the UE terminals) [3][4] and power consumption increase. Equivalently, the consequence is a poor AEE performance.

3.3. The Effect of packet length on AEE at different Antenna numbers

Figs. 10 and 11 consider how numbers of antennas influences AEE at varying packet length and SNR values. With Nt = 10 antennas, the gain in AEE attains 206.4 and 207 performance at increasing packet length and SNR values. However, for Nt = 100 antennas, the AEE performance improve to 197 and 198 respectively, due to increase in M-MIMO antenna array gain. The results also shows that longer packets are more energy efficient compared to shorter packets. The results also shows that longer packets are more energy efficient compared to shorter packets.

At supersonic speeds design charts are presented for estimating the normal- Finally we present the influence of both packet length and SNR variation on the AEE and M-MIMO system throughput as shown in Figs. 12 and 13. It can be grasped from the plot that the best simulated AEE and throughput are achieved at higher packet lengths and SNR values. These results show that energy-aware M-MIMO based- link adaptation technique can be exploited to enhance the system throughput while maintaining some level of transmit power and BER target per information.

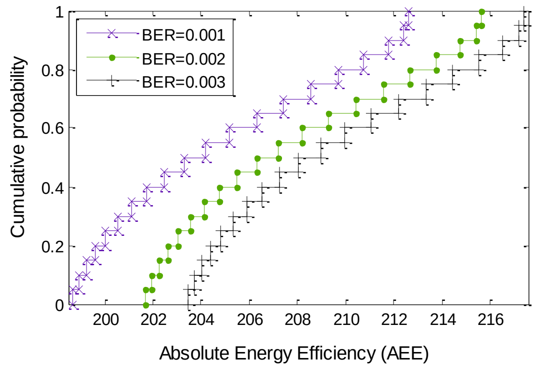

Fig. 2: AEE performance across varying BER channel constraints

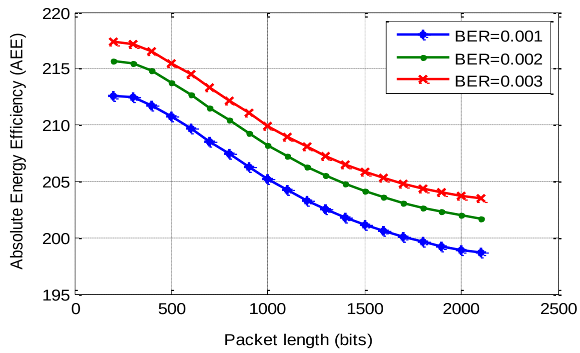

Fig. 4: AEE performance across varying packet length with different BER channel constraints.

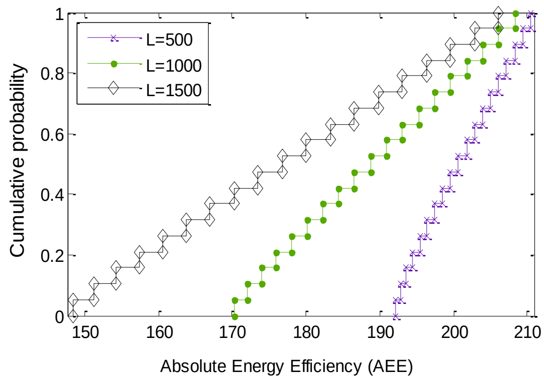

Fig. 3: AEE performance with different packet lengths.

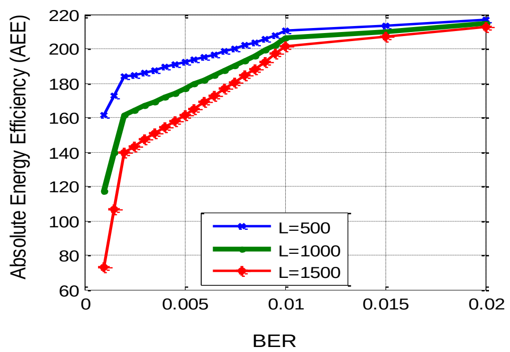

Fig. 5: AEE performance across varying packet length with different BER constraints.

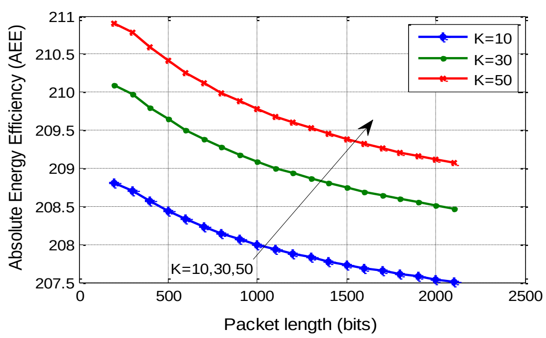

Fig. 6: AEE performance across varying K users with different packet lengths for Nt = 200, BER=0.001

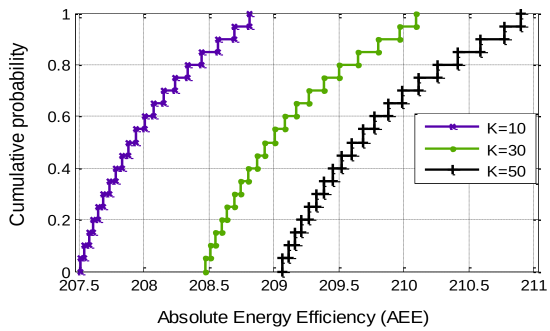

Fig.7: CDF plot of AEE performance with different K users for Nt =200, BER=0.001

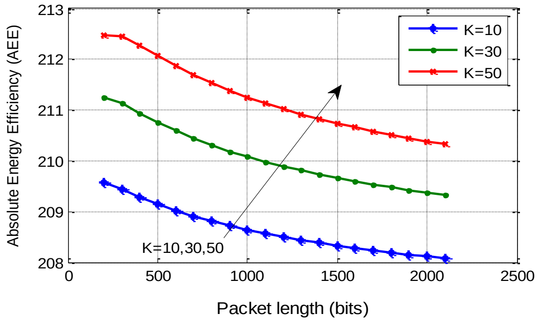

Fig. 8 AEE performance across varying K users with different packet lengths for Nt = 100, BER=0.001.

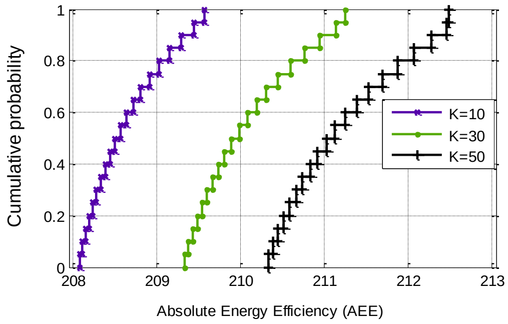

Fig.9: CDF plot of AEE performance with different K users for Nt =100, BER=0.001

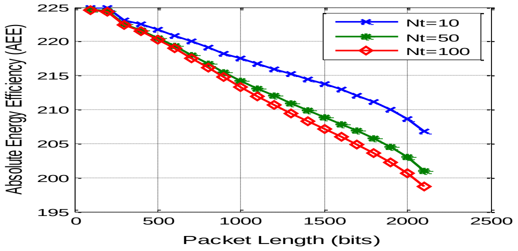

Fig. 10: AEE performance across varying packet length with different M-MIMO antenna numbers

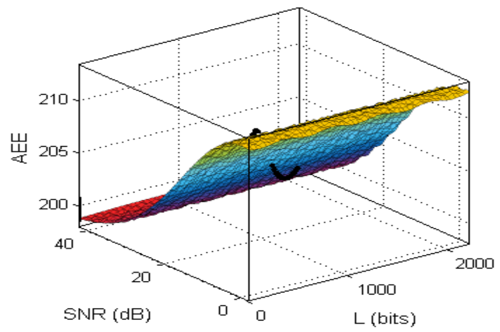

Fig. 12: AEE performance versus varying packet length and SNR for Nt=100, BER=0.001

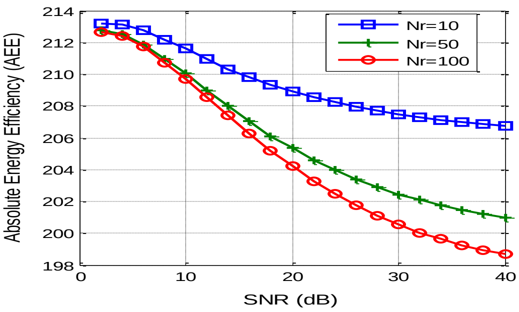

Fig. 11: AEE performance across varying SNR with different M-MIMO antenna numbers.

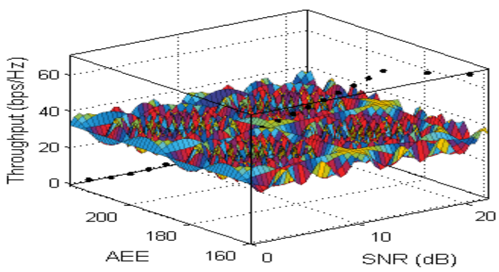

Fig.13: Throughput performance versus AEE and varying SNR for Nt =100, BER=0.001

IV. Conclusion

The growth of wireless communication technology has been very remarkable in the last few years. This in turn has increase the power consumption by the mobile station devices and their base stations infrastructure.

In this is work, energy-aware link adaptation technique is studied in a large scale multiple antenna systems called Massive MIMO (M-MIMO), under a broader range of system service quality constraints: frame packet lengths, varying traffic loads and error rate targets, using extensive link level simulations. The results shows that energy efficiency performance degrade with increasing number of users, owing to pilot pollution and power consumption increase. Moreover, it was shown from the results that longer packets are more energy efficient than shorter packets, which is because of less payload data overheads with long packet lengths. However, longer packets are more are affected by channel variations due to fading compared to short packets. Therefore, future work should be targeted at examining the maximum energy efficiency that can be attained if optimum packet length is adaptively tuned subject to different channel conditions and estimation.

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