Power Efficient Transmission of Time Multiplexed Unicast and Broadcast Cellular Communications

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Abstract—In this paper, a new power adjustment technique for the time multiplexing of LTE unicast and broadcast is proposed to reduce the wasted downlink power in unicast slots. In addition to compensating the propagation losses (distance-loss, shadowing and fast fading), the proposed technique adapts the signal-to-interference-plus-noise ratio (SINR) to be fit in the required range. The power adjustment algorithm uses a predefined SINR threshold ($SINR_{\_th}$) specific for each service and data rate. When the measured SINR of the user equipment $SINR_{\_UE}$ is above (lower) than the $SINR_{\_th}$, the decrease (increase) of power is ordered adaptively depending on the difference between the two values. The proposed technique is evaluated by simulation where numerical results quantitatively outline the benefits on system performance, achieved in terms of average downlink transmitted power, average saved energy and outage probability of $SINR_{\_UE}$ versus user speed.

Index Terms— MBSFN; unicast; time multiplexing; wasted energy; Power adjustment, propagation losses; outage probability.

I. INTRODUCTION

Power control has long been proposed as a crucial technique to improve performance for cellular radio systems. Its goal is to transmit at the right amount of power needed to support a certain data rate. It minimizes the interference level by decreasing the unnecessary power dissipated into the network while reaching a quality target criterion for each communication. Too much power generates unnecessary interference, while too little power results in an increased error rate requiring retransmissions and hence resulting in larger transmission delays and lower throughputs.

In long term evolution system (LTE) [1], power control is implemented in the uplink and consists of both open-loop and closed loop mechanisms. An open-loop mechanism implies that the transmit power from terminal depends on estimates of the downlink path loss. A closed-loop mechanism implies that the network can, in addition, directly adjust the transmit power of the terminal by means of explicit power-control commands transmitted on the downlink. In practice, these power control commands are determined by prior network measurements of the received uplink power. Unlike the uplink power control, the LTE specification does not define downlink power control. It is similar to what was done in GSM. The enhanced Node-B (eNB) could reduce the power if the user equipment (UE) was near or it could use a fixed power constantly. There is no explicit feedback from the UEs to control the eNB transmit power for the downlink power control [2]. The downlink transmit power control is basically a power allocation scheme rather than a power control scheme. Dynamic power allocation is applied to dedicated control channels for a single UE or a group of UEs. Different power levels can be allocated to different resource blocks used for data transmission in a semi-static way to support inter-cell interference coordination (ICIC). The interference caused to a cell from a neighboring cell depends on the neighbor cell's transmit power. Without ICIC, the transmit power spectral density is generally constant over the whole system bandwidth. However, with ICIC, the transmit power is varied on different parts of the frequency while the total eNB transmit power is fixed.

Besides, to improve eNB power utilization, two different power levels can be used on OFDM symbols used for data transmission within a sub-frame. This is due to the fact that the available power for data resource elements is different between OFDM symbols containing reference signals and OFDM symbols containing no reference signals. More precisely, The eNB evaluates the downlink transmit Energy Per Resource Element (EPRE). The downlink cell-specific Reference-Signal (RS) EPRE is kept constant across the downlink system bandwidth and across all sub-frames until different cell-specific RS power information is received [3]. The downlink RS EPRE is set by the parameter Reference-signal-power provided by higher layers.

In LTE system, a simple time-multiplexing approach for MBSFN (Multicast Broadcast Single Frequency Network) and unicast multiplexing is employed. Other techniques such as frequency multiplexing and superposition of MBSFN require more complex UE composition and are currently under investigation for the LTE-advanced system [4]. In an interference-limited scenario (the case for most cellular systems), the background noise can be ignored as its value is negligible compared to the interference value. The unicast SINR in an interference-limited case is independent of the eNB transmit power, hence the unicast SINR does not benefit from the increased eNB power, see Eq.1, section 2, in the case of ignoring the background noise. This is because when the power is increased in the own cell, the transmit power is also increased in the interfering neighboring cells. If increased transmit power does not help increase SINR, lowering transmit power should not affect SINR either. Therefore, an excess eNB power is available in unicast resources (time slots) time multiplexed with MBSFN slots. In other words, a significant amount of power is wasted in unicast time slots as total transmit power cannot be shared with broadcast slots in time multiplexing scheme. Unlike unicast slots, the MBSFN enjoys full power in its slots as its SINR and hence, capacity, increases when power increases. Hence no power is wasted in MBSFN slots [5][6].

In this paper, a power adjustment technique for the time multiplexing of LTE unicast and broadcast is proposed to reduce the wasted downlink (eNB transmitted) power in unicast slots. The suggested method aims at compensating fast fading, described by Rayleigh statistics, together with long-term fluctuations (distance path-loss and shadowing). Besides, it focuses on the SINR ratio and tries to adapt it to be in the desired range. The objective of the simulation is to evaluate the performance of the proposed power adjustment technique in terms of average transmitted power, average saved energy and outage probability of SINR-UE versus mobility speed.

There have been a few research in literature concerning power saving for time multiplexing of LTE unicast and broadcast. In [7], a power-saving scheduling algorithm for mixed multicast and unicast traffic was proposed. It was designed on the purpose of reducing the UE's energy consumption by decreasing the transition times between sleeping and active status in the use of discontinuous reception mechanism applied for UE's battery power saving in LTE. A power adaptations algorithm was introduced in [8] for LTE MBMS systems. When compared with fixed transmit power operations, the algorithm yielded lower communications energy consumption levels and better throughput rate performance. In [9], a simplified power allocation algorithm was presented to the different downlink sub-channels of a multi-carrier system containing both unicast and multicast users and shown to approximate the maximal achievable performance under certain circumstances. In a hybrid multicast and unicast transmission scheme with superposition coding, a power allocation algorithm was proposed in [10] to provide QoS guarantee for multicast and unicast services concurrently . The optimization objective was to maximize the rate of unicast service under the constraints of power.

While there are a number of uplink power control schemes for unicast transmission in LTE already in the literature, no research to the extent of my knowledge, however, has addressed downlink power adjustment technique for the time multiplexing of LTE unicast and broadcast to reduce the wasted power in unicast slots, as done in this paper. The rest of the paper is organized as follows. Section 2 illustrates MBSFN and unicast time multiplexing. Section 3 introduces the channel model used, and section 4 illustrates the power adjustment approach. Section 5 describes the power adjustment considered scenario and simulation parameters. Section 6 presents the numerical results and section 7 gives a conclusion for the achieved results.

II. MBSFN AND UNICAST TIME MULTIPLEXING

MBSFN and unicast traffic are time-multiplexed on the same carrier leading to lower MBSFN duty cycles. This approach results in UE battery power savings as the UE needs to turn on its receiver during unicast time slots only. Figure 1 shows a simplified radio frame structure that consists of 10 time-multiplexed MBSFN and unicast traffic slots with 80% duty cycle for the unicast traffic and 20% duty cycle for the MBSFN traffic.

In unicast time slots, different information contents are transmitted to different UEs in different cells in the network. A UE at the cell-edge as shown in the scenario of Figure 2 experiences interference in the unicast slots from 6 cells, assuming a 7-hexagonal cell-layout, 1-tiers of interferers and universal frequency reuse factor i.e. N=1. In this case, two interferers are at distance R (cells: 2 and 3), another two interferers at distance $2R$ (cells: 4 and 5) and two interferers at a distance of 2.7 R (cells: 6 and 7), where R is the cell radius. The worst-case SINR (cell-edge case) with 6 interferers is [2]:

$$SINR_{N=1} = \frac{PR^{-v}}{P(2\times R^{-v} + 2\times(2R)^{-v} + 2\times(2.7R)^{-v}) + N_0W}) \qquad (1)$$

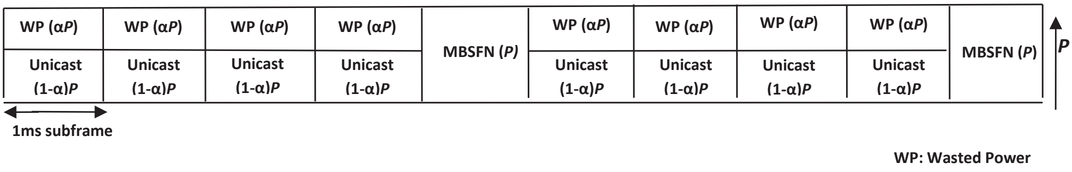

Figure 1: Time Multiplexing between MBSFN and unicast

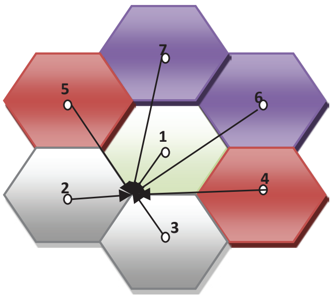

Figure 2: Interference experienced by a cell-edge UE

Assuming that all eNBs transmit at the same constant power P watts and ν is the path-loss exponent. If only the two interferers that are located at the same distance *R* from the UE as the desired cell (cells: 2 and 3) are considered and if the background noise is ignored (interference-limited scenario) then the maximum SINR is upper bounded by 0.5 (−3 dB). This low SINR of −3 dB means that low rates can be supported at the cell-edge for transmission in unicast slots.

Larger transmit power is needed for users located at the cell edge than to users at the cell center. But this larger power to users at the cell edge also cause more interference to the neighboring cells! On the other hand, the transmissions to users at the cell center needs less power and causes less interference to the neighboring cells in the unicast slot. Hence, the proposed power adjustment technique aims at compensating all types of propagation losses to give the UE the needed amount of power based on its location and channel quality.

The wasted transmitted energy (*WE*) for time multiplexed

$$WE = \beta.\alpha.P \quad \text{Joules} \tag{2}$$

where β represents the duty cycle for the unicast traffic (80% in the Figure 1), P represents the full power transmitted by eNB , αP represents the fraction of the excess power (wasted power) in the unicast slots.

III. Unicast Transmission's Channel Model

In the case where Rayleigh fading (fast fading) and log-normal shadowing are present along with distance path loss, assuming that at time *t*, the squared envelope of the transfer function for the downlink unicast channel (path gain) can be modeled as a random variable (RV) [11]:

$$G_t = D^{-\nu}.F.S \tag{3}$$

where D represents the distance between the eNB and the UE and ν the path-loss slop. F is an exponential RV with unitary mean and S is a log-normally distributed RV with unitary median and decibel spread equal to 8 dB. The adopted Jakes' model of the normalized autocorrelation function between two received signals with time separation (Δt) at the UE traveling with a velocity *V* is given as [12]:

$$\rho(\tau) = J_0(2\pi f_m |\Delta t|) \tag{4}$$

where $f_m = f_c.V / c$, c is the velocity of electromagnetic radiation, f_c the carrier frequency, f_m the maximum Doppler shift and $J_0(.)$ the Bessel function of the first kind and zero order. Due to the time variability of the channel as the UE changes its location, the RV representing the downlink unicast channel's path gain changes with time: at time $t + \Delta t, G_t$ will be replaced by $G_{t+\Delta t}$

$$G_{t+\Delta t} = D^{-\nu}.F^{'}.S \tag{5}$$

Since Δt is a short interval of time, the distance D and the RV S , describing a slow log-normal shadowing, are nearly unchanged, hence $D^{-\nu}$ and S values are the same appearing in (3). Their values at time $t + \Delta t$ are considered the same as observed at time t. Only the RV F , representing fast fading fluctuations, has changed to the RV $F^{'}$ in this short period of time as it represents fast fading.

IV. Power Adjustment Approach

At time $t + \Delta t$, the useful received power by the UE, C is the product of the transmitted power by the e-Node-B (eNB) and the path gain $G_{t+\Delta t}$. The transmitted power, however, depends on the target received value $RX_{UE,target}$ as well as on a function PA(.), which describes the adopted power-adjustment law. It follows that at time $t + \Delta t$, the RV, C can be expressed as

$$C = RX_{UE,target}.PA(G_t).G_{t+\Delta t} \tag{6}$$

If the adjustment law on log-normal shadowing $PA_S(.)$ is distinguish from the one imposed on Rayleigh fast fading $PA_F(.)$, Eq.6 can be written as:

$$C = RX_{UE,target}.PA_S(D^{-\nu}.S).PA_F(F).D^{-\nu}.F^{'}.S \tag{7}$$

The received signal, C should be fit near to the target-received value $RX_{UE,target}$. This can be achieved by full compensation of all types of loss, i.e., path-loss, shadowing and fast fading. For this purpose, the power adjustment lows $PA_S(D^{-v}.S) = 1/(D^{-v}.S)$ and $PA_F(F) = 1/F$ are used as full compensation for long-term and short-term signal fluctuations respectively. These lows are substituted in Eq.7 and the resultant equation becomes:

$$C = RX_{UE,t\arg et}.F^{'} / F \tag{8}$$

Notice that the long-term signal fluctuations (path-loss, shadowing) are cancelled since their values at time t and time $t+\Delta t$ are considered equal. However, the short-term signal fluctuation (fast fading) cannot be cancelled completely since its value changes from the time t to $t+\Delta t$.

Beside the full compensation of losses, the proposed power adjustment adapts the $SINR_{-UE}$ ratio in a way to ensures a quick convergence of the power adjustment loop. For this purpose, the algorithm chooses a suitable step size according to the difference between the measured value and the target value. The UE generates the TPC by comparing the received SINR power of the downlink channel ($SINR_{-UE}$) with the predefined thresholds of the SINR; $SINR_{-th}$. The power adjustment Step Size (SS_{-i}) can take four values: 0.5, 1, 1.5 or 2 dB, where the smallest is SS_{-1} and the largest is SS_{-4}.

As shown in Figure 3, if the difference between the $SINR_{-UE}$ and the $SINR_{-th}$ is more than 0.5* SS_{-i}, then the absolute value of generated TPC will be equal to SS_{-i}. To understand the functioning of the examined power adjustment loops and the delay involved in assessing system performance, the UE evaluates the channel at the present unicast slot (time *t*) and measures the path gain (Eq.3). This includes the effect of the path-loss, shadowing and fast fading. The UE calculates the power:

$$\mathrm{TX}_{\_eNB\_next\_initial} = RX_{UE,t\arg et}.PA_S(D^{-v}.S).PA_F(F) = RX_{UE,t\arg et}.1/(D^{-v}.S).1/F \tag{9}$$

that the eNB should transmit at the next unicast slot (time $t+\Delta t$), in order to have the received signal *C* at the UE near to the target value. In decibel, the $TX_{\_eNB\_next\_initial}$ will be the summation of the target received value plus distance pathloss, shadowing and the fast fading, evaluated at the present frame. The UE then checks the $SINR_{-UE}$ ratio and adopts the power $TX_{\_eNB\_next\_initial}$ by adding a suitable SS_{-i} in order to have the SINR ratio- at the next unicast slot in the desired range. The final power, issued as the changing power command by the UE to the eNB, is $TX_{\_eNB\_next\_final}$ if it is not above the maximum power allowed $TX_{\_eNB\_max}$, otherwise it is set to the maximum power. Since the slot period for the LTE system is fixed to *1msec*, this time represents the power control delay Δt.

The quality parameter used to evaluate the performance of the proposed power adjustment was the average downlink eNB transmitted power (averaged over all cells), the saved eNB energy and the outage probability of the SINR ratio as a function of user speed. The outage probability was defined as the probability that the SINR ratio drops below a given threshold $SINR_{-th}$

$$Pout = P\{SINR_{UE} < SINR_{\text{-th}}\} \tag{10}$$

V. Power Adjustment's Considered Scenario And Simulation Parameters

An LTE macro deployment, composed of 7 hexagonal cells, is simulated as shown in Figure 2 in section 2. The developed simulation platform takes into consideration: network configuration, propagation conditions, fast fading and incorporates the appropriate functionalities to evaluate the benefits of power adjustment algorithm. The cell diameter is fixed to 1732m [3]. To simulate propagation losses, the propagation model introduced in [13] is used for the LTE deployment as shown in Eq.11.

$$Path\text{-}Loss=128.1+37.6\ log10(R),\ R\ in\ km \tag{11}$$

Slow Fading is added, with Standard deviation of 8dB. The Rayleigh fading is included by simulating Jake's implementation of Clarke's fading mode l, normalized to 0 dB. The threshold $SINR_{-th}$ defining the outage condition is fixed to -3 dB. 700 unicast users are randomly and uniformly dropped in the cells. The simulation program runs for 15000 slots (corresponding to 1500 frames and 12000 unicast slots; 80% duty cycle), representing 15 seconds of real time simulation. The positions of users are updated every 80 unicast slot (corresponding to 10 frames equivalent to 100 ms) and a check-for-handover algorithm is carried out at that time to perform intra-system handover if necessary. In each simulation run, one speed is given to all users and the average values of the transmitted downlink power and the outage probability are calculated. In the next simulation run, another speed is given to all users and so on. The developed software simulation platform- using C++ language and based on modified IST-FITNESS Simulation Platform [14] incorporates the appropriate functionalities to examine the proposed power adjustment algorithm taking into account the simulation parameters listed in Tables 1.

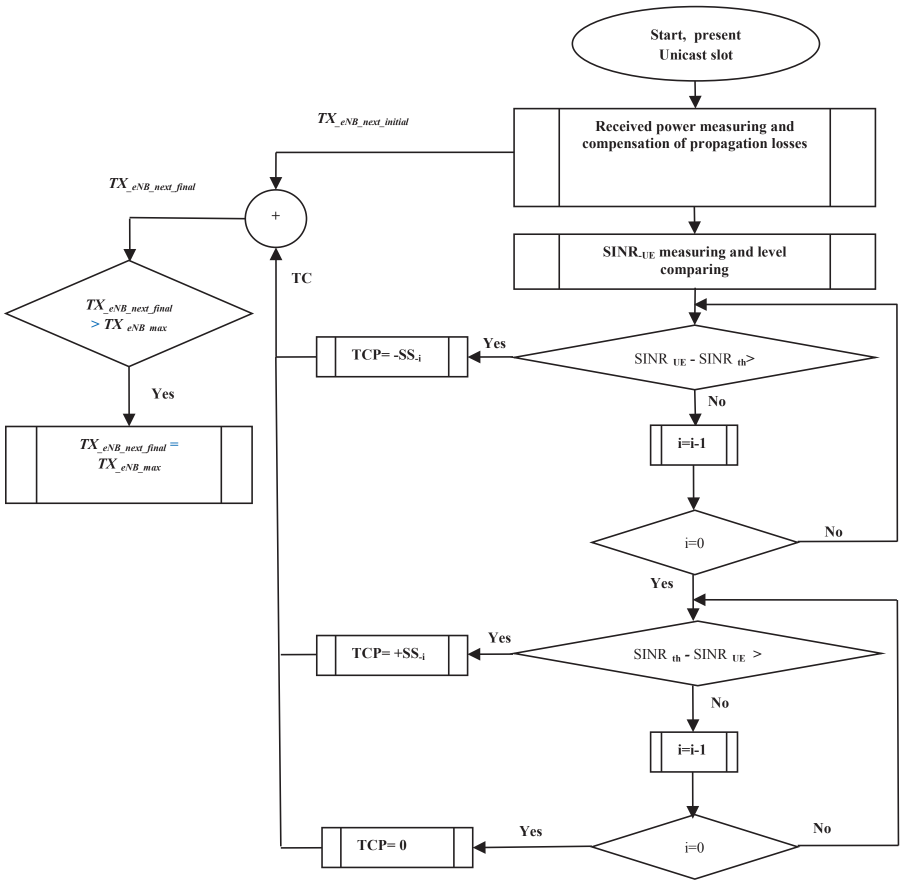

Figure 3: Unicast Slots Power Adjustment Flowchart

Table 1
Simulation parameters for the considered scenario

Parameter	Value/Assumption	Comments
Carrier frequency	2GHz	
Channel Bandwidth	10 MHz	
eNB total TX power	46 dBm.	
Propagation model	L(dB) = 128.1+ 37.6log10(R)	
Shadow fading	model Log-normal, 8dB standard deviation	
$SINR_{-th}$	-3 dB	
User distribution	Uniform	100 users per cell
Cell layout	Hexagonal grid, 7 cell sites	
Inter site distance	1732m	Macro case 3
SS_{-i}	can take four values: 0.5, 1, 1.5 or 2 dB	i=[1,4]

VI. Numerical Results

Figure 4 shows the outage probability of the carrier to interference and noise ratio as a function of user speed. The best curve, giving the lowest outage probability, represents the proposed power adjustment approach while the upper one represents the case of transmission at full (maximum) power. It is clearly noticed that the difference in performance between the two curves is small (in the order of 5% at low speed and vanishes at high speed). This is expected due to the fact that the unicast SINR in an interference-limited case is independent of the eNB transmit power; the unicast SINR is slightly affected by the increase/decrease of eNB transmit power. This is because when the power is increased in the own cell, the transmit power is also increased in the interfering neighboring cells. Notice that in Eq.1, if the background noise is ignored (interference-limited scenario), then the unicast SINR is independent of eNB transmit power. At high speed the compensation of short term losses becomes very difficult, hence the effect of the proposed power adjustment technique vanishes as shown in Figure 4.

However, looking at Figure 5, which shows the average transmitted eNB Power as a function of user speed, it is obvious that the gain (less power) of the proposed power adjustment approach over transmission at full (maximum) power is clearly significant (in the order of nearly10dB at low speed and gradually decreases at high speed). This gain in power is more attractive than the modest gain in the SINR outage probability performance since the decrease in the downlink average eNB transmitted power yields, in addition to the power saving, low inter-cell interference and also low interference with other systems. Finally, Figure 6 shows the saved eNB energy as a function of user speed. The saved energy is about 30 joules when all the UEs are stationary and decreases as speed increases due to the compensation of short term propagation losses.

VII. CONCLUSION

A proposed power adjustment technique for the time multiplexing of LTE unicast and broadcast was presented where Performance was assessed by simulation focused on the outage probability of SINR ratio, the average eNB transmitted power and saved energy versus speed as performance metrics. It was noticed that the gain in the average transmitted eNB Power of the proposed power adjustment approach over transmission at full (maximum) power is clearly significant (in the order of 10dB at low speed and gradually decreases at high speed). This gain in power is attractive since the decrease in the downlink average eNB transmitted power yields, in addition to the power saving, low inter-cell interference and also low interference with other systems. Consequently, the saved energy is about 30 joules when all the UEs are stationary and decreases as speed increases due to the compensation of short term propagation losses. However, the gain in the outage probability of the carrier to interference and noise ratio of the proposed technique was small (in the order of 5% at low speed and vanishes at high speed). This was expected due to the fact that the unicast SINR in an interference-limited case is independent of the eNB transmit power; the unicast SINR is slightly affected by the increase/decrease of eNB transmit power.

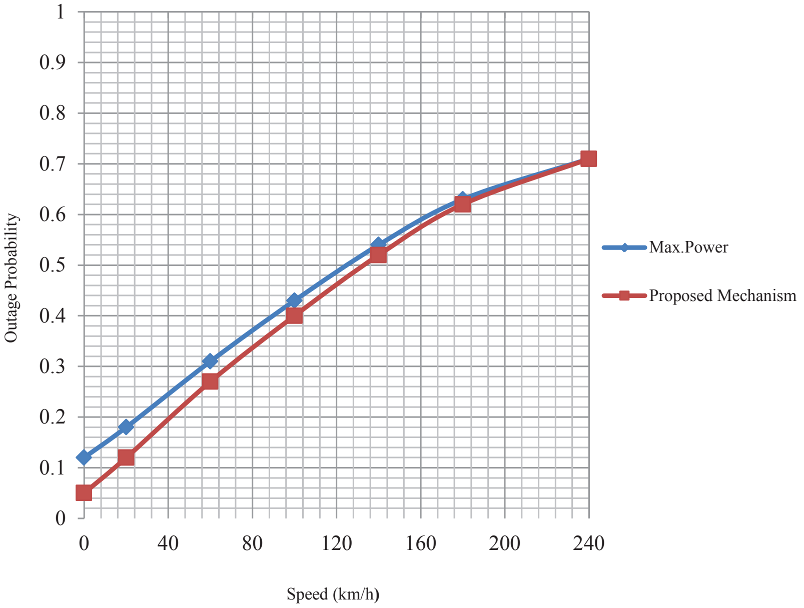

Figure 4: Outage Probability as a function of user speed

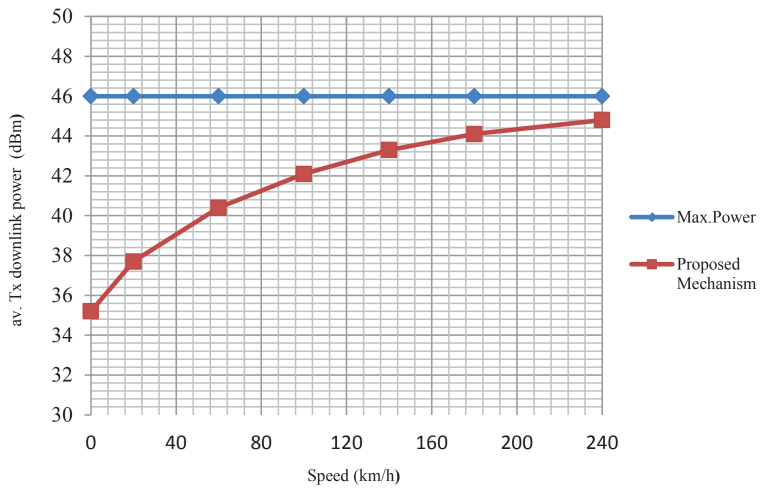

Figure 5: Average Transmitted eNB Power as a function of user speed

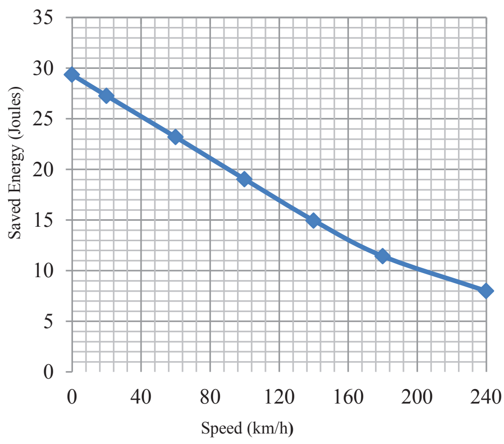

Figure 6: Saved eNB energy as a function of user speed

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