Comparative Study of Two Signal-to-Noise Ratio Calculation Methods in LTE Downlink Simulations

Yu-Sun Liu[1(✉)], Shingchern D. You[2], Zong-Ru Jhan[3], and Meng-Fan Li[1]

[1] Department of Electronic Engineering, National Taipei University of Technology, Taipei, Taiwan
ysliu@ntut.edu.tw
[2] Department of Computer Science and Information Engineering, National Taipei University of Technology, Taipei, Taiwan
[3] Quanta Computer Inc., Taipei, Taiwan

Abstract. It is well-known that the bit error rate (BER) of a mobile communication system is strongly affected by the signal-to-noise ratio (SNR). Because the term SNR is so fundamental that most papers did not explain how SNR is calculatd in simulations. In this paper, we report the BER perfomrance for Long Term Evolution (LTE) downlink simulations with two different SNR calculation methods. It is found that using short-term SNR not only yields much smaller BER than using ensemble-average SNR, but also reverses the ordering of BER performance among the channel models. We thus suggest that in order to fully disclose their implications on performance, the BERs measured against the two SNRs should be presented side by side in LTE downlink simulation studies.

Keywords: Long term evolution · Signal-to-noise ratio · Simulated channel

1 Introduction

Nowadays almost all communication engineers rely on computer simulations to evaluate the performance of a digital communication system. To conduct simulations, one of the fundamental parameters for simulations is the signal-to-noise ratio (SNR). SNR is the ratio of signal power over noise power. The calculation of SNR seems so trivial that not too many technical papers have fully discussed how this value was obtained during simulations.

To calculate SNR, we need to know the signal power. When closely examining the calculation of signal power for a fading channel, we have two options. The first one is to average the transmitted power over multiple channel realizations. The SNR thus obtained is called ensemble-average SNR in the following. The

J.-L. Chen et al. (Eds.): WiCON 2018, LNICST 264, pp. 14–23, 2019.
https://doi.org/10.1007/978-3-030-06158-6_2

second one is to measure the short-term signal power for only one realization. The obtained SNR is called short-term SNR in the following. It seems reasonable to assume that either ensemble-average SNR or short-term SNR would not severely alter the observed performance. Therefore, most existing literature does not explicitly mention which SNR is used in the simulations. Previously, we also believed this conjecture. Later on, we found some interesting results when conducting simulations on the bit error rate (BER) performance of Long Term Evolution (LTE) downlink (DL) transmission [1–6] over three widely used channel models, known as Extended Pedestrian A model (EPA), Extended Vehicular A model (EVA), and Extended Typical Urban model (ETU) [7]. They are established by ETSI (European Telecommunications Standards Institute) to represent short, medium, and long delay spread environments, respectively. Our simulation results showed that the performance ranking of the three channels would be reversed if switching from ensemble-average SNR to short-term SNR. After an in-depth study, we found that the method used to calculate the SNR value significantly affects the BER performance in the mentioned ETSI channel models. In this paper, we would like to share our findings on this issue and give some recommendations on the use of SNR in simulations.

The rest of the paper is organized as follows. Section 2 presents the channel models and two different definitions of SNR, the ensemble-average SNR and short-term SNR. Section 3 describes the LTE DL physical layer. Section 4 presents the simulation method which uses ensemble-average SNR as the basis of comparison and analyzes the distributions of channel frequency responses. Section 5 presents the simulation method which uses short-term SNR as the basis of comparison and comments on the differences in BER performances based on the two different SNR calculation methods. Finally, conclusions are summarized in Sect. 6.

2 Channel Models and SNR Definitions

The multipath fading phenomenon in a mobile wireless channel is typically modeled as a tapped delay line with a constant delay for each tap. Specifically, the channel impulse response is modeled as

$$h(t) = \sum_{\ell=0}^{L-1} h_\ell \delta(t - \tau_\ell) \tag{1}$$

where L is the number of paths in the channel, and h_ℓ and τ_ℓ are the complex gain and the delay of path ℓ, respectively. Each τ_ℓ is a constant, and each h_ℓ is an outcome of a complex-valued random variable. As uncorrelated scattering among paths is usually assumed in channel modeling, all h_ℓ are outcomes of independent random variables. To generate a channel, the complex gains h_ℓ, $\ell = 0, 1, \ldots, L-1$, are obtained as outcomes from independent zero-mean complex Gaussian random variables $\boldsymbol{h}_\ell$. In the following, we call a set of h_ℓ produced in one probability trial as one realization (of the channel impulse response).

As mentioned previously, the ETSI defined three channel models, EPA, EVA, and ETU, for LTE DL simulations. The power-delay profiles of the models are listed in Table 1 [7]. In the table, the average power gain in a tap is defined as $P_\ell = E[\boldsymbol{h}_\ell \boldsymbol{h}_\ell^*]$. It is observed that the EPA model has a much shorter delay spread than the EVA and ETU models have. Not that although the sum of average powers over all taps is not 0 dB in the table, a widely acceptable implementation is to multiply each h_ℓ by a constant to ensure that the *expected* channel power gain is unity.

Table 1. Channel profiles

	EPA model		EVA model		ETU model	
Tap ℓ	τ_ℓ (ns)	P_ℓ(dB)	τ_ℓ (ns)	P_ℓ (dB)	τ_ℓ (ns)	P_ℓ (dB)
1	0	0.0	0	0.0	0	−1.0
2	30	−1.0	30	−1.5	50	−1.0
3	70	−2.0	150	−1.4	120	−1.0
4	90	−3.0	310	−3.6	200	0.0
5	110	−8.0	370	−0.6	230	0.0
6	190	−17.2	710	−9.1	500	0.0
7	410	−20.8	1090	−7.1	1600	−3.0
8	N/A	N/A	1730	−12.0	2300	−5.0
9	N/A	N/A	2510	−16.9	5000	−7.0

At the receiver side, if the cyclic prefix (CP) is longer than the length of the multipath channel, the received signal within an OFDM (Orthogonal Frequency Division Multiplexing)symbol can be expressed as

$$y[m] = x[m] \otimes h[m] + w[m] \tag{2}$$

where $\otimes$ denotes the circular convolution, $x[m]$ and $h[m]$ are the sampled versions of transmitted OFDM signal and channel impulse response, respectively, and $w[m]$ is the complex-valued additive white Gaussian noise (AWGN) with mean zero and variance $N_0/2$. By applying discrete Fourier transformation (DFT) to $y[m]$, the frequency-domain representation of the received signal at OFDM symbol n and subcarrier k is given by

$$Y[n,k] = X[n,k]H[n,k] + W[n,k] \tag{3}$$

where $Y[n,k]$, $X[n,k]$, $H[n,k]$, and $W[n,k]$ are transformed results of $y[m]$, $x[m]$, $h[m]$, and $w[m]$, respectively. In this paper, we assume that perfect side information, namely channel impulse response, signal power, and noise power, is available to the receiver.

As mentioned previously, simulated channel models are probabilistic models. Therefore, the channel power gain

$$\sum_{\ell=0}^{L-1} h_\ell h_\ell^* \tag{4}$$

fluctuates from one particular channel realization to another. Only the (ensemble) average over infinitely many realizations approaches unity due to normalization. An SNR calculated based on ensemble-average power gain is called ensemble-average SNR. It has been shown that the resulting experimental BER performance closely matched to the analytical one [8–10].

It is also possible to use the individual channel power gain of each realization to compute SNR. We firstly compute the signal power at the receiver as

$$P_{\mathrm{r}} = \frac{1}{|\mathcal{M}|} \sum_{m \in \mathcal{M}} |x[m] \otimes h[m]|^2 \tag{5}$$

where $\mathcal{M}$ is the set of sample indexes in a codeword, and $|\mathcal{M}|$ is its cardinality. SNR is then computed as the received signal power P_{r} over noise power. As this SNR is calculated based on a particular channel realization, and typically the codewords are short, we call it as short-term SNR. Note that in an experiment, if we want to generate channel realizations based on a given short-term SNR value and a fixed noise power (and thus a fixed P_{r}), h_{L-1} will depend on $h_0, h_1, \ldots, h_{L-2}$, which violates the assumption of uncorrelated scattering in the channel model. Therefore, the theoretical BER analysis developed in [8–10] cannot be directly applied in this case. However, in terms of user experience, the short-term SNR is a better indicator because it is the instantaneous SNR at the user's device, but not the average SNR over many devices. Considering these factors, we think it is worthy to study the performance discrepancy between these two SNR calculatio methods.

3 LTE DL Physical Layer

The LTE system uses 10 ms radio frames, with each frame containing 10 subframes of 1 ms duration. Each subframe is divided into two slots of equal length, where each slot is composed of seven OFDM symbols, namely, symbol 0 to symbol 6, if normal CP is used. The time-frequency representation of a DL subframe is depicted in Fig. 1, in which each small cell represents one subcarrier in one OFDM symbol period. Pilots, denoted by green cells, are inserted in the first and the third last OFDM symbols of each slot with a frequency domain spacing of six subcarriers. The basic unit for resource allocation is the physical resource block (PRB), which consists of 12 consecutive subcarriers in one slot. In this paper, the LTE system with 20 MHz bandwidth/100 PRBs which comprises of 1200 subcarriers (excluding DC) is considered.

In DL transmission, data are carried in PDSCH (Physical Downlink Shared Channel) in units of transport blocks. Each transport block is firstly segmented

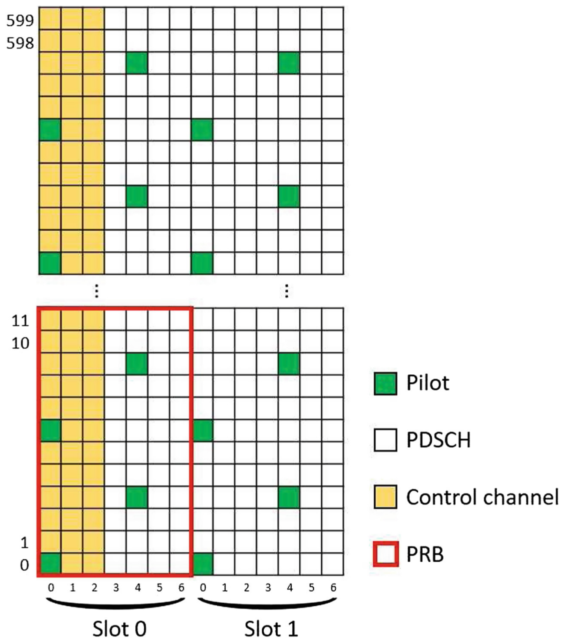

Fig. 1. Time-frequency representation of a DL subframe.

into code blocks if its size is larger than 6144 bits. Each code block is then encoded with a rate-1/3 symmetric turbo code which is the parallel concatenation of two identical 8-state (1, 15/13) constituent codes. Finally, coded sequence of each code block is processed by a rate matching module which matches the total number of coded bits in a transport block to the number of bits supported by the assigned PRBs. In the following simulation experiments, half a subframe which comprises 50 PRB/600 subcarriers in both slots is assigned to one transport block of length 1408 bits (which is transmitted using one codeword). Note that the resources available to the PDSCH do not include the pilots and the first three OFDM symbols in each subframe, as shown in Fig. 1, since these symbols are occupied by control channel. Finally, the coded bits are modulated with the QPSK scheme and then transmitted using OFDM with system parameters listed in Table 2. The resulting code rate is 0.11175, which is close to the lowest rate supported by the LTE standard.

4 Experiments with Ensemble-Average SNR

We now describe the experiment with ensemble-average SNR values. One experiment for a given SNR comprises 10,000 trials, and in each trial a new realization of the specified channel model is generated. The reported BER is the averaging BER over all trials, each having the duration of one DL frame. In the experiment, the noise power is calculated based on the the unity-channel-power-gain

Table 2. System parameters

Parameter	Value
Channel bandwidth	20 MHz
Carrier frequency	1.8 GHz
Subcarrier spacing	15 KHz
Sampling frequency	30.72 M
FFT size	2048
CP duration (Normal CP)	160 samples for symbol 0. 144 samples for symbols 1–6
OFDM symbol duration	66.6 µs
TX/RX antenna	SISO
PDSCH modulation scheme	QPSK
Code rate	0.11175

assumption and the given SNR value. The obtained BER performance after demodulation are plotted in Fig. 2. It shows that all three channel models, as well as the analytic results, have identical demodulated BER.

When examining the BER after 6 decoding iterations of error correction decoding (decoded BER), we notice three channel models yield different curves, as shown in Fig. 3. Furthermore, the decoded BER for the EPA channel model is considerably larger than those for the other two channel models. The results are counter-intuitive. Firstly, as the three channel models yield the same demod-

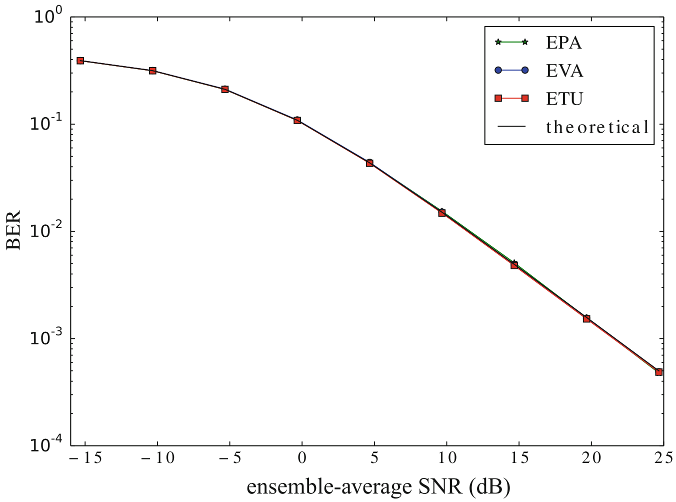

Fig. 2. Demodulated BERs using ensemble-average SNR as basis of comparison.

ulated BER performance, we would expect that they also have similar decoded BER performance. Secondly, if one channel model induces a much higher decoded BER than the other two, we would expect it to be ETU because ETU has a delay spread longer than CP and thus suffers from intersymbol interference (ISI). Note that our previous study on WiMAX (Worldwide Interoperability for Microwave Access) [9] also shows that different channel models yield similar decoded BER performances (within experimental uncertainty).

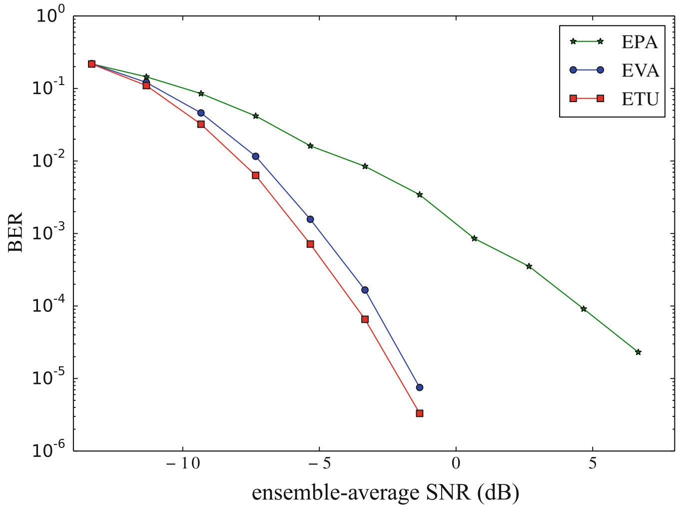

Fig. 3. Decoded BERs using ensemble-average SNR as basis of comparison.

One explanation for this situation is that some channel realizations have much higher decoded BER, and then dominate the average BER, due to extremely low channel power gain (much lower than unity). Among the three used models, the EPA model can be proved to have a higher probability to yield such a “bad” channel realization. Unfortunately, due to space limitation, we are unable to show more evidences in this paper to support our argument.

5 Experiments with Short-Term SNR

We mentioned in Sect. 2 that there are two different measurements of SNR, namely, ensemble-average SNR and short-term SNR. The ensemble-average SNR is typically employed in simulations, but it shows the average performance over many channel realizations. In reality, the instantaneous SNR over subcarriers affects the decoded BER at the receiver. Therefore, this information, after conversion, can be sent to the base station to adapt the modulation and coding scheme (MCS) [11,12]. Note that the short-term SNR discussed in this paper is closely related to the instantaneous SNR over subcarriers.

We now describe how to perform simulations with a given short-term SNR value. Basically, one experiment for a given SNR value comprises a large number of trials. In each trial, a new realization of the specified channel model is generated, and then, the noise power is calculated based on the received signal power and the given SNR value. The reported BER is computed by averaging BER over 10,000 trials. Using the above procedure, we obtain the demodulated BER and decoded BER (after 6 decoding iterations), which are plotted in Figs. 4 and 5, respectively. It is observed that the EPA model gives smaller demodulated BER than the other two channel models. It is because EPA has a shorter delay spread and then smoother channel frequency response. In terms of decoded BER, when comparing Fig. 5 with Fig. 3, we find that the BER results obtained based on short-term SNR are significantly smaller than those based on ensemble-average SNR. This is because in the short-term SNR case, all channel realizations have

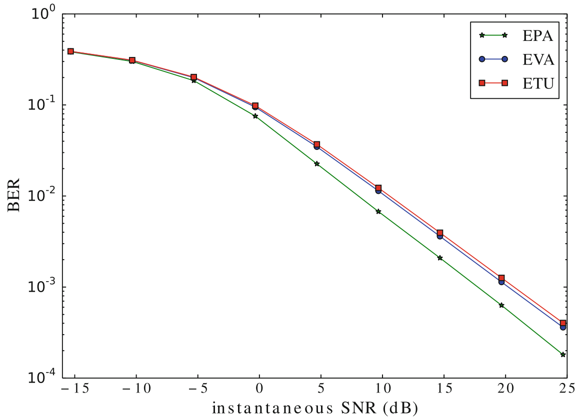

Fig. 4. Demodulated BERs using short-term SNR.

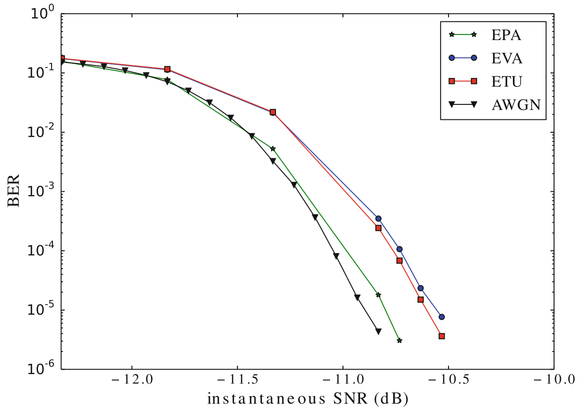

Fig. 5. Decoded BERs using short-term SNR.

comparable (per realization) SNR. Therefore, not a single codeword is transmitted through a channel (realization) with much lower SNR. Moreover, since source data are transmitted with very low code rate, the low BER results are understandable. Thus, the decoded BER performances of the three channel models in Fig. 5 are close to each other.

6 Conclusions

In this paper, we investigate how different SNR calculation methods affect simulated system performance for the EPA, EVA, and ETU channel models in LTE DL transmission. It is found that the received signal power averaged over a codeword can be very different from the power averaged over an ensemble of channel realizations. This disparity is especially evident for small Doppler-shift cases. Consequently, if ensemble-average SNR is employed in the simulations, the trials with low channel power gain dominate the overall decoded BER performance. As a result, the EPA model with a shorter delay spread exhibits higher decoded BER than the EVA and ETU models with longer delay spreads, an intuitively unreasonable phenomenon. As the short-term SNR is a better indicator of system performance, we therefore also use short-term SNR to evaluate the BER performance. Simulation results show that short-term SNR not only yields much smaller decoded BER than its counterpart for the same channel model, but also reverses the ordering of BER performance among the channel models as one would expect. The downsides of using short-term SNR is that the uncorrelated scattering property in the channel models is violated, and theoretical BER analysis becomes much more difficult. Considering these factors, we thus suggest that in presenting the performance results of LTE DL transmission, the BER results obtained by employing ensemble-average SNR should be presented alongside with those obtained by using short-term SNR. In this way, the reader can have a better understanding on the performance of the LTE DL transmission.

Acknowledgements. This work was supported by the Ministry of Science and Technology, Taiwan, under Project 104-2221-E-027-034.

References

1. Adegbite, S., Stewart, B.G., McMeekin, S.G.: Least squares interpolation methods for LTE system channel estimation over extended ITU channels. Int. J. Inf. Electron. Eng. **3**, 414–418 (2013)
2. Weng, F., Yin, C., Luo, T.: Channel estimation for the downlink of 3GPP-LTE systems. In: Proceedings of 2010 2nd IEEE International Conference Network Infrastructure and Digital Content, pp. 1042–1046 (2010)
3. Sesia, S., Toufik, I., Baker, M.: LTE-The UMTS Long Term Evolution: From Theory to Practice. Wiley, New Jersey (2011)
4. Rumney, M.: LTE and the Evolution to 4G Wireless: Design and Measurement Challenges, 2nd edn. Wiley, New Jersey (2013)

5. You, S.D., Liu, Y.-S.: Comparative study of channel estimation methods for LTE downlink transmission. In: Proceedings of 2015 IEEE 4th Global Conference on Consumer Electronics, pp. 642–643 (2015)
6. Liu, Y.-S., You, S.D., Liu, Y.-M.: Iterative channel estimation method for long-term evolution downlink transmission. IET Commun. **9**, 1906–1914 (2015)
7. 3GPP: LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) Radio Transmission and Reception, 3GPP TS 36.101. (2014). 3GPP
8. You, S.D., Chen, K.-Y., Liu, Y.-S.: Cubic convolution interpolation function with variable coefficients and its application to channel estimation for IEEE 802.16 initial downlink. IET Commun. **6**, 1979–1987 (2012)
9. Liu, Y.-S., You, S.D., Wu, R.-K.: Burst allocation method to enable decision-directed channel estimation for mobile WiMAX downlink transmission. EURASIP J. Wireless Commun. Netw. **153** (2013) https://doi.org/10.1186/1687-1499-2013
10. Prasad, R.: OFDM for Wireless Communications Systems. Artec House, Washington, DC (2004)
11. 3GPP: System-level Evaluation of OFDM - Further Considerations, 3GPP TSG-RAN WG1 35, R1–031303. (2003). 3GPP
12. Donthi, S.N., Mehta, N.B.: An accurate model for EESM and its application to analysis of CQI feedback schemes and scheduling in LTE. IEEE Trans. Wireless commun. **10**, 3436–3448 (2011)