Channel Estimation for LTE Downlink in High Altitude Platforms (HAPs) Systems

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***Abstract*—We describe in this paper, channel estimation performance evaluation of Long Term Evolution (LTE) downlink that uses Orthogonal Frequency Division Multiplexing (OFDM) technique, which employs High Altitude Platforms (HAPs) as radio communication channel. HAPs have advantages due to unique altitude position between terrestrial and satellite systems and hence promising as alternative candidate for radio communication channel in the future. LTE is predecessor of LTE Advanced that has been selected as Fourth Generation (4G) of mobile communication systems. Channel estimation is the vital part of receiver if the system uses coherent and multilevel demodulation. Therefore, we choose two estimation methods, Least Square (LS) and Linear Minimum Mean Square Error (LMMSE), to evaluate the performance in term of Mean Square Error (MSE) and Bit Error Rate (BER) versus Signal Noise to Ratio (SNR). The evaluations are performed in different elevation angles from HAPs to user in the ground, velocities of user, and modulation orders. The performance evaluation results of MSE and BER for LMMSE are better than LS, which lower elevation angle has lower performance. Furthermore, higher velocity make increases the performance gap between elevation angles. Finally, higher modulation order also produces lower performance.**

I. Introduction

Long Term Evolution (LTE) is also called as Evolved Universal Terrestrial Radio Access (E-UTRA) that uses Orthogonal Frequency Division Multiplexing (OFDM) technology for downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink, in order to get bandwidth efficiency and robustness against multipath fading in wireless communication systems. LTE also uses Multiple Input Multiple Output (MIMO) technology to increase data capacity. The drawback of OFDM is high Peak to Average Power Ratio (PAPR) and hence OFDM is used only for LTE downlink. Orthogonal Frequency Multiple Access (OFDMA) is used to support multi-user services in downlink part with assigning minimum one Resource Block (RB) per user by scheduler. In addition, OFDM is also used by Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and broadcast technology such as Digital Video Broadcasting (DVB) [1], [2].

Major deployment of mobile communication systems are using terrestrial cellular systems with satellite communications systems as alternative. Because of increasing demand for reliable and high speed wireless communication broadband, the deployment of terrestrial and satellite networks are very fast. However, current interesting investigation in telecommunication world is about the application of High Altitude Platform Station (HAPs) that have unique altitude position to fulfil communications gap between terrestrial and satellite stations. Hence, HAPs handle the coverage limitation of terrestrial and satellite link budget. By communication established between platform with user terminal on the ground, HAPs have capability to serve more user with lower infrastructure compare to terrestrial networks. Therefore, HAPs has been potential to provide broadband high speed wireless service as complement to terrestrial and satellite systems [3], [4]. HAPs can be aircraft and also airship with altitude in stratosphere at 17–22 km [5]–[7] or 21–25 km [8] above the ground.

Channel estimation algorithm is used in downlink LTE system for coherent demodulation and multi-level demodulation to OFDM symbol. Furthermore, a dynamic estimation and fading channel tracking in receiver is very important to be done before coherent demodulation of OFDM symbol because OFDM systems offer high speed transmission through frequency selective and time variant channel radio for broadband mobile communication. Channel effect in the transmitted information has to be estimated in order to recover the received information. Two widely used channel estimation methods are Least Square (LS) and Minimum Mean Square Error (MMSE) that has one variant called Linear Minimum Mean Square Error (LMMSE). LS is simpler and lower performance rather than LMMSE, while LMMSE more complex because it needs the knowledge of channel and also has to do matrix inverse [9]–[12].

A. Related Works and Contributions

Author in [13] performs channel estimation evaluation for LTE downlink by analysing several channel estimation techniques in frequency domain such as Slepian, Linear Interpolation, LMMSE Channel Impulse Response (CIR) Estimator, Downsampled CIR Estimator, and Reduced Rank LMMSE Estimator. However, he only uses Slepian sequence in time domain. After that, all of these five estimators were compared to 2x1D Wiener Interpolation that gives the best result but has highest complexity. The channel used in this research was Spatial Channel Model Extended (SCME) developed by 3GPP. Finally, It is shown that LMMSE CIR is the best fit between performance and complexity.

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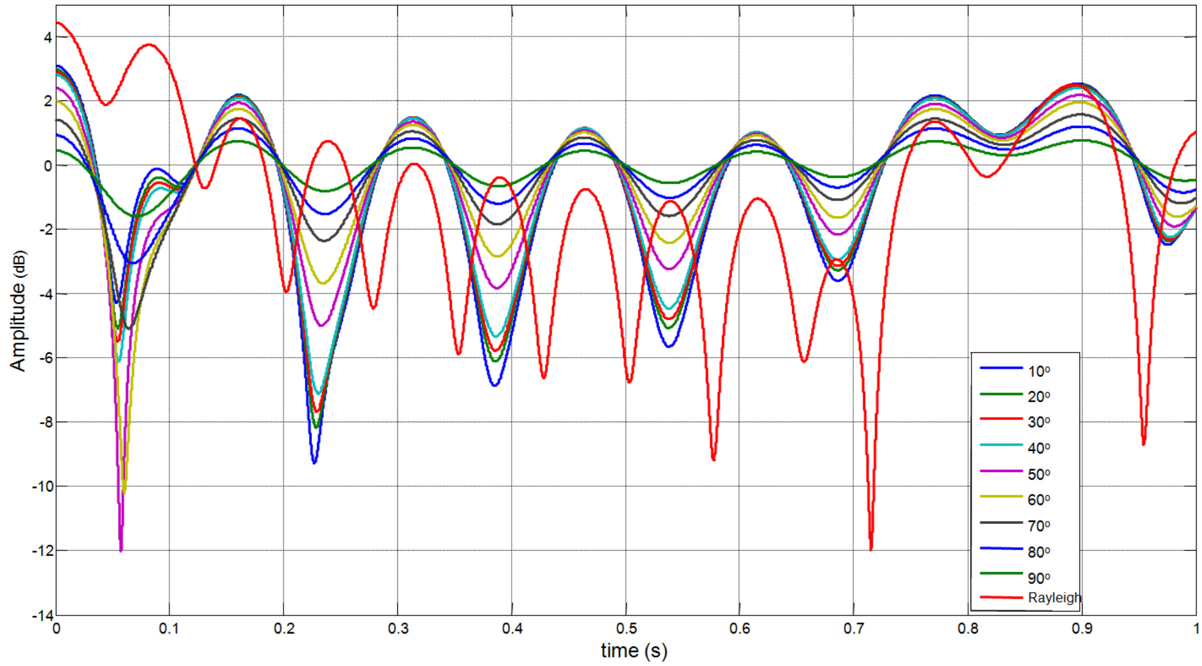

Fig. 1. Jakes model for Rician in 1 s with user velocity 3 km/h, sampling time 0.52 μs.

Authors in [10] evaluate the performance LS and LMMSE channel estimation for LTE downlink. In this research, the performance is evaluated in Bit Error Rate (BER) and Symbol Error Rate (SER) for two channel models from International Telecommunication Union (ITU), i.e., Extended Pedestrian B with velocity 3 km/h, and Vehicular-A with the velocity 120 km/h and 350 km/h. The result shows that LMMSE has better performance rather than LS, but LMMSE is more complex in calculation because it needs knowledge of noise variance.

Authors in [12] develop an LTE channel estimation algorithm that has better performance rather than LMMSE but it has higher complexity. The algorithm is derived from the LMMSE algorithm, then performs iterative Wiener filter in two dimensions of time and frequency. Next, authors in [1] have done implementation of 65 nm process Complementary MetalOxideSemiconductor (CMOS) with 49 kgates for channel estimation in LTE downlink. After that, they compare LS and LMMSE with the algorithm that is developed to reduce the complexity of LMMSE by using the channel model of ITU Pedestrian B. This algorithm is called as Approximate Linear Minimum Mean Square Error (ALMMSE). Finally, the results show that ALMMSE has better Means Square Error (MSE) performance rather than LS but lower than LMMSE.

Research in HAPs is done by authors in [14] that study small scale fading in HAPs system and derive theoretically channel model to obtain Power Delay Profile (PDP) for communication between HAPs and mobile terrestrial. However, this model still does not include elevation angles to performance evaluation. Therefore, our work in [3] conducts measurement of Rician K-factor for HAPs systems. The results of measurement are K-factor for elevation angles from 10^o until 90^o by step of 10^0 in frequency carrier 1.2 GHz and 2.4 GHz. Also we evaluates in [4] the performance of fixed power control for Code Division Multiplexing Access (CDMA) and Wideband CDMA (WCDMA) in HAPs environment by using Jakes model with Rician K-factor from our measurement in [3].

Our contributions in this research are to evaluate the performance of two estimation channel methods, i.e., LS and LMMSE to OFDM technology in LTE downlink system. Indeed, we use HAPs systems as wireless channel in this evaluation. Furthermore, the performance results are in MSE and BER versus Signal to Noise Ratio (SNR).

II. High Altitude Platforms (HAPs)

We use Jakes model in our research to generate Rayleigh fading channel that is flat fading in multipath environment in frequency domain. If we want to apply frequency-selective fading in multipath channel, we need PDP. However, the PDP values are not available for HAPs environment. Besides, there are many PDP values available now for terrestrial communication systems. Therefore, we can not use PDP measured on ground level in terrestrial system for HAPs [14]. In addition, OFDM technique with multi-carrier overcomes the effect of frequency-selective fading. Then, we focus on fast fading that is caused by user velocity to every elevation angles of HAPs. Thus, we use flat fading generated by Jakes model as well as we use in [4].

HAPs channel model follows Rician distribution because there is dominant LOS component present. Then, we modify the Rayleigh probability density function (PDF) of Jakes model output to Rician PDF by using K-factor from our HAPs 2.4 GHz measurement with nine elevation angles in [3] as below expression

$$p_{rician}(r) = \frac{1}{K+1} p_{rayleigh}(r) + \frac{K}{K+1}. \quad (1)$$

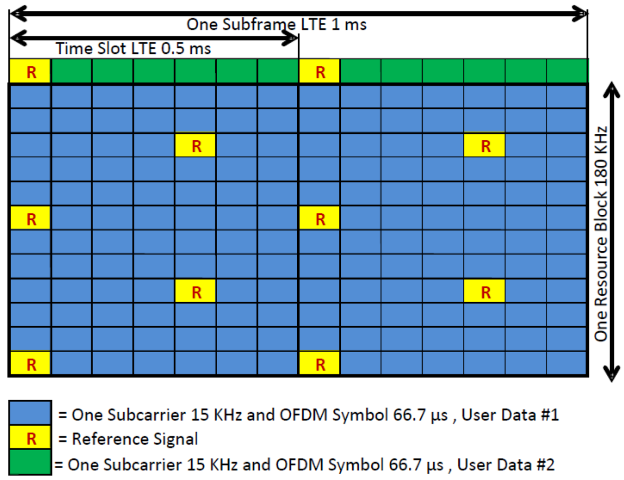

Fig. 2. Reference Signal of LTE position for channel Estimation.

Fig. 1 shows the output of Jakes model for Rayleigh and HAPs channel in Rician with $1,000$ subframe of LTE standard, duration 1 s, K-factor of HAPs 2.4 GHz with elevation angle 10^o until 90^o, Doppler shift 6.67 Hz, user velocity 3 km/h, sampling time 0.52 μs. After that, we apply the output of Jakes model to transmitted data by using Tapped Delay Line (TDL) for flat fading without PDP as below

$$\begin{aligned} y(n) &= h_r(n)x(n), \\ &= \left(\frac{K}{K+1} + \frac{1}{K+1}h(n)\right)x(n), \end{aligned} \tag{2}$$

where $h_r(n)$ and $h(n)$ are Rician channel and Rayleigh channel, respectively.

III. LTE Channel Estimation

We employ LS and LMMSE channel estimation to reference signals (name of pilot symbol in LTE standard) of LTE, that we already know their positions and values. We can see the position of reference signal base on LTE standardization in Fig. 2.

We assume that the system model only for one transmitter antenna and one receiver antenna that we call it as Single Input Single Output (SISO) system. Then, we write in frequency domain as below expression

$$Y = \mathbf{X}H + Z, \tag{3}$$

where Y is received signal, H is channel coefficient, and Z is additive zero mean white Gaussian noise (AWGN) with σ_Z^2 as the variance at receiver. $\mathbf{X}$ is diagonal matrix that consists of data symbol X_d and pilot symbol X_p permuted in main diagonal. P is permutation vector in column vector with reference signals in first line and data symbol in the rest of lines that we can represent as below [1]

$$\tilde{X} = \left[X_d^T X_p^T\right]^T, \tag{4}$$

$$X = P\tilde{X}, \tag{5}$$

$$\mathbf{X} = diag(X). \tag{6}$$

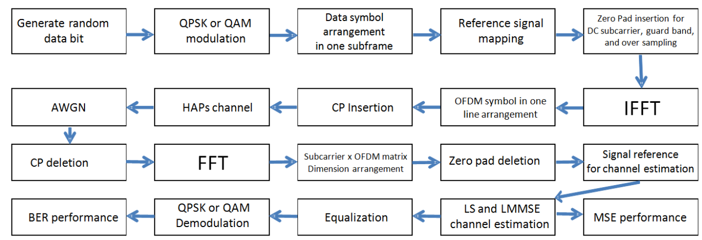

Fig. 3. Block diagram of system model for simulation.

We use LS channel estimation before apply linear interpolation as below

$$\hat{H}_{p,LS} = \mathbf{X}_p^{-1} Y_p. \tag{7}$$

After that, we interpolate linearly between reference signals in frequency domain direction, then we interpolate linearly in time domain direction. Therefore, we obtain channel estimation in whole subcarrier in one LTE subframe.

We use equation (7) to obtain LMMSE estimation channel as below expression [1], [15]

$$\begin{aligned} \hat{H}_{LMMSE} &= \mathbf{W}\hat{H}_{p,LS} \\ &= \mathbf{R}_{HH_{p,LS}} \mathbf{R}^{-1}_{H_{p,LS}H_{p,LS}} \hat{H}_{p,LS} \\ &= \mathbf{R}_{HH_p}\left(\mathbf{R}_{H_pH_p} + \frac{1}{SNR}\mathbf{I}\right)\hat{H}_{p,LS}, \end{aligned} \tag{8}$$

where $\mathbf{R}_{HH_p}$ is cross-correlation between channel in all subcarrier and channel in subcarrier with reference signal position. $\mathbf{R}_{H_pH_p}$ is auto-correlation between channel in subcarrier with reference signal position. After we find channel estimation, we evaluate MSE performance. Finally, we perform equalization and coherent demodulation before we calculate BER performance of the system as shown in Fig. 3.

IV. Simulation Results and Performance Evaluation

In our simulation, the channel estimation of LS and LMMSE in HAPs channel model are generated by modified Jakes model to Rician distribution base on K-factor from our measurement in [3]. We evaluate 9 elevation angles from 10^o until 90^o, with user velocity 3 up to 350 km/h, QPSK and 64-QAM modulation.

We run for each realization in one duration of LTE subframe with 14 OFDM symbols, 1.4 MHz as bandwidth, 72 subcarriers that consist of multi-level modulated data symbol, 128 IFFT-point, and 2.4 GHz as carrier frequency. Then, we simulate $1,000$ subframes that is contained $14,000$ LTE OFDM symbols. Each subframe contains $1,920$ bits uniform random bit data. Thus, we use total almost 2 million bits in the simulation to get BER achieve 10^{-6}.

Channel estimation LS for user velocity 3 km/h in Fig. 4 has almost equal performance for all elevation angle from 10^o up to 90^o. For user velocity 350 km/h in Fig. 5, MSE performances have difference value between angle elevation start from SNR 5 dB. After SNR 20 dB, the MSE performances of elevation angles below 60^o become stagnant. However, elevation angles 60^o up to 90^o increase the performance

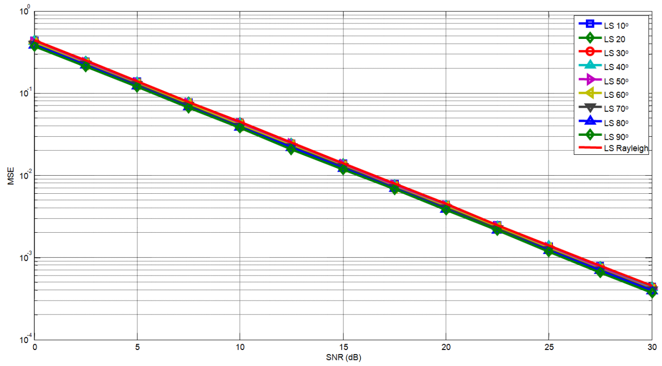

Fig. 4. MSE of LS channel estimation, QPSK, 1.4 MHz, 2.4 GHz, 3 km/h.

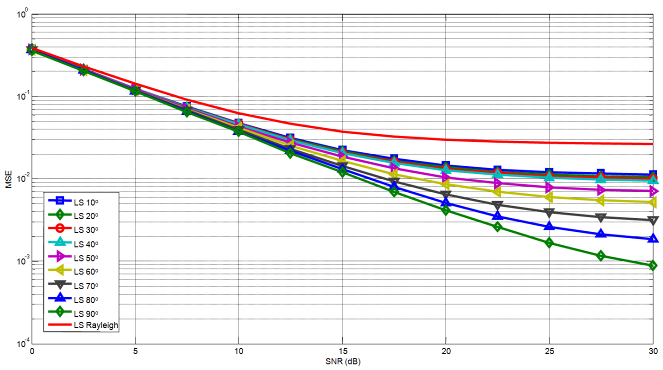

Fig. 5. MSE of LS channel estimation, QPSK, 1.4 MHz, 2.4 GHz, 350 km/h.

significantly by increasing SNR values. Fig. 4 and 5 show that higher user velocity as well as lower elevation angles results in lower MSE performance. Performance gap between elevation angles start increase from low SNR in higher velocity. Fig. 6 shows that MSE performance of QPSK modulation in LS channel estimation for QPSK modulation are slightly better than 64-QAM for higher user velocity and lower elevation angles.

In Fig. 7, we compare MSE performance between LMMSE with LS channel estimation. Hence, MSE performances of LMMSE are better than LS. However, higher user velocity

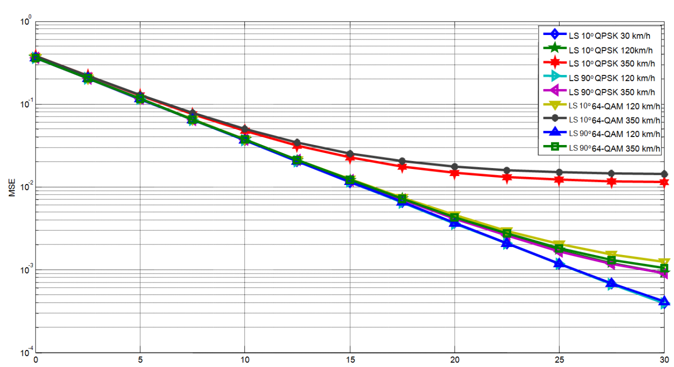

Fig. 6. MSE of LS channel estimation, QPSK and 64- QAM, 1.4 MHz, 2.4 GHz, 120 and 350 km/h.

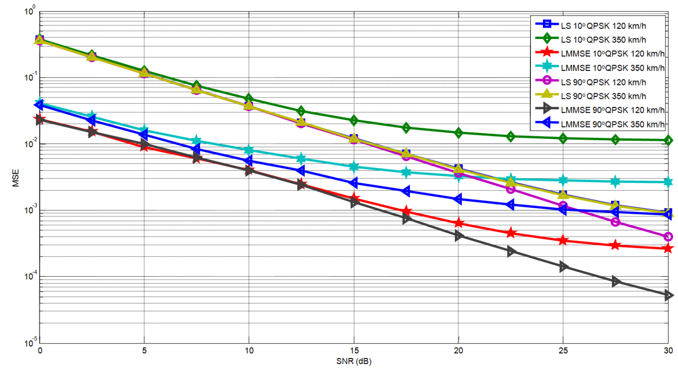

Fig. 7. MSE of LMMSE & LS channel estimation, 10^o, 90^o, QPSK, 1.4 MHz, 2.4 GHz, 120 km/h, and 350 km/h.

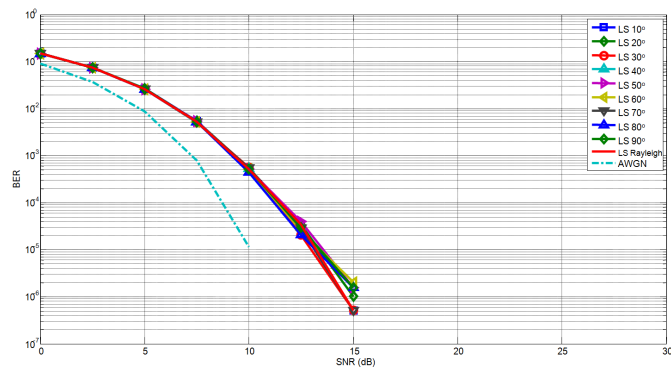

Fig. 8. BER of LS channel estimation, QPSK, 1.4 MHz, 2.4 GHz, 3 km/h.

gives impact to degradation MSE performance of LMMSE. Therefore, MSE performances are almost same between LS and LMMSE channel estimation in elevation angle 90^o with user velocity 350 km/h and SNR 30 dB. In addition, performance gap between elevation angles increase from 0 dB to higher SNR.

Next, we evaluate the BER performance of LS in Fig. 8 and 9. Lower user velocity makes the performance between elevation angles are almost equal. Then, higher user velocity 350 km/h with elevation angles below 60^o with SNR above 20 dB have BER above 10^{-3} and become stable. Next, elevation angles 60^o dan 70^o with SNR above 20 dB are between BER 10^{-3} and 10^{-6} and stable. Finally, BER 10^{-6} is achieved by elevation angles above 70^o with SNR above 15 dB.

Higher modulation order that is 64-QAM needs higher SNR to achieve equivalent BER with lower modulation order, i.e., QPSK. Fig. 10 shows that 64-QAM has SNR around 24 dB compare to QPSK in Fig. 9 has SNR around 10 dB to achieve the equivalent BER performance values. Finally, Fig. 11 shows that LMMSE has BER performance better than LS channel estimation for all elevation angles and velocities.

V. Conclusion

Increasing user velocities affect degradation of MSE performance and increase the performance gap between elevation angles. In addition, MSE performances for lower modulation order are slightly better than higher modulation order for

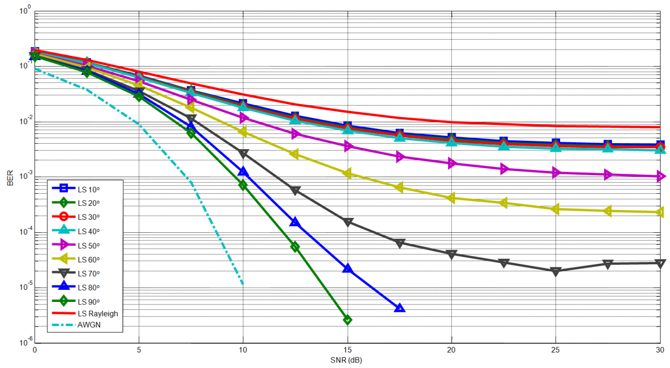

Fig. 9. BER of LS channel estimation, QPSK, 1.4 MHz, 2.4 GHz, 350 km/h.

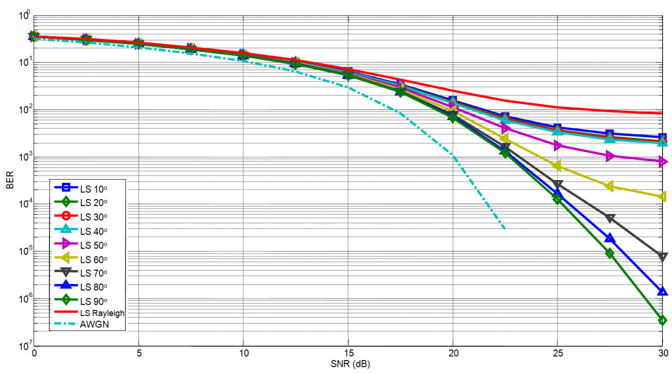

Fig. 10. BER of LS channel estimation, QPSK, 1.4 MHz, 2.4 GHz, 350 km/h.

higher user velocity and lower elevation angles. However, MSE performances for all elevation angles and modulation order are almost equal when user velocities are very slow. LMMSE channel estimation has better MSE performance rather than LS channel estimation but the performance gap between elevation angles are getting almost equal in higher SNR, higher velocity and lower elevation angle.

BER performances are decreasing along with the increasing of the user velocity and the decreasing of elevation angles. Higher modulation order needs higher SNR to get equivalent BER performance with lower modulation order. BER performance of LMMSE is better than LS channel estimation in any user velocity and all elevation angles. However, LMMSE channel estimation has higher complexity rather than LS because it needs the knowledge of channel correlation and SNR system.

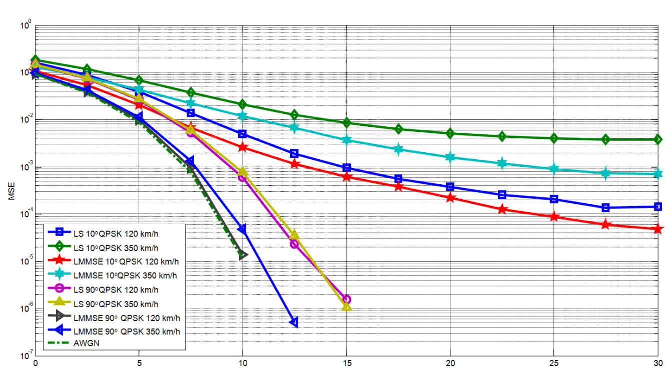

Fig. 11. BER of LMMSE & LS channel estimation, 10^o, 90^o, QPSK, 1.4 MHz, 2.4 GHz, 120 km/h, and 350 km/h.

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