Transmission performance of OFDM-based 1024-QAM in multipath fading conditions

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Abstract: Higher-order modulation is promising technique of 5th-generation mobile systems to increase data rate within a limited bandwidth. This paper presents the transmission performance of the orthogonal frequency division multiplexing (OFDM)-based 1024-QAM in multipath fading propagation conditions by link-level simulation, as well as under static propagation condition. The BER performance is investigated for two types of propagation models, i.e., “extended pedestrian A” and “extended vehicular A” models, specified by 3GPP as parameters of the coding rates. The SNR penalties are also described with respect to the case of AWGN with phase error to meet a BER of $10^{-2}$ for OFDM-based 1024-QAM. Using these results, we validate the application of OFDM-based 1024-QAM to mobile communication systems.

Keywords: mobile communications, 1024-QAM, OFDM, multipath fading, EPA/EVA models

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

References

[1] 3GPP TR 36.932, “Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN (Release 12),” Dec. 2012.
[2] Q. Mu, L. Liu, L. Chen, and Y. Jiang, “CQI table design to support 256 QAM in small cell environment,” Proc. WCSP2013, pp. 1–5, Oct. 2013. DOI:10.1109/WCSP.2013.6677171
[3] S. O. Elbassiouny and A. S. Ibrahim, “Link level performance evaluation of higher order modulation in small cells,” Proc. IWCMC2014, pp. 850–855, Aug. 2014. DOI:10.1109/IWMC.2014.6906467
[4] J. Mao, M. A. Abdullahi, P. Xiao, and A. Cao, “A low complexity 256QAM soft demapper for 5G mobile system,” Proc. EuCNC2016, June 2016. DOI:10.1109/EuCNC.2016.7560996
[5] T. Nakamura, S. Nagata, A. Benjebbour, Y. Kishiyama, H. Tang, X. Shen, N. Yang, and N. Li, “Trends in small cell enhancements in LTE advanced,” IEEE Commun. Mag., vol. 51, no. 2, pp. 98–105, 2013. DOI:10.1109/MCOM.2013.6461192
[6] W. Lee, S.-R. Lee, H.-B. Kong, and I. Lee, “3D beamforming designs for single
1 Introduction

In order to improve data rates within a given bandwidth, a straightforward method is the use of higher-order modulation. In LTE and LTE-Advanced systems, quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (QAM), and 64-QAM are being used for the symbol modulation of orthogonal frequency division multiplexing (OFDM). Furthermore, from Release 12 in the standards body, 3rd Generation Partnership Project (3GPP) defines to support 256-QAM in downlink, although 3GPP introduced 256-QAM as a part of small cell enhancement (SCE) feature [1, 2, 3, 4]. The maximum bandwidth utilization of 256-QAM is in principle eight times that of QPSK, although the higher-order modulation scheme is at the cost of robustness to noise and interference. However, the combination of channel coding and the higher-order modulation, i.e., modulation and coding scheme (MCS), will be more efficient.

SCE and heterogeneous network (HetNet) have been developed to potentially increase system capacity. The small cell approach is to deploy a denser infrastructure that includes support by a low-power evolved Node B (eNB). The cell radius covered by a small cell will be short; therefore, it is expected that such a small cell environment could mitigate the fading impact [1, 5].

Three-dimensional (3D) beamforming has been also considered for enhancing system performance, which can adapt the antenna beam individually for each user equipment (UE) in the elevation domain, i.e., UE-specific elevation beamforming. The 3D beamforming directs the transmitted carrier power toward the target UE, thereby promises to potentially increase the received signal-to-interference plus noise ratio (SINR) while directing less interference to adjacent cells/sectors and other UEs [6, 7]. The use of SCE, HetNet, and 3D beamforming and so on enhances the introduction of a higher-order modulation scheme, since these technologies can increase the received SINR.

Motivated by this observation, in this paper, we focus on much higher-order modulation, i.e., the use of 1024-QAM. We demonstrate the bit error rate (BER) performance of the OFDM-based 1024-QAM with turbo coding in multipath fading propagation conditions [8, 9]. The transmission model of the proposed OFDM-based 1024-QAM and the computer simulation conditions are described in Section 2. In Section 3, we present the BER performance versus received SNR in multipath fading propagation conditions, i.e., extended pedestrian A (EPA) and
extended vehicular A (EVA) models, as parameters of the coding rates. The influence of phase error on 1024-QAM is also provided. Finally, conclusions are summarized in Section 4.

2 Transmission model

Fig. 1 shows a transmission model of the OFDM-based 1024-QAM consisting of a single antenna branch. The channel between the transmitter and receiver is modeled by an additive white Gaussian noise (AWGN) and multipath fading channel. In the transmission side, turbo encoder is applied. This employs parallel concatenated convolutional encoders with a constraint length of 4 and a pseudo-random interleaver. The encoded signals are mapped to 1024-QAM by symbol modulation. OFDM modulation computes the inverse fast Fourier transform (IFFT) of the input QAM signals. Finally, cyclic-prefix insertion is used as a typical OFDM transmission. In the receiver side, a soft decision turbo decoder is used to increase reliability of the decision.

The coding rate is varied within the range from 1/3 to 1. The OFDM bandwidth is set to 20 MHz. QAM signals are mapped by the rule of Gray-code. The main simulation parameters are summarized in Table I. The multipath fading propagation conditions specify the following two profiles, EPA and EVA, whose delay profile represent low and medium delay spread, respectively. The Doppler shift is fixed at 5 Hz.

3 Simulation results

3.1 Signal constellation and OFDM spectrum

Fig. 2 shows simulation results for OFDM-based 1024-QAM transmission in multipath fading conditions. Fig. 2(a) illustrates the signal constellations of the 1024-QAM at the transmitter side, and the OFDM spectrum composed of 1200 subcarriers, in EVA fading propagation conditions.

3.2 Influence of phase error

Fig. 2(b) shows the SNR penalties with respect to the case of AWGN with phase error to meet a BER of $10^{-2}$ for 1024-QAM. It is observed that the SNR penalty increases when the phase error increases, and of course, 1024-QAM is more sensitive to the phase error compared with conventional QAM or QPSK.
As shown in Fig. 2(b), the SNR penalty of 1024-QAM is around 6 dB for the phase error of 0.05 when the coding rate of 3/4 is used. If the SNR penalty has to be less than 2 dB, the allowable phase error is 0.1 for the coding rate of 1/3 or less.

| Table I. Primary simulation parameters |
|---------------------------------------|
| Symbol modulation | 1024-QAM |
| Signal mapping | Gray code |
| Turbo encoder | Coding rate: R = 1/3, 1/2, 2/3, 3/4 |
| | Constraint length: 4 |
| Turbo decoder | Soft decision |
| Bandwidth | 20 MHz |
| FFT size | 2048 |
| Cyclic prefix length | 144 |
| Number of Tx/Rx antennas | 1 |
| Fading type | Rayleigh fading |
| EPA | Doppler shift 5 Hz |
| | Path delay 0, 30, 70, 90, 110, 190, 410 ns |
| | Path gain 0, −1.0, −2.0, −3.0, −8.0, −17.2, −20.8 dB |
| EVA | Doppler shift 5 Hz |
| | Path delay 0, 30, 150, 310, 370, 710, 1090, 1730, 2510 ns |
| | Path gain 0, −1.5, −1.4, −3.6, −0.6, −9.1, −7.0, −12.0, −16.9 dB |

As shown in Fig. 2(b), the SNR penalty of 1024-QAM is around 6 dB for the phase error of 0.05 when the coding rate of 3/4 is used. If the SNR penalty has to be less than 2 dB, the allowable phase error is 0.1 for the coding rate of 1/3 or less.

(a) Signal constellation at transmitter side and OFDM spectrum at receiver side.

(b) SNR penalty versus phase error for 1024-QAM.
3.3 BER performance

Fig. 2(c) shows the BER for 1024-QAM versus the received SNR with the coding rate of $1/2$. When the EPA model is used, the required SNR to meet a BER of $10^{-2}$ is approximately 31 dB. Compared with the performance in static propagation condition, the required SNR increases to 6 dB. When the EVA model is used, 1024-QAM can no longer meet a BER of $10^{-2}$, even though SNR is increased.

Fig. 2(d) shows the BER for 1024-QAM under the EPA model as parameters of the coding rate. The required SNR to meet a BER of $10^{-2}$ for the coding rates of $1/3$, $1/2$ and $3/4$ are approximately 26, 31, and 35 dB, respectively. Compared with the performance in static propagation condition, the required SNR increases around 6 dB.

4 Conclusion

This paper presented the transmission performance of OFDM-based 1024-QAM in multipath fading propagation conditions by link-level simulations. It was clarified that the SNR penalty of 1024-QAM was around 6 dB for the phase error of 0.05 when the coding rate of $3/4$ was used. We also showed the BER performance as
parameters of coding rate using two types of propagation conditions, i.e., EPA and EVA. When 1024-QAM with the coding rate of 1/2 is used in the EPA model, the required SNR to meet a BER of $10^{-2}$ increased to 6 dB compared with that in static propagation conditions.