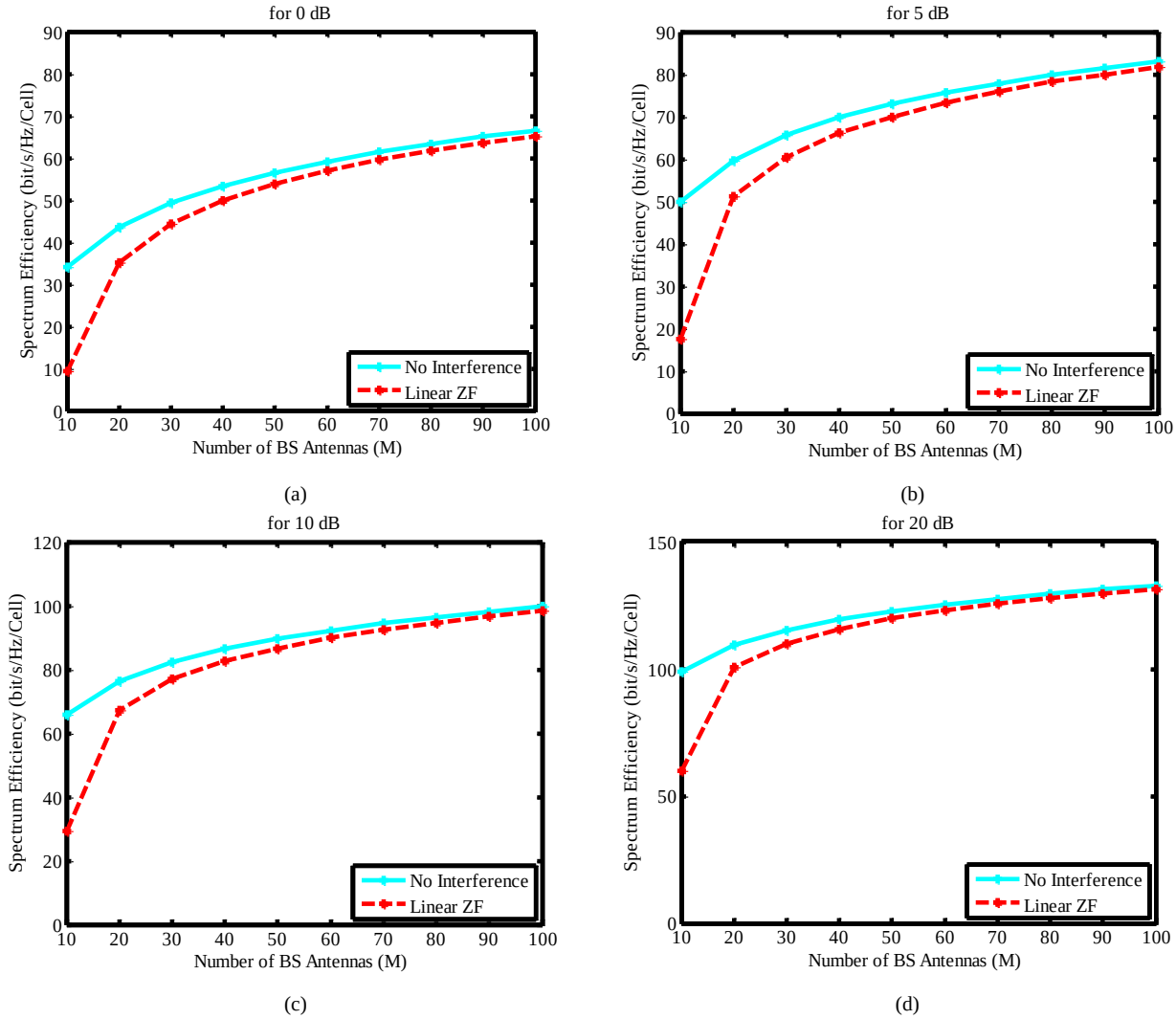

Fig. 5. Spectrum efficiency in massive MIMO system with different number of BS antennas and constant number of user: (a) for 0dB; (b) for 5dB; (c) for 10dB; (d) for 20dB.

Moreover, in MRC, it is observed that the pilot reuse factor 3 is more suitable for the number of antennas in the base station is about a hundred as in the literature. However, unlike in the literature, it is observed that the pilot reuse factor should be selected a more appropriate value when considering the number of more antennas in future technologies. When the system with MRC is examined, the selecting pilot reuse factor 3 around a hundred antennas is important to increase the spectrum efficiency. But, when the number of antennas is about 200 and above, it is considered that selecting reuse factor 1 is ideal.

A similar situation is seen in ZF detection. It is understood that the pilot reuse factor used when the number of antennas is a hundred or less needs to be changed in order to increase spectrum efficiency in the system, where the number of antennas increases to about a thousand. In ZF, it is important to select pilot reuse factor 1 when number of BS antennas is above 600. Similarly, using pilot reuse factor 3 is very efficiency, while the number of BS antennas is up to about 600. It is possible to state, which pilot reuse factor is used for which antenna number ranges using the results obtained. These results make it easy to determine the design conditions also.

Another observation to be obtained as a result of the numerical analysis, is that the spectrum efficiency between ZF and MRC (Fig. 6 and Fig. 7) is the different. These results show that ZF is better than MRC. Briefly, the pilot reuse factor is a significant ratio in Massive MIMO systems, and the most suitable selection rely on the number of BS antennas.

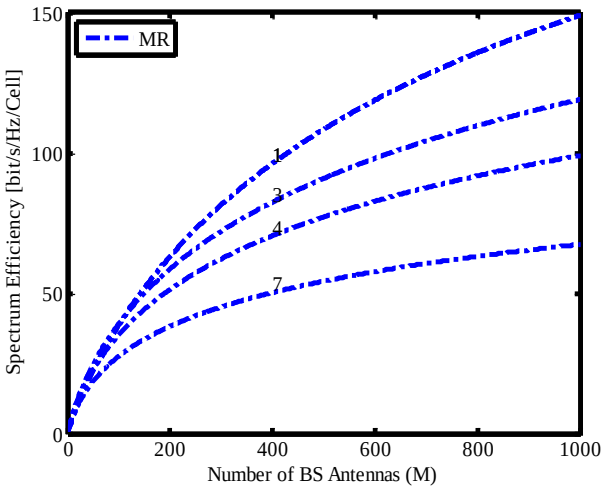

Fig. 6. Spectrum efficiency in different pilot reuse factors for MR detection.

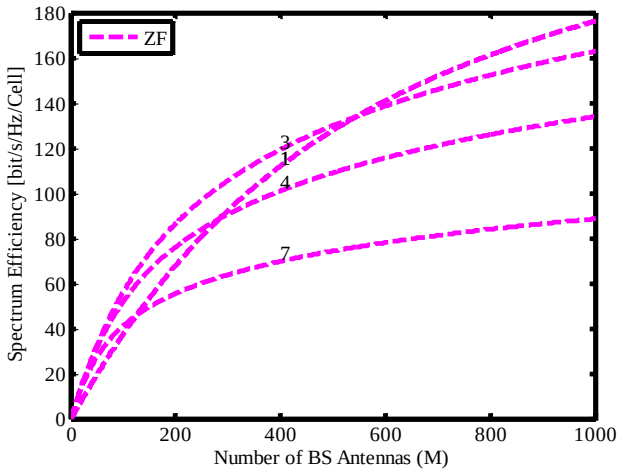

Fig. 7. Spectrum efficiency in different pilot reuse factors for ZF detection.

C. Spectrum Efficiency with Massive MIMO in 5G Networks

The contributions of Massive MIMO systems for the spectrum efficiency are tried to be shown in the above results. In this section, it is shown the spectrum efficiency performance that will be achieved with Massive MIMO uplink and downlink of 5G networks. The pilot reuse factor is set to $f = 3$ ZF detection is considered and 5 dB SNR is assumed to each user.

Figure 8 shows the spectrum efficiency as a function of the BS antenna number M. Also, the maximum number of users per cell is 10. The performance of these results is compared to 4G networks [2]. When compared with International Mobile Telecommunications-Advanced (IMT-Advanced), $39 bit/s/Hz/cell$ is obtained for $M = 100$ antennas and an increase of 15 to 25 times in spectrum efficiency is observed. In $M = 400$ antennas massive MIMO system, the spectrum efficiency is $57 bit/s/Hz/cell$. This improvement provides from 35 to 50 times more gain than IMT-Advanced.

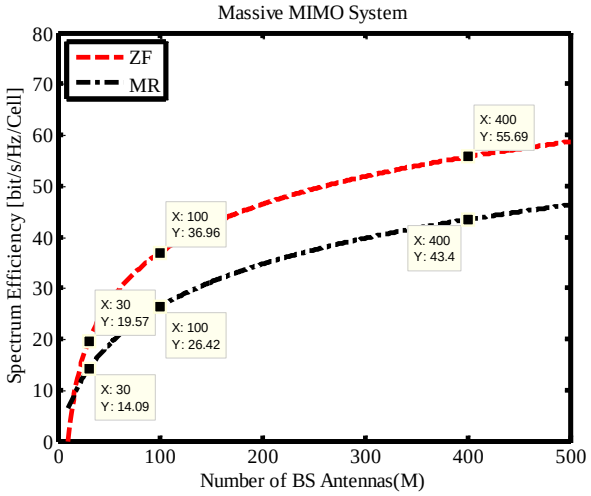

Fig. 8. Spectrum efficiency in pilot reuse factor f = 3 and 5 dB SNR depending on BS antenna for ZF and MR detection.

V. CONCLUSIONS

In this study, the spectrum efficiency performance of Massive MIMO to be used in next generation wireless networks is analysed. For this purpose, the theoretical analyses in the literature are examined and only the output obtained at the point of spectrum efficiency is presented. Thus, numerical analyses for spectrum efficiency, which is a special field, are carried out for Massive MIMO, instead of general concepts in the literature. As a result, if the number of M antennas is much larger than the number of K users, it is shown that the theoretical results are approached. It is also emphasized that the pilot reuse factor is a significant index in Massive MIMO systems and should be selected according to the number of antennas. Finally, it is observed that spectrum efficiency improvements of ten times or more are achieved according to the IMT-Advanced, which is theoretical results presented for 4G systems.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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