A Study on the Modulation Requirements for Personal Satellite Communications

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Abstract

This paper presents a comprehensive study on the digital modulation techniques for use in personal satellite communications. Herein are discussions on the possibility of use of satellites for personal applications, challenges and possible remedies especially concerning the modulation schemes required. We make recommendations on the potential modulation techniques that would support personal satellite communications.

Ⅰ. Introduction

Present day communications are faced with the spectrum challenge, a problem which could be because of the development of Internet of Things (IoT). The exponential increase in the resulting traffic imposes pressure on the existing spectral framework and could overwhelm the current cellular infrastructure in the future. In this study we consider the use of satellites as a complement for the existing mobile networks to support personal communications. Personal communications may include wireless communications inform of data, voice and video, and others as shown in Fig 1.

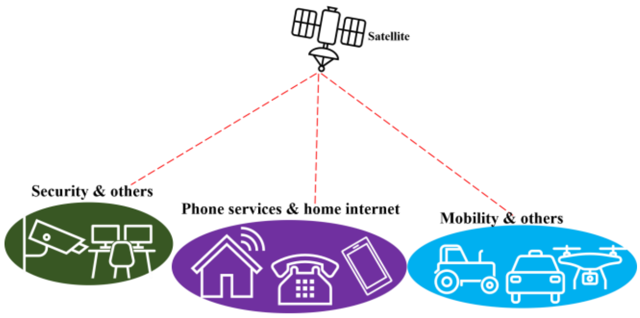


Fig. 1. Examples of personal satellite applications

Satellites are known for their provision of wide coverage especially in out-of-reach areas which are not adequately served by terrestrial networks. The idea of integration of integration of non-terrestrial networks with terrestrial networks is research in progress [1, 2] and could be beneficial for seamless service delivery in personal communications. Unlike terrestrial networks which are limited by co-channel interference, satellites are limited by power due to thermal noise and bandwidth due to bandwidth restrictions. Feasible solutions to issues such as modulation and coding, link margin requirements, frequency planning and orbit choice are necessary [1, 2]. In this paper we discuss the different digital modulation schemes which could support personal satellite communications. We present the challenges and possible solutions to the problems that could be encountered while using a given modulation scheme.

Ⅱ. Main part

To maximize power efficiency in satellites, high power amplifiers (HPAs) such as solid-state power amplifiers (SSPAs) and traveling-wave tube amplifiers (TWTAs) are operated in full-saturation mode. Consequently, undesirable amplitude modulation-amplitude modulation conversions (AM-AM) and amplitude modulation-phase modulation (AM-PM) conversions are introduced into the transmitted signal. On the other hand, operating in a nonlinear mode at or near saturation incurs spectral spreading which results from the nonlinearity caused by band-limiting the modulation prior to amplification [3].

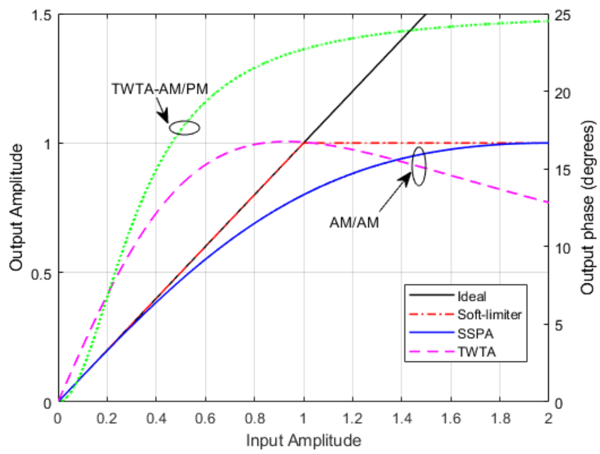


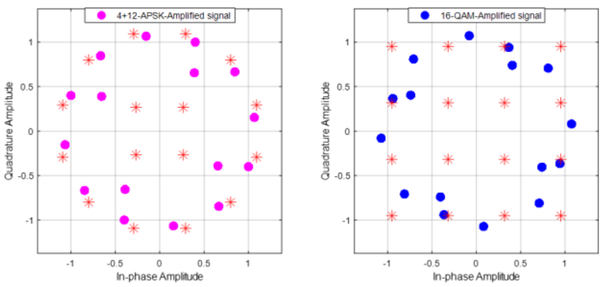
Fig. 2. Nonlinear distortion effects in HPAs

Fig. 2 shows the AM-AM and AM-PM arising from amplification by SSPA and TWTA amplifiers. Generally, the criteria of choosing modulation techniques depends on factors such as power efficiency, robustness to channel impairments, bandwidth efficiency and system complexity. Several techniques have been proposed to compensate the effect nonlinear distortions at the transmitter side in the form of predistortion and at the receiver side in the form of equalization.

In this paper the discussed modulation schemes are grouped into constant envelope and non-constant phase envelope modulations. The term constant envelope is derived from the concept that all points on the constellations have a fixed distance from the center. Constant envelope modulation schemes include binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), offset quadrature phase shift keying (OQPSK), differential quadrature phase sift keying (π/4-DQPSK), M'ary phase shift keying (M-PSK), amplitude phase shift keying (APSK) and continuous phase modulation (CPM). Quadrature amplitude modulation (QAM) is an example of a non-constant phase modulation scheme.

We select QAM and APSK as sample modulation schemes and perform MATLAB-based simulations with constellation points arrangement and bit error rate (BER) as our performance metrics. In terms of constellation structure, APSK constellation points are represented on concentric circles in the I/Q plane while a 2n-QAM scheme has a series of n bits represented by 2n-constellation points on either rectangular or square lattices.

Due to power limitations, modulations such as QAM, that convey information via their amplitude require a linear amplifying feature, i.e., the radio frequency (RF) amplification requires a wider linear range of operation which leads to reduced power efficiency. This makes them unsuitable for use on channels operated beyond maximum transmitted power efficiency condition. Therefore, constant envelope modulation schemes are preferable since they attain bandwidth efficiency through other ways rather than multilevel amplitude modulation [3].



(a) 4+12-APSK (b) 16-QAM

Fig. 3. Constellation diagrams for 4+12-APSK and 16-QAM after amplification

Moreover, by comparing the constellation plots of QAM and APSK (Fig. 3), QAM achieves better resistance to signal impairments by increasing the distance between the constellation points, however the number of rings in QAM is greater resulting into higher amplitude levels. Additionally, the uneven spacing of the rings with some closer to others makes it harder to mitigate nonlinearities. Fig. 4 compares the BER performance of OFDM-based 16-QAM and 4+12-APSK under the linear and nonlinear regimes of the operation of an amplifier. It shows that the constant envelope modulation scheme (4+12-APSK) outperforms the nonconstant envelope modulation scheme (16-QAM) in the nonlinear regime.

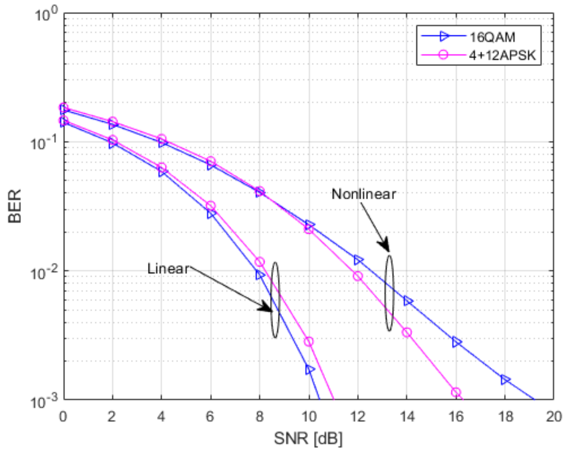


Fig. 4. BER performance of 16-QAM and 4+12-APSK for OFDM when subjected to nonlinearities.

Ⅲ. Conclusion

In this paper, the performance requirements of the digital modulation techniques were investigated for implementation in satellites to support personal communications. Advantages and limitations of different schemes have been discussed. The studies show that several trade-offs exist when determining the choice of modulation technique to use. For instance, to attain high data rates and capacity, a higher-order modulation scheme could be adopted.

However, such modulation schemes are prone to nonlinear signal distortions and high error-rates. Additionally, bandwidth is a scarce resource. It would be beneficial to deploy constant envelope modulations which are adaptive to channel conditions to achieve quality of service in personal satellite communications. In the future, we would like to investigate the combined effect of doppler conditions and nonlinearities on the performance of multicarrier transmission in personal satellite communications.

ACKNOWLEDGMENT

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government (MSIT)(No.2021-0-00260, Research on LEO Inter-Satellite Links)

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