Sequence Design Technique for UAV Communication over Cellular Networks with Down-tilted Antennas

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Abstract— **In this paper, we discuss problems that may occur in unmanned aircraft (UAV) communications over cellular networks with down-tilted antennas for extending terrestrial cellular services to aerial users. To overcome the difficulties arising in UAV-cellular networks, we propose a new sequence design technique for UAV-cellular networks using a scalable sequence (SS). An m-sequence based scalable sequence (M-SS) is proposed for efficient use of battery power in UAV-cellular networks. The properties of the M-SS are analyzed and compared by simulation in different channel environments.**

Keywords— Unmanned aircraft, UAV communication, UAV-cellular network, sequence design

I. Introduction

Unmanned vehicles (UAVs) are currently gaining increased interest because of a wide range of applications. Although UAVs have been developed in the military to reduce pilot losses in hostile territories, the use cases of commercial UAVs are growing rapidly [1][2]. Recently, tele communication industry and third generation partnership project (3GPP) have shown a great interest in cellular-based communication for UAVs to extend terrestrial cellular services to aerial users in future 5G networks. According to the measurement results in [3], the UAV whose heights is above the boresight of antenna array at the base station (BS) is likely to be served by sidelobes of antenna array because current cellular networks are optimized for terrestrial users. Since BS antennas are down-tilted to confine cell radius for reduction of inter-cell interference, the characteristics of radio links for UAVs will be different from terrestrial cellular connection. The UAV will receive a different signal strength depending on altitude because the pathloss varies depending on sidelobe pattern [4]. When the UAV does not receive a signal due to the presence of null in the sidelobes, it may be served by a faraway BS than the one that is geographically close. In this case, the pathloss will increase due to the long distance. Thus, the UAV will experience a large variation of pathloss and need to be connected to other BS, depending on its altitude. Another important issue to be addressed for the use of UAVs is the limited battery life. The length of time that a UAV can stay in the air is restricted to only about 20 minutes because the UAVs are limited by their on-board battery life.

To overcome the difficulties arising in UAV-cellular networks, we propose a new sequence design technique for next-generation UAVs, using a scalable sequence (SS). The proposed SS is generated at the BS with full available bandwidth because there is no power constraint at the BS. However, the UAV receives the SS with different bandwidth depending on the channel condition. The proposed SS is designed to provide correct synchronization parameters and cell ID (CID) even with different bandwidth in the receiver side. The SS enables UAVs to increase detection performance with a large bandwidth when the channel is bad, and to reduce battery consumption with a small bandwidth when the channel is good.

II. Sequence design for UAV communication

Fig. 1 shows a typical scenario for UAV communication over cellular networks. The BS in cellular networks normally has down-tilted antennas to reduce the co-channel interference and to confine the cell coverage area. As shown in Fig. 1, UAVs flying in the sky are likely to be served by the sidelobes of BS antennas. The UAVs will receive a different signal strength depending on the altitude because of the sidelobe pattern of BS antennas. The UAV may receive a relatively strong signal when it is aligned with the direction of sidelobe. It may not receive a signal when it is in the direction of null in the sidelobes. In this case, it may be served by a neighbor BS after making a handover. Thus, the UAV will experience a large variation of channel characteristic and be served by different BSs, depending on its altitude.

In this paper, we describe a new sequence design technique for UAV-cellular networks to efficiently use battery power of UAV in the channel environment with down-tilted antennas. In the proposed technique, the sequence is generated at the BS with a full length and transmitted using full available bandwidth, because there is no power problem in the BS being supplied by external sources. However, the UAV in the proposed technique receives the signal with different bandwidth depending on the channel condition. When the UAV receives a weak signal, it detects the signal using a full bandwidth. When the UAV receives a strong signal, it detects the preamble using a small bandwidth, In this case, a small portion of sequence is used as a reference signal in the receiver to reduce the power consumption of UAV.

In this paper, the SS is defined as a sequence which can provide the same information (synchronization parameters and CID) even with a small portion of sequence in the receiver side. In general, the same information cannot be obtained from the received signal if the signal is received with a bandwidth smaller than the one used in transmit side. However, when the SS is used for preamble in UAV-cellular networks, the same information can be detected in the receiver side even with a smaller bandwidth.

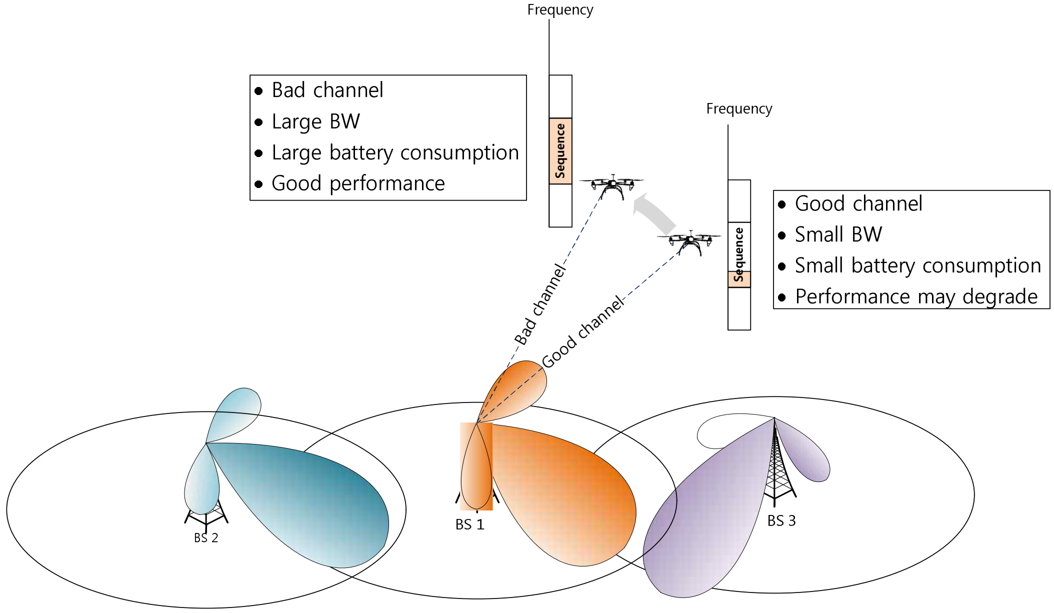

Fig. 1 A typical scenario for UAV communication over cellular networks

M-sequences are used for sequence design in OFDM-based systems such as LTE and 5G NR system. Since this paper is also based on OFDM-based cellular system, an M-SS is generated in the same way as the NR-PSS in the transmitter side. An m-sequence of length N is generated at the BS and allocated to N subcarriers in the frequency domain. The CID corresponding to the BS is mapped to the cyclic shift of m-sequence in the frequency domain. Then, the time-domain sequence of length N, obtained by taking IDFT of the m-sequence, is transmitted from the BS as a preamble. However, in the proposed M-SS, the signal is received at the UAV with a different size of bandwidth depending on the channel condition. The bandwidth corresponding to subcarriers are used at the receiver to detect the signal. For signal detection, the receiver generates a frequency-domain reference signal by mapping the m-sequence of length L and padding zeros of size of (N - L) in the frequency domain. The time-domain reference signal is obtained by taking an N-point IDFT of the frequency-domain reference signal. The CID and timing instant are detected by correlating the received signal of length N with the time-domain reference signal of length N.

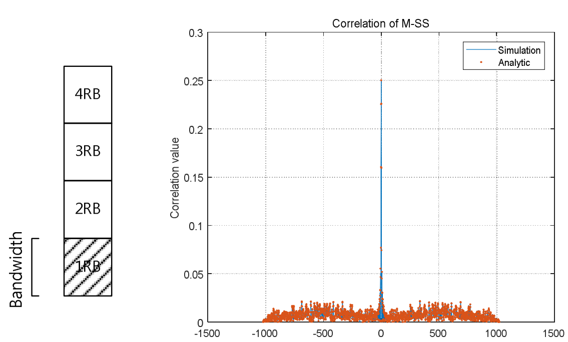

Fig. 2 Autocorrelation property of M-SS ($L=N/4$)

Fig. 2 shows an example of autocorrelation property of M-SS when $L \approx N/4$. The bandwidth used in the receiver side is marked with diagonal lines. It can be also seen that peaks always exist at the correct timing. The peak value decreases with the size of bandwidth (resource block: RB).

III. Conclusion

In this paper, we proposed a new preamble design technique for UAV communication over cellular networks to efficiently use battery power of UAV. It is shown that the proposed M-SS enable the UAV to correctly detect the CID and timing instant with different bandwidth depending on the channel condition. The M-SS provides the highest detection probability when there is no Doppler shift.

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