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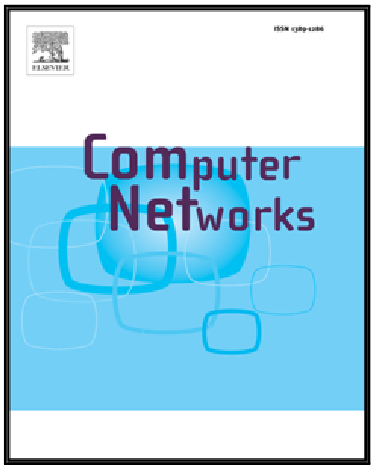

3-ent (Resilient, Intelligent, and Efficient) Medium Access Control for Full-Duplex, Jamming-Aware, Directional Airborne Networks

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3-*ent* (Resili*ent*, Intellig*ent*, and Effici*ent*) Medium Access Control for Full-Duplex, Jamming-Aware, Directional Airborne Networks

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***Abstract*—In this research, we target the MAC design issues in the airborne network with the following features: (1) *Long-distance Ku-band links*, In airborne networks, Ku-band (15GHz) is often is used in long-distance links ($> 10km$). Such a frequency is weaker to line-of-sight (LoS) blocking than 2.4GHz Wi-Fi signals, but with much better signal directionality. The nodes need to coordinate closely for detour communications since LoS path can be easily blocked. (2) *Multi-beam antennas*: All beams of an antenna can be set to sending or receiving mode. But at a particular time we cannot make some beams in sending and others in receiving mode. This feature requires all neighboring nodes coordinate with each other to get ready for simultaneous reception or transmission. Otherwise, the beam bandwidth is wasted. (3) *Full-duplex communications*: With the rapid progress of signal cancelation, full-duplex becomes a reality. This means that each node can simultaneously send or receive data. Our MAC design has 3-*ent* properties, i.e., it is *resilient*, *efficient*, and *intelligent*. Particularly, it is *resilient* to jamming attacks through the encoding of traffic in each beam. And it achieves throughput-*efficient* communications through the integration of full duplex traffic control and multi-beam data forwarding. Finally, it has *intelligent* beam traffic profile prediction via machine learning algorithms, and thus each beam can better prepare for next-step communications based on the prediction of traffic amount and neighbor movement. The 3-ent MAC protocol can be used for airborne/UAV networks or other long-link wireless networks.**

***Index Terms*—Airborne Networks, MAC, Full Duplex, Jamming, Ku-band, Multi-Beam Antennas**

I. Introduction

With the release of Ku-band (15GHz) for non-satellite systems, we can build a high-speed airborne network among flying objects (such as airplanes, UAVs, etc.). In this research, we aim to build a MAC scheme for the next-generation airborne networks (ANs) with the following 3 network conditions:

(1) *Long-distance Ku-band links*: Ku-band provides a much better signal directionality than Wi-Fi frequency (2.4GHz) [1]. Although it cannot achieve the wire-like signal propagation, it can well limit all signal energy within a small angle. This means that by using a narrow-beam directional antenna, we can maintain signal quality for a long distance (>1km) since the signal power does not diffuse in a wide angle. Higher frequency also means higher data rate. Today, we can use around 1GHz of bandwidth in the central Ku-band for uplink/downlink communications [2]. However, higher frequency also means shorter wavelength, and thus Ku-band signal is weaker to line-of-sight (LoS) blocking since a signal typically can only travel across an obstacle with the size similar to its wavelength. Therefore, a node needs to coordinate with all of its neighbors closely in case that it needs to find a detour path when the LoS path is blocked. This research will use detour beam and rateless codes to overcome single-path blocking issue.

(2) *Multi-beam antennas*: As mentioned above, by integrating with directional antennas, a Ku-band signal can propagate for a long distance. Multi-beam smart antenna (MBSA) has much less manufacturing cost and complexity than MIMO antennas, since it just simply extends general directional antenna from a single beam to multiple beams. Thus a node can dispatch different packets in multiple beams *concurrently*. The reason of using concurrent Tx (transmission) or Rx (reception) is because the all beams are involved in the same coefficient vector calculations [3]. One beam's side lobe can seriously leak energy to another beam's main lobe if those two beams operate in different modes (i.e., one in Rx and the other in Tx). The concurrent Tx/Rx rule requires all neighboring nodes to be synchronized well.

(3) *Full-duplex communications*: Most of existing wireless products only support half-duplex communications, that is, a node can be in either Tx or Rx mode (but not in both). But full-duplex (FD) [4] allows a node to send out data in one set of antennas while simultaneously receive data in another set.

Although the above 3 features can enhance the network throughput, it also brings many challenges to the MAC design. For example, in Ku-band networks, the interference is not the major concern. But all neighbors need a distributed coordination scheme to maintain detour links. Although a MBSA can theoretically enlarge the link capacity for N times (N is the number of beams), it needs a beam-based distributed coordination function (DCF) as well as accurate clock synchronization scheme. The FD links need a MAC to deal with simultaneous DATA/ACK scheduling after RTS/CTS exchange.

Motivations of this work: Our work is motivated by the obvious drawbacks in conventional MAC designs when applied in multi-beam mesh networks. most conventional MAC schemes use carrier sense multiple access (CSMA) based random access scheme (such as IEEE 802.11 standards), which may be effective in Wi-Fi with omni-directional antennas. However, it can seriously degrade the throughput in multi-beam transmissions because it is extremely difficult to coordinate the queue management in different beams.

Our MAC design has the following 3-ent (*efficient*, *resilient*, and *intelligent*) features (Fig.1):