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MANET, Adaptive Routing and Cognitive Radio for UAV Networks in Contested Environments

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As military forces increasingly rely on remotely deployed, unmanned vehicles, the need for robust, secure, and reliable wireless communication becomes more vital than ever. Interference from dense urban environments and a congested radio frequency (RF) spectrum can lead to reduced operating range and loss of important reconnaissance data. Electronic warfare measures deployed by an enemy force can result in the complete loss of an unmanned aerial vehicle (UAV) and sensitive, technological, and intellectual property. In this report, various methods to combat the negative effects of RF congestion and electronic warfare are investigated. Ad-hoc networks, adaptive routing, and cognitive radio techniques can extend the operating range of a UAV, avoid harmful RF interference, and deploy instantaneously around the world. This report finds that each of these techniques is available in many tested and deployed radio products and can be integrated quickly into airborne or ground-based networks.

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ABSTRACT

As military forces increasingly rely on remotely deployed, unmanned vehicles, the need for robust, secure, and reliable wireless communication becomes more vital than ever. Interference from dense urban environments and a congested radio frequency (RF) spectrum can lead to reduced operating range and loss of important reconnaissance data. Electronic warfare measures deployed by an enemy force can result in the complete loss of an unmanned aerial vehicle (UAV) and sensitive, technological, and intellectual property. In this report, various methods to combat the negative effects of RF congestion and electronic warfare are investigated. Ad-hoc networks, adaptive routing, and cognitive radio techniques can extend the operating range of a UAV, avoid harmful RF interference, and deploy instantaneously around the world. This report finds that each of these techniques is available in many tested and deployed radio products and can be integrated quickly into airborne or ground-based networks.

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1.0 TI Request

1.1 INQUIRY

How can unmanned aerial vehicle (UAV) networks operate in contested and uncontested environments?

1.2 DESCRIPTION

Unmanned vehicles are highly dependent on data and communication networks for command and control, vehicle status, data transfer, and a multitude of other functions. Disruptions to UAV networks range from annoyances, such as intermittent communication, to the loss of a UAV. The inquirer is also interested in mobile ad-hoc networks, adaptive routing, dynamic spectrum access, and cognitive radio and network technologies.

2.0 TI Response

2.1 DEFINITIONS

"Mobile Ad-Hoc Network," or MANET, refers to a decentralized wireless network infrastructure comprised of multiple routing nodes (radios) [1].

"Adaptive Routing" and "Self-Forming/Self-Healing" refer to the capability of the network to dynamically choose the best nodes through which to send traffic based on current environmental conditions, traffic priority (QoS), and network state [2].

"Cognitive Radio" specifically refers to the ability of a MANET to sense which radio frequency (RF) channel is best for network transmission. The MANET will then use a technique known as "Dynamic Spectrum Access" (DSA) to dynamically access the unused RF spectrum or band [3]. Dynamic/adaptive waveforms are not assessed.

"Link Quality" refers generically to all metrics of communication link quality, including, but not limited to, signal-to-noise ratio, bit error rate, received signal strength indicator, etc.

2.2 MANETS

As a decentralized system, the MANET can be deployed without the need for a large central base station or access to existing wireless infrastructure. The MANET is completely mobile and self-contained; only two nodes are required to establish a baseline communication path (Figure 1). This flexibility allows MANET infrastructure to be deployed instantaneously wherever the situation demands.

Figure 1: Basic MANET *(Source: Chris Leon).*

The number of nodes in a MANET is dynamic—a UAV can begin its flight far from any other radio node. As a UAV travels during its mission, it may come within range of an arbitrary number of radio nodes, mounted to unmanned ground vehicles (UGVs) or body-worn soldier radios, that become part of the MANET. This ad-hoc process enables network capabilities to expand to mission needs, protecting the UAV from intentional disruptions, such as jamming and congestion, or environmental disruptions in the form multipath fading and weather interference [4, 5].

Additionally, as a UAV enters its mission theater, a MANET connection with other UAVs or ground-based nodes can greatly increase situational awareness for all MANET nodes. Nearby UGV platforms and other ground-based units can share information with the UAV operator in real time to, for example, avoid areas experiencing active electronic warfare that may compromise the mission [6].

Commercially available MANET radio systems are abundant, and the technology has become mainstream [7–9]. Offerings from Persistent Systems scale the MANET to allow nodes well outside the line-of-sight to communicate: "The network gets stronger with each additional node, thus creating more line-of-sight (LOS) data paths and heightening network efficiency. Users that would not be able to "see" each other can now connect and distribute situational awareness data without packet loss" [8]. These systems also employ state-of-the-art adaptive routing, self-healing, and dynamic spectrum allotment to achieve maximal uptime of the MANET.

2.3 ADAPTIVE ROUTING, SELF-HEALING, AND SELF-FORMING

MANET systems must expand, contract, and reroute traffic on demand. When choosing the optimal path for traffic flow, the MANET will employ some form of adaptive routing. While the specifics of these techniques vary greatly, each solution attempts to maximize data throughput while minimizing latency and power consumption [10].

Adaptive routing is critical to maintaining constant communication with a deployed UAV as it moves down range. An adaptive MANET can take advantage of nodes with higher link quality and free bandwidth to route high-definition video and other data in a more efficient manner. QoS can also be implemented with adaptive routing to ensure that critical control and system status information is prioritized over other MANET traffic. Many adaptive routing protocols exist, and an intelligent MANET will use the method best suited for the environment [11].

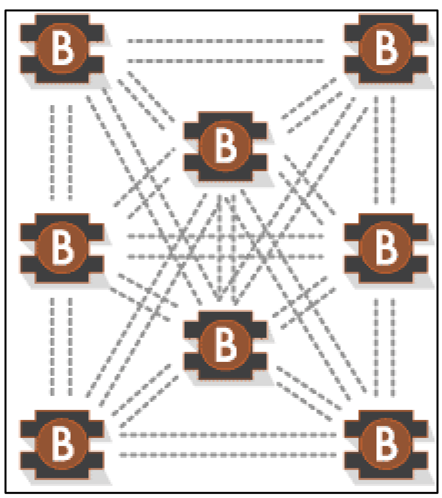

Figure 2: Adaptive Routing – Mesh [12].

As new nodes drop in and out of range with the MANET, they are seamlessly added (self-forming) or subtracted (self-healing) from the network. Adaptive routing protocols will automatically place these nodes in the routing tables and join them to the network where needed. This dynamic capability is one of the defining features of a MANET and the core technique enabling the ad-hoc nature of the network. Nodes under direct attack or those which have otherwise been compromised can be easily bypassed without disrupting UAV operations.

Commercial radios such as the Silvus Streamcaster will "optimally configure its transmission parameters (constellation, FEC coding, and MIMO techniques) to maximize the data rate and robustness of the links to each of the other radios it is communicating with [2, 9]." These commercial-off-the-shelf solutions provide adaptive MANET solutions in mature product offerings from multiple vendors for UAV, UGV, and body-worn applications.

2.4 COGNITIVE RADIO AND DYNAMIC SPECTRUM ACCESS

Whereas adaptive routing and self-healing work to determine "where" the traffic in a MANET is routed, cognitive radio and DSA techniques can be considered the "how" of MANET operation. In a world that has ever-increasing congestion of wireless spectrum, a cognitive radio can "recognize spectrum availability and reconfigure itself for much more efficient communications and spectrum use" [13].

A UAV can no longer be expected to perform in an environment where its radio or MANET is the only wireless network in operation. Interference can come from high-power radio signals in urban environments, other friendly MANETs in the same band as the UAV, or antagonistic electronic countermeasures (jamming/spoofing).

As shown in Figure 3, a cognitive radio can detect when the RF channel is becoming compromised by some external interference [14]. When this interference is detected, a network-level determination is made to choose a new baseline frequency using Dynamic Spectrum Access. The MANET will continuously monitor RF traffic on each allowable band, and each node will change its operating frequency to a "clean" channel.

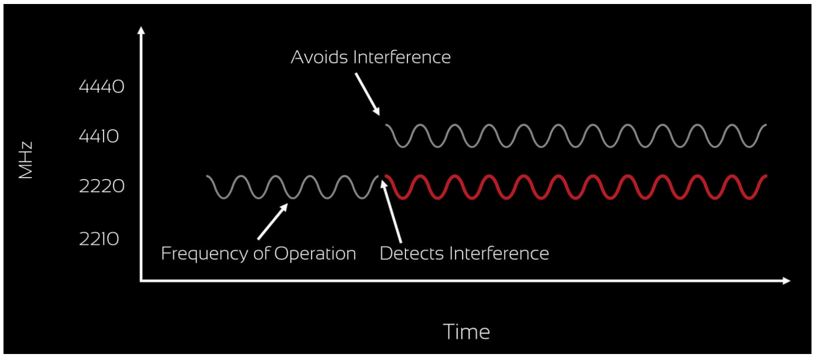

Figure 3: Interference Detection and Avoidance [14].

Cognitive radio demo applications are widely available, but mature OEM products with out-of-the-box capabilities are not as widespread as their Adaptive Routing counterparts [14–16]. Ettus and Silvus radios, for example, employ out-of-the-box DSA capabilities that can be deployed in body-worn, UGV, or UAV solutions [9, 15].

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BIOGRAPHY

Mr. Leon graduated from Rensselaer Polytechnic Institute in 2008 with a B.S. in Electrical Engineering. In the Spring of 2008 he joined Micronetics, based in Hudson, NH, where he designed various radar and RF communications components for ground and aerospace systems. His background is in high frequency design from S to Ku bands and joined the QinetiQ Maritime group to assist in development of the wireless LineWatch communication systems. Since joining QinetiQ in 2013, he has designed motor controllers, high power laser drivers, handheld C-Band RF radios and high-speed CPU assemblies for use in UGVs, underwater communications and mesh network applications.