UNLICENSED TECHNOLOGY ASSESSMENT FOR UAS COMMUNICATIONS

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Abstract

Effective Remote Identification of unmanned aircraft is critical to their integration into civil airspaces. This paper assesses the ability of proposed unlicensed technologies (Bluetooth and WiFi) to support Remote Identification, and also creates a framework for modeling communication performance for unmanned aircraft, both at scale. Through simulation, we show that most currently commercially available Bluetooth and WiFi implementations would require significant ground antenna support in order to be able to avoid saturation situations at even low demand rates. We also show the flexibility of the simulation framework to study regional coverage and the effect of tuning different parameters on performance.

Introduction

Communications, Navigation and Surveillance (CNS) are cornerstones of air traffic management today, and will become increasingly important for autonomous flight. CNS technologies are enablers for Unmanned Aircraft System (UAS) Traffic Management (UTM), and the new types of operations supported by UTM, such as drone package delivery. One such CNS technology enabler is the ability to remotely identify and track autonomous vehicles in a way that is expected to complement traditional technologies for manned aircraft, like ADS-B.

One of the first proposed solutions to the remote identification problem is the ASTM Remote Identification standard, which proposes a UAS identification methodology based on technologies that are widespread and readily available today: Bluetooth and WiFi. However, questions remain about the performance of these technologies for UAS applications, especially at scale, given their range and bandwidth characteristics. In this work, we use simulation to examine the bandwidth and saturation limitations of these technologies in package delivery operations at scale.

Based on forecast demand [1], UAS package delivery is likely to be one of the first big users of UTM services. It is a UTM use case that will require substantial CNS resources, and therefore provides a useful case study for evaluating CNS requirements at scale.

A critical piece in understanding the feasibility of a CNS technology lies in evaluating its ability to support the system that uses it. For Remote ID, that system is UTM, which can be further divided into subcomponents. Those subcomponents consist of the vehicles that are in the system that must be identified remotely, and the ground infrastructure that supports the identification process. For a unique choice of technology, these subcomponents create a single communication link. In this work, we analyze the susceptibility of that communication link to saturation. Specifically, we combine a simulated UTM traffic model with a variety of RF (Radio Frequency) models to determine the saturation sensitivities of a Remote ID technology. Because Remote ID is inherently a broadcast mechanism, we are evaluating the saturation sensitivities of the infrastructure on the ground to support identification broadcasts for traffic models of varying density.

The remainder of the paper is organized as follows. Background on UTM, the importance of remote identification, and related work are provided in the next section. This is followed by objectives for this work and the approach used for analyzing Remote ID Technology. Simulation results are then presented, followed by conclusions and future work.

Background

UAS Traffic Management

With increasing numbers of applications and business opportunities, including drone package delivery; inspection services and general hobbyists, the number of UAS is expected to dramatically increase in the coming years. Existing approaches to air traffic management (ATM) will not scale to handle this influx of traffic [2]—[5]. UTM concepts are under development to manage this traffic safely and efficiently, without significant burden on existing ATM systems. Concepts are proposed by NASA [6], the Federal Aviation Administration (FAA) [7], the Single European Sky ATM Research Joint Undertaking (SESAR JU) [8]—[9], and others around the world [10]—[11]. Most UTM ConOps are based on service-oriented, decentralized — or federated — architectures [6]—[7]. UAS Service Suppliers (USSs) - called UAS Service Providers (USPs) in Europe - provide services to UAS operators and other authorized entities. One such service is Remote Identification.

Need for UAS Remote Identification

One of the first principles of safely integrating UAS into national airspace systems is the ability to remotely identify the vehicles from the ground. It serves multiple functions: to ensure public safety and the safety and efficiency of the airspace; to facilitate more advanced operational capabilities such as detect-and-avoid; to support aircraft-to-aircraft communication; to enable beyond visual line of sight operations; and to develop the necessary elements for comprehensive UTM [12].

ADS-B (Automatic Dependent Surveillance - Broadcast) is used today to identify manned vehicles, and there is a mandate for its use in the United States for all manned aircraft in Class A, B, C, and special cases of Class E airspaces [13] in order to increase situational awareness in those airspaces. However, there are issues with using ADS-B for UAS identification, including spectrum saturation, identification number, and security limitations [14]. The FAA is concerned that ADS-B frequencies will be saturated by the large number of new Unmanned Aircraft (UA) entering the airspace, "affecting ADS-B capabilities for manned aircraft, and potentially blinding ADS-B ground receivers", and is therefore prohibiting the use of ADS-B for Remote ID [12].

Due to the expected limitations of ADS-B, regulators and industry have worked to design similar systems for UA identification, generally known as Remote Identification, or Remote ID. In 2017, the FAA brought together an Aviation Rulemaking Committee (ARC) to study the issue of Remote ID. Industry also spearheaded work through the ASTM International standards body on a Remote Identification standard which has now been published [15]. Additionally, the FAA developed their Notice for Proposed Rulemaking (NPRM) for Remote Identification - their proposed UAS Remote Identification laws [12]. For consistency throughout the paper, we will be using the ASTM and FAA terminology.

Common to all three of these efforts (the ARC, ASTM's standard, and the FAA NPRM) are two principal mechanisms that UAS can report Remote Identification information, illustrated in Figure 1:

1. Networking through the internet (Figure 1a), and
2. Broadcasting directly from the UA (Figure 1b).

The ARC, ASTM, and FAA documents prescribe different requirements for how these mechanisms are used, but the pros and cons of each approach are beyond the scope of this paper. Non-equipped network participants are also out of the scope of this paper.

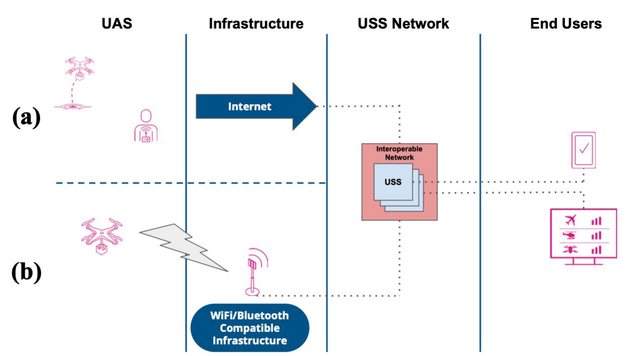


Figure 1: Remote Identification architecture, (a) Networked, and (b) Broadcast

Networked Remote Identification assumes a UAS has connection to the internet, and is able to transmit its Remote Identification message elements through the internet to a USS, which provides a Remote ID service. This Remote ID USS will then share the information with other USSs and other authorized entities, such as the FAA.

Broadcast Remote Identification allows the UA to directly broadcast its Remote Identification message elements. This is identified to be necessary in areas where network coverage is unreliable, disrupted, or not available [15], and could also be leveraged for more advanced capabilities in the future [12]. The ASTM Remote Identification standard proposes a broadcast mechanism that is compatible with commonly carried hand-held devices. While it is possible that additional transmit protocols may be added in the future as warranted by available technology, Bluetooth 4.x, 5.x and WiFi were chosen as the initial technologies in the first version of the standard [15]. These technologies are the focus of our study.

Related Work

CNS for UAS has been extensively studied, from the challenges [16] and considerations [14], to high level requirements for UAS CNS Architectures [17] and UTM. While a good basis for this work — covering a comprehensive review of UAS classifications and their effects on CNS architecture and requirements, [14], [16] and [17] do not include mention of UAS Remote Identification, as it was likely not a fully formed concept at the time of writing. UAS Remote Identification, while in development for several years, is still a relatively new research topic. NASA outlined Remote ID flow diagrams, and set up test scenarios to collect initial data of the retrieval time of UAS remote identification, however it does not fully analyze the bandwidth or saturation characteristics of Bluetooth or WiFi [18]. Experiments were conducted with a specific implementation of LoRaWAN (Long Range low-power Wide-Area Network) [19], a technology that is not currently specified in the ASTM Remote ID standard. Arguments have been made for utilizing current unlicensed command and control (C2) links such as Bluetooth and WiFi [20], but a quantitative analysis of these technologies has not been published, and this work aims to provide one method for such analysis.

Evaluating Remote ID technologies

The performance of communications technology can be generally measured by the bandwidth available, its range, and the degree to which this bandwidth is saturated for the chosen use case (as well as latency and reliability, which are out of scope of this paper). Many factors impact or are impacted by these performance metrics. These include the type of operational use case; the hardware size, weight, and power requirements; the hardware cost; the security of the system; and the readiness of the technology.

Particular UAS use cases will drive requirements of Remote Identification technologies, as it will likely affect the size of the UA, its power consumption capabilities, need for technical readiness and availability, and the amount of bandwidth required.

For aerial vehicles, SWaP-c (size, weight, and power, cost) are important metrics to consider for any hardware installation, as all of these factors are constrained. As the vehicle gets smaller, these factors generally become further constrained. Communication system performance can be directly related to these factors (i.e., greater range and bandwidth is usually associated with higher SWAP-c), but they are not in scope of this paper.

The performance of technologies examined in this work - Bluetooth and WiFi - can be tailored to the needs of the use case, which affects the SWAP-c, technical readiness and availability. For example, increasing the power output to increase communications performance will increase power consumption requirements and correspondingly, the size and weight of the communication hardware and UA. Similarly, increasing the antenna gains on the UA to increase range and bandwidth performance will also affect vehicle size and weight directly, which may indirectly affect power consumption necessary to complete a mission. All of these factors must be assessed in order to make a complete evaluation of a given Remote Identification technology for a specific use case.

In addition to SWAP-c, a security risk assessment should be performed when evaluating not only Remote ID technologies, but all technologies in the UTM and aviation ecosystems. Different technologies and implementations have different security implications, which should be assessed against factors such as those included in the (United States) Federal Information Processing Standard (FIPS) 199: confidentiality, integrity, and availability [21]. For Remote ID, all three of these factors become increasingly important as the use of the data becomes more critical. In the short term, it is expected that confidentiality would be important, as the Remote ID messages are meant to include identifying information (though care will be taken that Personally Identifying Information, or PII, will be protected). Differences exist between unlicensed technologies such as Bluetooth and WiFi and licensed technologies, especially when it comes to the three factors of confidentiality, integrity, and availability, so it is important that this is taken into account when assessing potential technologies for Remote ID solutions.

In this work, we assess the RF performance of Bluetooth and WiFi in dense airspace, which can be improved by a variety of methods that affect the above metrics, but we do not assess them directly in this paper.

Objectives

The objective of this paper is to take steps towards quantifying current proposed unlicensed technologies, particularly Bluetooth and WiFi, for Remote Identification of UAS at scale with static broadcast receivers on the ground. For the purposes of the paper, this is done by estimating communication link bandwidth, and quantifying communication link saturation at different UAS traffic densities. A comprehensive evaluation of Remote ID technologies requires analyzing a number of aforementioned factors, but this is left for future work. Specifically, the paper examines the saturation characteristics of Bluetooth and WiFi for UAS.

Approach

Simulation is used to quantify Bluetooth and WiFi technology performance for UAS operations at scale. The approach used to model the saturation of the communication link is described in the subsection below. This is followed by a description of the simulation environment and operational traffic scenarios simulated. The modeling of the required transmitting antenna performance, in terms of available bandwidth, is described in the final subsection.

A. Communication Link Saturation

We define saturation of a Remote ID communications link as a state in which the identification information broadcast by a vehicle can no longer be received by the infrastructure on the ground due to the high density of other broadcasters in the vicinity. In other words, the bandwidth of the antenna(s) that covers the area of interest is exceeded due to high traffic density. There are four primary factors that are critical to determining saturation:

1. The geographic distribution and characteristics of ground antennas
2. On-board antenna characteristics
3. Vehicle densities and traffic patterns in the airspace
4. Payload size of Remote ID messages

In this work, we analyze the saturation sensitivities with respect to each of the factors above.

To determine if a vehicle is in a saturated state, we consider if the available bandwidth in the location of the vehicle meets the demands of all the UAS in that location. If the traffic demand exceeds the available bandwidth, the vehicle is considered saturated. For simplicity, we discretize the region and represent the traffic density using a set of 3-D voxels. We use simulated UTM traffic (Section B) to overlay a time-dependent vehicle occupancy onto the voxel set. For each time-step in the simulation, each voxel contains a vehicle count. We can combine the vehicle count in each voxel with the size of the Remote ID payload to determine the required bandwidth needed to support the vehicles in that voxel at the time of interest. The available bandwidth in each voxel can be computed using the RF models in Section C. In this work, we use a voxel size of ~140m horizontally and 100m vertically. Time is discretized in one second intervals.

B. Simulation of UTM Operations

Flight requests are generated using a stochastic demand generation process. To model the vehicles in the simulation, we use a simple point-particle dynamic model with a hybrid proportional-integral-derivative (PID) and logic control for guidance. While the simulated vehicles have onboard sensing and conflict resolution capabilities, we do not use them in this work.

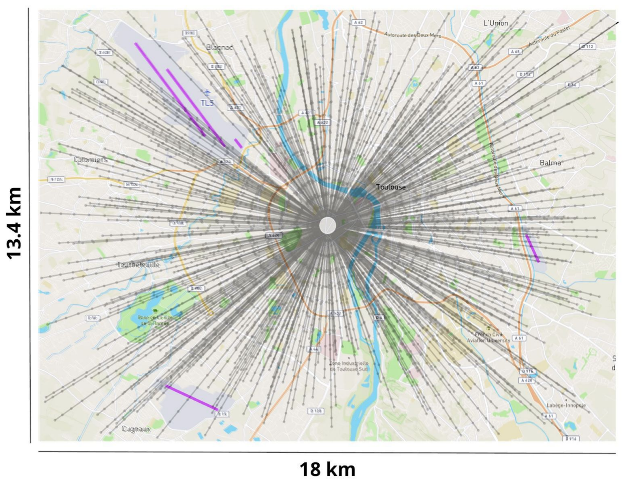


Figure 2. Simulation region of interest with a warehouse at the center, and vehicle trajectories over a two hour simulation

The simulated UTM traffic scenario represents a single-operator performing package delivery to a region surrounding its warehouse, as shown in Figure 2. All flights originate at the warehouse, in the center of the region. The delivery sites (flight destinations) are randomly distributed across the specified region according to a Gaussian distribution with the standard deviation forming a circle with radius of 6km around the warehouse. Each flight segment follows a straight path from origin to destination, with climb and descent to and from the cruise altitude at the origin and destination, respectively. For simplicity, the return flight segments, from the delivery site to the warehouse, are not simulated. These studies were performed over an area representative of a medium-sized urban region, which spans 13.4 km by 18 km, or 214.2 km^2. Other simulation parameters are described in Table 1.

Table 1. Traffic parameter values

Parameter	*Value*
Origin type	Point source fulfillment center
Operation type	Point-to-Point small UAS Package Delivery
Average hourly demand	[25; 50; 100; 250; 500; 1000] flts/hr
Cruise altitude	150 m
Cruise Speed	20 ms^{-1}

This work models a uni-modal urban region, with demand highest in the areas surrounding the warehouse and decreasing radially away from the regional center. The simulated aircraft trajectories couple the vehicle dynamics and the operator demand model described above. This allows us to capture emergent behavior of package delivery traffic in a realistic way.

C. RF Models

A general model was taken from the literature [22, 23] to describe Bluetooth and WiFi transmitters. This model can be tailored by changing several parameters including: frequency of operation (in GHz); Signal-to-Noise Ratio (SNR) to data rate; percent time availability of the system; and Effective Isotropic Radiated Power (EIRP). Each is described below.

Typical frequencies of operation for WiFi are 2.4 Ghz or 5.0 GHz, among others, while Bluetooth operates at 2.45 GHz. In this paper, we assume the frequency of operation for WiFi to be 2.4 GHz. This is consistent with the ASTM Standard’s recommendation of the 2.4 GHz band to allow for operation of Neighbor-Awareness-Networking [15].

SNR-to-data-rate is a hardware-specific table that converts the available SNR to the data rate that the hardware's protocol can support with the given

SNR. The tables generally exist in the specification documentation of a particular antenna and convert SNR in decibels (dB) to supportable data rate in Mbps (Megabits per second). In this work, we used the 802.11 SNR-to-data-rate tables listed in [24].

The desired time availability percentage of a communications system can be tuned by changing the amount of link margin to account for fading due to multipath, which is the phenomenon where receivers receive radio signals from two or more paths. This phenomenon occurs whenever radio signals reflect off of surfaces and creates another path for the Radio Frequency signals in addition to the direct radio-line-of-sight (RLOS). Multipath is common in urban areas, and must be accounted for when modeling RF signals. Choosing a higher time availability percentage results in setting a higher fade margin in the model, thus resulting in a lower SNR and diminished data rate. To establish upper bound results, a desired time availability percentage of 99% was chosen. It is reasonable to assume higher availability percentages would be desired, in which case all of the results would result in much worse performance, factoring in 10 dB of fade margin for every extra magnitude of availability [23].

EIRP, also known as Equivalent Isotropically Radiated Power, is the sum of gains and losses relative to an ideal (theoretical) isotropic (uniformly radiating) antenna in a transmitting system when expressed logarithmically. EIRP (in dBm) can be expressed:

$$EIRP = P_T + G_T - L_C \qquad (1)$$

where P_T is the transmitter output power in dBm (decibels relative to a milliwatt), G_T is the transmitter antenna gain in decibels relative to an isotropic antenna (dBi), and L_C is the signal attenuation in the connecting cable between the transmitter and antenna, in dB[3] [22].

The available bandwidth was calculated for each three-dimensional block, or voxel, in the scenario by performing a link budget. A link budget in its simplest form, adds the RF power gains and losses between a transmitter and receiver in order to determine the RF power received at the receiver, as expressed below:

$$RX\ Power = EIRP_{TX} + Gains\ -\ Losses \qquad (2)$$

where *RX Power* is the received power in dBm; $EIRP_{TX}$ is the EIRP of the transmitter as defined above, including the transmitter output, transmitter antenna gain, and any cable losses; *Gains* are any remaining gains in the system, generally the receiver antenna gain,; and *Losses* are all losses in the system, including receiver cable loss, free-space path loss, fading due to multipath, etc.

Receivers are designed to be able to decode messages down to a specified RF power level specific to its hardware, known as the receiver sensitivity. The difference between the received power and the receiver sensitivity is the link margin.

The link margin is only representative of the difference in received power, and does not include the noise in the signal. Noise is incorporated into the link analysis with Signal-to-Noise Ratio, or SNR, which in logarithmic terms, is expressed as

$$SNR = RX\ Power\ -\ Channel\ Noise \qquad (3)$$

where *RX Power* is defined in (2) and *Channel Noise* is the summation of unwanted or disturbing energy introduced into a communications system from man-made and natural sources [25].

After calculating the SNR, we used the SNR-to-data-rate tables in [24] to determine the supportable bandwidths in a given voxel. As a first phase of this study, we studied static ground receivers, and chose two ground antenna configurations that could resemble possible scenarios:

1. Many currently available mobile phone receivers in a grid configuration to synthetically simulate many ground users, and
2. A set of antennas centered near the warehouse to optimize coverage near the warehouse.

In order to generalize, the EIRP of the vehicle transmitter systems was varied in order to reduce the dependency of results on specific hardware choices of transmitters and antennas.

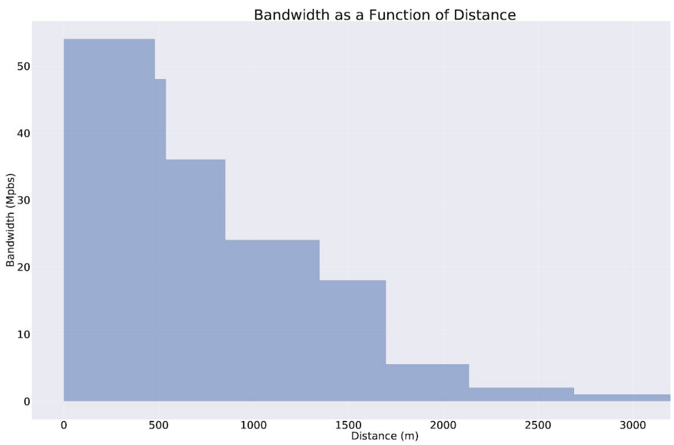


Figure 3. Bandwidth as a function of distance

For a given antenna configuration, available bandwidth was calculated as a function of distance from an antenna, as seen in Figure 3. These results are also overlaid on a map of a representative region, as seen in Figure 4(a) for the grid configuration, and Figure 4(b) for the cluster configuration. These provided the available bandwidth values used for analysis.

Simulation Results

Parameter settings across the simulation runs are presented in Table 2.

Table 2. Communication Parameters

Parameter		***Bluetooth***	***WiFi***
Ground Antenna Gain	*Low*	+12 dBi	+35 dBi
	High	+24 dBi	+49 dBi
Vehicle *Tx* *EIRP*	*Low*	+1 dBm	+11 dBm
	Medium	+5 dBm	+15 dBm
	High	+14 dBm	+19 dBm
Data Rate	*Low*	0.2 kbps	
	Medium	40 kbps	
	High	500 kbps	
Ground Antenna Config		Cluster, Grid	

Two ground antenna and three vehicle transmitter configurations were simulated for both Bluetooth and WiFi.

In order to examine the effect of traffic density and scale on the technology performance, results were generated for each antenna and vehicle configuration over different demand rates: 25; 50; 100; 250; 500; and 1000 flights per hour. A case study was also completed on coverage design, which follows the saturation results below.

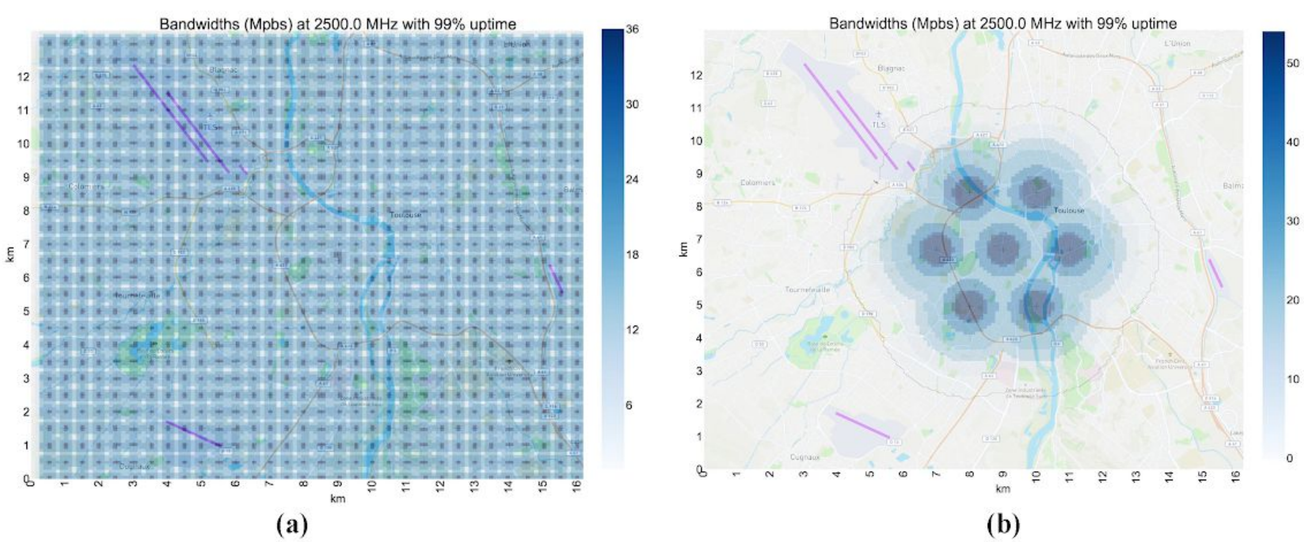


Figure 4. Available bandwidths for (a) a grid of low gain antennas spaced 500 m apart and (b) a few high gain antennas spaced 2 km apart centered, both around the warehouse.

Two different ground antenna configurations were simulated. In order to estimate upper performance bounds, for the first configuration we assume extremely optimistic, high-gain ground antennas, with a gain of +49 dBi for WiFi and +24 dBi for Bluetooth. In the second antenna configuration, we assume the use of more realistic lower gain ground antennas, with gain of +35 dBi and +12 dBi for WiFi and Bluetooth, respectively, based on readily available off-the-shelf hardware.

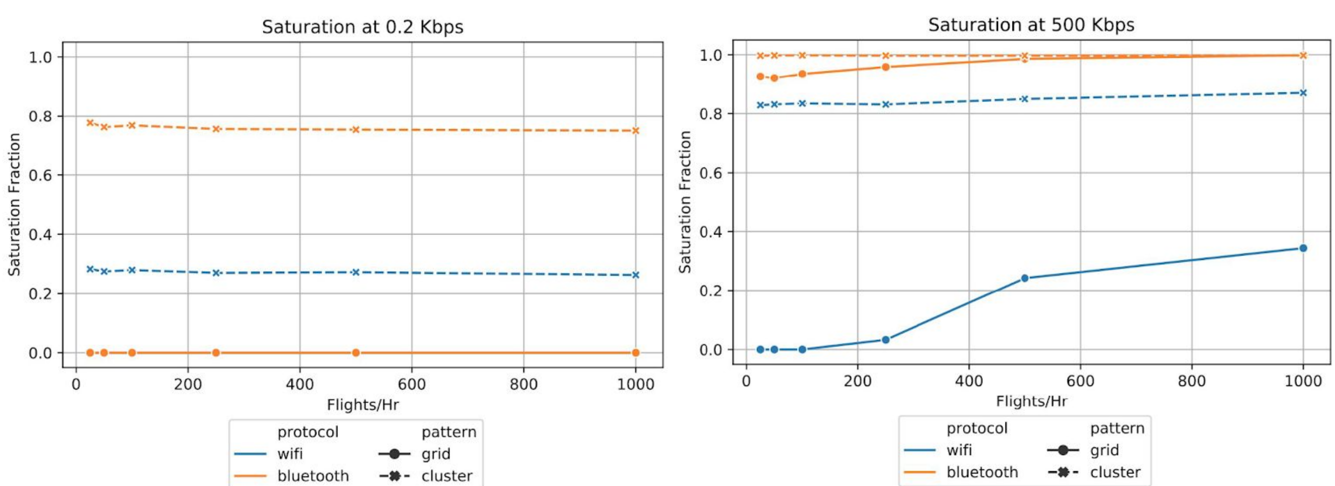
Since there is variability in hardware and antenna performance depending on antenna patterns and interactions with airframes, results are presented separately for the three vehicle EIRP values simulated - low, medium and high. The respective vehicle EIRPs were chosen based on the ASTM standard Broadcast Minimum EIRP values [15], as follows. For WiFi, the listed Type 1 United States Minimum Transmit EIRP in the horizontal plane (+15 dBm) was designated medium, while high and low EIRP were defined by increasing the medium EIRP by 4 dB to arrive at a high EIRP of +19 dBm, and decreasing it by 4 dB to arrive at a low EIRP of +11 dBm. For Bluetooth, mainstream market transmitters are generally +4 dBm conducted, but can be as high as +8 dBm conducted [26]. Antenna gain was assumed to vary between -3 dB and +6 dB. Therefore, for the lowest EIRP, the average +4 dBm was added to the worst case -3 dBi antenna gain to arrive at +1 dBm; and for the highest EIRP, the optimistic +8 dBm was added to the highest gain of +6 dBi to arrive at 14 dBm. The medium EIRP was defined by taking the optimistic +8 dBm and subtracting the worst case -3 dBi to arrive at +5 dBm, which is in the standard [15].

To examine the range of potential UAS communication bandwidths including Remote ID, we ran simulations at 0.2 kbps (suitable for identification), 40 kbps, and 500 kbps (suitable for supporting higher bandwidth transmissions).

A. Analysis of Remote ID Technologies

The key metric used in this work to quantify Remote ID technology performance is the saturation fraction, which is calculated by dividing the number of vehicles found to be in a saturated state by the number of vehicles in the air. Figure 5 shows plots of saturation fraction against traffic density (in terms of flights per hour) for each technology - Bluetooth and Wifi - in the two antenna scenario configurations simulated - a cluster and a grid - for the high vehicle EIRP. Figure 5(a) shows results of note for a low data rate of 0.2 kbps, with high vehicle EIRP and high ground antenna gain. Figure 5(b) shows results of note for a high data rate of 500 kbps, with the same vehicle EIRP and antenna gain.

For all configurations in the 0.2 kbps case (WiFi grid trendline is obscured by the Bluetooth grid



(a) **(b)**

Figure 5: Fraction of saturated vehicles vs flights/hr for (a) 0.2 kbps message payloads and (b) 500 kbps payloads

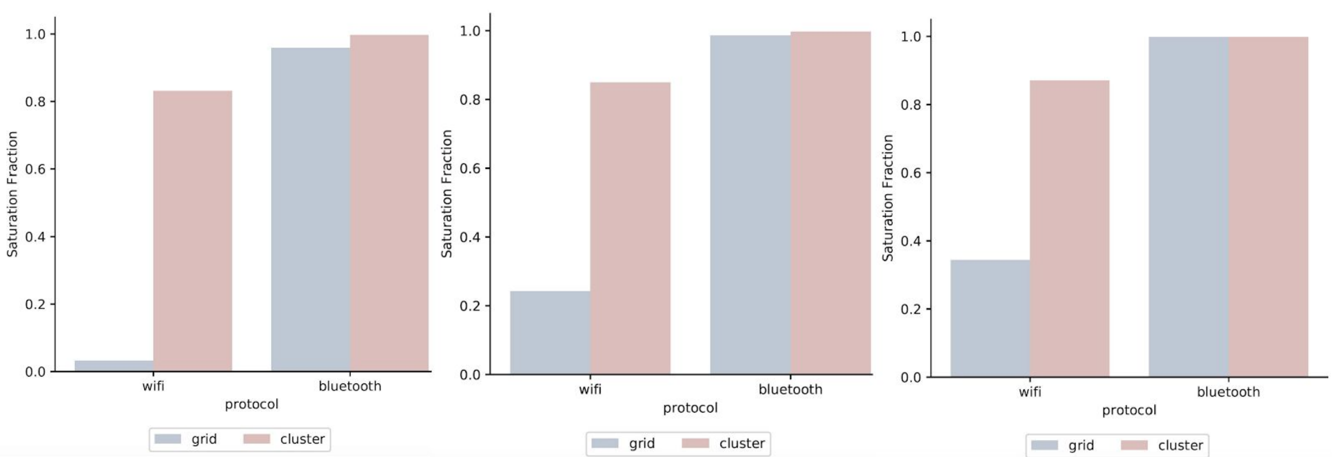
trendline), the saturation fractions remain the same across the traffic density rates, indicating traffic density does not affect the saturation fraction when data rates are low. Instead, as expected, configuration and technology type are the dominating factors. Only at 500 kbps does the traffic density begin to affect the result, as seen in Figure 5(b).

Figure 5(a) represents an upper bound for Bluetooth and WiFi performance for 0.2 kbps, or similar, to a Remote ID payload, since it represents the results of optimistically high vehicle EIRPs, and optimistically high ground antenna gains. In this optimistic case, grid configurations do not saturate for both Bluetooth and WiFi, as expected. However, the cluster configurations still have significant saturation fractions: between 28% and 37% for WiFi, and between 77% and 84% for Bluetooth, indicating that the cluster antenna coverage does not adequately support the trajectories of the vehicles. High gain grid configurations would be extremely costly and infrastructure-heavy to implement. This case is meant as an over-optimistic scenario to show an upper bound in performance.

For the 500 kbps case in Figure 5(b), the only configuration with less than 80% saturation is the WiFi grid configuration. This indicates that the other three configurations would not be suitable for reliable Remote ID support. The grid configurations are the most sensitive to traffic density increases. The WiFi grid saturation fraction is sensitive to the flight density rates, increasing to 24% saturation at 500 flights per hour, while the Bluetooth grid saturation fraction is not as sensitive, but does trend to 100% saturation at 500 flights per hour, indicating full saturation of the gridded antennas.

This phenomenon can also be examined in Figure 6, which more clearly shows which configurations can be supported and which cannot for different data rates and traffic densities. Only traffic densities of 250 flights per hour and above are shown, as the results below 250 flights per hour all show zero saturation fraction. This is because the dependency on traffic density is minimal below 250 flights per hour in the 500 kbps case. At 250 flights per hour, the WiFi grid has 3% of its vehicles in saturation, while at 500 flights per hour, the WiFi grid saturation increases 21% to 24%. At 1000 flights per hour, the increase in WiFi grid saturation begins to slow down, only increasing 10% to 34% saturation.

These results confirm the sensitivities of vehicle saturation to vehicle EIRP and ground antenna configuration (including gain and location), and reveal a moderate sensitivity to traffic density at high data rates and medium traffic density. The assumed ground WiFi antenna gain, even in the low case, is still relatively high and would result in an extremely directional antenna, yet for high vehicle EIRP, there are still up to 34% saturation fractions. Assuming



(a) (b) (c)

Figure 6. Fraction of saturated vehicles vs configuration for 500 kbps message payload at (a) 250 flights/hr (b) 500 flights/hr (c) and 1000 flights/hr.

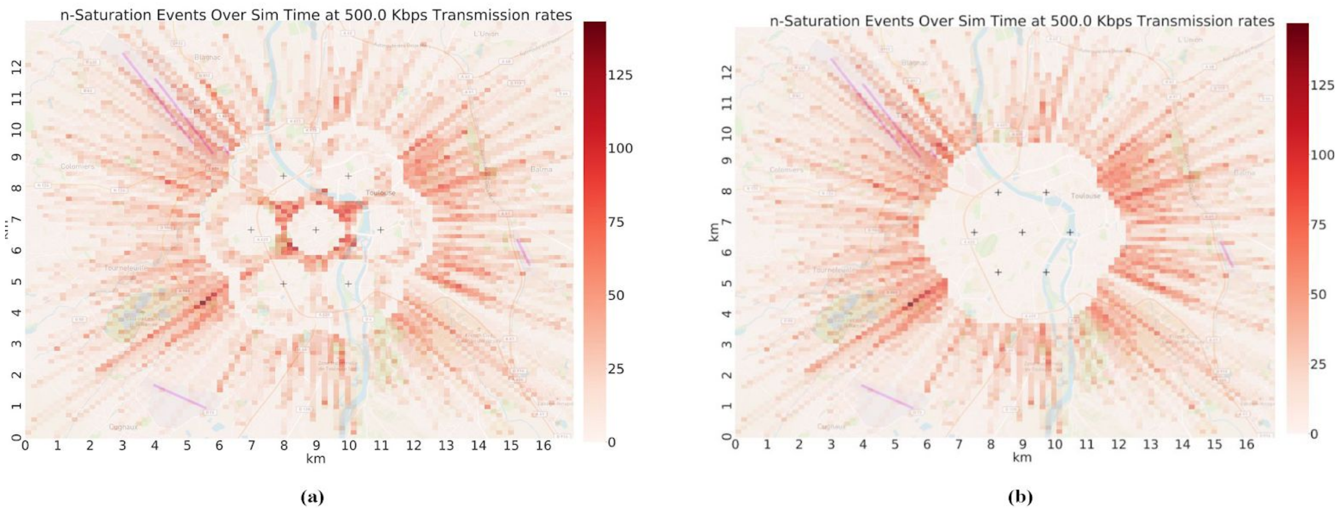


Figure 7. WiFi Cluster Case Study, 500 kbps, high vehicle EIRP, high gain ground antennas, (a) 2 km center-to-center, and (b) 1.5 km center-to-center

even a 20% tolerable saturation fraction, WiFi and Bluetooth would only be able to support vehicles in the grid configuration with high gain ground antennas, and would fare even worse in the cluster configuration.

The results also indicate that if interested parties were looking to build out specialized infrastructure to support the use of Bluetooth and WiFi, they would likely need to build out extensive infrastructure, provision for many ground antennas throughout an area, or suffer severe performance issues.

B. Case Study: Coverage Design

The methodology described in this paper, combining UTM simulations and RF models, can also be used as a design tool. It is flexible and easily configurable for a variety of parameters, including the EIRPs, gains, and data rates. In this section, we present results from a case study of coverage design for a UAS operational area at different data rates.

This framework can compute saturation events, in addition to visualizing them and their severity. Visualization can be a valuable tool in aiding the design of ground infrastructure by identifying hotspots that require optimization. For the WiFi configuration at 500 kbps with high vehicle EIRP and high gain ground antennas (see Table 2), saturation events exist between the antennas in the cluster. This can be easily observed visually in Figure 7(a), allowing areas with coverage needs to be identified. Based on the result shown in Figure 7(a), we moved the ground antenna positions closer together to examine the effect on coverage near the warehouse. Bringing the ground antenna positions 500 meters closer together, reducing the total antenna-to-antenna distance to 1.5 km, removed the areas between the antennas where the link was saturating, optimizing the coverage between antennas. This is shown in Figure 7(b).

The visual representation still shows further saturation events outside of the ground antenna cluster zone, and that could be further optimized by the addition of more antennas. This tool utilizes traffic simulation in order to be able to identify areas of concern or optimization, not only numerically, but also visually, as in Figure 7.

Conclusions

This paper explores the performance of Bluetooth and WiFi for UAS communications at scale, through different antenna configurations, EIRPs, and traffic densities. Since Bluetooth and WiFi are used today for UAS communications (though not exclusively), are specified for use in the ASTM Remote Identification standard [15], and concerns remain about their performance for their intended uses in

Remote ID, this paper studies its performance at scale.

In this paper, simulation is used to provide quantitative analysis of bandwidth saturation across the two technologies in different configurations, quantified by saturation fractions against traffic density.

For the simulated scenarios, results suggest that even with high gain antennas on both the ground and on the vehicle, there are still non-zero saturation fractions for both Bluetooth and WiFi cluster configurations even at 25 flights per hour, which is very low compared to expected demand. This provides an operational density limit for these configurations, depending on the saturation fractions regulators are willing to tolerate. This type of analysis can be instrumental in making decisions such as these.

For more realistic scenarios, such as the low and medium vehicle EIRPs, which are more representative of commercially available onboard hardware capability, saturation fractions range between 38% and 100% in some cases. These results should be considered in combination with singular link budgets that show range between single vehicles and ground antennas. The results presented in this paper suggest that, for certain ranges and traffic densities simulated, Bluetooth and WiFi will likely not be suitable, and other technologies should be considered.

When developing regulation for Remote Identification, regulators should consider the range over which they would like Broadcast Remote Identification messages to be received, as well as the traffic densities at which they would like to have reliable transmissions. The framework presented in this paper allows for analysis of both parameters, when configured appropriately.

The results therefore show that there will need to be complementary technologies beyond BlueTooth and WiFi for not only Remote Identification, but also for other UTM and UAM communications functions.

Future work includes developing further simulation capability and doing studies, including introducing uncertainty into the UA trajectories, simulating different vehicle traffic patterns, and simulating cellular networks to perform similar characterizations against simulated traffic patterns. If Bluetooth and WiFi are still technologies under consideration for Remote Identification or other UAS communication methods, future work would also include increasing the fidelity of the Bluetooth and WiFi models, especially exploring the nature of ground based interference on UA's, including the work done by MITRE in [27]; more details of the protocols; and a further refinement of transceiver and antenna characteristics and configurations.

There are also other factors beyond broadcast saturation and density characteristics that must be evaluated to inform Remote ID technology requirements, including operational use case; the hardware size, weight, and power requirements; the hardware cost; the security of the system; the readiness of the technology; and spectrum considerations. This will include more analysis, simulation, validation, testing, policy, and standards work, which is left for future work.

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