XG Aviation Security

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Abstract

The technological advancements brought on by 5G (and soon 6G) creates new possibilities in various fields of aviation. Air traffic communication, passenger services, UAV tracking, and aerial base stations are some fields of aviation that will potentially benefit from these technological advancements. Each mentioned field of aviation is examined in relation to 5G/6G in a pure literature study. Current states and challenges of each area, methods for overcoming these challenges, and an analysis of the proposed methods are provided. Finally a conclusion is made for the different areas. With 5G around the corner, the techniques it enables seem promising in regards to aviation. However, with most of these techniques, new security challenges emerge that need to be taken seriously.

1 Introduction

As the world is entering a new generation of wireless communications, plenty of new technical solutions are made possible in various fields. Around the corner is the paradigm shift to 5G which will improve wireless capabilities in different ways such as speed and also realize the full societal deployment of Internet of things. Further on, we can expect the deployment of 6G and with it even faster wireless speeds, more automation, and eventually many other revolutionary concepts not yet determined. Some of the things that 5G will bring are in theory possible to implement with current infrastructure but 5G makes it more realistically implementable.

The different technological areas in aviation can potentially see much needed improvements thanks to the progress being done in wireless communications. Aviation communication, for example between Air Traffic Control (ATC) and airplanes, is in much need of a fundamental revision. Airplane communication used today was not developed with security as one of its main concerns which have lead to noticeable security issues. Unwarranted access to these kinds of communication systems are easily obtained using an appropriate signal receiver within range of the targets. This means that these systems have serious vulnerabilities in terms of confidentiality that could possibly be mitigated using 5G/6G wireless encrypted communications.

Not only the communications have room for improvement but also the various services provided to commercial airline passengers. In-flight internet today is often expensive and low-bandwidth, resulting in a lackluster experience for passengers. With the use of new improved wireless capabilities one could potentially improve the speed and lower the costs of such connections.

Another challenge faced in the field of aviation is tracking the positions of UAVs in challenging areas. The conventional way of determining a UAV's position is by using satellite positioning (GNSS), which requires a clear unobstructed line of sight between the UAV and the satellite. In areas with tall buildings or other obstacles preventing the signal from reaching the UAV, alternative solutions for navigation must be considered. For example, the position of a UAV could be determined using narrow directed antenna beams in a wireless network.

In areas where the wireless communications infrastructure is unavailable or non-operational, it is a challenge to provide a connection to devices. Whether a plane is in a remote location or an area has had its infrastructure damaged, a way of establishing long-range communication to working infrastructure is required.

This survey intends to discuss the above mentioned areas of aviation and by so doing answer the following questions:

1. If possible, how will the technological breakthroughs in XG networks lead to the improvement of air traffic communication?
2. How can XG networks be used to improve passenger services and, if possible, realize new services such as real-time baggage tracking and improved in-flight internet?
3. How can XG networks be used to position UAVs in GNSS-challenged environments such as urban areas?
4. If it is possible, how can UAVs effectively act as base/relay stations in XG environments to provide internet access to remote locations such as disaster areas and planes?

The approach chosen in this survey is to make a literature study using only papers with 20 or more citations in order to ensure some form of trustworthiness. However, exceptions are made for especially new articles and papers where a high amount of citations is unrealistic to expect. In the first section of this report a more detailed description of the current states and challenges, for each of the four subareas defined by the questions above, will be presented. Then the different potentially suitable methods will be described for each subarea. These methods will then be evaluated and compared in the report's analysis. Finally a conclusion will be drawn based on the analysis made.

2 Background

This section explains both the current state of aviation communication and security as well as challenges and problems that occurs with it. It also gives some background about 5G in general.

2.1 3GPP and 5G

With 5G being in full development to take over 4G, it creates a variety of new possibilities within mobile networks. The 3rd Generation Partnership Project (3GPP), an organization that unites seven telecommunications standard development organizations, produces reports and specifications that define 3GPP technologies. These technologies covers cellular telecommunications and publishes new releases, each containing new standards within networks where release 15 and onwards is focusing on 5G. [1]

In June of 2018, 3GPP approved the first standard with Release 15 of the 5G networks. With the launch of Release 15 networking standards, 5G communications has been distributed to several countries and is still being distributed today to more and more. Release 15 focuses mainly on commercial requirements of broadband within enhanced mobile and provides basic requirements such as low-latency and multi-connection services. With 5G technology, if you have 100 MHz bandwidth, the peak rate of 10 Gbit/s can be achieved and is doubled if the bandwidth is doubled. This is more than 10 times faster than compared with 4G and has a network structure of network slicing. Network slicing being a network structure where you divide up the same geographic network into diverse segments that have different speeds and different security statuses.

In the end of 2019, Release 16, which also can be called as 5G phase 2, was approved and is now in full development. Release 16 and all the later versions planned will completely resolve problems such as massive connection and low latency. All together, 5G creates stronger privacy protection, security mechanisms and authentication mechanisms. It provides faster communication, lower latency and enables the availability of more connections. The fully completion of Release 16 will be finished in June of 2020 and it already exists plans for Release 17 that is expected to be delivered in 2021. [5]

So it can easily be said that 5G and the next generation is in constant development, and with the new improvements it brings, is surely opens up new possibilities within communication and networks in aviation that could solve the different problems that exists there today.

2.2 Current state and challenges

2.2.1 Aviation communications

Ever since man managed to build aircrafts that allowed humans to soar over the ground and reach the skies, the techniques in aviation grew rapidly. Today aviation is the main method in the modern world for civilian transport of long distances and shows no signs of slowing down with the world-wide flight movement being expected to be doubled by the year 2030 in comparison with the year 2017 [12].

With airplanes being able to transport hundreds of people through the skies concurrently with thousands other airplanes, communication is a key aspect in aviation for everything to go smoothly and make sure no unnecessary risks are taken. Because of this, numerous technical equipment are in use during the flights of aircrafts which can be seen in figure 1.

In aviation there are two sets of regulations for governing civil aircraft operation. One is Instrument Flight Rules (IFR) and the other one is Visual Flight Rules (VFL). These two are general rules for how to operate planes and usually applies to large commercial aircraft, meaning that they operate in the same way worldwide, usually with the same technical equipment that is displayed in figure 1.

Two of the more interesting systems used in communication in aviation are Controller-Pilot Data Link Communication (CPDLC) and Aircraft Communication Addressing And Reporting System (ACARS). The most important communication in aviation are between the pilot and the Air Traffic Control (ATC) which is a unit on the ground that monitors and guides the pilot through his flight. The most common tool of communication is voice communication between them which is conducted with analog radio on Very High Frequency (VHF) and High Frequency (HF). CPDLC and ACARS however allows for communication in form of text-based messages as a two way data link. By using those systems it decreases the amount of traffic in the radio frequencies and also mitigates the risk of not hearing or forgetting of what was said because it is received in writing. Also, unlike radio frequencies that everyone can listen to, these messages are intended to only be able to be read by the two endpoints in the two-way link system. But as we enter the next section of this study we can see that this is not always the case. [12]

2.2.2 Aviation security

With aviation being a major part of the worlds transportation of civilians and supplies you could think that security plays a major in these communication systems. However, the fact is that it's almost the opposite with security usually because security never was a part of the basic design of the system when it was designed. Instead for commercial aircraft, safety is something that is focused upon. To make sure that it is safe for the civilians to fly with countermeasures if something would happen and so on. But safety it's not the same as security and does not consider techniques and solutions against, for example, cyberattacks.

As was mentioned in the previous section, CPDLC and ACARS that are suppose to be confidential with

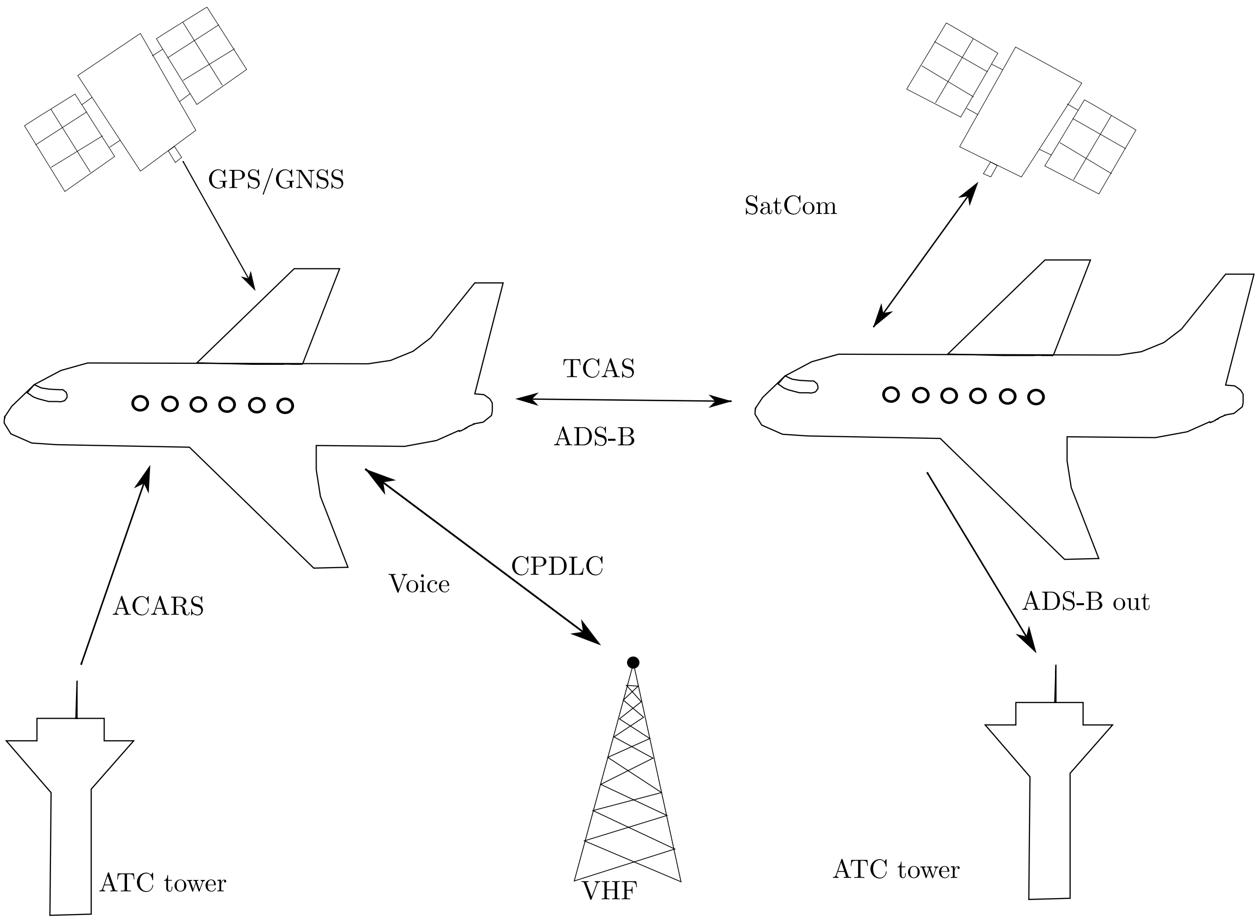

Figure 1: Techniques used in aviation communication

only the persons in the end points of the two way link being able to read the messages is not actually confidential at all. Now days with the constant evolving of the worlds technology, powerful tools are getting easier to get hands on with lower and lower prices which now is enough to be able to hack into the data-link and decode the transmitted messages between the pilot and air traffic controllers. For example, to simply buy a Software-Defined Radio (SDR) that is both cheap and powerful is enough to access the data link communication and get unauthorized information. For CPDLC it has even been done and proven by two students last year and can be read about in their thesis called "CPDLC in Practice" [10]. By simply using a SDR and staying close to the airport of Arlanda they managed to retrieve several messages sent between the pilots and the ATC.

In figure 2 you can see a table that contains many different systems and techniques used in aviation. It gives an overview of what requirements the systems lack of, and that both CPDLC and ACARS is missing both for confidentiality and integrity.

2.2.3 Passenger services with XG

There are many different needs and conveniences for airplane passengers that need to be taken into consideration. Passengers need comfort, security, and preferably the ability to remain online on their devices. In order for the travel experience to be adequate it is crucial that personal baggage is looked after and delivered safely on time.

The baggage handling around the world today is often automatized to some degree but there is always some form of manual handling done. Baggage can be lost during both the manual and the automatic handling of baggage. Airport personnel may accidentally or deliberately prevent the baggage from reaching its intended destination. The automation may fail as well, the conveyor belt might for example fail in picking up the bag correctly.

In a situation where the baggage doesn't arrive as intended, man-hours need to be put in to retrieve said baggage and return it to its rightful owner. This costs time and money, and in the worst case the baggage is lost which can be devastating for the passenger. The airports try to ensure the safe arrival of the baggage by keeping track of when it reaches various checkpoints and also by tracking the conveyor belt trays carrying the bags.

According to a recent report by the U.S Department of Transportation, more than 0.5% of all luggage handled by U.S airlines have been reported as mishandled. In this context mishandled luggage means luggage that has been stolen, damaged, delayed, or lost.[14]

The amount of luggage that gets mishandled is not negligible due to its potentially dire consequences for passengers. There is in other words still a decent amount of room for improval when it comes to baggage tracking and handling.

In-flight internet is a service provided by some airlines today. A common issue with in-flight internet is the slow, unstable connections as well as the expensive pricing. Present infrastructure does not allow for affordable and fast in-flight internet, which results in an experience that doesn't cater to the web-related needs of passengers adequately.

There are various reasons as to why in-flight internet hasn't evolved alongside consumer needs. The often remote and dynamic positions of airplanes make internet provision exceptionally challenging. Today there are primarily two ways of obtaining internet access on an airplane: One is by using a satellite connection and the other is by connecting to ground-based towers in a so called Air-to-ground (ATG) network. Both options require antennas attached to the airplane which increase drag and therefore fuel costs, impacting the consumer price for in-flight internet.

The challenges in satellite connections arise due to satellites being far away and therefore hard to maintain and improve. It is for this reason that satellites today have poor internet speeds which renders them outdated.

	Confidentiality	Integrity
VHF	-	X
PSR	-	X
SSR	-	X
CPDLC	X	X
MLAT	-	X
ACARS	X	X
TCAS	-	X
GPS	-	X
ILS	-	X

Figure 2: A table that shows what requirements a specific system is missing [12]

Connecting to ground infrastructure with an airplane works similarly to how a cellphone would connect to it. The airplanes antenna establishes a connection to the closest ground-based tower and forwards this connection to the passengers' devices. The main issue today with this option is that an airplane must be in range of the ground infrastructure in order to establish a connection. If it is too far away, at sea for example, then this becomes an impossibility.

2.2.4 UAV positioning

Unmanned Aerial Vehicles (UAVs) such as drones and others is a technology that in recent years has become of good use in military, public and even civil projects. The technology was originally used for military purposes such as surveillance, exploration and ranged attacks. [9]. They may also be used by companies for transportation and emergency services for public safety.

One of the primary advantages of UAVs is that they can be used in places that would otherwise be dangerous for human beings. In disaster areas such as wildfires, gas leaks, floods etc. UAVs can provide aid without putting additional lives at risk. Whether it is a single larger UAV that for example is used for transportation or swarms of smaller UAVs used together in for example emergency services, the navigation of the UAVs primarily comes down to Inertial Navigation System (INS) together with Global Navigation Satellite System (GNSS) receivers [16].

However, the use of GNSS for navigation is not always free from faults. If the UAVs are placed in urban environments or other dense areas containing an abundance of obstacles, tgh that the straight path from the satellite to the UAV is not so clear and can therefore cause loss of data. It can happen for different reasons such as interference, multipath effects, obstruction or other and this will eventually impact the positioning of the UAVs in a negative way. Therefore, alternative techniques are in development that can solve this issue in one way or another.

2.2.5 Aerial XG base stations

Not all of the earth's land surface is covered with ground infrastructure for wireless communications. This can be due to areas that being very remote or areas containing terrain which is challenging to build upon. The seas, which constitute a large part of the earths surface, do not have any said infrastructure either. There are in other words multiple areas across the globe that must receive wireless connectivity in some other way.

In the case of a natural disaster or other forms of danger, there is a possibility that built wireless communication infrastructure breaks down partially or completely. This would impede the flow of information to the public, government officials and rescue workers. In a disaster, information is key and can save many lives. The problem must be mitigated somehow in order to provide information to people inside the disaster area. This could potentially be done using aerial base stations.

3 Possible solutions

This section will consists of several methods, both practical and theoretical that are made possible thanks to XG and other new technologies that could be used to change and improve how communication and security in aviation are used today.

3.1 Aviation communication

There are many types of attacks that can target insecure data link communications. There is eavesdropping, flooding, alteration, jamming and many more that are possible do perform due to lack of security. To counter these threats and make sure that a system is completely secure against all types of attacks it needs to follow five requirements. These are authentication, confidentiality, integrity, non-repudiation and availability, and is what's needed for a fully secure system.

3.1.1 PACARS

As stated earlier, ACARS is in it's default state not secure at all and an easy target to attacks. However, there exist extensions of the system that expands what the system is capable of. For example there is the so called Protected ACARS (PACARS) that brings more security to the system, enabling support for data confidentiality, integrity and authentication. This is achieved with Elliptical Curve Cryptography (ECC) which is a unique approach to use in public-key cryptography that thanks to its design only requires small keys while still implementing high level of security. However, it still does not fulfill the requirements for the systems availability. [2]

PACARS was originally developed for the military as a way to communicate securely within the military by encrypting data link traffic. It can without any hardware modification be added as a software application to an aircraft without generating any other issues to the system. It has been tested and validated in several avionic data link systems, adding security to the communication. However, PACARS is expensive and is a commercial system closed to the public which is why information containing the system is mostly concealed and poorly documented.

3.1.2 URLLC

One new major technology being developed as a part of 5G is 5G New Radio (NR). It is being developed by 3GPP and had its first appearance in the 3GPP Release 15 standard. 5G NR supports 3 categories of services which are evolved mobile broadband (eMBB), massive machine-type communication (mMTC) and ultra-reliable and low-latency communications (URLLC). URLLC refers to applications that require secure data communications from one end to another with both ultra-high reliability and low latency requirements. Meaning that this could absolutely be something that could be used to improve communication in aviation both in terms of security and speed. [4]

In Release 15, the requirements for URLLC includes the latency of one millisecond over the air interface and the reliability of 99.999%, meaning that when one hundred thousand packets are delivered in one millisecond, a maximum of one packet can be lost. So far, the use cases involving URLLC has been about robotics and autonomous vehicles and not yet been tested in commercial aviation communication.

3.1.3 L-DACS & AeroMACS

Larger organizations such as the International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) are also in progress to develop and upgrade the current communication systems in aviation. The new systems called L-band Digital Aeronautical Communication System (L-DACS) and Aeronautical Mobile Airport Communication System (AeroMACS) are in development and are planned to replace the current VHF systems that is the base of what most aviation communication systems works on.

They are planned to take care of the issues with wireless security and will provide a much higher throughput of data. [12]

L-DACS is currently planning to not be available until the years of 2030s and is still in its early phases of development with its specification still being worked on. AeroMACS which has an intention of providing data link endpoints for communication between the aircraft and other stations to be available. However, it will not solve the security issues currently in aviation communication. Most of the security issues are still undecided of how to be handled due to the early phases of development. AeroMACS has however gone further in development compared with L-DACS with AeroMACS currently being tested at airports around the world. [12]

3.2 XG passenger services

Huawei, one of the largest telecom companies and pioneers in 5G, have recently made breakthroughs in passenger services. Some chinese airlines collaborating with Huawei provide passenger services living up to the 5G standards. With airport Wi-Fi speeds exceeding 1.2 Gbit/s, consumers get real 5G speeds.[7]

A smart travel system based on Huawei 5G technology has also recently been deployed at chinese airports. With it, customers only need to pass a face scan in order to check-in, get security clearance, and access a paperless luggage service. Passengers apply for reusable RFID luggage cards which can be used to keep track of their luggage using their smartphones. With their smartphones the status of the passengers luggage can be read at any times, which will be updated by airlines.[7]

An alternative to RFID tags is to use Narrowband-IoT (NB-IoT) nodes. By attaching a NB-IoT node to luggage its GPS coordinates, temperature, humidity and pressure can be transmitted in real-time. Designed for power effectiveness, NB-IoT nodes can sends all its information in a 14 byte UDP packet. The data is transmitted to a base station which in turn sends the data to a secure cloud server that can be accessed given the right credentials.[3]

3.2.1 Improved in-flight internet

Providing in-flight internet via the airplane itself is possible using a satellite connection. This however introduces high latency and high expenses. An alternative would be to use ground infrastructure with beamforming capabilities.

Beamforming is a technique used to create constructive or destructive interference at particular angles by combining elements in an antenna array. 5G infrastructure will have beamforming solutions supporting Space-division multiple access (SDMA), a method that significantly narrows down the signal emission to targets.

Using beamforming in 5G infrastructure increases the reusability of transmission resources for each cell tower, improving data throughput. Since the signals sent are emitted very narrowly, the signal-to-noise-and-interference ratio (SINR) is improved in both direction, leading to higher data throughput.[15]

By utilizing the unlicensed spectrum the bandwidth for in-flight connections can be improved. An already established 4G technique called License-Assisted Access (LAA) has proven to significantly improve the speeds of LTE connections. It uses the licensed spectrum to establish a connection and the unlicensed spectrum to transmit the content data. Utilizing the unlicensed spectrum in this way interferes with other wireless technologies such as Wi-Fi, a conflict within the unlicensed spectrum can degrade the quality of both technologies.

Stratospheric balloons could be used in order to provide a wireless connection to airplanes, something that will be described in further detail later on.

Airplanes in remote areas cant rely on a direct connection to ground infrastructure and instead use satellite communications for large data. An alternative would be to establish an airborne ad hoc network between airplanes in proximity of eachother.

An aeronautical ad hoc network could be made using ground stations and aircraft. The aircrafts in range of ground infrastructure access it via a direct air-ground link. Otherwise, the aircraft use an air-to-air multi-hop path to a ground station. The ground stations act as gateways in the network. An ad-hoc network spanning the North Atlantic Ocean could potentially provide connectivity to remote airplanes flying over the ocean. For such a network, with an assumed communications range between aircrafts of 200 nautical miles, most remote aircrafts would, in theory, have an almost permanent connectivity and an average link duration greater than half an hour.[13]

Gogo, on of the leading providers of broadband connectivity in aviation, have announced that they will launch their 5G ATG (Air-to-ground) network in 2021. It will be available for various kinds of aircrafts such as business and commercial aircrafts. The network will cover the United States and Canada using 250 towers operating in the 2.4GHz range as well as using a proprietary modem with beamforming technology. Gogo chose not to include satellite technologies in their network due to higher expenses and latency.[6]

3.3 UAV positioning

3.3.1 Signals of opportunity

In urban environments where it is hard for GNSS signals to fully reach the UAV without losing some of the data it is instead possible to use other kinds of available signals. These signals are called signals of opportunity (SoOP). Analogue/digital radio, analogue/digital television and Wi-Fi signals are all possible to use as SoOP for the UAV to navigate more effectively. There are also different types of methods that can be used to benefit from these signals. These methods are Angle of Arrival (AoA), Time of Arrival (ToA) and Received Signal Strength (RSS) that all in different ways use these signals to calculate the position. As of now SoOP is not yet realistically implementable but with the latest breakthroughs in XG networks it could potentially become a solution to the navigation errors for UAVs in the future. [16]

AoA is characterized as the angle between the propagation direction of a wave and a reference direction. It can be used for localization with the help of triangulation. It is similar to what in GPS is called trilateration but here the receiver knows the angles of the received signals from the transmitter instead of the distance from the transmitter as in trilateration. With this knowledge the UAV can calculate its location with help of three or more signals of opportunity. The issues with AoA is that angular measurements are more prone to errors as well as the accuracy of the final UAV position rapidly worsen as the sources of the signals moves further away from from it.

ToA that in a way is quite similar to AoA instead determines the location of the UAV based on the intersection of three or more circles whose radii being the distance of the respective transmitter from the UAV. Here, unlike AoA, trilateration is used to calculate the distances. The issue here is that small errors in the circle radius reading lead to a region of uncertainty for the UAV position.

RSS is another method to use SoOP that also is a quite low-cost localisation solution because it does not require any additional hardware to be used. RSS focuses mostly on the use of Wi-Fi and Bluetooth signals and can calculate distance by a range-based approach, signal fingerprinting or range-free approach. However, by being a cheap method it does come with its disadvantages such as time consuming to create data maps for the fingerprinting approach, large margin of error and therefore unpredictable. It also gets affected by multipath obstructions.

3.3.2 UGV-UAV cooperation

Sometimes it's not enough to achieve what you want with just one technique, that's why it has become popular to collaborate with other techniques to achieve the perfect result. That is something that has been thought about in UAV navigation and one solution that consist of cooperation is to use both a UAV and a Unmanned Ground Vehicle (UGV) that communicates with each other. They way it would work can be seen in figure 4. While the UAV is positioned in a

GNSS-challenged environment where there is no easy path from the satellites signals to the UAV, the UGV will be in an area that is not GNSS-challenged. For example just outside of the city the UAV is positioned with an easy view to a clear sky.

How it would work is not to be an replacement to the GNSS signals, but rather an extra help to increase the accuracy of the UAVs positioning. The single UGV is used as a ranging source and is able to yield a wide range of geometry with the UAV as a reference to its own position. Meaning that the UGV is positioning itself to improve the accuracy of the UAVs navigation. Ultra-Wideband (UWB) radio is used to provide range measurements between the two while the UGV thereafter is strategically positioned itself to reduce the Position Dilution of Precision (PDOP) of the UAV. PDOP itself is a characterization of the user-satellite geometry, simply meaning that the lower the PDOP, the better the geometry is that in the end improves the position estimation of the UAV. [17] By using this cooperative peer-to-peer method, it has been proven that the accuracy of the UAVs navigation was improved with the help of the UGV, given that the UGV itself is placed in a non GNSS-challenged environment.

3.4 Aerial XG base stations

In an area where some ground stations do not work properly, large-scale UAVs can act as temporary aerial base stations, covering the users in said ground stations area.

The data exchange between the disaster area and the outside can be made possible by multihop UAV relaying. Relaying the data exchange across multiple UAVs is done to increase the potential range that the ad-hoc network can reach. Optimally, this range suffices in order to connect to working ground infrastructure located further away from the disaster area. The result is that devices in the disaster areas can stay connected to the rest of the world and under optimal circumstances use the internet as usual.[18]

The use of aerial base stations is illustrated in figure 4. The figure presents two scenarios, the first (scenario 1) is when there is one damaged ground BS (base station) but adjacent ones that are operating. In such a scenario, a UAV can cooperate with the surviving BS in order to provide connections to the devices belonging to the damaged BS area. In scenario 2 there are no operating base stations and a large UAV is used to substitute the ground BS.

By using the device-to-device (D2D) multi-hop technique the range of the aerial base station can be extended. Devices outside the UAV coverage can have their connection relayed by other ground devices.

In [11], some security issues pertaining to UAV base stations are examined. A primary concern is the risk of wireless communications being wiretapped by a party with malicious intent. To make wiretapping harder UAVs can use beam-forming with multiple antennas to direct the signal to a specific target. It is important to note that beam-forming requires more power than otherwise needed to transmit a signal.

An alternative could be to use a lighter-than-air vehicle with an attached base station. These vehicles can provide low data rate communications omnidirectionally or high data rate communications with directed antennas.
In 2013 Google announced *Project Loon*, a project which aims to provide internet access to remote and disaster areas using stratospheric balloons. Multiple balloons in the stratosphere form a network at an altitude of around 20 kilometers. Positioning the balloons is done by descending/ascending them to utilize winds blowing towards the desired location. The result is a compromise between a satellite network and a network of low-altitude drones. Each balloon can cover an area 40 km in diameter and deliver 3G speeds (Up to 10 Mbps). [8]

4 Analysis

In this section, the above described solutions are evaluated and compared analytically.

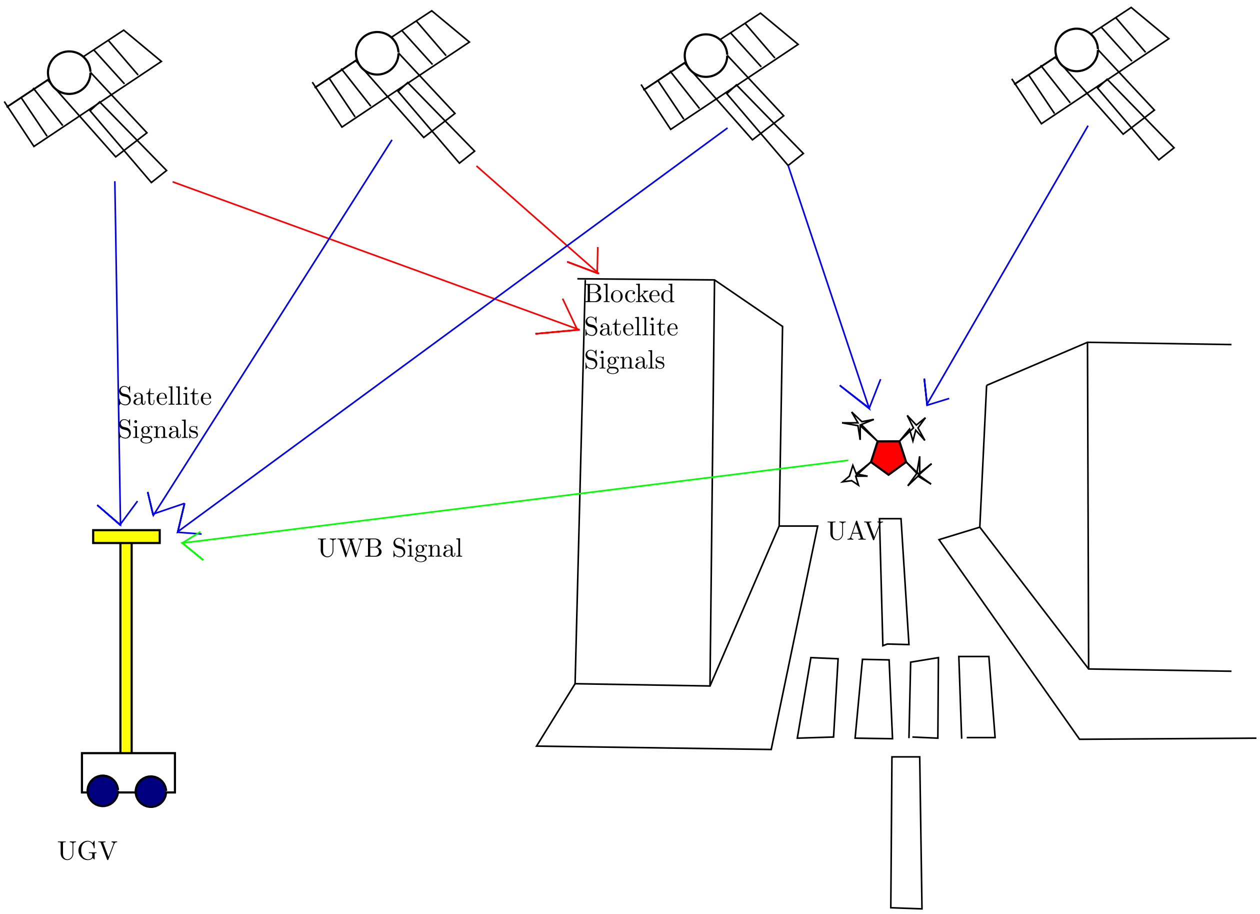

Figure 3: UAV and UGV cooperation

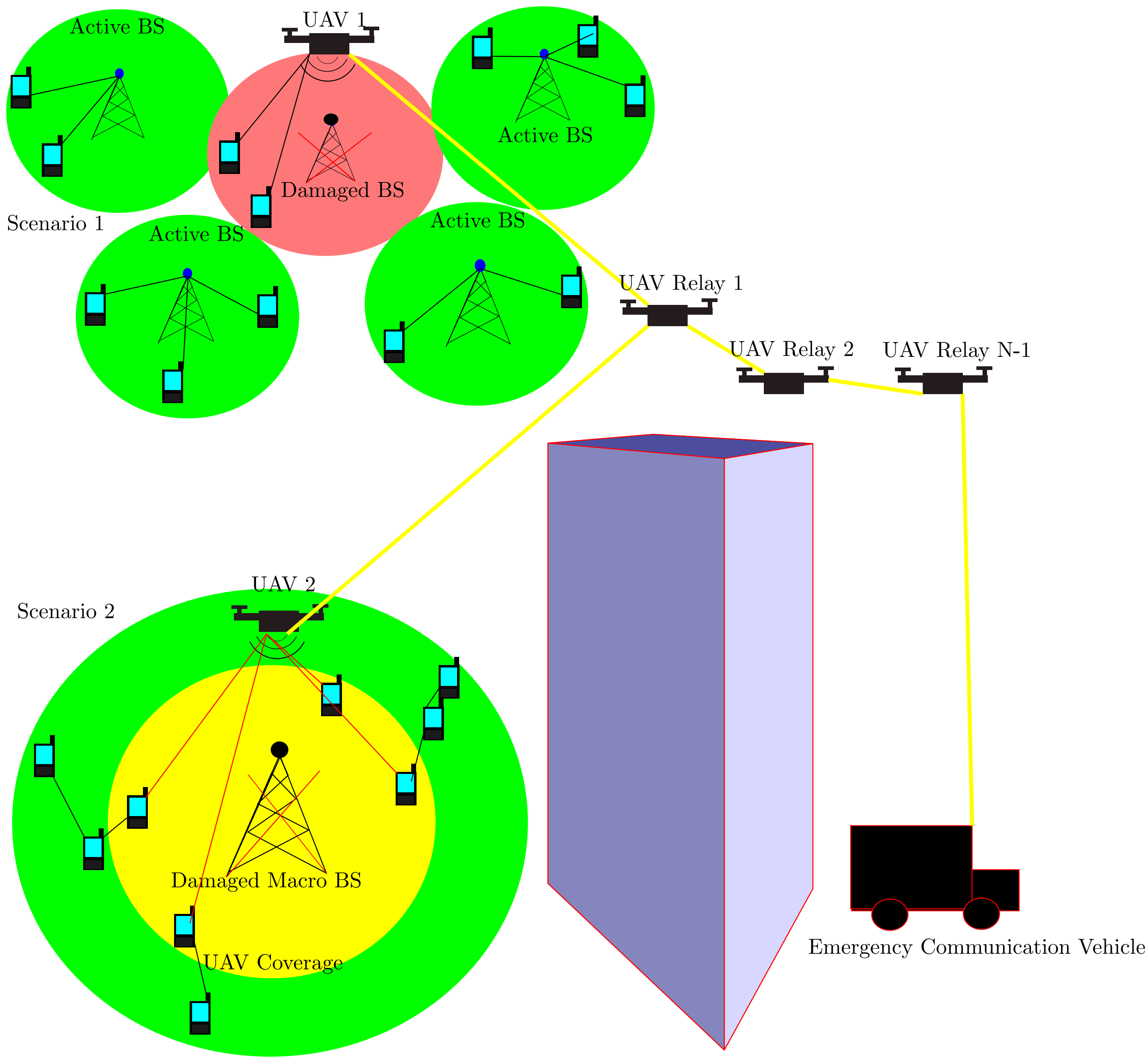

Figure 4: Example use of UAV base stations in a disaster area

4.1 Aviation security

It is certain that security within aviation have many flaws and can greatly be improved in the modern world, something that more likely can be done with the breakthroughs in XG technologies. As could be seen in figure 1 there are a lot of different techniques used when flying an aircraft where most of them in one way or another has vulnerabilities, as could be seen in figure 2.

With URLLC looking very promising coming from the breakthroughs of 5G, it certainly looks like a future technology that could improve both security and reliability in aviation communication. However, it still feels a technology in it's development that isn't fully finished and far away from being use in commercial airplanes. Release 16 is still in development and therefor URLLC is as well but does look like the solution communication in aviation needs, and even if it's not soon, it could eventually become a standard in aviation.

One of the solutions described in a previous section that is planned to eventually solve most of the aviation issues is the L-DACS and AeroMACS systems by completely replacing the usual VHF system. Being developed by larger organizations around the world that focuses on aviation, it sounds like a promising solution to the communication issues in aviation. However, it is at this time to little progress that has happened. With the goal to be finished around 2030 it is now not more than a distant dream that hasn't even gone past the phase of planning how the system will work and look like.

By instead looking at the bigger issues in aviation security we come to the systems CPDLC and ACARS, which both are very important in aviation communications by sending messages through texts instead of voice. One promising solution for ACARS at least is Protected ACARS that is a system that brings confidentiality, integrity and authentication to the system. Even though it doesn't protect attacks that focuses on availability it is something that today already seems like a optimal solutions to improve security. Unlike L-DACS, PACARS is something that already has been tested and implemented so far without any problems. It is also something that easily can be added as a software application to an aviation system. However, this system was primarily built for the military and is a closed commercial system that is very expensive. With the cost of the system being very high it is very likely that other commercial airlines wont install it because of economical reasons. Other then that it looks promising and could also very likely be something that could impact the evolution of other systems, such as CPDLC. But with the documentation of PACARS being concealed to the public it will at this time be hard to improve security in aviation with the help of it.

4.2 XG passenger services

Smart airports introduces a variety of different services that aid both personnel and customers. The matter of digital security as well as privacy becomes a growing concern as an increasing amount of airport services become digitized. In the smart airports designed by Huawei in China there is a heavy reliance on face recognition. As previously stated, check-in, security clearance and the luggage services are only provided after going through a facial scanning procedure. For the sake of availability it is critical that such a procedure is very accurate or that a backup system is available if it would fail.

There is also a question of privacy that needs to be asked regarding facial recognition. Relying on such a technology would imply the storing of individuals facial data which could be argued as a breach of privacy. However, if the services are optional the argument could be made that it is up to the customer to decide whether to use it or not.

4.2.1 IoT baggage tracking

Baggage tracking with IoT devices is in many ways convenient for airlines as well as passengers, but it introduces potential risks that needs to be considered. First of, there is a risk that airlines will come to rely to heavily on IoT baggage tracking. If said tracking system were to fail then mitigation strategies should be in place to remedy the situation.

A baggage tracking system like the one used by Huawei can potentially fail in many ways. The RFID scanner could fail, the client API may not work as intended, or the central server could stop handling incoming requests. These are only a few of the possible points of failures, which goes to show that a robust backup solution is needed.

One advantage the RFID solution has over NB-IoT nodes is that it has a smaller attack surface. NB-IoT nodes transmit their data wirelessly in simple power-efficient packets that can be intercepted by malicious users. RFID tags however are not as easily interceptable and would require a malicious person to be in close proximity in order to tamper with it.

Another important aspect to take into consideration is that of security. Confidentiality, integrity, and availability are crucial aspects to consider in this kind of system. A malicious hacker could locate luggage belonging to specific passengers and steal it (confidentiality), deliberately send a phony location for luggage (integrity), or DDoS-attack the system to prevent users from tracking their luggage (availability).

Carefully using encrypted connections and authentication in a baggage tracking system could all-in-all make it a convenient and secure solution for both passengers and airline companies.

4.2.2 Improved in-flight internet

The next iteration of wireless communication ground infrastructure will provide higher speed connections for passengers in airplanes located somewhere above it. The big challenge is how to provide the same high speeds in remote areas. Satellites are expensive to launch and difficult to maintain and modify, which makes them an inconvenient solution in this regard. They might however become cheaper and more accessible, resulting in good providers for in-flight internet.

The stratospheric balloon base stations could potentially be an economically feasible way to cover remotely positioned airplanes with internet. Google have shown that they work very well although the speeds provided doesn't live up to modern consumer needs. There will definitely be improvements made in this regard in the near future and these improvements can easily be applied to already active stratospheric balloons compared to satellites.

The idea of establishing an ad-hoc network using airplanes and ground infrastructure introduces security-related challenges that need to be dealt with. The network can become a vulnerable target for malicious parties in different ways depending on how it's designed, especially in regards to which routing protocol is used.

Ad-hoc networks don't have a central authority and are sometimes vulnerable to denial-of-services (DoS) attacks. A malicious node in the network could potentially hijack the network bandwidth by performing certain actions. A DoS-attack could be done in some ad-hoc networks by making a large amount of routing requests, resulting in a crash or parts of the network becoming disabled.

Another well known vulnerability for ad-hoc networks is black-hole attacks. Such an attack is done by a malicious node that uses the routing protocol to market itself to other nodes as the shortest way to a destination. By doing this, the malicious node will have the connections to the destination routed through itself leading to an interception. The action done by the malicious node during interception can vary.

Fortunately, an ad-hoc network consisting of airplanes and ground infrastructure is not as open to hackers as others, but there are still serious issues to deal with. In such a network there is a set of nodes that can be determined and "whitelisted" in different ways. With security measures implemented nodes can make sure they only interact with other authorized nodes. For example, a system where one has to sign their routing request using asymmetric encryption could be used to verify a nodes authenticity. Although such measures wouldn't prevent whitelisted nodes from misbehaving, it would make it easier to reprimand and blacklist them. There is a risk that malicious parties could impersonate other nodes or act as a man-in-the-middle.

There are many threats that need to be considered when establishing an aerial ad-hoc system.

Although airplane ad-hoc networks come with some security challenges, they are a promising way to provide internet to remote areas. The trend towards IoT coincides with this technique and will likely see widespread use. In areas where the airplanes are too far apart to effectively establish such a network, they could instead rely on satellites or stratospheric balloons. Which one depends on economic feasability and the airlines connection requirements.

4.3 UAV positioning

4.3.1 Signals of opportunity

One promising solution to the problems that occur with UAV positioning is to use Signals of opportunity together with the GNSS signals to improve the UAVs navigation. With the different methods that can be used with SoOP, it looks like a very promising solution that will easier be realised with the breakthroughs in XG networks.

With SoOP being able to be used in different ways, with different signals to calculate the positions, it has a lot of capabilities to improve the UAVs navigation. However, it is still not free from faults with the different methods having their own complications in one or more aspects. For example with the AoA method it looses its accuracy when the source of the signals move further away from the UAV. But there is not doubt that it is today a very promising solution that will only improve with the evolution of XG.

4.3.2 UAV-UGV coopertaion

Compared with the SoOP methods where many different types of signals that already exists is used to improve the navigation for the UAV, with the UAV-UGV cooperation technique there is instead a single UGV designed to talk to the UAV and improve its accuracy in positioning. When looking at the results that was achieved from this method, the 3D positioning error that occurs with the positioning in UAV was improved from about 1 meter to 10 centimeters. Meaning that around 90% of the error was removed.

However, other problems occur with this solution. As said before, the UGV always needs to be in a non GNSS-challenged area to be able to help the UAV. This could sometimes be hard to achieve, to always have the UGV placed at an acceptable location not too far away from the UAV where it can move freely. Also, it does not look like a cheap solution, to have a single UGV for every UAV simply doubles the amount of hardware and therefore rises the economical cost for it. So by only looking at the result, it sounds like a very promising solution to the UAVs navigation issues. However, it does not look like a realistic solution that will always work.

4.4 Aerial XG base stations

There are certainly different advantages to UAV base stations and balloon base stations. First of, there is a difference in deployment speed and adaptability. When using UAVs for base stations one can expect a faster deployment because of the short time required to lift off drones and position them at a target location. Balloons however are less adaptable and more suited for reaching high altitudes and covering large areas. In most cases balloons will also be more affected by winds than conventional drones because of their aerodynamic characteristics.

As of now, stratospheric balloons seem to only be able to provide 3G speeds which can by modern standards be considered lackluster. 3G speeds suffice for sending instant messages and small media files but can't be used reliably for i.e streaming high-quality video. In a disaster scenario, stratospheric balloons could be used for sending textual information to the public which would help in saving lives.

The security of aerial base stations need to be taken seriously. Using beam-forming is most likely going to be key in providing secure and reliable wireless coverage. Not only is beam-forming an effective way of minimizing eavesdropping but it also helps reduce interference between user equipment.

The aerial base stations have a limited battery capacity which must be used economically. The process of transmitting data consumes a lot of power, especially when using beam-forming. Minimizing the amount of power consumed for securely transmitted data requires further investigation.

5 Conclusions

We conclude with this survey that 5G/6G will have a major impact on aviation in many ways. Even if it's not now nor tomorrow, it will eventually bring about a much needed security overhaul for aviation communications. With URLLC evolving from the XG breakthroughs, it truly brings many possibilities to improve air traffic communication in a not so distant future. If not URLLC, then L-DACS and AeroMACS surely will eventually improve aviation communication, even though it might be much longer until we get there. NB-IoT nodes are without a doubt the more sophisiticated baggage tracking solution, providing many different types of data in real-time. It is noteworthy that the use of RFID is more robust and a more economically viable way of tracking luggage. A much needed move towards better in-flight internet will be enabled by airplane ad-hoc networks and complementary high-altitude balloons or satellites. For geographical regions such as the US, in-flight internet will likely only make use of ground infrastructure seeing as how it is both affordable and fast.

UAVs have the option to improve their navigation in urban areas by using different techniques such as signals of opportunity or UAV-UGV cooperation when the GNSS signals alone isn't enough. UAV-UGV cooperation gave better results when improving the UAVs navigation but is much harder and more expensive to implement compared with SoOP, whereas SoOP is a cheaper but somewhat inferior solution. Disaster areas can be provided internet access both with UAV base stations and also with lighter-than-air base stations depending on how coverage, deployment speed and adaptability is prioritized. For all said areas there is an important need for security as wireless connections are especially vulnerable.

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