Direct Access to Mobile Services by Users in Airplanes

5TONIC White Paper

OCTOBER 2020

ABSTRACT

This white paper explores a potential new operational model for the provision of mobile services to users in airplanes, based on the reuse, as far as possible, of the mobile network infrastructure of terrestrial operators, as well as the frequencies they have licensed. This model is made possible by the fact that new airplanes get not affected by the transmission of mobile devices inside them, at least outside the landing and take-off maneuvers. The advantage of this model is that it would not require a special device for its support, and it will not require air carriers to provide any specific support, as happens with other models. On the other hand, there are potential coverage and interference issues that need to be addressed; some of them are tackled in this white paper.

We think that this new model is viable from a technical viewpoint with no significant negative impact on the terrestrial network, and its performance can be optimized by the introduction of several innovations, some of them also proposed in this white paper. And while we do not examine in detail the economic and regulatory viability of the model, we are confident that it represents an opportunity for operators, as it fulfills a need from mobile users in a simple way.

Introduction

The objective of this white paper is to analyze the viability and implications of supporting the direct access to mobile devices in airplanes through a specific network infrastructure (i.e., exclusive for the connection of airplane users) that reuses as much as possible the terrestrial mobile network infrastructure and the spectrum for which the operator has a license. The idea is that users can access mobile services in airplanes the same way as when they are traveling by land transport such as train or bus, in the area where an operator has a license for providing terrestrial coverage.

Direct use of phones at planes has been forbidden due to potential interference, specifically in the 800-900 MHz range, with unshielded cockpit instrumentation. In other words, the reason the mobile phone cannot be used in a plane as in a train has been the potential interference issues the use of the mobile phone inside the plane can cause, and not so much the technical feasibility of such a service model. On the other hand, there is significant, though anecdotal, evidence that the use of phones connecting to the terrestrial network is feasible, at least when flying at a moderate height, and it is not rare that some users fail to shut off their phones on while flying, without causing major problems. There are, however, other reasons for believing that these interference issues are currently not as severe as to preclude the use of the mobile phone inside the plane.

To start, for some years the use of Wi-Fi is permitted on many flights, using a frequency band very close to some mobile services frequency bands and similar transmission power. But on top of this, it can be argued that it is very likely that planes have been (and are) experiencing a significant amount of interference from the transmissions of both mobile base stations and users in the areas they are flying over, in some situations, potentially higher than the one that can be generated by a user device operating inside the plane. After all, when a plane flies over a large city, it receives signals from hundreds of base stations and thousands of user devices, potentially attenuated by the radiation diagram of the transmitting antennas but in some cases with line of sight propagation between the plane and the antennas.

In this white paper, we will look at some of the main technical challenges that the implementation of such a service would have and provides an initial analysis of their impact. We will also propose some innovative solutions that may help to overcome these challenges.

On top of the technical issues that such an operating model implies, there are other aspects, related to regulations or how operators can monetize the services provided, that are not being analyzed in this white paper but should be looked at.

Direct communication from the airplane

The proposed service is characterized by the following aspects:

- Users should be able to use the same devices that they use to connect with the conventional terrestrial network, using the same SIM cards.
- The frequencies used for the communications are the same ones that are being used for the terrestrial communications and the service is supported by the same operators that support the terrestrial service on the area the plane is flying over.
- Roaming should be provided in the same conditions as in the terrestrial network.

For supporting the service, a set of new cells, with antennas pointing towards the sky, should be deployed. These cells may share the site with terrestrial cells, and may also share the processing infrastructure, e.g., baseband processing.

Other options to support the service are also feasible. E.g., communications in airplanes using conventional mobile devices can also be supported by deploying a picocell/small cell in the aircraft, which is connected to the rest of the network either via satellite or an ad-hoc terrestrial network. However, this option would require some coordination between the operators and the airlines, as well as the establishment of a transport link between the cell in the airplane and the terrestrial network. And airlines probably would prefer to push for proprietary solutions that allow them to charge users more for the services provided.

Also, Nokia proposed a ground to air LTE based communications system, that would use the spectrum reserved for mobile satellite systems **[1]**. Compared to this proposal, it has the advantage of limiting interference issues between the terrestrial and aerial networks, as the latter use of different set of frequencies from the former, but, on the other hand, the bandwidth available is much more limited.

Extending the normal use of mobile UEs to the passengers in airplanes requires that:

- it would not cause undue interference in the airplane instrumentation;
- the quality of service/quality of experience for the users is adequate;
- it would not cause significant interference problems to terrestrial networks;
- and it can be provided at a lower cost than other alternatives.

It should be pointed out that the services would only be provided in the area where the operator has a license. This means that they would not be supported when the airplane is flying over seas and oceans.

To assess the viability of this proposal, we will examine some of the main technical challenges the implementation of such a service faces, as well as some technical innovations that may facilitate its deployment. The analysis assumes that 4G and 5G are the radio technologies supported, although some conclusions could also apply for previous technologies.

Coverage

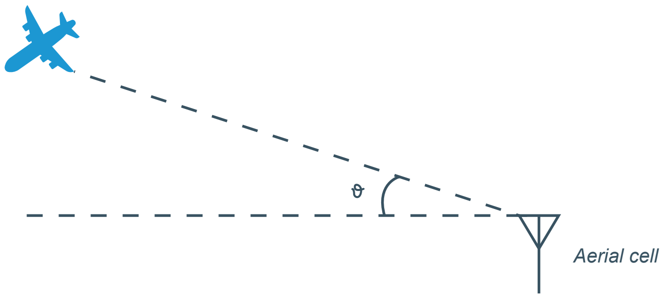
As indicated above, the service is expected to operate in the same operational conditions as the terrestrial one, so the same methodology will be used for estimating the coverage, which is determining the Maximum Allowable Path Loss (MAPL) using the link budget and deriving the associated maximum cell radius, taking into account the propagation conditions. In the link budget different factors that should be taken into account, like the expected cell throughput to be provided at the cell edge, the antenna gains at the base station and the UE, the interference margin, as well as margins associated with fast and slow fading, etc., may differ for the terrestrial and the aerial service. However, in an initial approximation, we will assume that all these factors are the same for the terrestrial and the plane service.

A rough coverage estimation for the service is relatively simple to carry out, as it can be assumed that the total propagation losses are basically those due to line of sight propagation between the terrestrial antenna and the airplane, plus penetration losses into the airplane.

The path between the terrestrial antenna and the plane can be safely assumed to be unobstructed, so path loss can be estimated based on the distance and the frequency used using the free space power loss formula:

$$FSPL = 32.74 + 20 \log_{10}(d(\text{km})) + 20 \log_{10}(f(\text{MHz}))$$

The maximum distance to be considered should be based on the fact that planes fly at a height that can reach 10 km and a minimum grazing angle should be guaranteed (otherwise, the cell size would be quite large and the diffraction losses would increase). The concept of the grazing angle is depicted in the following figure.



For planes flying at 10 km height, the path loss, depending on the distance and the frequency used, can go from 89 dB at 10 km operating at 700 MHz to 133 dB at 30 km distance (which corresponds to a grazing angle of 20 degrees and a cell radius of 28 km) operating at 3500 MHz.

Additional losses are associated with the penetration of the signal through the fuselage of the plane. Some measurements are available (e.g., **[2]**) that indicate that, depending on the position of the UE inside the plane and the operating frequency, interface losses can go from a minimum of 15 dB at 1800 MHz to 25 dB at 2450 MHz. Unfortunately, there are no measurements at 700 MHz and 3500 MHz, but we can assume that they will be lower for the former and higher for the latter. So total propagation losses for cruise altitude can be estimated to range from 100 dB to 160 dB, assuming a reasonable grazing angle higher than 20 degrees.

A typical LTE UE is expected to support a total MAPL of 147 dB, while a 5G UE is expected to support at least 30 kbit/s in the uplink and Mbit/s in the downlink with a coupling loss of 143 dB[1]. This means that the service availability cannot be guaranteed unless certain actions are adopted that allow improving the link budget up to 10-15 dB. Because of some of the characteristics of the service, it can be assumed that the link budget for the aerial cell would require lower margins (e.g., interference margin can be assumed to be lower, and shadowing margin is not necessary to be included, as propagation conditions are expected always to be LoS). On the other hand, the UE antennas may have a lower gain when the signal is intended to go in the opposite direction it usually goes to reach the cell antenna. But in any case, an improvement of 5-10 dB of the link budget may be necessary if we want to have large cells and use high frequency bands.

There are several ways in which the link budget can be improved to guarantee the desired quality and availability:

- Increasing the number of cells, so the distance between the terrestrial antenna and the aircraft is lower.
- Supporting the service only in low frequency bands, to minimize propagation and interface losses.
- Improving the link budget through beam steering or antennas with higher directionality.

None of these options is without drawbacks. Increasing the number of cells implies an increase in the capital and operational expenses of the network supporting the services, especially if the dimensioning criteria for determining the minimum number of cells required is the coverage and not the capacity. Using lower frequency bands usually limits the bandwidth available and may increase the interference issues that will be discussed later. Using beam steering may require the use of TDD spectrum, although a potential solution for supporting beamforming with FDD spectrum will be discussed later.

We can distinguish different deployment strategies for the aerial cells, mainly based on the kind of antennas that are being used.

- Single antenna, so each aerial cell covering a section of the firmament determined by the grazing angle. This is a strategy that benefits from the use of low frequency bands, that allows supporting the required MAPL with a relatively large cell radius. But as all the planes that fly over the same cell share the same spectrum resources, this option may have a limited capacity. So, this is a solution adequate for areas that are flown over by a limited number of planes simultaneously or if there are some restrictions on the service level to be provided.
- Sectorized antennas deployed in a site, each representing either a single cell or multiple cells. This will allow to increase the capacity as well as improving the coverage due to the higher antenna gain. On the other hand, this deployment option will increase mobility related events, like handovers or cell reselections.
- Beam steering antennas, that can point in the direction of the plane and follow it as it moves. It should be noticed that, due to the characteristics of the service operational conditions, with a lack of multipath propagation and deterministic trajectories of the UEs, the beam steering process is expected to be simpler than in a terrestrial environment, and to provide enhanced performance. Both mechanical and electronic beam steering can be used, although it seems that the former is the best option from a performance/cost point of view. This is the deployment strategy that would be associated with the use of high frequency bands in TDD mode (e.g., n78 for 5G, band 42 for LTE). It should be noticed, however, that the use of beamforming for this service is not intended mainly for the support of multiuser MIMO but for providing the required coverage margin in the high frequency bands.

It should be noticed that the three options can coexist in a given network deployment, allowing the operator to adapt the infrastructure to the

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[1] The coupling loss is measured between the UE antenna connector and the base station antenna connector.

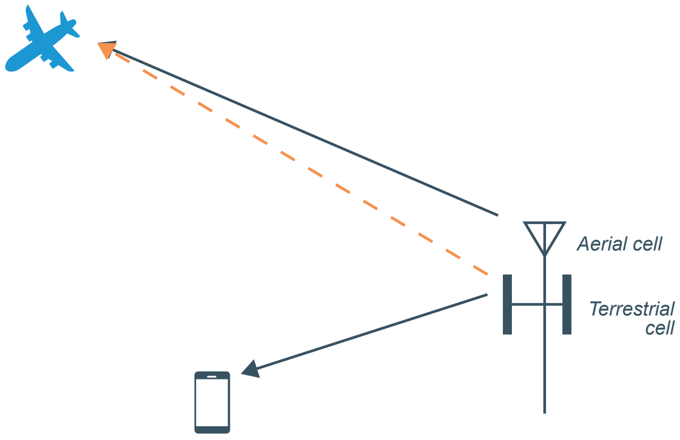
characteristics of the area being covered, e.g., a higher number of cells per site in the proximity of airports, where plane density is expected to be higher, and large cells deployed in areas with low plane traffic density.

Interference issues

Another aspect that requires consideration is the potential interference issues associated with service support. They include the potential interference of the plane network (both users and radio infrastructure) over the terrestrial network, as well as the interference of the terrestrial network on the plane supporting network.

Downlink interference will depend on the characteristics of the antennas used for supporting the service, as interference on terrestrial users will come from the signal radiated over side and back lobes of the antennas supporting the planes, and interference on a plane user will come from the signal radiated over side and back lobes of the terrestrial network antennas. But it is clear that it is the terrestrial network interference the one that could have a greater impact.

- Antennas for the plane service will be new and could be designed so they minimize the interference on the terrestrial network.
- The number of antennas that will be deployed will be significantly lower than the number of terrestrial antennas, and given the flexibility in their location, they can easily be placed in areas with low terrestrial traffic.



On the other hand, the terrestrial network will have a much higher number of transmitting cells and it is not realistic to consider that the antennas will be changed to minimize interference in the sky (minimization of potential radiation towards the sky has not been a criterion used for cellular antenna design). Elevation patterns with sidelobe attenuation of 15-20 dB (or even lower) with respect to the main lobe are not uncommon. This means that there may be significant power radiation towards the sky from the terrestrial antennas. In certain areas, like cities, the number of potential interfering terrestrial antennas can be very large, of the order of thousands. The amount of interference will depend on the plane position with respect antenna, and the radiation pattern of each one. This would translate into an increase of the noise floor of devices in the plane. A rough estimation of the ratio of the signal received from the aerial cell to the interference from the terrestrial cells can be carried out:

- We assume that only the interference of the terrestrial signal coming from the first upper side lobe is significant enough to be considered.
- We can assume that the values for the antenna gain and the first upper side lobe suppression are very close, so the terrestrial antenna gain towards the plane is 0 dBi.
- If the aerial antenna is at the same distance of the terrestrial ones, the SIR of the received downlink signal at the plane can be calculated (assuming the same transmission power for aerial and terrestrial cells) as the aerial antenna gain minus the number of interfering terrestrial cells in dB (NAt)[2]:

$$\mathrm{SIR} = G_a(\mathrm{dBi}) - NA_t(\mathrm{dB})$$

- If we relax some of the assumptions, then the SIR margin of the received signal at the plane can be estimated as:

$$\mathrm{SIR} = G_a(\mathrm{dBi}) - NA_t(\mathrm{dB}) - 20\log_{10}(\mathrm{da(km)} - d_t(\mathrm{km})) + (P_a(\mathrm{dBm}) - P_t(\mathrm{dBm}))$$

So, we can help to overcome a potential interference issue by:

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[2] In this calculation we are ignoring thermal noise, as the objective is to focus on additional interference generated by the aerial network and how to overcome it.

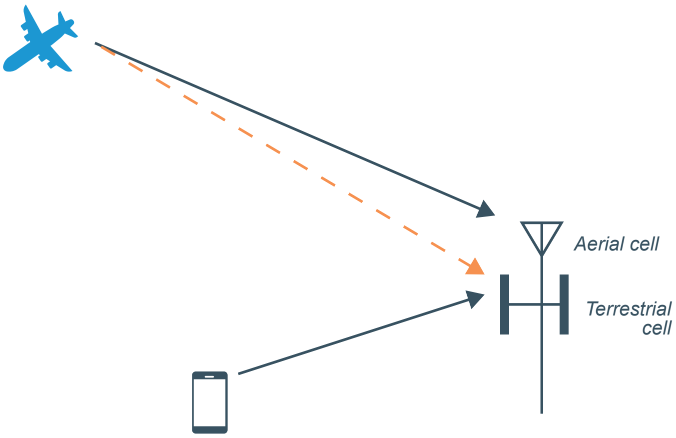
1. Increasing the antenna gain of the aerial cell (G_a).
2. Reducing the distance between the aerial antenna and the plane (d_a) when the former flies over an area with a significant deployment of terrestrial cells.
3. Increasing the transmission power of the aerial cell.

The last one may not be a good option as it may result in an imbalance of the link budget (the UE power cannot be increased). But the other two are the same ones that we can use to improve the coverage.

Concerning the uplink, interference of terrestrial users towards the receiver aerial antenna is not expected be very significant:

- Only users in the proximity of the aerial antenna or with LoS propagation conditions would produce significant interference.
- As the aerial antennas will be new ones, they can be designed to limit potential uplink interference, e.g., having a high front-to-back ratio.

Following similar reasoning as for the downlink, the location for the antenna can be chosen to preclude LoS propagation from terrestrial users in areas with low traffic.



On the other hand, as interference from the plane users may potentially reach a large number of terrestrial antennas when flying over a densely deployed area. This interference may be substantial if terrestrial users experience a large path loss compared to the attenuation experienced by the interfering user in the plane. This could be the case of indoor users or users in severe NLoS propagation conditions, whose path loss can be more than 20 dB higher than the one from the plane, and thus able to compensate for the lower antenna gain in the direction towards the plane.

This analysis only contemplates the situation that, for TDD, the terrestrial and the airplane networks are synchronized, i.e., both networks are time synchronized to the same clock reference and use the same frame structure. Otherwise, the interference analysis gets more complicated as there are new interference situations to consider, as, e.g., airplane users uplink transmissions may interference the reception of terrestrial users in the downlink.

Capacity issues

The number of planes that may fly in the area of a cell at a given point in time will depend on the location and the radius of the cell and can be quite variable. This information can be obtained, e.g., from online radars that collect information from ADS-B. In the following figure, the area surrounding the Madrid airport is depicted with the airplanes flying over the area. The red circle represents an aerial cell with a 20 km radius.

Alternatively, we can estimate the number of planes that can be served by a cell, based on existing data and assuming that usage in terrestrial and aerial cells is similar.

Considering that a typical urban site provides theoretical coverage to a population from 1800 to 36000 inhabitants[3], this means that an aerial cell of the same capacity can provide coverage from 3 up to 60 airplanes with an average occupancy of 200 passengers (assuming 3 terrestrial cells per site). Assuming that 1/3 of the passengers connect to a given operator, and a maximum of 20% of them are in active (RRC connected) state at a point in time, this means

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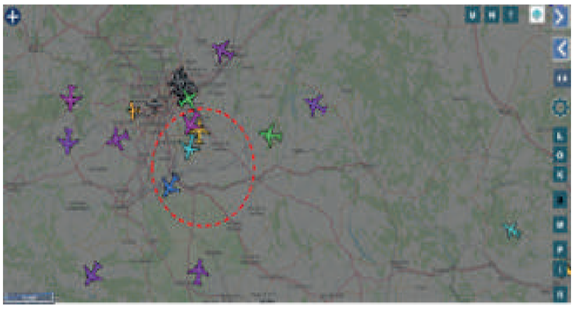
[3] This calculation is based on assuming a theoretical radius of 300 to 1000 meters per site, and using census data from Spain, UK and Germany to estimate the population that lives in the covered area. The actually covered population may be lower (due to coverage holes in the cells) or higher (due to people living in other areas moving into the coverage area for working or other reasons).On average, the site is providing service to 1/3 to 1/4 of the inhabitants, as there are more than one operator providing services.

that the aerial cell must be able to support from 40 to 800 active users. While the former figure is quite reasonable for a cell to support, the latter not only stresses the capacity of the cell but is not compatible with an adequate quality of experience for the users.

We can analyze how reasonable these estimations are, i.e., how likely is that we may have to provide coverage to a high number of planes (up to 60) within a cell. For providing coverage in Spain, assuming a 20 km radius for the aerial cell, around 400 cells are required to cover the country. The highest number of airplanes flying over Spain is around 8000 per day; if the busy hour concentrates 20% of the daily airplane traffic, there will be 1600 airplanes flying during this period. If 20% of the planes concentrate in 20% of the cells, this means that 320 aircraft will be served by 80 cells, i.e., 4 planes per cell. So, it is likely that the number of planes per cell would be in the lower range of planes per cell. However, this is a very optimistic estimation, as planes usually fly following routes that concentrate them in a given area. But there is a significant margin that makes us believe that capacity should not be a major issue in the service provision[4].

For a more accurate analysis of potential capacity issues for the system proposed, some additional information would be required, such as a more accurate spatial distribution of flying airplanes, as well as the activity patterns and traffic loads of the onboard users.



TDD communications

The use of 4G/5G TDD transmission mode has some implications that require additional analysis. On one hand, TDD facilitates the use of beamforming, which may help to improve the coverage and reduce interferences. On the other, the switching from the downlink transmission to the uplink transmission requires a guard period that is composed of three periods of time:

- The time required for the downlink transmission to reach the users at the cell edge.
- The time for switching between downlink to uplink operation in the UE[5].
- The maximum time advance associated with the cell radius, so uplink transmissions from the users located at maximum distance arrive at the same time at the base station receiver.

Switching time is relatively small compared to the propagation delay in a very large cell, as it is the case for airplane service proposed. Based on the assumptions used in previous sections, we can assume a maximum cell radius of around 20 kilometers, with a distance between the base station and the plane up to 25 kilometers. This means that the maximum one-way propagation delay is 83 ns, so the minimum guard period is 166 ns.

To implement the guard period for a given cell size, one or more symbols should not be used either for transmission or reception. In LTE, this implies that a specific TDD subframe configuration (out of ten defined in the standard) should be used, e.g., configuration 4 as defined in the standards, with 4 symbols reserved for guard period. In NR, depending on the subcarrier spacing used, for a 25 km cell, a minimum of 3 and 5 symbols should be reserved for guard period when using 15 kHz and 30 kHz subcarrier spacing, respectively. The allocation of resources between uplink and downlink is much more flexible in NR, but the requirement of a minimum guard period should be respected. Having 3 symbols reserved for guard period obviously decreases the available resources with respect to the normal TDD operation in 5G, which assumes one symbol guard period, enough for cells with 10 km radius. The question is whether having a different guard period in the terrestrial and aerial networks may have an impact on interference experienced. As we have commented when dealing with interference issues, it seems necessary that the terrestrial TDD network will be time synchronized with the aerial

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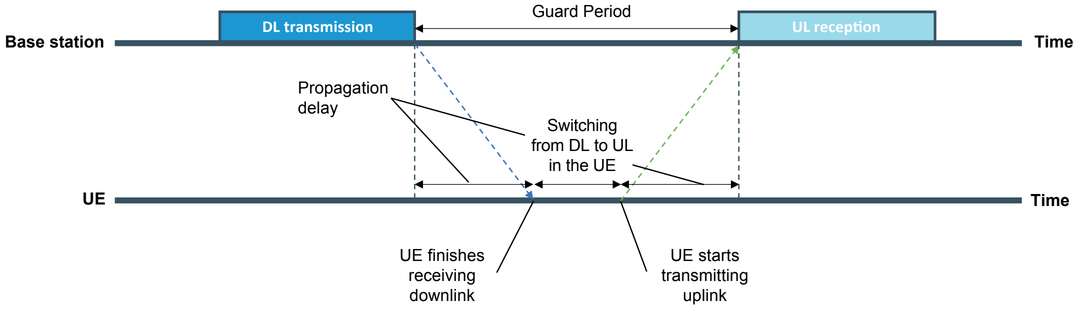
[4] We do not know the service usage patterns of the airplane users, that may be a significant factor to be considered. In this sense, the most likely pattern is the one observed in high speed trains.

[5] It is assumed that the transition from reception to transmission in the base station can be performed in much faster way.



one. If this is the case and we assume that the guard period start at the same time in both networks.

- Aerial downlink transmission may reach the terrestrial cells when the terrestrial users have already started to transmit. However, we are assuming that aerial cells antenna design will preclude this to be a problem.
- Terrestrial uplink transmissions will reach the aerial antenna before the aerial UEs have started transmitting, so causing no harm.

TDD operation, when fully synchronized[6] with the terrestrial network, is feasible. However, the long guard period required will have an impact on the aerial capacity.

5TONIC proposed innovations

To overcome some of the problems, it may be necessary to implement some new techniques. For this purpose, 5TONIC has identified several potential innovations:

- Use of Luneburg lens antennas, that allow for the implementation of multisector sites with a reduced footprint and a large gain over different frequency bands.

  Luneburg antennas have been used by former 5TONIC member Cohere Technologies to test OTFS with Telefónica, as well as by some operators to support high capacity solutions for special events. Luneburg antennas have other advantages, like reduced weight and wind load, a large front-to-back ratio, and the fact that the same antennas provide coverage for multiple bands.

- New optimized antennas, developed ad-hoc for this applicaction, that fulfill a set of requirements:
  - Low back and side lobes, to reduce interference issues with the co-channel terrestrial network.
  - Support of multiple sectors with high antenna gain.
  - Low deployment cost, low maintenance antennas.

  The design of such antennas can be carried out by 5TONIC member CommScope.

- Use of the location information broadcasted by the planes with the automatic dependent surveillance–broadcast (ADS-B) protocol for beam steering. Planes broadcast their identity, position, velocity, and other information derived from onboard navigation systems in the plane usually very half second. The information can be easily decoded and used to steer a beam towards the plane.

  The great advantage of using ADS-B beam steering is that it can be used with both TDD and FDD spectrum. However, there are several technical challenges, as is, for FDD, the determination of the plane the UE is inside of when a cell is covering several aircraft.

- Interference cancellation for limiting uplink interference from aerial users. A relatively simple analog interference cancellation mechanism can be designed and deployed for

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[6] This means not only that frames start at the same time in both networks, but swithching the direction of the link happens also at the same time.

cells that experiment high uplink interference, which also makes use of the ADS-B information to estimate the direction of arrival for the interfering UE signal.

Conclusions

Limitations on the use of mobile devices in planes were probably justified in a time when planes' instrumentation could be susceptible to the interference they generated. However, it seems clear that we are now in a situation where phone generated interference is no longer a major issue. Consequently, it is a good moment to open up the debate on whether the mobile services can be provided to users inside an airplane in flight in the same way that they are provided when they are on a high-speed train. This approach will surely be met with some resistance, as airlines get significant benefits from providing in-aircraft communications services with proprietary solutions. But it looks unfair that users are precluded to use their devices and access mobile services if this does not imply any issue for the aircraft functioning and does not require an extra cost for airlines.

The support of such services should be based on a system that does not require the implementation of any network element inside the aircraft and, as far as possible, reuses the existing terrestrial infrastructure. The antennas, as they should be pointing towards the sky, cannot be reused, but other elements, as radio units and baseband processing units, can serve both terrestrial and aerial cells. On top of this, some additional level of intelligence should be provided, e.g., to preclude phone operation during aircraft landing and takeoff maneuvers.

From the analysis we have carried out, we consider that the provision of services for airplane users is feasible from a technical viewpoint, although more measurements are required for, e.g., estimating the attenuation the aircraft structure produces. The main challenge is the coverage provision, while capacity may be an issue in areas where the number of airplanes per cell is high, i.e., in the proximity of airports – but it is very likely that for safety reasons services should not be provided in these areas. The cost of deploying the required infrastructure can be minimized by the partial reuse of the terrestrial infrastructure, as well as the optimization of the coverage areas to match the airplanes' routes. Intelligent planning may also help to minimize the potential interference issues towards the terrestrial network.

Because of the need of deploying new antennas, it is an open question whether it is more convenient to use FDD spectrum in lower frequency bands, maximizing coverage, or TDD spectrum, in higher frequency bands that would support a higher capacity thanks to more bandwidth and multiuser MIMO supported by the Massive MIMO solutions available. Our preliminary analysis indicates that coverage, rather than capacity, will be the main planning factor that needs to be addressed. In this sense, it should be understood that using massive MIMO for serving airplanes should look to balance capacity, attending more users over the same resources, and coverage, that would require using more antenna elements per user to get the higher beamforming antenna gain that would guarantee a good coverage in high frequency bands. This means that no significant multiuser MIMO gains will be obtained from the use of TDD. On top of this, the long guard periods required to the large distance between antenna and airplane and the need for synchronization with the TDD terrestrial networks are also factors that go against the use of TDD spectrum.

In this sense, we consider that the use of FDD spectrum is a more adequate solution, especially if it is combined with cell sectorization to increase the capacity. The use of Luneberg lens antennas is one solution that 5TONIC supports for increasing the capacity while improving coverage thanks to sectorization. The design of a specific antenna is also an alternative that can facilitate the deployment and help to minimize the interference issues. Also, potential interference issues on the terrestrial network are easier to manage when operating an FDD aerial network.

Another area that may help to facilitate the implementation of the proposed services is the use of ADS-B information for enhancing the radio communications, either facilitating beamforming with FDD spectrum or supporting the processing for interference cancellation at the terrestrial network. These innovations require to overcome some significant challenges when the number of airplanes served by a cell is high. ADS-B could be substituted by an IoT (e.g., NB-IoT) device in the airplane that provides additional information beyond the airplane position and speed that can be used for the service support, although this would require some cooperation with airlines.

In any case, the assessment of the technical feasibility of the service is only a first step towards a potential implementation in the real world and further analysis is required. Fundamentally, it is still an open question how the services can be monetized by the operators; also, whether the infrastructure deployed for providing the services can be reused for other purposes, e.g., supporting communications with drones. Of course, it may be possible to charge these services independently from terrestrial services (although at a lower cost than the proprietary solutions implemented by airlines). And the system may allow operators to get roaming users before the plane they travel in lands, generating additional revenue. Analysis of the regulatory implications is also needed and, in general, further work, both in technical and economic fronts, is required.

References

[1] **Nokia**, Using air-to-ground LTE for in-flight ultra-broadband, *Strategic White Paper,* 2018

[2] N. Moraitis, A.D. Panagopoulos, "Aircraft Attenuation Measurements and Radio Interference Scenarios Between In-Cabin and Terrestrial Cellular Networks," *IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS* Vol. 47, Nº 4, pp 3051-3061, October 2011

About 5TONIC

5TONIC is an open research and innovation laboratory focused on 5G technologies founded by Telefónica and IMDEA Networks based in Madrid.

The goal of 5TONIC is to create a global open environment where members of industry and academia work together on specific research and innovation projects related to 5G technologies in order to boost technology and innovative companies.

The laboratory promotes the development of joint projects, in addition to entrepreneurial projects, discussion forums, events and conferences in an international environment.

Among the members that are part of the laboratory are:

Founders:

Telefónica
institute imdea networks

Members:

ERICSSON
intel
COMMSCOPE
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InterDigital.
altran

As a fundamental part of their activity, 5TONIC scientists actively contribute to the development of 5G in a series of European research projects. This research is carried out in collaboration with the main infrastructure and equipment suppliers, international operators, research institutes and leading universities, as well as SMEs. These projects are aimed at empowering vertical industries such as Industry 4.0, Transportation or Energy. Some of these projects are: 5GROWTH, 5G-VINNI, 5G EVE, 5RANGE, 5GENFIRE or 5GTRANSFORMER.

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