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LTE Handover Design for Cellular-Connected Aircraft

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***Abstract*—Ubiquitous accessibility worldwide and superior performance of cellular networks of communication data like fourth generation (4G) and fifth generation (5G) make them a perfect candidate for air to ground (A2G) communications for low to medium altitude aircraft systems such as unmanned aerial vehicles (UAVs) and urban air mobility (UAM). However, cellular networks are designed and optimized for terrestrial users, and can be employed for electric vertical take-off and landing (eVTOL) aircraft flying at higher altitudes and faster speeds is accompanied with some issues which should be resolved prior to application. Mobility handovers and other measurements including radio link failures, delays, and degraded throughput is a major issue in wider employment of cellular networks for A2G communications. In this paper we have considered two main issues of eVTOL aircraft handover using LTE networks. We proposed novel handover algorithms addressing mobility issues, which will help to decrease the number of unnecessary and ping pong handover, as well as radio link failure rate for cellular connected aircraft. The improved performance of the proposed algorithms has been verified by extensive simulations in a bespoke designed simulation model for cellular connected aircraft served by LTE networks.**

Keywords— eVTOL Aircraft, UAV, UAM, Cellular Networks, 4G, LTE, Handover, Air to Ground Communications.

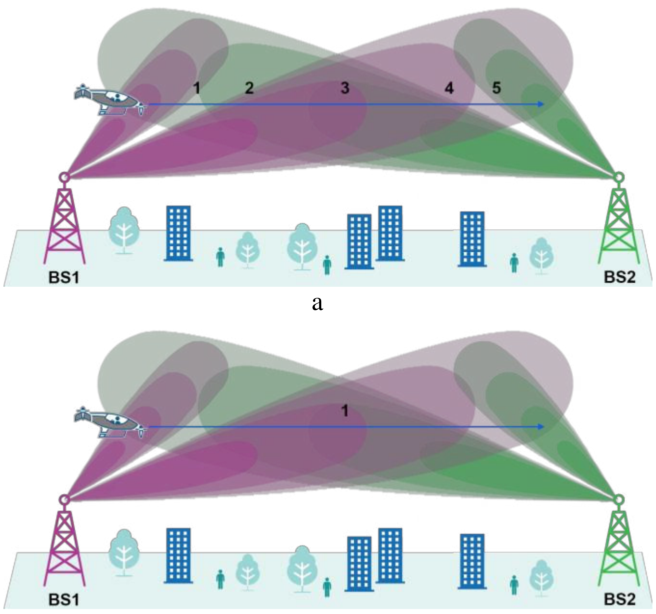
I. INTRODUCTION

Communications is one of the most important components of unmanned aircraft systems (UAS), and urban air mobility (UAM) systems to ensure safe and efficient operation of them in low to medium altitudes. Thanks to the almost ubiquitous accessibility worldwide and superior performance of today's 4G- Long-Term Evolution (LTE) [add future 5G wireless networks cellular-enabled air-to-ground (A2G) communications is expected to achieve significantly enhanced performance over the existing point-to-point A2G communications, especially for extended range beyond visual line of sight (BVLOS) operations. Despite its promising future, many new design challenges need to be tackled for realizing effective cellular-enabled A2G communications, since the present cellular communication networks have been designed for terrestrial users with considerably different characteristics to the aerial users.

One of the main challenges in employing cellular-enabled A2G communications is inefficiency of handover processes for electric vertical take-off and landing (eVTOL) aircraft. The conventional handover mechanism is suitable for terrestrial aircraft, which are served by the main beams of the cellular antennas tilted towards the ground where the transition of signal strength from one cell to another is relatively smooth and not too frequent. However, for an eVTOL aircraft flying above the cell towers served by the weak sidelobes of the cell antennas at relatively higher speeds than eVTOL aircrafts, the case is different. Unlike aircraft will sense the reference signals of a larger number of cells which are very similar, and a minor change in the value of these reference signals will lead to frequent and unnecessary handovers followed by delays and service interruptions. In addition, weak and inconsistent lobes of side beams provide intermittent network coverage to eVTOL aircrafts that causes ping-pong handovers. The other factor is the high speed of eVTOL aircrafts on conventional aircraft or UAM vehicles. Although the LTE air-interface has been designed to accommodate up to 350 km/h speeds, with some modes supporting up to 500 km/h in anticipation of its use in high-speed train applications [1], in practice the performance of LTE network degrades with speed and this degradation is severe at speeds more than 300 km/h. These characteristics of cellular networks and eVTOL aircrafts make mobility management a challenging task and require handover decision schemes for eVTOL aircrafts that take these characteristics into account and avoid unnecessary handovers as much as possible.

In conventional 4G/LTE networks, handover decisions are made by the serving cell based on the information within the measurement reports (MRs) sent by eVTOL aircrafts [2]. Therefore, most of the new handover schemes to improve the performance of the network for any eVTOL aircrafts are designed in the way to be implemented on the network side (base stations and core network). However, such approaches require some modifications to software, hardware and standards of the whole system which is timely and need considerable changes and investments. Thus, there is an urgent need to evaluate the capabilities of each technology to determine its feasibility for future applications in the sky.

In this paper, we have introduced novel modified handover methods to be applied on the eVTOL aircrafts side, which is much easier to implement and consistent with the current network standards. In the proposed handover techniques, the eVTOL aircrafts generates a modified MR and via sending this modified MR, directs the serving cell to make the desired handover decision dictated by eVTOL aircraft.



a

b

Fig. 1. a) unnecessary ping-pong handovers due to sidelobes null spaces. b) minimized handovers through modified LTE handover procedure.

II. HANDOVER ISSUES FOR A2G COMMUNICATIONS

In this paper, we have considered two major handover issues for cellular connected aircraft and have proposed methods to resolve these issues.

The first issue for eVTOL aircraft is the unnecessary ping pong handovers during short sojourn period between LTE sidelobes. As illustrated in Fig. 1.a. the aircraft travelling over BS1 towards BS2 will have 5 handovers, 4 of which are due to transition between sidelobes. These unnecessary handovers could be avoided if the sojourn time between sidelobes is quite short within an acceptable range, and aircraft may remain in connected state to the serving cell during these short service interruption periods. In this way we can avoid 4 unnecessary ping-pong handovers in Fig 1.a and the result would be just one handover as shown in Fig. 1.b.

The second issue corresponds to unnecessary and inefficient handover to neighbour cells. As mentioned in the previous section, when the number of detected cells by aircraft increases, the aircraft may handover to a neighbor cell even if the serving cell still can guarantee a reliable connection. In addition, when the serving cell cannot offer good service to aircraft and a handover is needed, the service may be handed over inefficiently to a neighbour cell which may lose its competency very soon and initiates another handover. These unnecessary handovers, if successful, will increase the total service interruption time as well as delay, and if not successful will end in radio link failure (RLF). To mitigate this problem, a list of preferred cells along the trajectory of flight would be prepared in advance and aircraft will prefer to be handed over to these cells if possible.

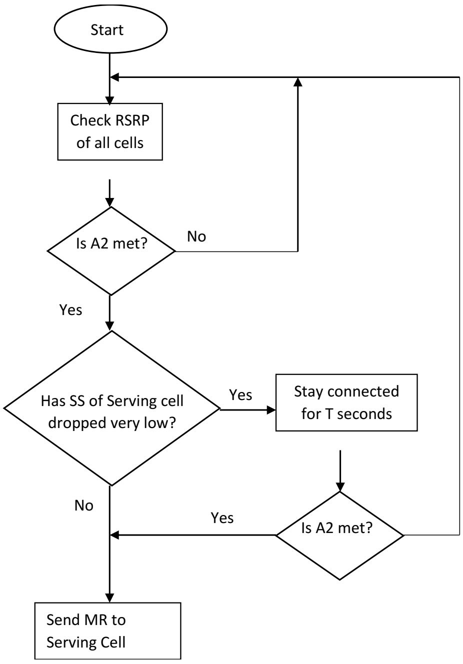


Fig.2. Algorithm 1 flowchart.

As mentioned previously, in LTE networks, the decision on handover is made by serving cell and not the user equipment. However, it doesn’t mean that aircraft has no role in this process. In fact, it is the aircraft who alerts the serving cell on the status of the reference signal received power (RSRP) and reference signal received quality (RSRQ) of detected neighbour cells via sending periodic or event triggered measurement reports. and initiates the process of decision making and handover by serving cell. If the aircraft sends a tailored MR containing the status of preferred neighbour cells (and not all detected cells), it can direct the serving cell to initiate handover process according to aircraft preferences.

Considering the above points, we have proposed two handover algorithms addressing above issues and reducing the number of handovers for an aircraft which are described in the next section.

III. ALGORITHMS

The first algorithm (Algorithm 1) is based on a different trigger event (Event A2) rather than conventional trigger events (Events A3 and A5) used in default handover procedure [3]. Like default LTE handover procedure, in this algorithm the aircraft periodically measures the signal strength of serving cells and detected neighbour cells. In the first step, it compares the RSRP of the serving cell ($RSRP_s$) against a minimum acceptable threshold ($RSRP_{min}$). If $RSRP_s > RSRP_{min}$, it means that serving cell still can serve the aircraft reliably, so there is no need to handover, even if other cells can provide higher RSRPs. If $RSRP_s < RSRP_{min}$, A2 event is triggered and aircraft would decide on possible handover to neighbour cells.

In the second step, aircraft will check if it is within a null space between sidelobes or not. When an aircraft flies into the null space of antenna lobes of the serving cell, the RSRP suddenly drops to a very low value. In this case the serving

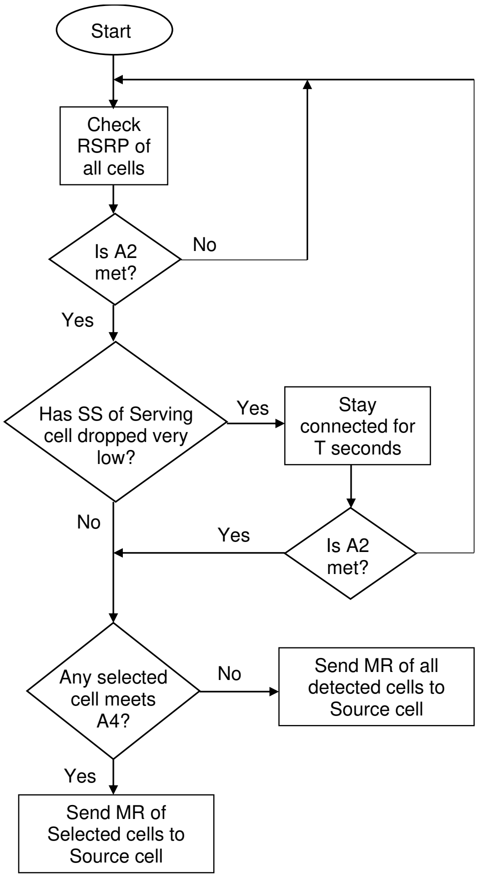


Fig. 3. Algorithm 2 flowchart.

cell or the aircraft calculates the remaining time of the aircraft being in this space according to the location information and velocity vector of the aircraft. If the remaining time is less than a pre-defined maximum, the aircraft will not send measurement report to serving cell to initiate handover process. This maximum timeout value depends on the aircraft and application. The flowchart of this algorithm is shown in Fig. 2.

The second algorithm (Algorithm 2) inherits the functionality of the previous algorithm with some added features to address the second issue highlighted in the previous section. In this algorithm, the criteria for handover to a target cell is not only the signal strength, but also the location of the candidate cell and its distance to the flight trajectory is important.

Assume that the RSRP of the serving cell is going to be less than $RSRP_{min}$, and the aircraft detects a few neighbour cells with higher signal strength. In this algorithm the aircraft would not include the signal strength of those cells in its measurement report if it were flying away from them according to the predicted trajectory of the aircraft. As the flight route from origin to destination in known in advance, the aircraft will prepare a list of priority cells which are closer to the flight route than the other cells. This list would be available prior to flight provided that the information on the location and number of cells along the flight trajectory was known to the aircraft.

When the RSRP of the serving cell falls below $RSRP_{min}$, aircraft will send the MR to the serving cell which includes the results of the detected cells of the priority list. If no cells from this list meets the criteria for handover, then the ordinary MR including the RSRP of all detected cells would be sent to the serving cell. And the serving cell will decide on the handover based on the received MR.

The flowchart of this algorithms are depicted in Fig 3. These algorithms created use of A2 and A4 events to initiate handover process rather than A3 and A5 which are used in ordinary handover procedure for terrestrial users.

IV. SIMULATIONS

In this section, we conducted simulation level to perform the proposed handover algorithms and compared the output results with the default LTE handover procedure designed for terrestrial users.

As there is no simulation tool or software modelling the operation of LTE networks for aircrafts at high altitudes and speeds communicating through sidelobes of cell towers, we created a simple simulation model focusing on handover performance of LTE networks for aircrafts at different speeds and altitudes. The simulation scenario designed for a rural or urban scenario with just macro cells with identical characteristics (transmission power, radiation pattern, tower height, etc.). Our model considers 7 cells as shown in Fig. 4 with a tower at the centre of each cell covering 360 degrees.

Furthermore, we assumed that each tower is equipped with three Katherin 800 10123 directional antennas [4] with horizontal and vertical radiation patterns shown in Fig. 5.

Moreover, we have assumed that each antenna is down tilted by ten degrees, and we did some approximations in combining multiple sidelobes into three main sidelobes as shown in Fig. 5.

Each flight round would be along a straight line between two points (A to B, Fig. 4) at a fixed altitude and constant speed. The horizontal cross section of three sidelobes of each tower at a fixed altitude is shown with different colors and the null spaces between sidelobes with white areas in Fig. 4.

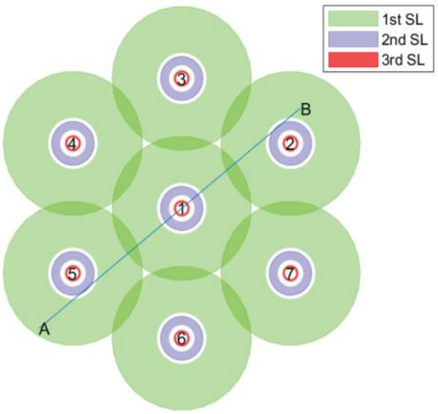


Fig. 4. Flight route and coverage area of sidelobes of each cell

It has been assumed that the aircraft is equipped with an omnidirectional external 4G antenna installed under the fuselage of aircraft facing ground and the aircraft onboard the aircraft can be reprogrammed to execute proposed handover algorithms. The other parameters of simulation scenario are summarized in Table I.

TABLE I. SIMULATION PARAMETERS

Macro cell Transmission power	45 dbm
Main beam gain	17 dbi
1st Sidelobe gain	10 dbi
2nd Sidelobe gain	7 dbi
3rd Sidelobe gain	4 dbi
Cell diameter	3000 m

For evaluation of the performance of the proposed handover algorithms (Algorithm 1 and Algorithm 2) in terms of handover rate, RLF rate, and ping pong rate, a series of simulation rounds at different speeds and diferent altitudes with different flight routes were conducted and the average result of these rounds have been presented in this section.

Fig. 6. depicts the RSRP of detected cells at the height of 100 m AGL along its trajectory from point A to B. At low altitudes aircraft does not fall within the coverage area of any sidelobe of remote towers, and only detects the propagation of the closest tower. Fig. 7. shows the same metric at a higher flight altitude (1000m AGL) and as it is seen, all 7 cells are detected during the whole flight path.

It should be mentioned that in these simulations we have not considered the multipath reflections from main beams or strong sidelobes of the serving or neighbour cells at low altitudes. But at higher altitudes these multipath reflections are too weak to be considered.

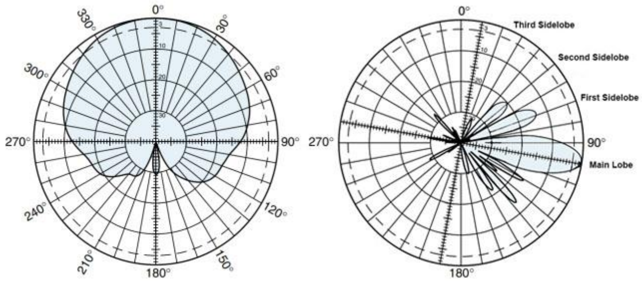


Fig. 5. Katherin 800 10123 antenna radiation pattern at 1710-2180 Mhz.

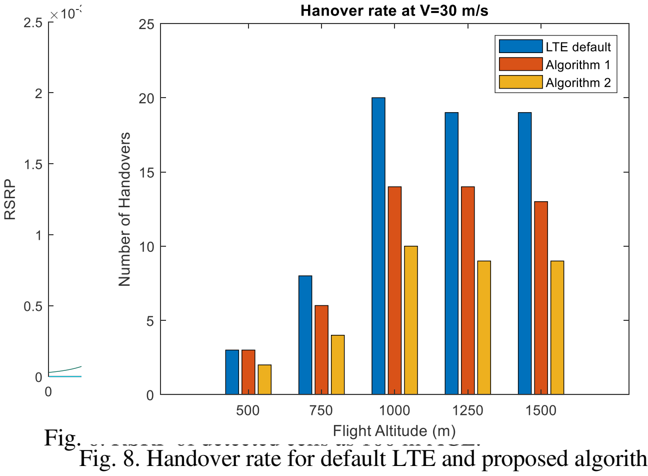


Fig. 8. Handover rate for default LTE and proposed algorithms.

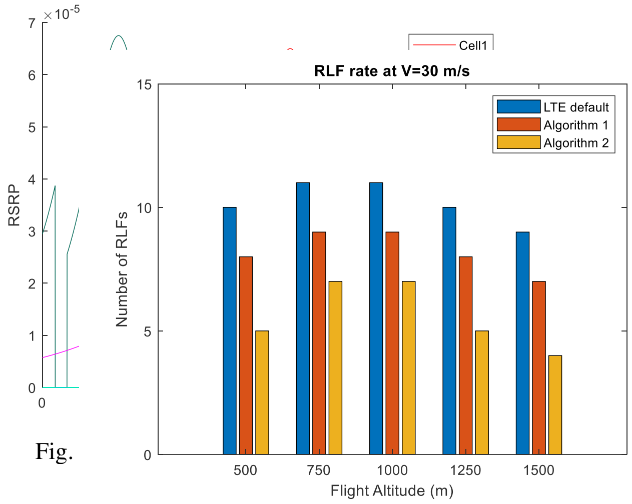


Fig. 9. RLF rate for default LTE and proposed algorithms.

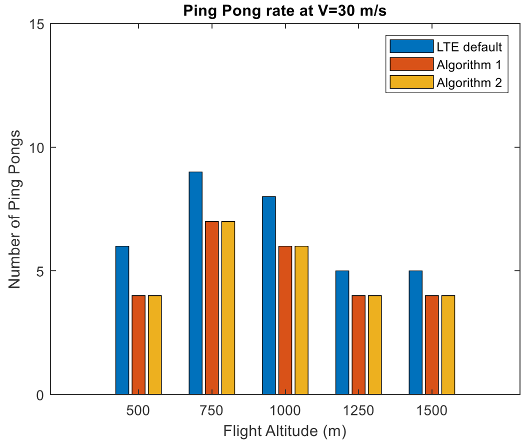


Fig. 10. Ping-pong rate for default LTE and proposed algorithms.

Fig. 8. shows the handover rate for a series of flights at different altitudes and at the cruise speed of 30 m/s for three

different handover algorithms (LTE default algorithm, proposed Algorithm 1, and Algorithm 2). As it is obvious, both proposed algorithms decrease the number of total handovers at all altitudes, where Algorithm 2 outperforms Algorithm 1. From this graph we notice that the number of handovers depends on the altitudes of aircraft, and as was anticipated, at higher altitudes, more celles are detected, hence more handovers may occur. We have simulated the same metric for higher cruise speeds where the results follow the same trend as Fig. 8, and for brevity, we have not included them in this paper.

Fig. 9 depicts the RLF rate for the default and proposed handover algorithms at different heights at 30 m/s cruise speed. As it is seen the number of RLF declarations by aircraft in proposed algorithms is less than that of default handover procedure. When the number of unnecessary handovers decreases, the RLF caused by unsuccessful handovers decrease as well. In addition, the aircraft stays in connected mode over the short null spaces, instead of trying for an unnecessary handover. This result confirm that our proposed algorithms does not improve the handover rate at the price of higher RLF rates.

Fig. 10 shows the rate of ping pong handovers at different altitudes. The modified algorithms were able to reduce the number of unnecessary handovers during short null space transitions of antenna sidelobes, decreases the number of ping pong handovers. The difference between two algorithms performance are not recognised, as the ping-pong handovers are mainly due to null spaces of antenna sidelobes, and both algorithms have a similar function towards them.

V. Conclusion

Although cellular communication with ubiquitous coverage and superior services seems to be a viable and ready solution for A2G communications in low to medium altitudes, there are some major issues in their wide application which should be addressed. Unnecessary mobility handover for eVTOL aircraft could be mitigated by modifying software for handover algorithms and hardware of cellular networks. The proposed handover algorithms in this paper are examples of low-cost and easy to implement solutions with satisfactory results. To conclude, the urban community to benefit from the potential of drones and eVTOL aircraft, they must embrace the large-scale adoption into the advanced technology infrastructure. To support the drive towards public acceptance, there is an opportunity to place drones with positive social impact at the forefront of development.

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