DISTRIBUTION NETWORK MAINTENANCE WORK ENHANCEMENT WITH DRONES DURING LIMITED MOBILE NETWORK ACCESS

Joonas SÄE
Tampere University
Finland
joonas.sae@tuni.fi

Jarkko LAAJA
Tampere University
Finland
jarkko.laaja@tuni.fi

Heikki PAANANEN
Elenia Oy
Finland
heikki.paananen@elenia.fi

Mikko VALKAMA
Tampere University
Finland
mikko.valkama@tuni.fi

ABSTRACT

Severe storms can cause major disturbances to electricity distribution. To restore power, distribution system operators (DSOs) deploy an extensive repair operation. The repair workers are dependent on a working cellular network connection. However, mobile networks are reliant on electricity networks. The cellular base stations (BSs) that serve the repair area might be affected by the power outage resulting in cellular network dead zones. Although these base stations have reserve batteries, they last only a few hours after which the BSs cease to function. In order to communicate with a control centre or update the data of mobile network information systems, the linemen have to travel to an area where there is still some mobile network coverage. This can significantly slow down the recovery process of major disturbances. This paper shows an innovative way to utilize unmanned aerial vehicles (UAVs), or drones, in the distribution network's maintenance work. The results of this paper introduce a substantial extension to the normal mobile network coverage area with the help of drones. It is shown that the aerial signal power is 100–1000 times stronger (20 dB to 30 dB) compared with the ground level measurements, which enables a substantial increase to the maximum distance between the mobile network base station and the user equipment (UE). The measurement field tests show that even under normal network conditions the cell distances of UEs are increased from several kilometres in the ground-level to tens of kilometres in the air.

INTRODUCTION

Large-scale and severe storms can cause substantial damage to society's infrastructures. Nowadays, the most critical ones of them are electricity distribution networks and mobile networks. These two are especially problematic, as there are many interconnections between them. Mobile networks need electricity to power themselves and electricity networks utilize mobile networks for communications purposes, which enables in example real time situational awareness functionality. Although some backup power exists with mobile network base stations, it can run out fast, especially when the users of mobile networks increase the utilization rate in these disturbance situations [1].

Mobile networks are initially designed to provide service coverage for the ground level users. However, this does not mean that there would not be any coverage in the sky [2]. Lately, this has aroused the 3rd generation partnership project (3GPP), the standardization body behind mobile networks, to study how long-term evolution (LTE) networks could serve aerial user equipment [3]. In fact, mobile network signal strength is usually stronger with a higher altitude of the receiver, because commonly, the mobile network antennas are above rooftop levels in urban areas and much higher in rural areas. This implies that if the signal power level of the mobile network is too low in the ground level, it is strong enough for communication higher above ground level [4].

This opens up new possibilities to be utilized especially in disturbance scenarios, where the normal mobile network coverage can be limited or not even available to normal, ground level mobile phones [5]. These possibilities are interesting to many companies and operators of different fields, but they are especially useful for electricity network distribution operators because it is important to have communications in all situations.

The target of this paper was to study the capabilities of mobile networks to serve airborne transceivers (mobile phones attached to drones) at different altitudes above the ground level. Measurements were performed in five different locations in Finland under normal mobile network conditions, where pre-designed flight routes were performed for three altitudes above ground level with an unmanned aerial vehicle (UAV): 50 m, 100 m, and 150 m. Moreover, the measurements were repeated for three different commercially available mobile network technologies: global system for mobile communication (GSM, or second generation (2G)), universal mobile telecommunications system (UMTS, or third generation (3G)), and LTE (or fourth generation, (4G)). It should not be forgotten that while the signal power level is better in the sky, also interference levels are higher as noted in [6]. In addition, the normal mobile network functionality differs when operating in the air, but these aspects are excluded from this paper [7].

DRONE USAGE IN ELECTRICAL GRID REPAIR WORK

During disturbance events, the distribution system operators (DSOs) of electricity networks deploy maintenance teams to the field to re-establish in example power lines that have been cut apart by trees falling due to strong winds. The linemen need to operate with the control centre to keep up with the ongoing situation and to update the status of their work. This specific requirement can slow down the process if no mobile network coverage is available in the repair area. However, linemen need mobile networks to update the status of mobile network information or work order systems. As a result, the repair workers need to travel to an area where there still is some coverage. This usually translates to driving over 10 km away from the repair area, which again slows down the whole repair process. If UAVs, or drones, can be utilized to provide communication capabilities to these repair areas, time can be saved. Furthermore, this helps to speed up the repair process and shorten the time a power blackout is occurring.

Drones are already utilized to some extend in the repair work for DSOs. Now, repair teams are using drones to figure out those exact areas where there is a problem in the power lines [8]. This is helpful especially in those areas, where power lines are hard to reach due to the environment. Drones are also utilized to update the situation awareness for the control centre. This is usually implemented with the help of images and videos taken with a drone from higher altitude up in the air at the sites or updates of the fault locations.

MEASUREMENT METHODS

Measurement setup

The measurements were performed with a commercially available drone, the DJI Inspire 2. To measure the effectiveness of mobile networks at different altitudes, a Samsung Galaxy S8 phone was attached to the bottom of the drone. The phone was running two separate measurement software and the drone itself gathered telemetry data. This measurement data was saved to the internal storage of the phone and to the secure digital (SD) card in the drone. In addition to mobile network measurements, the connection between the airborne drone and the user at the ground level was tested. This was done by connecting a hands-free Jabra Talk 2 Bluetooth device to the measurement phone. Figure 1 depicts the drone setup for measuring cellular data.

Figure 1. *Measurement drone setup for data collection with a DJI Inspire 2 drone.*

Measurement plan

After requisitioning the appropriate permits regarding using an unlicensed transceiver (a mobile phone) in the sky and measuring the signals from cellular network base stations, the first step was to determine appropriate measurement sites. These sites were selected to simulate the circumstances of electrical grid repair situations. Therefore, the sites had to be close to 20 kV or 110 kV overhead power line and be in a sparsely populated, rural area. Additionally, the control zone of the local airport was a limiting factor for the site selection. With these criteria, five locations were chosen: Pinsiö, Valkeakoski, Orivesi, Nokia, and Savonkylä. The names are based on the closest city or municipality.

Mission plan

The mission plan was to use an approximately 1 km long mobility route around each measurement site to establish a connection to different base stations. This length was decided based on the flight it would take to fly one route, which was around five minutes per flight. To achieve comparable and reproducible results, these mobility routes were flown as autonomous missions where the drone's altitude, heading and flight route was programmed with a number of waypoints. These flights were planned using a Google Maps based mission planner. Figure 2 shows an example of the planned flight routes.

The most significant restraint to the mission planning was the limited battery life. A single flight utilized about 20% to 30% of the total battery for the planned routes. For each location, nine flights were flown with every technology (4G, 3G, and 2G) and every altitude (50 m, 100 m, and 150 m). Additionally, at the beginning of every flight, ground measurements were taken with the measurement software for comparison purposes.

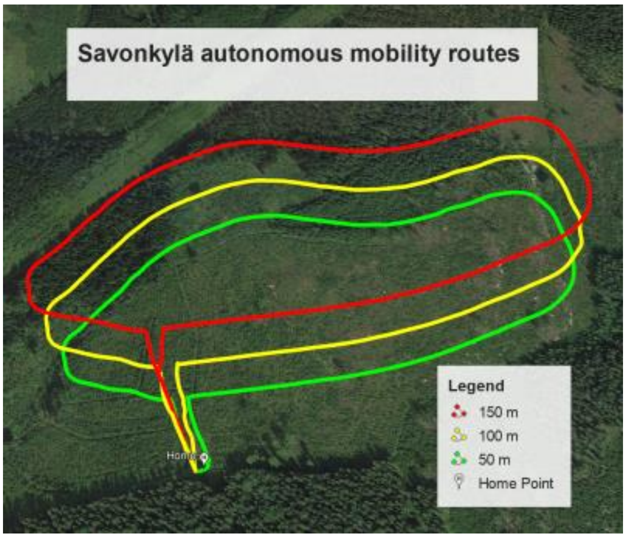

Figure 2. *Autonomous mobility route example. Map: Google Earth – Landsat / Copernicus.*

DATA PROCESSING

After every flight, the key performance indicator (KPI) and telemetry data was extracted from the phone and drone, respectively. This data was then manipulated for post-processing purposes in Matlab. This data was then visualised and analysed. Since base station location data is proprietary information that is not openly available by the internet service providers (ISPs), the physical location of base stations had to be determined by using a third party service, called CellMapper, which is a crowdsourced service [9]. By inputting the extracted network data from the measurements, this service provides an approximation of the location of the cell tower. Using this location data, the distance from the measurement site to the serving base station was calculated. Figure 3 shows the flowchart of gathering and combining data from different sources.

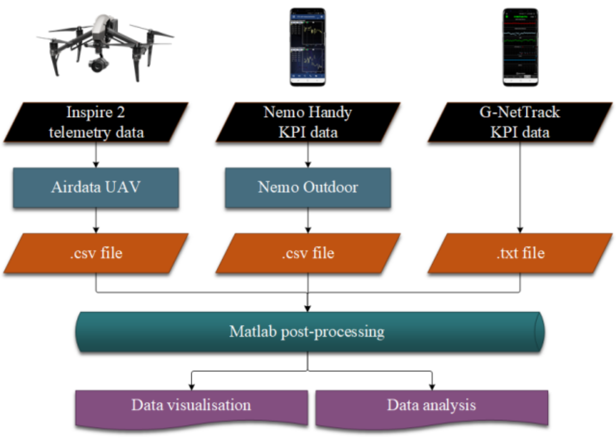

Figure 3. *Data processing flowchart.*

MEASUREMENT RESULTS AND ANALYSIS

The measurement results portray three different characteristics: received signal power, received signal quality, and signal range. Comparing the results between different technologies is not pertinent because the relevant KPI parameters have different definitions between all three technologies. Furthermore, each measurement location has different circumstances (propagation conditions, base station distances, network parameters, and antenna arrangements) that effect the measurement results. Therefore, every measurement figure depicts the results from a single site with a singular technology. As there are so many results, only one example case is analysed more carefully. After this, a collection of all measurements is summarized.

Figure 4 shows the results for UMTS (3G) signal strength (upper picture) and signal quality (lower picture) versus drone altitude. The received signal code power (RSCP) is around -90 dBm at the ground level and as the drone ascends to its mission altitude of 150 m, the signal strength increases to about -70 dBm. This 20 dB difference means that the received power is 100 times stronger in the air compared with the ground level. However, signal quality (Ec/N0) decreases with increased altitude. At ground level, the quality is about -5 dB, while in the air it varies between -10 dB and -20 dB.

The overall 3G field trial results in Valkeakoski are summarised in Tables 1 and 2 and depicted in Figure 5. The received power difference (in the top part of Figure 5) between the ground and aerial measurements is noticeable. However, in this instance, there are no significant disparities between the different UE heights. At the 50th percentile, the signal power gap between ground and aerial results is about 18 dB. Additionally, the signal quality comparison (in the lower part of Figure 5) shows that the signal quality is considerably better at the ground level. The signal quality gab is 7–10 dB between aerial and ground results at the 50th percentile.

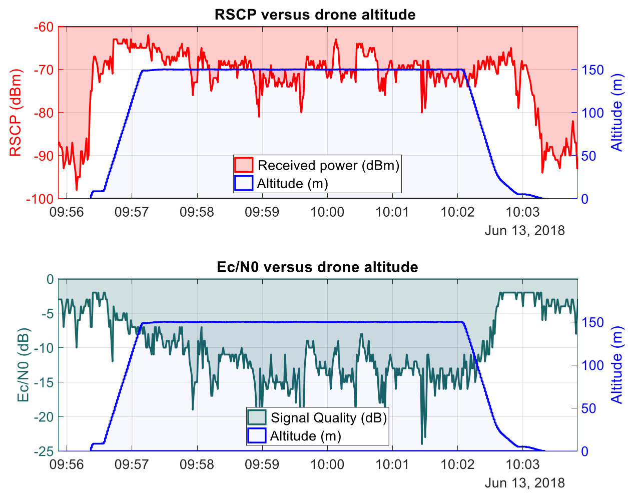

Figure 4. *Valkeakoski 3G measurement at 150 m.*

Table 1. *Valkeakoski 3G signal power values (dBm).*

	UE Height			
Percentile	**Ground**	**50 m**	**100 m**	**150 m**
90%	-83	-64	-65	-66
50%	-88	-69.5	-70	-70
5%	-93.65	-75.4	-76	-75

Table 2. *Valkeakoski 3G signal quality values (dB).*

	UE Height			
Percentile	**Ground**	**50 m**	**100 m**	**150 m**
90%	-2	-6	-8	-9
50%	-3	-10	-12	-13
5%	-10	-15	-17	-18.4

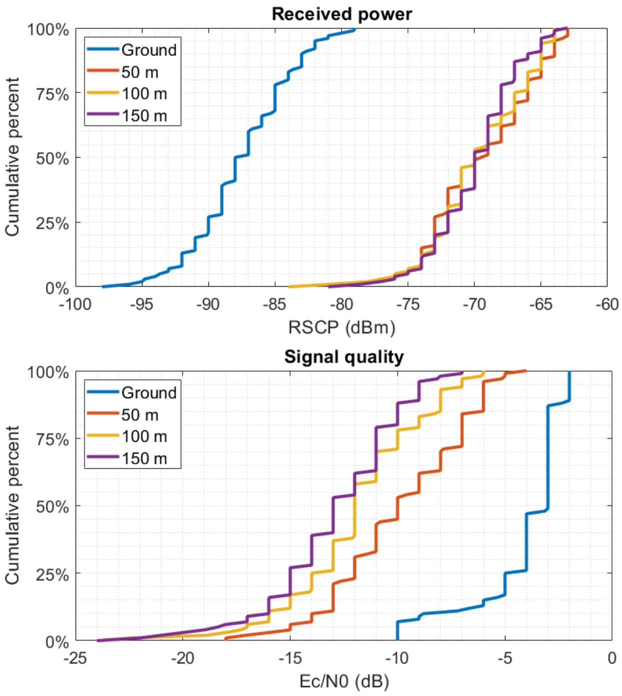

Figure 5. *Cumulative distribution functions for Valkeakoski 3G measurements.*

For the majority of the measurements, using an aerial UE results in an increased signal power with lower signal quality. However, there can still exist some situations where the propagation conditions over the treetops are not favourable due to antenna patterns. Table 3 shows the 50th percentile results (i.e. the median values) of LTE (4G) signal power results for every measurement site. The first three locations show an increase of 17–38 dB when the UE is elevated off above the ground level, while in the last two locations the received power stays relatively constant. The corresponding signal quality values are depicted in Table 4.

At the first measurement site, the signal quality is higher at 50 m and 100 m altitudes, and slightly lower at 150 m altitude. At every other site, the quality decreases 1–7 dB when the drone is airborne. The degradation of signal quality is caused by increased line-of-sight (LOS) connections to interfering base stations. The signal from these other cells results in the decrease of the serving cells signal quality. The results for the other technologies (GSM and UMTS) show similar results.

Table 3. *4G 50th percentile signal power values (dBm).*

	UE Height			
	Ground	**50 m**	**100 m**	**150 m**
Pinsiö	-116	-78	-80	-81
Valkeakoski	-102	-83	-85	-83
Orivesi	-106	-75	-76	-78
Nokia	-96	-102	-97	-97
Savonkylä	-108.5	-110	-106	-105

Table 4. *4G 50th percentile signal quality values (dB).*

	UE Height			
	Ground	**50 m**	**100 m**	**150 m**
Pinsiö	-14	-10	-13	-16
Valkeakoski	-8	-13	-15	-15
Orivesi	-9	-10	-10	-12
Nokia	-11	-12	-18	-17
Savonkylä	-11	-14	-17	-18

Signal range

In addition to the signal power and quality, signal range was also of interest. With a LOS connection to distant base stations enabling better propagation conditions, aerial UEs are able to connect to far away cells that are not available at the ground level. Table 5 shows the distance to the furthest base station in kilometres that the UE was connected to during its mobility route.

Table 5. *Distance to the furthest serving base station (km).*

	4G	**3G**	**2G**
Pinsiö	8.2	33.2	2.8
Valkeakoski	14.1	3.7	4.3
Orivesi	4.2	11.6	22.9
Nokia	11.2	39.0	7.7
Savonkylä	29.6	6.2	12.3

It can be noted that connections up to several tens of kilometres are possible with the help of drone. Furthermore, the Bluetooth connection between the airborne phone and the ground level user showed promising results. It was noted that in the case of no obstacles, i.e. no tree branches, the voice connection over Bluetooth was still working up to 200 meters with LOS connection.

CONCLUSIONS

From the obtained results, it can be concluded that the signal strength improves 20–30 dB (100–1000 times stronger in the linear scale) when a mobile phone is lifted from the ground to the air above the tree top level. In normal conditions, this translates to being able to communicate with distances from 14 km up to 39 km keeping in mind the possible errors mainly from possible crowdsourcing inaccuracies.

Although the interference conditions are worse than on the ground level, the communication is still possible. Furthermore, in disturbance scenarios, when the nearest base stations in the outage area are offline, it is expected that the interference impact for the connection is milder.

Based on the measurement results achieved in this paper, utilizing drones to provide extended link distance to the mobile network connection is feasible. This is especially useful in the maintenance work of the electricity distribution network and eliminates the need for time consuming driving between repair missions during connection outages. Furthermore, utilizing e.g. a Bluetooth headset enables a hands-free voice connection from the ground level to the linemen further easing up the utilization of the drone.

Acknowledgments

The authors would like to thank Finnish Communications Regulatory Authority (FICORA) and Elisa Oyj in providing the permissions to perform the needed measurements in a commercial mobile network.

REFERENCES

[1] J. Säe and J. Lempiäinen, 2016, "Mobile network service demand in case of electricity network disturbance situation," *IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Valencia, 1-6.

[2] X. Lin et al., 2018, "The Sky Is Not the Limit: LTE for Unmanned Aerial Vehicles", *IEEE Communications Magazine*, vol. 56, no. 4, 204-210.

[3] 3GPP TR 36.777, "Enhanced LTE support for aerial vehicles", Techn. rep., 2017. Available: ftp://www.3gpp.org/specs/archive/36_series/36.777/

[4] A. Dhekne, M. Gowda, R.R. Choudhury, 2017, "Extending cell tower coverage through drones", *Proceedings of the 18th International Workshop on Mobile Computing Systems and Applications*, 7–12.

[5] M. Deruyck, J. Wyckmans, W. Joseph, L. Martens, 2018, "Designing UAV-aided emergency networks for large-scale disaster scenarios", *EURASIP Journal on Wireless Communications and Networking*, vol. 2018, iss. 1, 1–12.

[6] B.V.D. Bergh, A. Chiumento, S. Pollin, 2016, "LTE in the sky: trading off propagation benefits with interference costs for aerial nodes", *IEEE Communications Magazine*, vol. 54, iss. 5, 44-50.

[7] S. Euler, H.L. Maattanen, X. Lin, Z. Zou, M. Bergström, J. Sedin, 2018, "Mobility support for cellular connected unmanned aerial vehicles: Performance and analysis". Available: https://arxiv.org/abs/1804.04523

[8] R. Homma, O. Sohn, R. C. Bose 2017, "Analysis of the recognition and localisation techniques of power transmission lines components in aerial images acquired by drones", *CIRED - Open Access Proceedings Journal*, iss. 1, p. 29-32

[9] CellMapper. Available: https://www.cellmapper.net/