Coverage Aspects of Temporary LAP Network

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***Abstract*—This paper studies the coverage aspects of a low altitude platform (LAP) system that can form a temporary communication network. The system consists of multiple autonomous drones equipped with dual-band Wi-Fi access points (APs) with ad hoc capabilities to form a mesh network. The suitability of the LAP system is evaluated from the coverage point of view with calculations and simulations. The results show that more drones are needed to cover (dense) urban than rural environment and the drone altitude should also be higher in urban areas compared with the rural areas.**

***Index Terms*—low-altitude platform, drone, UAV, Wi-Fi, mesh network, Ad Hoc, disaster scenarios, temporary network, emergency coverage.**

I. Introduction

Cellular networks should maintain their operational status even after (mild) disaster scenarios, however, a major problem arises when a key part of the network infrastructure is destroyed or unavailable. One such problem can be a damaged power grid or broken power lines (e.g. because of fallen trees) which supply electricity to the base station (BS) sites. The lack of electricity from the network is not a problem at first, since nowadays many operators around the world have equipped their BS sites with backup power. However, this just extends the operational time of the mobile network for a couple of hours after the electricity blackout.

Repair and emergency teams move to disaster (or blackout) areas usually as fast as possible. When they arrive at these areas, in the best case scenario, the mobile network might still be operational for a while with backup power. However, in the worst case, the cellular network might not be operational or the infrastructure might be damaged to the point that it can not function.

The emergency teams have usually their own way of communicating, e.g. through terrestrial trunked radio (TETRA) system, which is commonly used in public safety networks. However, cellular and electricity network repair teams have no possibility to use these systems. Thus, they have to rely on the existing network and pre-planned processes on how to start the repair actions. As a result, this means that there is no way to communicate between these repair teams and a lot of time is spent on moving around in the disaster-hit area in order to contact other teams for prioritizing important or critical areas.

In order to enable the use of conventional user equipment (UEs), like smart phones with Wi-Fi, a new temporary mobile network could be easily formed. There has been a lot of research around high altitude platform (HAP) systems for providing emergency coverage and recently Google's project Loon has brought this subject back on the hot topics of future networks with their HAP balloons [1]. To compete with Google's project Loon, Facebook has also invested in HAP systems with their own high-altitude long-endurance planes combined with their Internet.org project [2].

This paper studies the coverage possibilities of a temporary low altitude platform (LAP) network with the use of drones, or more generally known as unmanned aerial devices (UAVs). The idea of a temporary LAP network is based on a simple design principle: *a quick and easily deployable communication infrastructure for emergency coverage in disaster-hit areas with relatively low costs and fairly simple maintenance*.

In this study, it has been assumed that the temporary LAP network can be deployed such that the operation of LAP drones is semi-automatic. This means that field teams in the disaster areas only need to launch a drone, after which the drone will automatically take off to a predefined altitude from its take off location and form a mesh network with other drones.

The aim of this paper is to study the coverage aspects of temporary LAP systems as an emergency network for disaster areas, mainly intended for repair teams and as a backup network for rescue teams. Simulations are performed to dimension the coverage capabilities of different configurations, including the inter-drone distances (IDDs) and the operation altitude of the drones. The study also investigates the coverage aspects in two different environments: flat rural environment and (dense) urban environment with the Manhattan grid, i.e. with a dense building layer.

II. Related Work

The suitability of a disaster network has been studied from many perspectives in the literature. The authors in [3] have presented the idea of providing emergency broadband coverage with the utilization of LAPs. Their idea is based on utilizing balloons as the platforms for LAPs, like with the majority of other authors in the field, and Wi-Fi for the transmission. A similar idea is refined in [4], where TETRA and worldwide interoperability for microwave access (WiMAX) systems were also tested as the candidates for a temporary wireless network. The authors in [5] have expanded the idea and considered the use of drones with Wi-Fi to form resilient networks in order to communicate to isolated disaster areas. However, their implementation involves a moving drone in very low altitudes

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and needs to be in the close proximity of any client to collect data.

In this study, the drone altitudes of few hundred meters are considered together with mesh networking as a base for the LAP concept. It has the similar kind of idea as presented in [6], [7]: the use of unmanned aerial vehicles to form a temporal network for a disaster response. However, in [6] the authors are focusing on the localization, navigation and coordination of these devices and not the possible size of the service coverage areas, which could be possible with UAVs. In [7] some service area related aspects are taken into account, however, the authors have simulated an area of 100 m × 100 m with 50 nodes, and a fixed transmission radius of 20 m. Obviously, this kind of dense drone network would not be realistic in a rural area because the number of drones to deploy would be huge.

The authors in [8] explain the concept of flying ad hoc networks (FANETs), which is the ideology utilized in this study. The authors in [9] have also implemented an experimental study utilizing this concept. Although, they have performed the study with only two drones, they manage to establish communication for a distance of 1000 m in between the drones. The altitude of the drones in [9] is set to 10 m, so the coverage area of one drone is quite limited.

III. LAP CONCEPT

A. Propagation modeling for simulations

In order to simulate wireless communication systems, a proper radio wave propagation model is required. The basic free space path loss model would suit well with the scenarios, where mostly line-of-sight (LOS) connections are simulated. The initial IDD was calculated with the logarithmic free space model [10]. However, in order to achieve more realistic results, a deterministic propagation model was chosen for the actual simulations.

The outdoor radio channels are modeled using a deterministic radio propagation model called the dominant path prediction model (DPM) [11]. The DPM model makes the path loss prediction based on the premise that in most propagation scenarios, there are only one or two paths that contribute 90 % of the total received signal energy, hence the model determines the dominant path(s) between a transmitter and receiver for the received power estimation. As such, the accuracy of the DPM model has been reported to have accuracy similar to (and in some cases better than) the ray tracing models, while the computation time is comparable to that of empirical models (e.g. COST-231 Hata model and Walfisch-Ikegami model) [11].

The computation of the path loss in DPM is based on the following equation [11]:

$$L = 20\log_{10}\left(\frac{4\pi}{\lambda}\right) + 10n\log_{10}(d) + \sum_{i=0}^{k} f(\varphi, i) + \Omega + g_{\mathrm{t}} \quad (1)$$

where d is the distance between a transmitter and receiver, n is the path loss exponent, and λ is the wave length. The sum of individual interaction losses function, $\sum_{i=0}^{k} f(\varphi, i)$, is due to diffraction for each interaction i of all k with φ as the angle between the former direction and the new direction of propagation. The wave-guiding (tunneling) effect, Ω, considers the effects of reflections (and scattering). It is empirically determined and described in detail in [11]. Finally, g_{t} is the gain of the transmitting antenna in the receiver's direction.

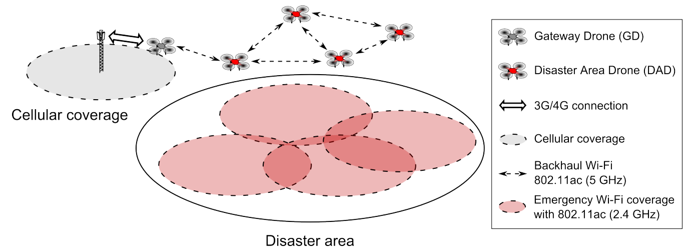


Fig. 1: An example of the temporary LAP network concept.

The recommended value for the path loss exponent, n, depends on the propagation environment (rural, suburban, urban, indoor) and the height of the transmitter. The authors in [12] have performed field tests with 2.4 GHz Wi-Fi and compared the path loss exponent with the existing ones for several propagation models. They found that the values for n in LOS range from 2.54 to 2.76. Thus, in this paper the value was chosen to be 2.6.

B. Temporary LAP network concept

The LAP concept considered in this study is shown in Fig. 1. It consists of utilizing dual band Wi-Fi equipped drones that will form an ad hoc network with IEEE 802.11 family wireless local area network (WLAN) technology utilizing 5 GHz frequency band with 40 MHz bandwidth as the backhaul connection between the disaster area drones (DADs). The actual emergency coverage is then formed with access points (APs) utilizing 2.4 GHz frequency band with 20 MHz bandwidth. In order to connect the emergency network to the Internet, some drones have to be equipped e.g. with a third generation (3G) or fourth generation (4G) cellular network modems. These drones, called the gateway drones (GDs), have to be placed in between the disaster areas and the unaffected operational cellular network area next to it.

IV. SERVICE AREA SIMULATIONS

The coverage aspects of the LAP concept were studied with the help of simulations. Different deployment cases were implemented with the help of simulation software called WinProp Software Suite with its ProMan tool for simulating wave propagation and radio network planning. The simulation results were then visualized with Matlab software.

A. Simulation setup

The rural environment simulations were implemented on a 6 km × 6 km flat terrain. The calculation resolution was set at 20 m and all other general parameters are presented in Table I.

The maximum inter-drone distances, where the communication should still be possible, were calculated with free space

TABLE I: Simulation environment parameters.

Parameter	*Value*
Simulation area	6 km × 6 km
Path loss model	Dominant path model
LOS Path loss exponent	2 (free space), 2.6 (after break point)
OLOS Path loss exponent	3.5
Calculation resolution	20 m (rural), 10 m (urban)
Calculation environment	Flat (rural) / Manhattan (urban)
Building dimensions (urban)	100 m × 100 m
Building height (urban)	25 m
Street width (urban)	20 m
Inter-drone distance	960 m (rural) 960 m, 480 m (urban)
Receiver (UE) antenna height	1.5 m

TABLE II: Drone parameters.

Parameter	*Disaster Area Drone*
Standard	802.11ac/n/g/b/a
Wi-Fi frequency band	2.4 GHz / 5.8 GHz
Bandwidth	20 MHz / 40 MHz
max. EIRP (backhaul)	35 dBm
max. EIRP (emergency coverage)	20 dBm (ETSI) / 36 dBm (FCC)
Antenna heights (Drone altitudes)	50 m, 100 m, 150 m, 200 m, 250 m, 300 m 350 m, 400 m, 450 m, 500 m,
Antenna HPBW (backhaul)	360° × 45° (azimuth & zenith)
Antenna HPBW (emergency)	60° × 60° (azimuth & zenith)
Antenna model (backhaul)	HVG-2458-05U [13]
Antenna model (emergency)	NanoStation locoM2 [14]
Antenna tilting (backhaul)	-
Antenna tilting (emergency)	90° (Facing downwards)
Antenna gain (backhaul)	5 dBi
Antenna gain (emergency)	8.5 dBi

loss model [10]. Based on the calculations, in the simulations the DADs were placed 960 m apart from each other to hover in the following altitudes: from 50 m to 500 m. The path loss exponent was assumed to match free space before the break point distance and after it the exponent was set to 2.6 according to Table I to match the values in [12] for LOS connections. For non line-of-sight (NLOS) regions, the obstacle line-of-sight (OLOS) path loss exponent was utilized and set to 3.5 to match the path loss exponent value for (dense) urban environment.

The key drone parameters for the simulations are presented in Table II. In Europe, the effective isotropic radiated power (EIRP) of Wi-Fi is limited to 20 dBm for 2.4 GHz frequency band and 36 dBm for 5.8 GHz frequency band by European Telecommunications Standards Institute (ETSI). The corresponding values set by Federal Communications Commission (FCC) in the United States are 36 dBm for 2.4 GHz frequency band and 35 dBm for 5.8 GHz frequency band. In this study, 5 GHz frequency band EIRP is 35 dBm when a 5 dBi omnidirectional antenna is utilized. 2.4 GHz Wi-Fi EIRP was set to 20 dBm (ETSI) and 36 dBm (FCC) when a 60° × 60° (azimuth & zenith) half-power beamwidth (HPBW) antenna was utilized. This antenna was faced downwards (tilted 90°) and mounted below the drone in order to form a *spotlight* or *data-shower* coverage on the terrain below.

In order to have some urban environment comparison, the next simulation rounds were set up also with 6 km × 6 km area and the IDD was kept the same at first (960 m) to be in line with the values used in [15]. Next, the IDD was reduced to 480 m to study the effect of densification of these drones. These urban simulations had the Manhattan grid to see the effect of dense urban environment and the calculation resolution was set at 10 m. Table I shows the parameters for the Manhattan grid (the dimensions of the buildings and the width of the streets).

The simulation of gateway drones was not included with the simulation of the mesh network, since the implementation of a 3G or 4G cellular network modem to the system was not possible. However, this was not relevant from the coverage point of view, and in this study it has been assumed that the GD has enough capacity to the existing cellular network that it would not be a bottleneck for the functionality of the mesh network. The mesh network capabilities were only considered in the idea level, so practical equipment related to them were not studied.

B. Results

The emergency coverage area of one DAD is larger with higher altitude as expected. However, the difference in the actual coverage areas between the different altitudes is not large. The lowest coverage is achieved with the lowest drone altitude of 50 m resulting in a service area (−80 dBm) of 0.14 km^2 (ETSI) and 3.51 km^2 (FCC). Correspondingly, the highest emergency coverage was simulated to be 0.56 km^2 (ETSI) and 7.4 km^2 (FCC) with a drone altitude of 500 m. The results for different drone coverage areas with respect to the altitude are shown in Fig. 2.

Fig. 3 shows results for the urban environment with the Manhattan grid. It shows the total (outdoor) area coverage percentage (the area where the minimum received signal power level is greater than or equal to −80 dBm with respect to the simulation area of 36 km^2) as a function of drone altitude for different configurations. Fig. 3a shows the results for the ETSI regulations and Fig. 3b for the FCC regulations. The coverage increases when the number of drones and the drone altitude increases, as expected. However, longer IDD with a lower number of drones is able to provide as good or better coverage than shorter IDD with a higher number of drones. It should also be noted that the coverage of the outdoor urban environment depends strongly on the dimensions of the buildings and the orientations of the streets with respect to the locations of the drones.

V. Conclusions and Future Work

The coverage study performed in this paper for the LAP concept shows that the emergency coverage for a disaster area would be possible to implement with a reasonable number of drones. The LAP concept can utilize the existing cellular infrastructure that is still functional next to disaster areas, thus

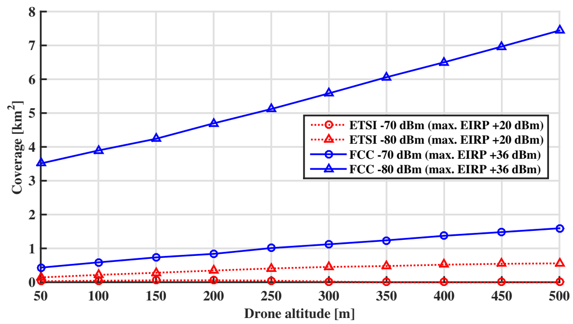
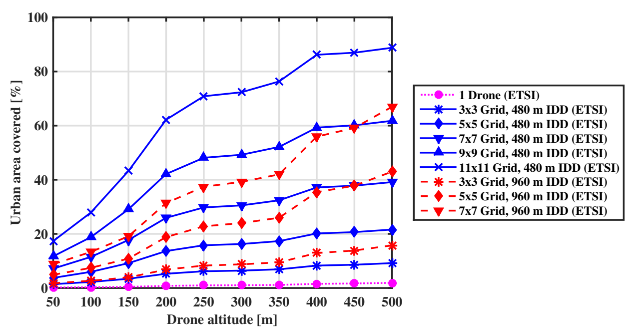
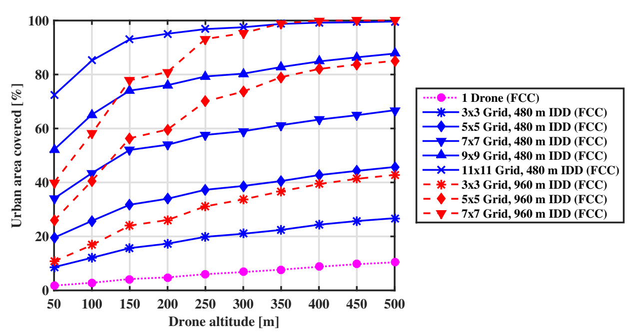


Fig. 2: Emergency coverage area of *one drone* as a function of drone altitude in rural area.



(a) Maximum drone EIRP 20 dBm (ETSI).



(b) Maximum drone EIRP 36 dBm (FCC).

Fig. 3: Dense urban environment outdoor coverage for the Manhattan Grid. Coverage limited to −80 dBm.

enabling cost-efficient solution to provide Internet connection to the disturbance area.

It should be noted that the altitude of the drones does not provide much gain for coverage, i.e. the coverage area for higher drone hovering altitudes is not significantly larger in rural environment. As a result, the drone hovering altitudes should be kept rather low. Therefore, the biggest limiting factor for larger coverage areas is IDD, but in order to extend it, some highly directive antennas would be needed.

The flight and hover time of the drones will not be a problem, since nowadays there exist drones [16] that can stay in the air with a microfilament system providing energy from the ground-level up to 150 m for as long as needed. Thus, the results are implementable at least to 150 m altitude. However, results for the higher altitudes provide insight on how much coverage could be possible to achieve without height restrictions.

The results of this paper relied on simulation scenarios and their accuracy might not correspond entirely with real life implementations although the utilized models are rather accurate. Thus, the future work on this topic will concentrate on more complex scenarios. The focus will also be on the capacity aspects, and eventually the target is to implement the proposed system.

Acknowledgment

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References

[1] Google, “Loon for all,” October 2015.
[2] Internet.org by Facebook, “Connecting the World from the Sky,” 2014.
[3] H. Hariyanto, H. Santoso, and A. Widiawan, “Emergency broadband access network using low altitude platform,” in *Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME), 2009 International Conference on*, Nov 2009, pp. 1–6.
[4] A. Vilhar, A. Hrovat, T. Javornik, and M. Mohorcic, “Experimental analysis of wireless temporary networks deployed by low altitude platforms,” in *Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2013 IEEE 18th International Workshop on*, Sept 2013, pp. 238–242.
[5] N. Uchida, M. Kimura, T. Ishida, Y. Shibata, and N. Shiratori, “Evaluation of Wireless Network Communication by Autonomous Flight Wireless Nodes for Resilient Networks,” in *Network-Based Information Systems (NBiS), 2014 17th International Conference on*, Sept 2014, pp. 180–185.
[6] G. Tuna, T. Mumcu, and K. Gulez, “Design strategies of unmanned aerial vehicle-aided communication for disaster recovery,” in *High Capacity Optical Networks and Enabling Technologies (HONET), 2012 9th International Conference on*, Dec 2012, pp. 115–119.
[7] G. Tuna, B. Nefzi, and G. Conte, “Unmanned aerial vehicle-aided communications system for disaster recovery,” *Journal of Network and Computer Applications*, vol. 41, no. 0, pp. 27 – 36, 2014.
[8] İlker Bekmezci, O. K. Sahingoz, and Şamil Temel, “Flying Ad-Hoc Networks (FANETs): A survey,” *Ad Hoc Networks*, vol. 11, no. 3, pp. 1254 – 1270, 2013.
[9] Y. Gu, M. Zhou, S. Fu, and Y. Wan, “Airborne WiFi networks through directional antennae: An experimental study,” in *Wireless Communications and Networking Conference (WCNC), 2015 IEEE*, March 2015, pp. 1314–1319.
[10] Study Group 3, “Calculation of free-space attenuation,” ITU-R, Recommendation P.525-2, 1994.
[11] “ProMan User’s Manual,” http://awe-communications.com/, AWE Communications, [Online; accessed 6-July-2015].
[12] L. Liechty, E. Reifsnider, and G. Durgin, “Developing the Best 2.4 GHz Propagation Model from Active Network Measurements,” in *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, Sept 2007, pp. 894–896.
[13] “HyperLink Wireless 2.4/5.8 GHz Omnidirectional antennas,” http://www.l-com.com/multimedia/datasheets/DS_HGV-2458-XXU.PDF, L-com, Inc., 2015, [Online; accessed 1-December-2015].
[14] “NanoStation M / NanoStation Loco M Datasheet,” https://dl.ubnt.com/datasheets/nanostationm/nsm_ds_web.pdf, Ubiquiti Networks, Inc., 2015, [Online; accessed 1-December-2015].
[15] U. Paul, R. Crepaldi, J. Lee, S.-J. Lee, and R. Etkin, “Characterizing WiFi link performance in open outdoor networks,” in *Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2011 8th Annual IEEE Communications Society Conference on*, June 2011, pp. 251–259.
[16] “The Persistent Aerial Reconnaissance and Communications (PARC) vehicle system,” http://cyphyworks.com/robots/parc/, CyPhy Works Inc., 2015, [Online; accessed 1-December-2015].