Unmanned Aerial Vehicle Base Station Assisted Licensed Shared Access

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ORIGINAL RESEARCH ARTICLE

Abstract- A major issue in deploying aerial base stations is the strain it places on the already scarce spectrum and the associated required re-design of the radio resource allocations. To solve this problem, we propose a Licensed Shared Access- (LSA-) based aerial-terrestrial system. The proposed scheme is an integration of unmanned aerial vehicle base station (UAV-BS), as a licensee system, utilising the radio spectrum allocated to other wireless systems- the incumbent system, with the ground base-station operating at the traditional frequency band for cellular systems. However, a major challenge in using LSA for D-BSs is the spectrum unavailability while the incumbent system is active. In conventional terrestrial networks, this leads to service unavailability in a wide geographical area. To tackle this, we define a dynamic UAV-BS positioning scheme that takes into account the presence or otherwise of the incumbent on the spectrum (incumbent Busy and, Idle mode) while taking into consideration the spatial capacity demand in the licensee network. In the busy incumbent mode, the problem of the UAV-BS positioning is tantamount to a goal programming problem with the first level priority goal of fulfilling the incumbent's interference threshold constraint. Simulation result show that in addition to, the proposed (LSA-) based aerial-terrestrial scheme, solving the challenge posed by scarcity of spectrum in aerial base station deployment, a significant improvement in the system efficiency is obtained. It is seen that the proposed dynamic UAV-BS positioning scheme achieved the desired capacity requirement of the licensee network, while ensuring the interference threshold is not exceeded, at a relatively smaller distance of 1000 m to the boundary of the incumbent's system transmission coverage as opposed to a larger distance of about 19 Km.

Keywords- Interference threshold, Spectrum sharing, Surplus traffic, Unmanned Aerial Vehicle-Base Station.

1 INTRODUCTION

Unmanned Aerial Vehicle/Drone Base Station (UAV-BS/D-BS), due to their deployment speed and low operating costs, are capable of addressing major capacity and coverage issues in cellular network, see, e.g., Mozaffari et al. (2015); Alzenad et al. (2017, 2018); Bor-Yaliniz et al. (2016); Kalantari et al. (2016, 2017); Rohde & Wietfeld (2012). The agility provided by the D-BSs mobility makes them a promising solution for (1) recurring temporal traffic hot-spots, e.g., sport venues, (2) recurring spatio-temporal hot-spots, e.g., daily commuting traffic, and (3) unexpected traffic surges during emergency situation and disaster management P. Popovski et al. (2013). Therefore, there have been several research works conducted on the different design considerations of deploying D-BS in 5G networks and beyond.

Alzenad et al. (2017, 2018); Bor-Yaliniz et al. (2016), investigated optimal drone positioning that ensures maximal user coverage with minimum transmit power Alzenad et al. (2018), users with different quality of service (QoS) requirements Alzenad et al. (2017), and minimum drone cell area Bor-Yaliniz et al. (2016). In the work presented by Kalantari et al. (2017), the limitation of the wireless back-haul link was factored into the D-BS positioning while the work of Kalantari et al. (2016) was about the placement and number of D-BS to provide coverage to a certain user population.

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Section B- ELECTRICAL/ COMPUTER ENGINEERING & RELATED SCIENCES
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In Mozaffari et al. (2015) the optimal drone's altitude for a specific transmit power was given as well as the optimal distance between two interfering D-BS, while Fotouhi (2017) proposed D-BS positioning scheme that dynamically reacts to ground users' mobility.

The work by Rohde & Wietfeld (2012) investigated placement, performance, and frequency planning of a UAV-relay system design for addressing cell overload and outage in terrestrial network. Ono et al. (2016) proposed a UAV relay network with adaptive optimized rate and evaluated the performance of their proposed scheme. In a device- to- device (D2D) wireless broadband network deployed for public safety, Li et al. (2015) proposed a drone relay for situations where deployment of terrestrial relay is not possible. Similarly, Jaziri et al. (2016) proposed a mechanism for placing drone relays in traffic hot-spots during periods of congestion in a 5G cellular network.

Despite the apparent merits of deploying D-BS or Aerial relays, a major issue, is the additional strain on radio spectrum availability in meeting the existing and future capacity demand of wireless broadband network. Along with this, comes the complications of resources restructuring and re-engineering (notably frequency re-use planning) to mitigate the probable interference with hitherto existing terrestrial network within and beyond the geographical area of the D-BS deployment.

Licensed Spectrum Access (LSA) provides the required spectrum without the added complications of system and resource provisioning re-engineering which are usually necessary if the UAV-BS/D-BS simply uses cellular band. The LSA grants spectrum access right to other users, the licensees, to co-exist with the initial occupant of the spectrum, the incumbent. It aims to address the under-utilization of the licensed spectrum caused in part by the exclusive right of spectrum usage hitherto granted to the incumbents under the individual licensing scheme. In view of this, we propose UAV-BS/D-BS as an enabler to more efficient spectrum utilization provided by LSA for the following reasons:

- The mobility of the D-BS is a fitting match with the spatial and temporal variation of spectrum availability of the LSA scheme,
- D-BS assisted LSA also provides connectivity and capacity, wherever and whenever necessary,
- The corresponding flexible network architecture is capable to address the heterogeneity and dynamism intrinsic to the cellular networks, and
- Comparing with the conventional terrestrial BSs, the line of sight (LoS) propagation provided by D-BSs enhances the spectral and energy efficiency of the network.

A major challenge in using LSA is the spectrum unavailability while the incumbent system is active. When this happens, the licensee has to shut down its transmission within the region of operation of the incumbent's system. This geographical area could be as wide as 25 Km radius Ponomarenko-Timofeev et al. (2016) or even larger Several works, e.g., Ponomarenko-Timofeev et al. (2016), proposed methods such as reducing the licensee transmitted power as an alternative to a complete shut-down. This, however, could lead to a reduction in the licensee's achievable capacity Gudkova et al. (2016). There are also several research works on the LSA such as Ngo et al. (2018) that proposed a new architecture for a faster LSA controller to suit the required speed of a public safety communication system. The objective of this research work, is to take advantage of the flexibility in the UAV-BS positioning to maximize the achievable rate of the licensee when the spectrum is busy, i.e., been utilized by the incumbent. Here we propose a dynamic D-BS positioning that adapts to the spatio-temporal capacity demand in a LSA based aerial-terrestrial system.

The remaining section of this paper is as follows. The system model is presented in the next section, while, we presented formulations for determining the altitude of the D-BS when the LSA spectrum is idle (not occupied by the incumbent's system) and also when it is occupied by the incumbent in Section 3. We formulated an optimization problem to obtain the best UAV-BS altitude which ensures the excess capacity requirement of the licensee network is achieved subject to meeting the incumbent's interference threshold. The simulation results are discussed in the fourth section while conclusions were drawn in section 5.

2 System Model

The LSA scheme allows multiple different systems, usually vertical technologies to co-exist on the same spectrum, originally allocated to one of them, the incumbent, on an exclusive usage basis. The other system(s), the licensees utilize the spectrum under authorization of the incumbent with probably a regulatory authority acting as an arbiter, facilitator and/or monitor in the agreements reached between them. Unlike previous opportunistic spectrum sharing scheme, such as the cognitive radio network, Obayiuwana et al. (2022); Gbenga-Ilori (2020) the LSA grants some rights of access to all stakeholders in the arrangement with the incumbent(s) taking priority over the licensee(s).

Our LSA system includes such incumbents as the police, emergency and safety services networks and the licensee is a cellular service provider or mobile network operator (MNO). Furthermore, the MNO system comprises of a ground base station (BS) utilizing the traditional cellular frequency and the UAV-BS using the spectrum borrowed from any of the police, emergency and safety services network operator (i.e., acting as the licensee) to meet excess capacity demand of the MNO system. As a paradigm shift from other works, where the licensee is the MNO ground network, here, the licensee is the UAV-BS complimenting the capacity of the ground BS in case of excess traffic demand that may arise as a result of the aforementioned scenarios and other possible causes. Distributed inside the MNO coverage area in a random manner are M user's or subscriber's equipment (UE) (Fig. **Error! Reference source not found.**). The UAV-BS is activated only when the capacity demand exceeds the maximum installed capacity of the MNO ground BS.

Fig. 1: System Diagram of the UAV-BS Assisted LSA system

2.1 User Equipment (UE) Spatial Distribution

The spatial distribution of UEs in each MNO cell area is modelled as a bivariate marked Poisson point process:

$$\varphi = \{[x_1;\xi_1],[x_2;\xi_2],\dots,[x_M;\xi_M]\} \quad (1)$$

where x_m is individual UE's position in the cell area, $\xi \in \{V, eB\}$ represents the mark for categorising the group of UEs that belongs to excess load traffic of the MNO network, i.e served by the UAV-BS, or otherwise. Specifically, V identifies the UAV-BS served UEs, while the ground BS served UEs are represented with the mark eB. Therefore, the Poisson marked process's distribution is given by Z(V)= $\frac{\lambda_U}{\lambda}$ where λ and λ_U are the densities for all the UEs and the set of UEs that makes up the system's excess traffic S respectively.

2.2 Capacity Demand Variation

The proposed UAV-BS LSA configuration is intended to supplement the capacity of the existing traditional ground-BS cellular systems, by dynamically adapting to

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the variations in traffic demand. Therefore, if R_m is defined as the the minimum data rate requirement for user m, the total traffic request or load demand of the system $\boldsymbol{R_T}$ is:

$$\boldsymbol{R_T} = \sum_{\varphi} R_m = \sum_{m=1}^{S\subset M} R_m^V + \sum_{m=1}^{M\setminus S} R_m^{eB} = B\log_2 \prod_{m=1}^{M}\left(1+\frac{P_m}{\mathrm{PL}_m(\theta)(N+I)}\right) \quad (2)$$

where $S\subset M$ denotes the subset of m UE that makes up the surplus network load, B, P_m are the transmit bandwidth and power allocated to user m respectively, $\mathrm{PL}_m(\theta)$, I, and N, are the path-loss in the transmitter receiver path between any m UE and either the ground-BS or the UAV-BS, the noise power, and the interference power. The QoS data rate requirement for each m user is achieved if $\gamma_m \geq \gamma_{th}$, where

$$\gamma_m = \frac{P_m}{\mathrm{PL}_m(\theta)(N+I)} \quad (3)$$

is the signal to- noise plus interference ratio (SINR) of user m, and γ_{th} denotes the minimum SINR threshold that ensures m QoS rate requirement is achieved. By substituting $\boldsymbol{R_{TG}} = \sum_{m-1}^{S\subset M} R_m^V$, $\boldsymbol{R_{NL}} = \sum_{m-1}^{M\setminus S} R_m^{eB}$, and assuming a mean rate R_m, (**Error! Reference source not found.**) simplifies to

$$R_T = R_{NL} + \frac{Z(V)}{1-Z(V)} R_{NL} \quad (4)$$

where R_{TG} and R_{NL} are the excess traffic and the normal traffic load of the MNO respectively. The implication of this is that, the proposed UAV-BS based licensee system is activated if and only if $Z(V)>0$, otherwise, it is not activated.

2.2 Path-Loss Model

Similar to Al-Hourani et al. (2014), we model the transmitter-receiver link or air-to-ground channel (ATG) in a low altitude aerial platform (LAP) as:

$$\mathrm{PL} = \sum_{g} \mathrm{PL}_g \mathrm{Pr}\{g,\theta\}, \quad (5)$$

where PL is the signal power loss in the path between the UAV-BS and the UEs, $g \in \{LoS, NLoS\}$, represents the signal propagation group, where LoS and NLoS are the line of sight and non-line of sight propagation respectively. In (**Error! Reference source not found.**), $\mathrm{Pr}\{g,\theta\}$ indicates the probability that one of g exists, while θ indicates the elevation angle between the UAV-BS and each individual UE. The PL is:

$$\mathrm{PL} = \mathrm{FSPL} + \eta_g \quad (6)$$

where FSPL denotes the free space path-loss and η, expectedly indicates the additional loss, which is environment dependent and whether LoS or NLoS propagation exist in the transmitter-receiver path. Parameter η_{LoS} can be estimated by ζ_{LoS}, a log-normal location variation distribution parameter (Saunders & Argo-Zavala, 2007). Additionally, the computation of η_{NLoS} involves an extra building roof top diffraction loss l_b (Holis & Pechac, 2008), i.e $\eta_{\mathrm{NLoS}} = \zeta_{\mathrm{NLoS}} + l_b$.

Furthermore, $\mathrm{Pr}\{g,\theta\}$ for LoS propagation was approximated as a Sigmoid function in Al-Hourani et al. (2014):

$$\mathrm{Pr}\{\mathrm{LoS},\theta\} = \frac{1}{1+a^{-b\left(\theta\frac{180}{\pi}-a\right)}}, \quad (7)$$

Where, $\mathrm{Pr}\{\mathrm{LoS},\theta\}$ is the probability that LoS propagation exists; a, b are parameters of the Sigmoid curve which are dependent on the propagation environment.

Substituting the formula for FSPL, (**Error! Reference source not found.**), and (**Error! Reference source not found.**) into (**Error! Reference source not found.**) and indicating that the distance between the transmitter-to-receiver $D = \sqrt{h^2+r^2}$, we can express the path-loss as a function of elevation angle:

$$\mathrm{PL}(\theta) = 20\log r + 10\log(1+(\tan\theta)^2) + k + \zeta_{\mathrm{NLoS}} + l_b + \frac{A}{1+a^{-b\left(\theta\frac{180}{\pi}-a\right)}}, \text{ if } r > h \quad (8a)$$

$$\mathrm{PL}(\theta) = 20\log h + 10\log\left(1+\frac{1}{(\tan\theta)^2}\right) + k + \zeta_{\mathrm{NLoS}} + l_b + \frac{A}{1+a^{-b\left(\theta\frac{180}{\pi}-a\right)}}, \text{ if } r < h \quad (8b)$$

or as a function of the UAV-BS altitude and the UEs' distance in the horizontal direction:

$$\mathrm{PL}(h,r) = 20\log r + 10\log\left(1+\frac{h^2}{r^2}\right) + k + \zeta_{\mathrm{NLoS}} + l_b + \frac{A}{1+a^{-b\left(\tan^{-1}\frac{h}{r}\frac{180}{\pi}-a\right)}}, \text{ if } r > h \quad (9a)$$

$$\mathrm{PL}(h,r) = 20\log h + 10\log\left(1+\frac{r^2}{h^2}\right) + k + \zeta_{\mathrm{NLoS}} + l_b + \frac{A}{1+a^{-b\left(\tan^{-1}\frac{h}{r}\frac{180}{\pi}-a\right)}}, \text{ if } r < h \quad (9b)$$

where r stands for the UEs' horizontal distance in Km, h, is the vertical distance of the UAV-BS also in Km, k=20log(f)+92.4, f is the carrier frequency in GHz, and $A = \eta_{LoS} - \eta_{NLoS}$

3 UAV-BS Licensee Placement

The system objective is to ensure optimal positioning of the UAV-BS licensee to achieve excess capacity requirement of the MNO system at the same time satisfying the incumbent's interference threshold constraint. To this end, a two-mode UAV-BS positioning is defined; the *idle incumbent* UAV-BS placement, i.e., when the incumbent is not utilising the LSA spectrum and the *active incumbent* mode, when the incumbent is active on the spectrum.

3.1 UAV-BS Placement: Idle Incumbent Mode

In this section, the mathematical expressions for the optimal UAV-BS LSA positioning is provided for when the incumbent's is not transmitting or when its transmission is not within the interfering radius of the

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licensee system.

From (**Error! Reference source not found.**) it is evident that a set of maximum path-losses, $\mathbf{PL}_S(\theta) = \{\mathrm{PL}_1(\theta), \mathrm{PL}_2(\theta), \ldots, \mathrm{PL}_S(\theta)\}$, exists for the minimum SINR for each user. Thus, the positioning of the D-BS, for satisfying the capacity requirement of all users, in the subset S, translates to finding the optimal height that ensures power allocated to the user with the maximum path loss is adequate for its minimum SNR requirement. In other words, the target path loss value for satisfying the surplus traffic requirement is:

$$\mathbf{PL}_{\mathrm{TG}}(\theta) = \max\{\mathrm{PL}_1(\theta), \mathrm{PL}_2(\theta), \ldots, \mathrm{PL}_S(\theta)\} \quad (10)$$

Obtaining the optimum altitude from the determined target path-loss corresponds to finding the optimal ground UE to D-BS elevation angle θ (Al-Hourani et al., 2014). By setting $\frac{\partial \mathrm{PL}_m(\theta)}{\partial \theta} = 0$, in 8(a) we have (Al-Hourani et al., 2014):

$$\frac{\pi \tan \theta^*}{9\ln(10)} + \frac{ab^{(-b(\theta^*-a))}}{\left(1 + a^{(-b(\theta^*-a))}\right)^2} = 0, \quad (11)$$

where θ^* is the optimal elevation angle between aerial UAV-BS and terrestrial UE. Thus, optimal height for satisfying the surplus capacity requirement can then be obtained by solving $\tan \theta^* = \frac{h^*}{r}$ where r is radius of area covered by the licensee system, i.e., the MNO. The idle incumbent D-BS positioning is outlined in Algorithm 1.

Algorithm 1:	Optimal altitude for idle incumbent UAV-BS
Step 1.	For a defined eNobeB coverage radius, initialise the set of all UE $M = \{m_1, m_2, \ldots, m_M\}$;
Step 2.	Identify the subset $S \subset M$ of all UE that make up the excess traffic requirement above the terrestrial eNodeB capacity;
Step 3.	Determine the individual UE rate requirement, R_m^S the equivalent SINR threshold γ_{th}, and the corresponding individual UE SINR γ_m;
Step 4.	Compute the set of maximum path-losses corresponding to the lowest SINR for each UE $\mathbf{PL}_S(\theta) = \{\mathrm{PL}_1(\theta), \mathrm{PL}_2(\theta), \ldots, \mathrm{PL}_S(\theta)\}$ and the target path loss $\mathrm{PL}_{\mathrm{TG}}(\theta)$ for the surplus traffic requirement $\boldsymbol{R}_S$
Step 5.	Solve for the optimum elevation angle $\theta^*$from (11) and obtain the idle incumbent D-BS position

3.2 UAV-BS Placement: Active Incumbent Mode

If transmission of the incumbent's system is within the interference radius of the licensee system, the challenge of UAV-BS placement is not limited to only ensuring the excess network traffic demand is achieved but, as a matter of higher priority, ensuring that the incumbent's interference threshold is not exceeded. Mathematically, this problem can be formulated as:

$$\max_{(\mathrm{PL}_m(\theta),h,\theta)} B \log_2 \prod_{m=1}^{S\subset M} \left(1 + \frac{P_m}{\mathrm{PL}_m(\theta)(N+I)}\right) = \boldsymbol{R}_S, \quad (12a)$$

$$\text{s.t.} \sum_{m=1}^{S\subset M} \frac{P_m}{\mathrm{PL}_m(\theta)} \mathrm{F}_m \le I_{th}, \quad (12b)$$

where F_m is the fading coefficient for each transmitter - receiver path between the UAV-BS and a UE and I_{th} is the interference threshold requirement of the incumbent's system. In (**Error! Reference source not found.**) the objective is to find the optimal values of the decision variables $(\mathrm{PL}_m(\theta), h, \theta)$ to ensure the surplus traffic requirement $\boldsymbol{R}_S$ is achieved. This has been obtained as $\mathrm{PL}_{\mathrm{TG}}$, θ^* and h^* in Section**Error! Reference source not found.** for instances that the LSA spectrum is free of the incumbent's system activity in the licensee's area of coverage. However, considering the incumbent's interference threshold constraint in (**Error! Reference source not found.**), those values are probably not ideal for reliable transmission of the incumbent's system.

Since fulfilling the incumbent's interference threshold constraint supersedes every other objective in the LSA paradigm, the problem of the UAV-BS positioning when the spectrum is busy, i.e., occupied by the incumbent's system, is tantamount to a goal programming problem with the first level priority goal of ensuring the transmissions from the licensee UAV-BS does not cause adverse interference to the incumbent. The second goal is meeting the surplus capacity demand of the licensee system. We can therefore formulate the D-BS positioning during the busy spectrum period(s) as a bi-objective lexicographic goal programming optimization Jones & Tamiz (2010) problem as:

$$\min_{(\mathrm{PL}_m(\theta),h,\theta)} \sum_{m=1}^{S\subset M} P_m[\mathrm{PL}_m(\theta)]^{-1}\mathrm{F}_m \le I_{th}, \quad (13a)$$

$$\max_{(\mathrm{PL}_m(\theta),h,\theta)} B \log_2 \prod_{m=1}^{S\subset M} \left(1 + \frac{P_m}{\mathrm{PL}_m(\theta)(N+I)}\right) = \boldsymbol{R}_S, \quad (13b)$$

While the first level priority goal of interference minimization must be strictly met, there is a strong possibility that the second level priority goal of surplus capacity demand might fall short of the required target. To solve the lexicographic goal problem, we start by focussing on the interference minimization goal (the first level priority goal) and completely ignoring the surplus capacity demand goal (the second level priority goal). From (**Error! Reference source not found.**), we can solve for the path loss value that makes the received interfering signal power at the incumbent's receiver just about equal to its interference threshold as:

$$\mathrm{PL}_{th}(\theta) \le \frac{I_{th}}{\sum_{m=1}^{S\subset M} P_m \, \mathrm{F}_m}, \quad (14)$$

Where PL_{th} is the path loss threshold value that ensures the received interference power for an incumbent receiver located at horizontal distance r is less than or equal to the interference threshold. From (**Error! Reference source not found.**), the solution to the second objective is therefore reduced to:

$$\min_{(\mathrm{PL}_m(\theta),h,\theta)} \Delta_R, \quad (15a)$$

$$\text{s.t.} \sum_{m=1}^{S\subset M} \mathrm{PL}_m(\theta) \ge \mathrm{PL}_{th}(\theta), \quad (15b)$$

where Δ_R is the possible deviation between the achievable capacity when the incumbent's system is transmitting on

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its spectrum and the actual surplus traffic requirement given by: $\Delta_R = |\boldsymbol{R}_{\mathrm{ACH}} - \boldsymbol{R}_S|$,

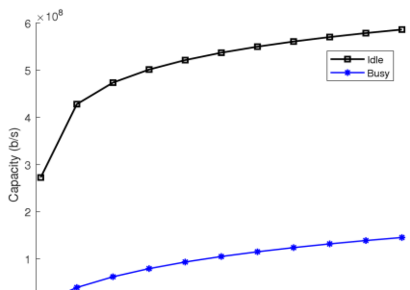
Algorithm 2:	Optimal height for active incumbent UAV-BS.
Step 1.	Initialise the incumbent's interference threshold I_{th}, and the licensee excess network traffic $\boldsymbol{R}_S$;
Step 2.	Compute the equivalent path loss value $\mathrm{PL}_{th}(\theta)$ that makes the incumbent's received interference power less than or equal to the threshold value;
Step 3.	Determine the D-BS height that ensures the path loss at a horizontal distance *r* location of the incumbent is greater than or equal to $\mathrm{PL}_{th}(\theta)$;
Step 4.	Solve 15(a) and 15(b) to obtain the equivalent D-BS height that ensures $\Delta_R = |\boldsymbol{R}_{\mathrm{ACH}} - \boldsymbol{R}_S|$ is minimal.

The implication of Δ_R in (**Error! Reference source not found.**) is that the achievable capacity $\boldsymbol{R}_{\mathrm{ACH}}$ might be less or greater than the actual surplus traffic requirement $\boldsymbol{R}_S$. The objective in (**Error! Reference source not found.**) is to reduce the magnitude of this difference irrespective of whether it is positive or negative. Furthermore, the interference threshold constraint is simplified to placing a limit on the minimum path-loss on the transmitter-receiver distance between the licensee UAV-BS and the incumbent's system. Thus, the problem in (**Error! Reference source not found.**) is solved by finding the optimal height that minimizes the possible deviation between the actual surplus traffic requirement and the busy spectrum achievable capacity while ensuring the incumbent's interference threshold constraint is satisfied. The active incumbent UAV-BS positioning is outlined in Algorithm 2.

4 SIMULATIONS

We consider a single coverage hosting both a terrestrial eNodeB and a D-BS, with radius = 1 Km, transmit power of 0.2 to 15.85 w (23–42 dBm), thermal noise= −96.99 dBm, and protection ratio $(I/N) = -6$ dB ITU (2004). The UAV-BS and the ground BS are assumed to be located in the centre of the MNO area of coverage. The ATG assumed propagation parameters are: $\theta^* = 42.44^0$ Alzenad et al. (2017), and $(\eta_{LoS}, \eta_{NLoS})$ = (1.0, 20.0) Al-Hourani et al. (2014).

The curves in Fig. **Error! Reference source not found.**, shows the surplus traffic requirement ($\boldsymbol{R}_S$) of the MNO network when the spectrum is busy, and the achievable capacity when the licensee UAV-BS height is adjusted for only achieving the incumbent's interference threshold. As it is seen, the achievable capacity significantly fell short of the target, i.e., the ($\boldsymbol{R}_S$), when the surplus traffic requirement is not considered. This situation is undesirable as it will lead to significant degradation in the QoS or outage of the affected UE in the MNO network.



However, by maintaining the same UAV-BS height in incumbent idle mode, the interference power received by the incumbent even at the edge of the area of coverage is about 40 dB higher than the maximum allowable interference (−102.99 dBm) even when the UAV-BS transmitting power is 23 dBm and even more when higher transmitting power is used. In fact, from Fig. 3, it is seen that even at a distance less than 5 Km the incumbent stands the risk of suffering harmful interference for a licensee UAV-BS transmission power of 23 dBm and for the transmission power of 42 dBm, the separation distance between the incumbent's system from the licensee UAV-BS transmission must not be less than 19 Km.

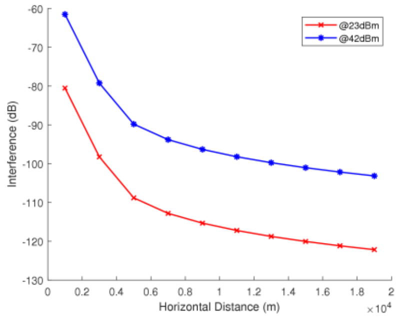


Fig. 3: Interference power vs. distance to the centre of coverage area.

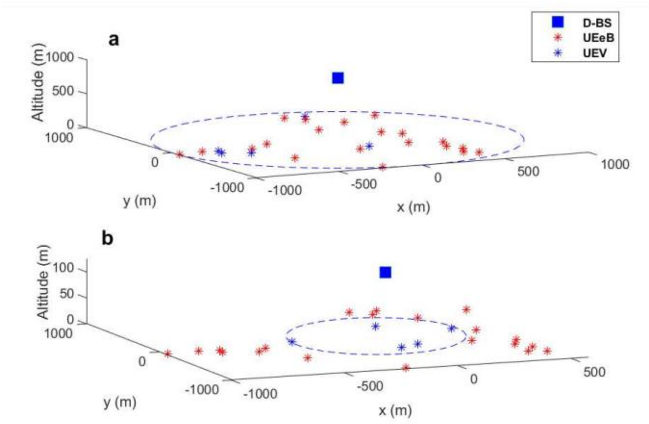


Fig. 4: Idle and busy spectrum UAV-BS positioning.

Fig. **Error! Reference source not found.**a shows the idle UAV-BS height while **Error! Reference source not found.**b shows the UAV-BS height adjusted to ensure both interference minimization to the incumbent system and achieving the target excess capacity requirement of the network. To ensure the surplus traffic is met, there is a re-association of UEs to the UAV-BS and the terrestrial eNodeB. This is a knapsack like combinatorial optimization with the objective of achieving capacity closest to the target surplus traffic while ensuring the interference to the incumbent system is minimized. In Fig. **Error! Reference source not found.**, we compare the obtained achievable capacity to the surplus traffic requirement ($\boldsymbol{R_S}$). It is seen that the achieved capacity is approximately equal to the required capacity $\boldsymbol{R_S}$.

However, for the transmitting power range considered in this work, (23−42 dBm) this can only be achieved at some geographical distance from the incumbent's activity as seen in Fig. **Error! Reference source not found.**. It is seen that for the ended capacity achieved in Fig. **Error! Reference source not found.** to be realised, the incumbent system must be no less than 2000 m from the licensee eNodeB coverage area centre (or 1000 m from the boundary). This separation distance between the incumbent system and the licensee UAV-BS is a significant improvement over what was obtained in Fig. **Error! Reference source not found.** of about 19 Km while achieving the desired target capacity requirement.

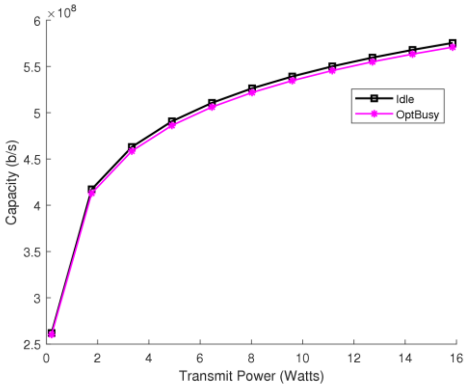


Fig. 5: Surplus capacity comparison between idle and busy spectrum.

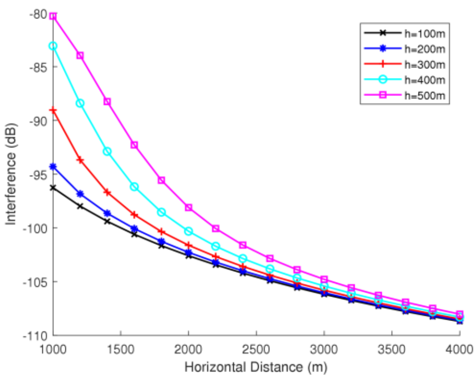


Fig. 6: Interference power vs. separation distance at optimal height in active incumbent mode.

This implies that, if the licensee transmits at maximum power, the incumbent system could suffer harmful interference if it operates closer to the licensee than the inferred separation distance.

5 Conclusion

In this paper, a UAV-BS assisted LSA architecture is proposed to cater for the excess network traffic of a traditional terrestrial BS of an MNO licensee in a vertical LSA sharing scheme. A dynamic UAV-BS placement problem corresponding to the cases where the incumbent system is idle or active is formulated. From the results, it is seen that the UAV-BS placement can be configured such that the target excess network traffic of the licensee is achievable while the incumbent is actively transmitting within its spectrum. We also showed that if licensee is operating at the maximum rated transmission power, there must be a certain separation distance between the two systems to prevent damaging interference to the incumbent system. For future work one may investigate if combining the reduced transmit power suggested in Ponomarenko-Timofeev et al. (2016) with optimal UAV-BS positioning can result in the simultaneous achievement of the excess traffic requirement and the maximum allowable interference even if the incumbent system is actively transmitting inside the licensee UAV-BS coverage radius.

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