RESEARCH ARTICLE OPEN ACCESS

Survey on High-Altitude Platforms: Channel Modeling, Optimization, and Performance Metrics

Abdulrahman Ali Almarhabi
Electrical and Computer Engineering Department, King Abdulaziz University, Jeddah, Saudi Arabia

ABSTRACT
Interest in high-altitude platforms (HAPs) has been increasing recently, especially with the rapid technical development in solar panels' efficiency, energy storage, antenna design, and lightweight materials for aircraft parts. These factors make high-altitude platforms more applicable in a wide variety of military, security, relief, and civilian applications. This paper provides overview on the high-altitude platforms and their advantages compared terrestrial and satellite communications. This paper also surveys the air-to-ground channel model used for HAPs, channel performance metrics, and optimizing various HAPs parameters.
***Keywords* -** air-to-ground channel, channel characterization, high-altitude platforms, optimization, unmanned aerial vehicle

---

Date of Submission: 12-05-2021 Date of Acceptance: 25-05-2021

I. INTRODUCTION

High-Altitude Platforms (HAPs) are located at 17 to 22 km above the ground level in the stratosphere layer [1]. HAPs are not a new concept as the international telecommunication union (IUT) studies began in 1996. By the end of the last century, several projects were launched, but few continued. Several companies have recently announced investments in HAPs projects that seek to provide Internet access to areas without terrestrial or satellite communications infrastructure. Previously, piston or jet engines were used for HAPs powering. However, in recent times, HAP has become more applicable as it is powered by using different power sources such as solar energy-based automated aerial vehicles, balloons, or airships. In addition to the development in antennas' design, and designing airframe to manufactured using lightweight composite materials. [2].

1.1 HAPs Advantages

The HAPs have advantages over terrestrial and satellite communication, which can be summarized in the following points [3]:

- **Deployment**: HAPs can be used to fly based on the need to provide temporary or permanent services for regions where telecommunication infrastructures are not available.
- **Infrastructure**: In comparison to terrestrial communications networks, HAPs have the minimal ground-based infrastructure.
- **Coverage area**: a single HAP has coverage area higher than the terrestrial cellular base station (BS). The HAP coverage reaches up to 150 km radius while the BS has a maximum coverage range of 20 to 30 km.
- **Quality**: Propagation delays in HAPs are lower than satellite communication; this leads to improved quality of service (QoS) in real-time applications.
- **Reliability**: HAPs offer better and superior signal strengths compared to satellite communication. Hence, there is no need for bulky user terminals.

1.2 HAPs Applications

HAPs are used in a broad range of applications. It used for navigational and position location systems, remote sensing, traffic monitoring, disaster recovery activities, environmental supervision, emergency communications, accessibility for high-speed wireless, etc.[4]

1.3 Radio Frequency Regulations

The ITU member state at the World Radiocommunication Conference 2019 (WRC-19) emphasized identifying additional bands of frequency used for HAP systems. The delegates at the WRC-19 agreed on the frequency bands 31 - 31.3 GHz and 38 - 39.5 GHz that would be used globally for fixed service for HAP systems. Furthermore, frequency bands 47.2 - 47.5 GHz and 47.9 - 48.2 GHz are also ready to be accessed globally by administrations for the implementation of HAPs. For Region 2, frequency bands 21.4 - 22 GHz, and 24.25 - 27.5 GHz for HAPs are also available for fixed services [7]. HAPs can use one or more than one gateway connection for different locations within the platform service area [5].

II. LITERATURE REVIEW

2.1 HAPs Overview

Among the contributions and surveys in the field of HAPs, this section presents the background of HAPs. The work was done by Karapantazis and Pavlidou in [6] describes channel modeling, features of antennas, transmission, and coding techniques. In [7], Elshaikh et al. describe that HAPs provide low-cost and fast services to many users to access modern wireless communication. Authors highlight challenges and issues of energy sources, modulation, propagation, interference, and antenna designing. Both works also show that HAPs have more benefits as compared to their alternates, such as terrestrial and satellite networks. HAPs can operate individually or with connections with other networks. Avdikos et al. in [8] analyzed different applications of HAPs on different types of networks, such as Such as networks of hybrid communications, networks used for environmental monitoring systems, and intelligent transportation. The paper shows that HAPs have many advantages that can be further expanded and utilized in multiple future applications. Researchers presented concerns about technical issues of links between HAPs, HAPs to satellites or earth stations. Also, the interconnectivity of HAPs with other networks such as terrestrial and satellite networks.

Airborne Communication Networks (ACNs) are heterogeneous networks that use different type of communication systems such as Low-Altitude Platforms (LAPs), HAPs, and satellites to provide communication transport services. Cao et al. in [9] claim that ACNs are good as compared with terrestrial networks, especially in cases where network topologies are frequently changed or more complex connections of communication. This paper describes integrated ACNs, HAPs, and LAPs based networks in detail. It also explains that ACNs are effective in the seamless integration of heterogeneous networks to improve the quality of service.

2.2 HAPs Channel Modeling

Channel modeling is a significant factor in making a solution for the communication system. Its techniques play a major role in understanding multiple features such as network protocol and the system's behavior. Dovis et al. in [10] discussed theoretical derivation for channel modeling to develop a link of communication between the platform and terrestrial stations. Multiples effects are discussed, such as modeling of small-scale fading effects. The paper also describes that specific geometry of propagation provides a specific model that applies to the stratospheric channel.

Cuevas-Ru´ız and Delgado-Pen´ın in [11] described the channel modeling in the L band. Multiples conditions are assessed with radio coverage. Paper describes a channel modeled with three states that can provide better representation than the channel modeled with two states. The semi-Markov systems allow taking to account the distribution of fading of each channel state for the model. In this way, the channel model can be better analyzed.

Over time, increasing the efficiency of HAPs led to an increase in the number of services, including the future generation of mobile, access to broadband wireless, navigation, remote sensing, and weather monitoring. Oluseyi in [12] focused on the need for the prediction of quality of channel and propagation of stratospheric. The author discusses four HAPs channel models and their performance based on Bit Error Rate (BER). The results show that the Rician model does not perform well in representing the channel in the presence of noise due to having data scattered near to ground level and hence not counted.

Holis and Pechac in [13] described another HAPs channel model of propagation in different environments. This model divides the link between platform and user into two propagation groups; the first group is a Line-of-Sight (LOS), while the second group represents the Non-Line-of-Sight (NLOS) component. The path loss due to the shadowing was calculated using the uniform theory of diffraction for the NLOS. Results are verified through multiple readings, which are taken from airships situated in different urban areas. Correlation is calculated between both experimental and theoretical data. Krahulec et al. in [14] explained two ways of channel modeling. This system takes real information about the environment of transmission to develop a realistic channel model as much as possible. This information can further be used to update the empirical models as well. Paper claims that a digital elevation map can help update the deterministic channel model's probabilities to get a realistic solution.

Cuevas-Ruiz et al. in [15] described 3-D multipath propagation for a communication system between HAPs and terrestrial users. This model characterizes reflected signals at the receiver end due to signals scattered around the system coverage area. Cumulative Distribution Function (CDF) expresses the delays produced due to scattered signals and the probability of their presence in a system. Paper also claims that with higher delay in a system, bandwidth of coherence decreases, and a limited spectrum can be linear. This model was evaluated using Quadrature Phase Shift Keying (QPSK) based modulation and BER. The paper shows that the elevation angle is the main feature of channel modeling.

Hasirci and Cavdar in [16] run model under four propagation environments (suburban, urban, dense urban, and urban high rise). The elevation angle is the primary function of models, along with Rayleigh and Ricean propagation factors. Correlation coefficients between different models and fade depth are calculated to study the effects of parameters on the model. This model contains cases of LOS and NLOS between HAPs and user end.

Aamir and Qamar in [17] integrate the channel models of HAPs, satellite, and terrestrial networks and analysis the performance of Multi-Input and Multi-Output (MIMO) channels by applying multiple antenna systems. At the first stage, different scenarios comprise of geosynchronous equatorial orbit satellite and some HAPs are considered, and then Land Mobile Satellite (LMS) with HAPs and then MIMO based channel model is constructed. Different system designing parameters are analyzed and performances are evaluated, which shows that proposed systems are better than conventional networks that combine terrestrial and satellite networks.

Zheng et al. in [18] described multipath fading and the effects of the attenuation of rain, cloud, and gas absorption on HAPs communication link with the ground station. It also discusses Rician fading using QualNet network simulator. Results show these elements have a clear impact on the performance, especially the packet delivery rate.

Ding et al. in [19] proposed a time-varying model of a channel to characterize continuous time properties of the transferring process. The geometric structure is first constructed, which is used to access the characteristic of the LOS and propagation path of ground reflection in the cases transferring process. Ground node's velocity and position are functions of continuous time. Furthermore, the value of the transition model factors is suggested with a dynamic scenario with respect to the stochastic tap delay line model and measured data.

Liu et al. in [20] described the properties of near space HAPs with a fast time-varying channel. The mathematical model of the link budget and channel model of the wireless communication network is suggested. BER with varying elevation angles and SNR are analyzed as well. The angle of elevation of the HAPs communication link decreases with an increase in BER. With an increase in bit power and Power Spectral Density (PSD) of thermal noise, the BER of HAPs communication link decreases. The paper also shows that BER in the coding case is better as compared with un-coded.

Apart from getting HAPs access in urban areas, HAPs provide a broadband wireless connection to rural areas. It is also a fact that getting Channel State Information (CSI) for HAPs at high altitudes is hard. Sudheesh et al. in [21] discussed the Interference Alignment (IA) method to get maximum sum-rate in HAPs based communications without CSI. Various antenna tethered balloon-based relay is used between various drones of HAPs and ground stations to analyze IA. This network system uses MIMO in a closed-form. Results show that the proposed system provides maximum sum-rate in HAPs based communications without CSI. The optimum altitude of the balloon is accessed to get the maximum sum-rate.

Qiu et al. in [22] proposed architecture for hierarchical network using software-defined networking to integrate cross-layer HAPs and LAPs with terrestrial networks to improve and increase the coverage for areas still underserved. The paper also proposes an architecture of a network of integrated air-ground and discusses its properties and advantages. Potential application cases are identified due to which the performance of conventional terrestrial networks can further be improved. Zakaria et al. in [23] proposed technique for joint transmission using coordinated Multi-Point (JT-CoMP) to increase the efficiency of terrestrial networks. The optimum solution is to balance the loss of capacity and Carrier to-Interference plus Noise Ratio (CINR) gain. Two techniques of identifying CoMP and non-CoMP users are used, which depend on thresholds of centralized and flexible CINR techniques. Paper claims that the flexible CINR threshold method provides a balance between loss and CINR gain.

Lin et al. in [24] proposed beam forming based solution for integrated satellite and HAPs networks. The multi-beam satellite and HAPs have the same millimeter waves spectrum. Weighted Tchebycheff method is discussed, and an optimized solution for multiple objectives is formulated to minimize the total transmit power and sum-rate along with fulfilling limitations of the QoS at both earth and mobile stations. Paper also uses CSI carrying incomplete angular information to get a comparatively simple discretization method to convert limitations and objective function of non-convex to convex form. The combined scheme of monotonic optimization and algorithm for iterative penalty function are discussed to get weight vectors of beam forming.

Table 1: Channel modeling

Ref.	Frequency	Sounding
[10]	2 GHz	small-scale fading, frequency-flat Rician, power delay profile

[13]	2/3.5/5.5 GHz	shadowing path loss, elevation dependent channel, ITU statistical parameter
[14]	Ka band	channel modeling using DEM (Digital Elevation Map), Loo model
[15]	2 GHz	multipath propagation, Rician, Rayleigh
[16]	2/2.5/3.5 GHz	statistical model depends on elevation angle, path loss
[17]	millimeter frequency band	MIMO channel, Integrated terrestrial/HAPs/satellites system.
[18]	10/15/20/25 GHz	small-scale fading, path loss, attenuations due to cloud, rain, and gaseous absorption
[19]	1.4 GHz	time-varying transition channel model, multipath fading, Rician, delay spread
[20]	48 GHz	Rayleigh channel in urban areas and Rician channel in suburban environments, sum-rate analysis
[21]	49 GHz	fast time-varying channel, HAPs link budget

2.3 HAPs Performance

Asvial in [25] proposed a traffic model along with analysis with HAPs systems. Methods of handling prioritized and non-prioritized call traffic are discussed. The prioritized method allows queuing of handoff attempts for assigning a channel in each spot beam of HAPs. In contrast, the non-prioritized method contains no difference between both call attempts and handoff attempts. Iskandar and Putro in [26] proposed a method for predicting the Rician channel K factor for HAPs communications. The HAP was simulated with an object carrying the transmitter floating on a earth's surface used to collect experimental data to estimate the K value for the multipath channel. They used the moment-based method to describe channel's characteristics for HAPs in a broad elevation angle interval. High-speed WiMAX performance simulated over estimated channels for HAPs communication. Results show that when the elevation angle is less than 40 degrees, it fails to achieve desired performance over the HAPs channel for high-level WiMAX services.

Mingxianget al. in [27] studied the performance of propagation wireless link, HAPs coverage area, and partition scheme of multiple spot beam cell for HAPs communications. The researchers suggested three partition schemes of the cell for different scenarios in the HAPs system. The performance of the propagation wireless link and the suitable scenario for each partition scheme were suggested using numerical calculation and computer simulation analysis. Adnan et al. in [28] studied the performance of HAPs based on the geometrical-statistical. They observe that the Gaussian channel always provides a lower SNR. In the same modulation order, SNR not affected if it is coded or uncoded. In addition, the Rayleigh channel has higher SNR and this leads to weak output. Smartphones can get direct access to HAPs based mobile communications services, which terrestrial networks use for mobile communications with 4G and 5G in the future. The cellular system requires reusing one-cell frequency, such as terrestrial mobile communications to increase coverage and capacity. HAPs can be used to provide multiple numbers of cells depending on the type of HAPs system and UAVs system, differing from terrestrial base stations with a maximum of six sectors. Shibata et al. in [29] proposed an optimization method for the cell configuration for HAPs based cellular systems integrated with Long Term Evolution (LTE) that can be used whatever the number of cells. Paper claims that cell configuration with antenna parameters can provide different numbers of cells that HAPs can serve.

2.4 HAPs Optimization

Ganhao et al. in [30] optimized the energy per useful packet on Time Division Multiple Access (TDMA) HAPs channel. The proposed work used a multi-rate turbo-code to support a Hybrid Automatic Repeat Request (HARQ) code to analyze performances of successfully received energy per packet, packet, delay, and goodput. The results show that the energy per useful packet decreases for a lower energy bit since no losses occurred when the number of transmissions per packet increases. This leads to extend the life of the wireless terminals because less transmitter power is required.

When using the ordinary Transmission Control Protocol (TCP) with the HAPs and satellite networks, some problems arise due to the nature of these networks, which is represented in long propagation delay, high BER, large Bandwidth-Delay Product (BDP), and traffic diversity. These problems are related to notification and control of congestion, the reason for packet loss recognition. Weiqiang et al. [31] proposed TCP-HAPs to solve these problems.

Both HAPs and terrestrial systems share the frequency band of 5.850 - 7.075 GHz by operating in the adjacent channel frequency band. Mokayef et al. in [32] discussed the performance of uplink and downlink communications of both systems. They also discussed the interference caused by HAPs into terrestrial systems as a function of distance from nadir point toward the HAPs ground station.

Coexistence performance is accessed, which is based on the CINR of the victim link.

III. CONCLUSION

This paper provides a literature review of the air-to-ground propagation channel modeling used for HAPs, channel performance metrics, and optimizing various HAPs parameters.

REFERENCES

[1]. A. Ibrahim and A. S. Alfa, "Optimizing radio resources for multicasting on high-altitude platforms," *EURASIP Journal on Wireless Communications and Networking, vol. 2019, no. 1, p. 213, 2019*.

[2]. T. Mahapol, "Design and optimisation of a power efficient highaltitude platform for equatorial operation," *IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific). IEEE, 2018, pp. 1–8*.

[3]. A. Mohammed, A. Mehmood, F. N. Pavlidou, and M. Mohorcic, "The role of high-altitude platforms (HAPs) in the global wireless connectivity," *Proceedings of the IEEE, vol. 99, no. 11, pp. 1939–1953, 2011*.

[4]. A. A. Ahmed Ibrahim, "Optimization Methods for User Admissions and Radio Resource Allocation for Multicasting over High Altitude Platforms", *River Publishers, 2018*.

[5]. ITU-R, "Deployment and technical characteristics of broadband high altitude platform stations in the fixed service in the frequency bands," *vol. 0, 2018*.

[6]. S. Karapantazis and F. Pavlidou, "Broadband communications via high-altitude platforms: A survey", *IEEE Communications Surveys Tutorials, vol. 7, no. 1, pp. 2–31, 2005*.

[7]. Z. Elshaikh, R. Islam, A. Ismail, and O. Khalifa, "High altitude platform for wireless communications and other services", *International Conference on Electrical and Computer Engineering, 2006, pp. 432–438*.

[8]. G. Avdikos, G. Papadakis, and N. Dimitriou, "Overview of the application of high altitude platform (hap) systems in future telecommunication networks", *10th International Workshop on Signal Processing for Space Communications, 2008, pp. 1– 6*.

[9]. X. Cao, P. Yang, M. Alzenad, X. Xi, D. Wu, and H. Yanikomeroglu, "Airborne communication networks: A survey", *IEEE Journal on Selected Areas in Communications, vol. 36, no. 9, pp. 1907–1926, 2018*.

[10]. F. Dovis, R. Fantini, M. Mondin, and P. Savi, "Small-scale fading for high-altitude platform (hap) propagation channels", *IEEE Journal on Selected Areas in Communications, vol. 20, no. 3, pp. 641–647, 2002*.

[11]. J. L. Cuevas-Ruız and J. A. Delgado-Penın, "Channel modeling and simulation in haps systems", *European Wireless, pp. 24–27, 2004*.

[12]. A. A. O. OLADIPO, Stratospheric propagation and haps channel modeling, 2007.

[13]. J. Holis and P. Pechac, "Elevation dependent shadowing model for mobile communications via high altitude platforms in built-up areas", *IEEE Transactions on Antennas and Propagation, vol. 56, no. 4, pp. 1078–1084, 2008*.

[14]. J. Krahulec, S. Marchevsky, and L. Macekova, "Communication channel model simulated using digital elevation maps and modified deterministic loo model", *International Conference Radioelektronika, 2009, pp. 103–106*.

[15]. J. L. Cuevas-Ruiz, A. Aragon-Zavala, G. A. Medina-Acosta, and J. A. Delgado-Penin, "Multipath propagation model for high altitude platform (hap) based on circular straight cone geometry", *International Workshop on Satellite and Space Communications, 2009, pp. 235–239*.

[16]. Z. Hasirci and I. H. Cavdar, "Propagation modeling dependent on frequency and distance for mobile communications via high altitude platforms (haps)", *International Conference on Telecommunications and Signal Processing (TSP), 2012, pp. 287–291*.

[17]. H. Aamir and U. Qamar, "Mimo channel modeling for integrated high altitude platforms, geostationary satellite/land mobile satellite and wireless terrestrial networks", *Space Technol, vol. 3, pp. 19–26, 2013. 6*

[18]. Y. Zheng, Y. Wang, and F. Meng, "Modeling and simulation of pathloss and fading for air-ground link of haps within a network simulator", *International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery, 2013, pp. 421–426*.

[19]. Y. Ding, Y. Xiao, J. Xie, and T. Zhang, "A time-varying transition channel model for air-ground communication", *IEEE/AIAA 36th Digital Avionics Systems Conference (DASC), 2017, pp. 1–8*.

[20]. X. Liu, H. Liu, C. Liu, and Y. Luo, "Time-varying communication channel high altitude platform station link budget and channel

modeling", *Information, vol. 9, no. 9, p. 210, 2018*.

[21]. P. G. Sudheesh, M. Mozaffari, M. Magarini, W. Saad, and P. Muthuchidambaranathan, "Sum-rate analysis for high altitude platform (hap) drones with tethered balloon relay", *IEEE Communications Letters, vol. 22, no. 6, pp. 1240–1243, 2018*.

[22]. J. Qiu, D. Grace, G. Ding, M. D. Zakaria, and Q. Wu, "Air-ground heterogeneous networks for 5g and beyond via integrating high and low altitude platforms", *IEEE Wireless Communications, vol. 26, no. 6, pp. 140–148, 2019*.

[23]. M. D. Zakaria, D. Grace, P. D. Mitchell, T. M. Shami, and N. Morozs, "Exploiting user-centric joint transmission – coordinated multipoint with a high altitude platform system architecture", *IEEE Access, vol. 7, pp. 38 957–38 972, 2019*.

[24]. Z. Lin, M. Lin, Y. Huang, T. d. Cola, and W. Zhu, "Robust multi-objective beamforming for integrated satellite and high altitude platform network with imperfect channel state information", *IEEE Transactions on Signal Processing, vol. 67, no. 24, pp. 6384–6396, 2019*.

[25]. M. Asvial, "Traffic model and performance analysis for haps networks", *IEEE International Conference on Telecommunications and Malaysia International Conference on Communications, 2007, pp. 278–282*.

[26]. Iskandar and D. R. Putro, "Performance evaluation of broadband wimax services over high altitude platforms (haps) communication channel", *The Fourth International Conference on Wireless and Mobile Communications, 2008, pp. 55–59*.

[27]. G. Mingxiang, Y. Fang, and G. Qing, "Performance of coverage and wireless link for haps communication", *International Conference on Wireless Communications Signal Processing, 2009, pp. 1–4*.

[28]. B. M. Adnan, S. Chakma, M. M. J. Alam, and F. M. Alamgir, "Matlab based performance replication in high altitude platforms (haps) communication system", *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), 2016, pp. 3606–3613*.

[29]. Y. Shibata, N. Kanazawa, K. Hoshino, Y. Ohta, and A. Nagate, "A study on cell configuration for haps mobile communications", *IEEE 89th Vehicular Technology Conference (VTC2019-Spring), 2019, pp. 1–6*.

[30]. F. Ganh˜ao, M. Pereira, L. Bernardo, R. Dinis, N. Souto, J. Silva, R. Oliveira, and P. Pinto, "Energy per useful packet optimization on a tdma hap channel*", IEEE 72nd Vehicular Technology Conference - Fall, 2010, pp. 1–6. 7*

[31]. W. Weiqiang, Z. Qinyu, and H. Siyao, "Optimization of tcp for haps network", *First International Conference on Instrumentation, Measurement, Computer, Communication and Control, 2011, pp. 666–669*.

[32]. M. Mokayef, W. A. Hassan, T. A. Rahman, and Y. A. Ahmad, "Optimizing the coexistence between haps platform and terrestrial system in 5.8ghz band", *International Conference on Computer and Communication Engineering (ICCCE), 2012, pp. 854–858*