Pricing Strategy for Non-terrestrial Networks in the Future Generation

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***Abstract*—The evolution of non-terrestrial systems, including satellites, High-Altitude Platforms (HAP), and Unmanned Aerial Vehicles (UAVs), has been made possible by improvements in Fifth-Generation (5G) and future Sixth-Generation (6G) dense networks, particularly for emergency applications. These systems tackle issues in dense networks when high throughput and low latency are required due to variations in bandwidth, traffic, and network density. These approaches require capacity augmentation. A minimisation-based optimisation strategy is proposed in this investigation to improve end-user access to services that are not offered on a terrestrial basis. Using 6 or 8 UAVs per network provider, the study investigates UAV-based optimisation further for lowering the acquisition price of decoder entities and compares the results with current approaches. According to the results of the simulation, the proposed approach lowers system acquisition costs by 27.5% while lowering decoder purchase prices by up to 79.9%. Radar systems have a 23.4% improvement in angular precision. A more dependable and secure solution is provided by the 30.5% reduction in buy prices that comes with putting the suggested Digital Converter Variety (DCV) architecture into practice. Based on the results, the proposed method is a strong option for dense UAV networks since it shows notable gains in system efficacy and cost efficiency.**

***Keywords*—non-terrestrial network, minimisation, Unmanned Aerial Vehicles (UAVs), Fifth-Generation (5G), satellites, pricing, optimization**

I. Introduction

The demand for quick wireless access has skyrocketed in the information technology and communication sector lately, putting increasing pressure on Terrestrially-Based Networks (TBNs) [1, 2]. Although innovations like Device-to-Device (D2D) and Ultra-Densely-Based Networks (UDBNs) have constantly demonstrated significant promise in boosting the capacity of Terrestrially-Based Networks (TBNs), they are not without their own set of difficulties [2, 3]. UDBNs are constrained by recurrent forwarding, congestion, and backhaul challenges. However, D2D communication has implementation constraints related to spectrum planning and resource allocation. The convergence of TBNs with Non-Terrestrially-Based Networks (NTBN) systems is one of the crucial enabling factors for the telecommunication technology's sixth era to address these issues and boost the TBN's capacity to provide ubiquitous broadband connection [4–8]. Furthermore, the various types of Unmanned Aerial Vehicles (UAVs): High Altitude Platforms (HAPs), Medium Altitude Platforms (MAPs) and Low Altitude Platforms (LAPs), as well as communications by satellite (ComSat), are among the NTBNs that are taken into consideration [2]. They equally possess some features that make them a good candidate for the 6G dense network. They fly at low heights, not higher than 10 kilometres over the surface of the earth, and are quite small and lightweight. The TBN layer encompasses stationary and mobile subscribers who access numerous cloud services made up of femtocells, pico, micro, and macro employing cognitive radio capabilities like Wi-Fi, 4G and 5G. The increasing penetration of Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites by businesses like One Web and Space, as well as the technological improvement in production and deployment procedures, are the driving forces for the integration of TBN with NTBNs [9]. The development and evolution of non-earthly or Non-Terrestrially-Based Network (NTBN) structures as an efficient approach to enhance TBNS in the provision of amenities to underserved areas such as suburban, rural [2, 3] and the sub-rural are encouraged by the advancement of wireless communication and Information Technology (IT).The growing request and demand for additional services and the massive growth of intelligence-based devices are also notably important in this regard. The motivation for this study is borne out of the desire that as more subscribers tend to have access to services and applications in real-time case, there is a need

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to shift the paradigm from the terrestrial-based system to a non-terrestrial network for better quality of service. Hence, this leads to identifying the problem of the unavailability of some services and applications that are not supported by the terrestrial-based network. Efforts are now geared towards providing solutions by using Unmanned Aerial Systems (UAS) through the formulation of the optimisation way to look at the cost of purchasing these devices and their angular accuracy and find a way to minimise this cost. The proposed UAV scheme offers a means of bringing down the cost of obtaining a UAV-based system for both satellite- and astronomically-inspired institutions with limited resources. Additionally, it hopes to enable aerial-based UAV system analyses outside of terrestrial dense networks. Aerial-based UAV measurements and variables are protected from radio interference while this is being done. By integrating UAVs into non-traditional radio systems, it is also possible to reduce the logistical challenges of reaching satellite and radio networks that are located far from populated regions. The contributions of this study are summarised as follows: At every imaginable terrestrial and aerial site, radio-based networks and satellite networks can be implemented. As a result, the proposed strategy in this work is considered a UAV-based plan. The proposed UAV-based system with multi-mode architectural antennas is also highlighted in this research. This study looks at a workable method for identifying antennas that, when included in an array of antennas, increases and improves angular accuracy and precision for the proposed multiple UAV-based network system. Additionally, the study proposes a synthesis of research on radio communications and television broadcasting. While the signals from UAVs are received on the other channels, the partnership permits the use of some UAV-based television channels that are accessible to electronic systems. In connection with the collaboration, the adjustable feature of the electronic system Programmable Radio (PR) architecture is employed to obtain television content from a range of broadcast television service providers. Moreover, for 6 and 8 UAVs per network provider, the proposed UAV-based minimisation for the purchase price for a decoder entity is developed and contrasted with other existing systems with and without digital converter variety. The remaining organisation of the study is structured thus: Section I explains the introductory aspect of the study, motivation, problem statement and contributions of the study. Section II discusses the reviews on the 6G network for a non-terrestrial-based system. In addition, Section III gives a detailed description of the problem and mathematical formulation of the problem of the system model with its algorithm and flowchart. Section IV presents and examines the numerical results and their interpretation. Section V concludes the study with some future studies.

II. Literature Review

This section presents related works and highlights the fundamentals of Non-Terrestrial Networks (NTN) in Terahertz (THz) communication. In particular, it describes Satellite Communications Systems (SatComSys) and Aerial Communications Systems (ACSs).

A. Non-Terrestrial Networks in Terahertz (THz) Communication

The development of NTN frameworks as a practical means of enhancing TNS services in underserved suburban, rural, and distant geographic areas is propelled by developments in radio communication, Information and Communication Technology (ICT), and smart devices [10, 11]. As described by the 3rd Generation Partnership Project (3GPP) and reported in [12], an NTN-based system can be defined as a network where deep space (space borne, i.e., Low-Earth Orbit, Geosynchronous Equatorial Orbit (GEO), and Medium-Earth Orbit satellites or aerial (airborne i.e., Unmanned Aerial Vehicle (UAV/Unmanned Aircraft Systems (UAS), High Altitude Platform (HAP), Low Altitude Platform (LAP), Medium Altitude Platform (MAP)) vehicles acting as a base station or a relay. Furthermore, the newness and innovativeness of NTNs is their ability to provide large area coverage beyond the areas that are either high-priced or challenging to cover using TNS (i.e., aeroplanes, rural, and sub-rural areas). Additionally, in the report by Ericson on mobility [13] regarding streaming video, it is envisaged that by the end of the year 2024 or so, the utilisation of phones and smart devices will rise to 45% by the consumption of 21Gigabytes of data in a month typically (four times over the amount of consumed data in the year 2018) leading to the generation of about 95% of the entire mobile data flows. Against this background, fulfilling entirely the user's demands and providing the required Quality-of-Service (QoS) ubiquitously has been viewed as one of the major problems that the upcoming radio communication systems face. The NTN will offer and deliver services where it is inexpensively difficult to provide coverage by the TNS, which guarantees the continuity of services undisrupted. Similarly, an NTN is supposed to become effective and capable of providing a solution to allow network expandability and adaptability due to the delivery of multicast resources for data provision to mobile user terminals and network edges [14]. For this reason, NTN is a good candidate that can guarantee, support and provide these benefits. Hence, NTN offers these benefits for future telecommunication systems. This paper surveys and proposes ways of improving user requirements by leveraging the significant role of Terahertz (THz) as a bridge between the electronics and photonics to play in the integration of NTN to TNS in the 6G era for seamless service delivery to the mobile end-users. Hence, in subsequent sections and subsections of this paper, the Satellites (LEO, MEO and GEO), HAPS and UAV are discussed comprehensively with THz as an operating frequency for NTN in the 6G domain [12].

B. Satellite Communications System (SatComSys)

The satellite communications system comprises three entities, namely the Geostationary Earth Orbit (GEO), Medium-Earth Orbit (MEO), and Low-Earth Orbit (LEO). Table I gives a summary of the comparative analysis of different satellite types. A satellite communications system also referred to as a spaceborne platform may belong to either the transparent or reformative payload they support. The translucent (or bent-pipe) payload arrangement anticipates only the wireless frequency refining, amplification, and frequency conversion onboard the satellite. On the contrary, in the regenerative payload design, the Non-terrestrial network platform efficiently executes all the 5G base station (gNB) functions onboard [15]. They are located at 35786km, 7,000–20,000 km, and 600–1500 km, respectively [16, 17]. In recent times, satellites have had the broadest geographical distribution and coverage. Consequently, it is appropriate to offer services to movable and portable platforms such as spacecraft (aircraft) and fast-moving devices (trains) with short or without any requirement redeployments or handoffs. Notwithstanding, satellite communication systems are marred with long propagation delays, thereby reducing their applications to direct communication systems in delay-sensitive services such as human operation, mining, etc. Generally, the satellite communications system finds its applications in telecommunications (global telephone connections, the backbone for global networks system, global mobile communications and connectivity for communications in remote areas), weather, radio and television broadcasting, Earth observation (climate change, agricultural sector), military (surveillance, imaging, early warning, intelligence gathering) and navigation and localisation (nautical, aeronautic applications). The satellite communications system can be classified based on numerous factors such as frequency (spectrum), Orbiting capabilities (Height: GEO, High-Earth Orbit (HEO), MEO, LEO; pattern: elliptical versus circular, inclination, etc.), Multiple access schemes supported: Time Division Multiple Access, Frequency Division Multiple Access, Code Division Multiple Access, Non-Orthogonal Multiple Access, etc., satellite capabilities: Bent versus onboard processing, Coverage and Utilisation type: By coverage(global, regional and national), by utilisation (broadcast, two-way communication system, mobile, etc.) [15, 18, 19].

1) Geostationary Earth Orbit (GEO)

The Geostationary Earth Orbit possesses an equatorial and circular orbit around the Earth at 35,786 km altitude. The orbital time it takes is equal to the Earth's rotational time. The GEO seems fixed in the space to the observer on the ground. The beam size footprint of GEO varies from 200 to 3500 km. The term beam footprint can be defined as an object with an elliptical shape; maybe mobile over the Earth with the NTN platform on its sphere or stays on the Earth-immovable provided the beam pointing devices are utilised to make up for the NTN base motion [12, 20]. This leads to unreasonable propagation delay and impracticability of integration with the conventional terrestrial cellular network. Therefore, a non-GEO satellite communication system is put forward to offer a high bit rate to global cyberspace connectivity, low latency, and many satellite galaxies that are beginning to emerge and fully be commercialised in the future. The merits of the GEO are highlighted as follows: no issue with changes in frequency, the satellite tracking is streamlined and simplified and possesses high coverage with a large beam footprint of about 34% of the Earth's surface. Despite its merits, the GEO has the following demerits: high latency owing to long-distance, polar regions being badly served, bad elevations in locations with latitudes beyond 60 degrees owing to its fixed position above the Equator [15, 18, 19].

2) Medium-Earth Orbit (MEO)

The Medium-Earth Orbit (MEO) is a circular orbit revolving around the Earth with an altitude ranging from 7,000 to 25,000 km. The beam footprint size of the MEO varies from 100 to 1000 km. It can also be said to have orbiting in the range of 5,000–12,000 km above the ground surface [12, 14, 16]. It is a slowing and moving satellite system with higher latency in 70–80 ms. The diametre of coverage falls between 10,000 to 15,000 km with fewer satellites required, simpler system design and no handover required for several connections. Additionally, the orbiting period is about 6 hours and above, with maximum satellite visibility time in a range of a few hours [15, 18, 19].

3) Low-Earth Orbit (LEO)

The Low-Earth Orbit is a circular orbit revolving around the Earth with an altitude ranging from 300 to 1500 km. The beam footprint size of the LEO varies from 100 to 1000 km. The visibility of this satellite varies from 10 to 40 min, with latency comparable with the terrestrial long-distance connectivity of about 5 to 10 ms [18, 19]. In this type of satellite, several satellites are required for global coverage. The handover is necessary from one satellite to another. More importantly, this type of satellite utilises spot beams with smaller footprints that enable frequency reuse. The system of this kind of satellite is more complicated owing to movable satellites [12, 15, 18, 19]. Table I shows the comparison of different satellites.

TABLE I. COMPARATIVE ANALYSIS OF DIFFERENT SATELLITE TYPES [15, 21]

Parameter	GEO	MEO	LEO
Propagation loss	Highest	High	Low
Satellite lifespan	Long	Long	Short
Number of Handoffs supported	Lowest	Extremely Low	Highest
Orbital Period	24 h	2−8 h	10−40 mins
Satellite Height	35,800 km	5000−12,000 km	500−1500km
Number of Satellites Supported	3	Between 8−10	Between 40−80
Cost of Gateway	Less expensive	More expensive	Most expensive

C. Aerial Communications System

The aerial communications system, which is also known as airborne, comprises an Unmanned aircraft system platform (UAS such as an Unmanned Altitude Vehicle (UAV)) generally has an altitude ranging between 8 to 50 km, including a High Altitude Platform Station (HAPS) with an altitude of 20km, Medium Altitude Platform Station (MAPS), and Low Altitude Platform Station (LAPS). Same as obtained in Satellites such as GEO, the

UAS position can maintain a fixed position in space to a given location on the ground surface. The UAS generally has a beam footprint varying from 5 to 200 km. These categories of aerial communication systems such as HAPS, MAPS, LAPS, and UAV are discussed summarily in the next subsection with their features, merits and demerits accordingly [12, 21]. Table II gives a comparison of different altitude platforms and UAVs.

TABLE II. COMPARISON OF DIFFERENT ALTITUDE PLATFORMS AND UAVS [15, 21, 22]

Performance Metrics	HAP	MAP	LAP	UAV
Overflight	Largest	Larger	Small	Relatively small
Cost implication	High	Medium	Low	Relatively low
Support for Multicast and Broadcast	Short	Extremely short	Low	Relatively low
Delay in Propagation	Short	Short	Short	Extremely short
Persistent Communication	Long	Short	Extremely Short	Moderately Short
Susceptibility to natural occurrences	Low	Low	Low	Low
Response time and flexibility	Medium	Fast	Faster	Faster
Footprint size and beam	Large	Small	Relatively Small	Relatively Small

1) High-altitude platform station

High Altitude Platform Stations (HAPSs) are generally referred to as repeaters flying at an altitude within the limits of 17–22 km or 17–24 km in the sky (known as the stratosphere) [22–24]. They can be categorised as aerodynamic and aerostatic. The aerostatic HAPSs are in the shape of balloons configured to stay in space for some time. At the same time, the aeroplanes are quasi-stationary with onboard propellers and electric motors for keeping the station intact [22]. Compared with satellites, HAPSs have low latency, reduced implementation, and deployment reduced launching costs and stronger received signal strength. They also have tendencies to fly to a given location or area in response to earthly or altitudinal/special requirements. Although the HAPSs offer numerous benefits, they possess a reduced coverage area than the satellites and require refuelling, reducing their service provision time. The merits of HAPSs over LAPSs and MAPSs are wider coverage and long endurance [25]. In terms of launch and insurance costs, dispersion losses, transmitter power demands, hop delay time and other factors, HAPSs are better than satellite types such as GEO. Thus, the comparative advantage HAPSs have over terrestrial networks and the like are the primarily beneficial line-of-sight propagation conditions. HAPS communication can utilise high-capacity, millimetre-wave (mm-Wave)/Terahertz-beam carriers that are not being impacted by precipitation losses in the sky, clouds and moisture [26, 27]. Additionally, HAPS can be classified further into Lighter-Than-Air (LTA) and Heavier-Than-Air (HTA). The LTA-HAPSs are commonly known as balloon aerostats or airships loaded with helium gas. The LTA-HAPSs require less energy for stabilization and launching over a fixed region. While the latter are stationed or crewed aeroplanes with an adequate forward thrust that is made available by the propellers energised by jet engines, electric motors and so forth [25].

2) Medium altitude platforms

The Medium Altitude Platforms (MAPSs) act between the HAPSs and LAPSs domains. They support applications that fall between the LAPS and MAPS. It is an airborne platform that works at the medium layer, which can be utilised as a relay between a LAP and HAP. Hence, based on the type of operations and application cases, the available MAP in the market is essentially a UAV type that supports long-endurance abilities and Human-Crewed Aerial Vehicles (MAVs). More importantly, it supports critical missions such as military applications, and its coverage area in terms of the radius is around 5 km [21, 28].

3) Low altitude platforms

Low altitude platforms (LAPs) can be UAVs that can fly at low altitudes, say some hundreds of metres, for an adequate capability to complete a mission. Hence, diverse applications can be achieved by the use of LAP. By way of illustration, An LAP can be employed as an airborne Base Station (BS), better known as a UAV-BS, in which a BS is installed on a LAP. It finds applications such as offloading network traffic from a jammed or crowded BS and enhancing network capacity and coverage. LAP is small in terms of footprint, restricted regarding the overflight applications, significantly reduced for vulnerability to natural occurrences such as disasters, rapid responsiveness and flexibility performance. Its communication ability is short, with a short propagation delay. It is capable of supporting both the multicast and broadcast network system, and more importantly, it is low in terms of the cost of building it [21, 22, 28, 29].

D. NTN-Enabled Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles (UAVs), also called drones, have been made the subject of a collaborative study in recent years due to their large number of applications comprising delivering medical supplies, telecommunications, operations, monitoring and surveillance and robotics [1, 21, 30]. Nevertheless, such standard UAV-based studies have generally centred on control, autonomy, and navigation problems, as the driving applications are typically military or robotics-based. Contrarily, the transmission problems of UAVs have usually been either overlooked or studied as an integral part of autonomy and control components. Compared to other networks, UAVs possess the following benefits: support for the lowest cost and are characterised by easy and fast deployment [22, 31, 32]. These features make them an appropriate and ideal candidate for delivering communication amenities for emergencies and acting as antenna base stations for direct and User Equipment (UE) connectivity and traffic offloading during the restricted duration of events such as sporting activities and festivals.

They are comparatively small and light, and operate at low altitudes, not surpassing 10 km above the Earth's surface. Their low altitude ability makes them an excellent candidate to possess decreased proliferation losses alongside the capability to initiate a clear line of vision between broadcaster and recipient. Despite their comparative advantages and benefits, they are marred with many constraints such as power, weight, and size, restricting their communication abilities and flight duration [22, 32]. Also, in [33, 34], a review of Terahertz was carried out thoroughly and a UAV-based system concerning 5G was investigated, respectively. Fig. 1 shows the system model of the non-terrestrial network system in 6G and how each layer is related and connected.

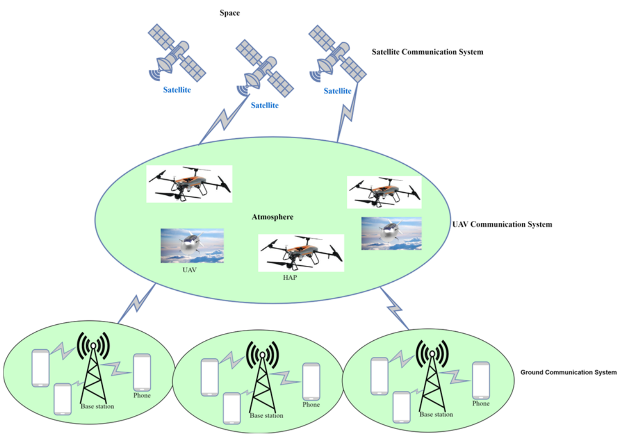

Fig. 1. The system model for the non-terrestrial network system in 6G.

Most research on pricing strategies now focuses on terrestrial networks, which leave a large knowledge vacuum regarding the efficient pricing of Non-Terrestrial Networks (NTNs), like satellites and high-altitude platforms. NTNs have distinct obstacles such as elevated infrastructure expenses, fluctuating service calibre, and amalgamation with terrestrial networks, necessitating customised pricing schemes. Current models frequently ignore these particular cost drivers and service metrics, along with the market and regulatory dynamics that affect NTNs. Subsequent investigations must concentrate on formulating pricing tactics that consider expenses peculiar to NTNs, distinguishing service quality, and integrating with terrestrial systems. This study involves investigating dynamic pricing models that adjust to changing consumer needs and technology developments to maintain competing and stable NTN pricing in the ever-changing telecom market.

III. Materials and Methods

A. System Model: Problem Description and Formulation

The case in consideration in this study has to do with the Price-Restriction UAV-based system (PRUAV). This scheme intends to gain access to low-priced antennas for the sake of making satellite services and radio applications available and accessible to end-users for emergency services/applications that the terrestrial base stations cannot offer in a dense network base. Furthermore, this is going to be achieved via the enhancement of the angular precision/accuracy of the UAV thereby reducing the prices associated with such services and applications.. Therefore, assuming that.

$$\theta = \{\theta_{uav}, \theta_{ion}\},\ \theta_{uav} = \{\theta_{uav}^{1} \dots, \theta_{uav}^{u}\}\ and\ \theta_{uav} = \{\theta_{ion}^{1} \dots, \theta_{ion}^{v}\} \quad (1)$$

where $\theta_{uav}\ and\ \theta_{ion}$ are the set of UAVs situated above the ground and in the ionosphere or stratosphere, accordingly. Additionally, $U\ and\ V$ are the total number of UAVs and ionospheric-based UAVs, respectively. Furthermore, let θ' represent the set of UAVs accessible to the RUAVs which houses the UAV-based proposed scheme compactly represented as

$$\theta' = \{\theta_{uav}, \theta_{ion}, \gamma_{uav}\},\ \gamma_{uav} = \{\gamma_{uav}^{1} \dots, \gamma_{uav}^{R}\} \quad (2)$$

where θ_{UAV} and θ_{ion} have the same meaning as defined previously and γ_{uav} is the set of multiple-based UAVs (antennas) achieved from parabolic-based antennas employed for the reception of satellite signals from the network and R indicates the aggregate of multiple-mode antennas. Compactly, these sets can be represented as

$$\alpha_{uav} = \mathrm{K}_{uav}\left(\sum_{u=1}^{U} max\left(\omega(\theta_{uav}^{u-1}, \theta_{uav}^{u})\right)\right)^{-1} \quad (3)$$

and

$$\alpha_{ion} = \mathrm{K}_{ion}\left(\sum_{v=1}^{V} max\left(\omega(\theta_{ion}^{v-1}, \theta_{ion}^{v})\right)\right)^{-1} \quad (4)$$

where $max\left(\omega(\theta_{uav}^{u-1}, \theta_{uav}^{u})\right)$ indicates the maximum value of the distance between the terrestrial-based antennas to UAV, and θ_{uav}^{u-1} ; $\theta_{uav}^{u-1} \in \theta_{uav}$ and θ_{uav}^{u} ; $\theta_{uav}^{u} \in \theta_{uav}$. Additionally, $max\left(\omega(\theta_{ion}^{v-1}, \theta_{ion}^{v})\right)$ represents the maximum value of the distance between the ionospheric-based antennas to UAV, and θ_{ion}^{v-1}; $\theta_{ion}^{v-1} \in \theta_{ion}$ and θ_{ion}^{v}; $\theta_{ion}^{v} \in \theta_{ion}$.

Hence, if the UAV-based scheme for a dense network is added to the existing approach, the new scheme for the computation of the angular accuracy/precision for the UAV becomes

$$\eta = K_{uav}\left(\sum_{u=1}^{U}\sum_{r=1}^{R} max\left(\omega(\theta_{uav}^{u-1}, \theta_{uav}^{u})\right) + max\left((\theta_{uav}^{u}, \gamma_{uav}^{r})\right)\right)^{-1} \quad (5)$$

where $max\left(\omega(\theta_{uav}^{u}, \gamma_{uav}^{r})\right)$ represents the maximum distance that exists between $\theta_{uav}^{u}\ and\ \gamma_{uav}^{r}$. Note that ω and Ω denote the distance between the UAVs and the electronic system connected to the service application, respectively. Therefore, the converted ground antenna, ionospheric (stratospheric) antenna and the proposed scheme are employed and the pricing for purchasing each is represented as $P_0(\theta_{uav})$, $P_0(\theta_{ion})$, and $P_0(\gamma_{uav})$), correspondingly. Compactly, the pricing for purchasing the UAV and multiple based types can be cast as

$$P_0(\theta_{uav}, \gamma_{uav}) = \sum_{u=1}^{U} . \sum_{r=1}^{R} (P_1(\theta_{uav}^{u})) + P_1(\gamma_{uav}^{r}) + P_2(\gamma_{uav}^{r}), \quad (6)$$

$$P_0(\theta_{ion}, \gamma_{uav}) = \sum_{v=1}^{V} . \sum_{r=1}^{R} (P_1(\theta_{ion}^{v})) + P_1(\gamma_{ion}^{r}) + P_2(\gamma_{uav}^{r}) \quad (7)$$

$$P_0(\theta_{uav}) = \sum_{u=1}^{U} P_1(\theta_{uav}^{u}),\ P_0(\theta_{ion}) = \sum_{v=1}^{V} P_1(\theta_{ion}^{v}) + P_2(\theta_{ion}^{r}) \text{ and } P_0(\gamma_{uav}) = \sum_{r=1}^{R} P_1(\gamma_{uav}^{r}) + P_2(\gamma_{uav}^{r}) \quad (8)$$

The Digital Converter Variety (DCV) or simply put decoder diversity for the applications and services offered can be described as $\mu = (\mu_1, \mu_2, \ldots, \mu_D)$. The D represents the total number of transmission channels for the UAV service provider. Therefore, the DCV can be cast as

$$P_3(D) = \sum_{d=1}^{D} \Omega_d \quad (9)$$

Let the cost of acquiring the DCV be $P_3'(C)$. The electronic system connected to the dth service application providers can be represented as μ_d; $\mu_d \in \mu$ as Ω and when modified with the new scheme of UAV for the dense network system model, it gives

$$P_3'(C) = \frac{1}{C}\sum_{c=1}^{C} \Omega_c + K_{PR}, \quad (10)$$

where K_{PR} is the pricing required to purchase a programmable radio (PR). The optimisation approach can be cast as a restricted optimisation problem to establish a pricing strategy for NTNs. Define the objective function as the DCV acquisition cost $P_3'(C)$ and the pricing/cost parameters. Fixed infrastructure costs, variable operating costs, and anticipated income are usually included in this function. Among the constraints are specifications for service quality. Regulatory limitations as well as service quality criteria like latency and bandwidth are among the constraints. The proposed optimisation scheme's algorithmic execution and computational formulation are described as follows: Firstly, there is a need to define objective function and constraints. This is carried out in the formulation of the problem as detailed under problem formulation. Secondly, the optimisation of the proposed algorithm using proposed UAV-based minimisation for the Purchase Price for a Decoder Entity (PPDE) or other metaheuristic algorithms such as genetic algorithm to iteratively modify and adjust the objective function. Finally, assessment and evaluation of the scheme are carried out to guarantee viability and optimality.

In addition, the Algorithm 1 is employed for the proposed UAV-based minimisation for the purchase price for a decoder entry entity as stated.

Algorithm 1: Proposed UAV-based minimisation for the Purchase Price for a Decoder Entity (PPDE)

Input: Number of UAVs, initial price, number of users/subscribers
Output: Obtain the angular accuracy, and purchasing price for the new model
Steps:
For u = 1: $\boldsymbol{U}$, v=1:V, r=1:R, c=1:C
Apply Eqs. (3.2-3.10) on the designed system to obtain PPDE and angular accuracy/precision of the scheme
Check if details of the UAV-base stations have been captured and processed
If the above step is true, go to the next step below; Otherwise, go back to the initialization stage
Repeat the step above for the proposed scheme in (3.6-3.10)
Compute the angular accuracy and PPDE for different values and number of UAVs
Repeat the steps above until convergence is attained
End

The flowchart for the proposed UAV-based dense network for the purchase price of a decoder entity is depicted in Fig. 2.

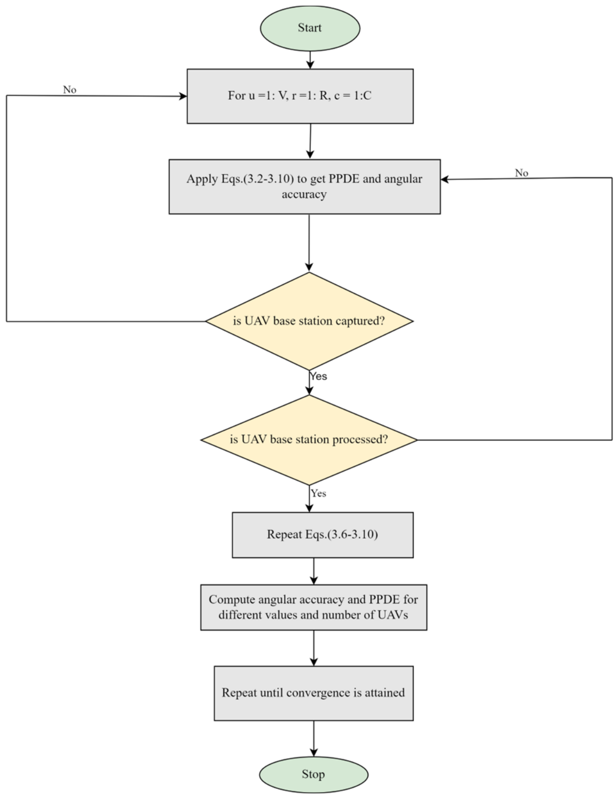

Fig. 2. UAV-based dense network for the purchase price of a decoder entity.

IV. Result and Discussion

A. Numerical Simulation Results and Interpretation of the Numerical Results

For this section, a scenario was created using satellites-based Unmanned Aerial Vehicles (UAVs) with and without digital converter variety simply termed decoder diversity. Also, the numerical and performance analyses are carried out and achieved in a MATLAB environment. In two situations, the cost of purchasing the system is examined. The very first scenario takes into account the usage of unused satellite television earth stations. The electronic system is missing from these abandoned earth stations. The conversion process in this instance necessitates the purchase of electrical equipment and communications system components to collect astronomy signals. The price of locating and purchasing the idle direct broadcast satellite earth stations is also included in the transformation in this respect. In the second scenario, the usage of current television channels and earth stations as a receptive unit for space science purposes is taken into account. Mostly in the second instance, the usage of current television channels and ground stations as a receptive unit for radio communications objectives is considered. The element, which is purchased in this instance, is a multi-mode electrical system inspired by Programmable Radio (PR). By adding a reprogrammable PR to the recommended UAV's present electronic system, the intended PR-enabled multi-mode electronic system is realised. Fig. 3 summarises the findings about the system cost of sales. Fig. 3 displays the costs associated with transforming underused television broadcast antennae under the current plan. In this instance, the acquisition costs are contrasted with the PR acquisition expenses recommended in the recommended UAV (proposed solution). The findings in Fig. 3 also take into account the scenario in which a PR is shared by numerous customers using the planned multi-mode television channel system. The acquisition costs for the PRs are approaching their limit in this situation. The mathematical model and simulation result take into account the scenario in which four or six subscribers divide a PR. According to the findings in Fig. 3, rebranded inactive satellite earth stations meant for communication systems have higher system purchase costs than the planned UAV's usage of telescopes, which is what is shown in Fig. 3. This is so because, in the case of the proposed UAV, just a PR module and associated systems are connected. The expenditures incurred, nevertheless, in the absence of the deployment of UAV, are those related to the search for damaged radio receivers, their repair, and the acquisition of a suitable electrical system. Additionally, employing the proposed UAV lowers system acquisition costs by an average of 32.5%. The price of acquiring PR is further decreased by the inclusion of PR sharing. This is because the subscribers split the costs of PR. When PR is split between two subscribers and four users, the price of purchasing a system is decreased by either 30% on average or 55%, respectively. Additionally, the angular modelling is examined in two different circumstances by the performance assessment. Within the first case, the performance evaluation takes into account that, in the absence of the proposed UAV, the astronomy organisation uses available telescopes. The network is limited to using terrestrial telescopes in this situation. At a particular location, the spacing here between the telescope impacts the angular resolution. Fig. 4 displays the angular resolution acquired through simulation before integrating the suggested UAV. Fig. 5 displays the angular resolution attained after adopting the suggested UAV. The lowering of angular precision in Figs. 3 and 4 denotes better output. This suggests that extra data was included in the graph because of the radio communications measurements. From the data shown in Fig. 4, it is clear that the planned multi-mode direct broadcast satellite telescopes do not provide a sufficient angular resolution when just terrestrial telescopes and stratospheric telescopes are used. Because inter-direct broadcast satellite antennas are installed in user homes, their spacing is reduced in areas with dense populations. Due to this low baseline, multi-mode satellite television telescopes perform worse in terms of angular resolution. In addition, stratospheric telescopes are located in the air rather than on the ground. Earth atmosphere telescopes have a greater separation since they are not constrained by terrestrial siting. The baseline of troposphere antennas is greater than terrestrial telescopes as a result of the capabilities and functionalities they possess (including but not limited to the number of co-television channel antennas). This investigation reveals that the angular accuracy of stratospheric telescopes is, on average, 34.2% higher than that of terrestrial telescopes (excluding the number of co-direct broadcast satellite telescopes). Further research reveals that, in contrast to the case in which only the earthly telescope (no UAV) is employed. The lateral accuracy is increased by an average of 24.3% when the ground telescope is employed, regardless of whether or not the usage of an unmanned aerial vehicle. Similarly, increasing the angular resolution by using the proposed UAV rather than only the stratospheric telescope improves it by 10% on average. The data made public demonstrate that using the suggested UAV improves angular resolution. This is so that radio communications investigations can be conducted with a significantly higher telescope by including the projected number of co-satellite television telescopes. Assuming several co-television broadcast telescopes are included. The proposed UAV increases the mean baseline from 7.5 km to 10 km in a case where only terrestrial telescopes are also used. Assuming that several co-television channel antennas in a setting where only stratosphere-based telescopes were directly employed, the threshold increases from 7 km to 13.5 km when they are incorporated into the suggested UAV. First, from the data shown, it can be inferred that the suggested UAV's independent use has been advantageous in terms of system purchase costs. This seems to be because including the suggested UAV would, on average, result in system purchase costs being reduced by 27.5%. Nevertheless, the angular precision needed to conduct radio communications observations is not increased by using the proposed multi-mode direct broadcast satellite telescope on its own. The angular precision involved with radar systems is improved by up to 23.4% when the suggested inter-TV broadcasting antenna in conjunction with either the terrestrial reflector or the subtropical telescope is utilised, as suggested in the provided UAV. When users can watch streaming digital cable or satellite, the use of the recommended digital TV variation is taken into consideration. The subscribers to this option do not receive digital satellite programming subscriptions. Because of services like the free satellite, this choice is practical. Subscribers can receive signals from many free-to-air satellites that are now in operation thanks to the employment of an electronic system, such as a decoder that incorporates decoder diversity. It looked at how much a decoder unit would cost to buy both with and without the suggested decoding variety framework. Fig. 6 displays the outcome of the purchase price for a decoder entity (PPDE). Each decoder in Fig. 6 is presumptively capable of receiving and processing television signals from providers of television broadcasting that each employs a pair of satellites. The outcomes in Fig. 6 also take various digital satellite television service subscribers into account. These users might negotiate differently and pay various amounts for the transponder. According to an analysis of the data in Fig. 6, using the suggested digital converter variety paradigm reduces the subscriber PPDE by an average of 30.5%. Evaluating the sum PPDE is just as important as studying the subscriber PPDE. End customers will have to pay more money to purchase more multi-mode electronic systems if the total price is higher. The subscriber's ability to obtain space-based television networks available for free is thereby limited. The angular accuracy and aggregate PPDE of the UAVS are shown in Figs. 7 and 8, respectively.

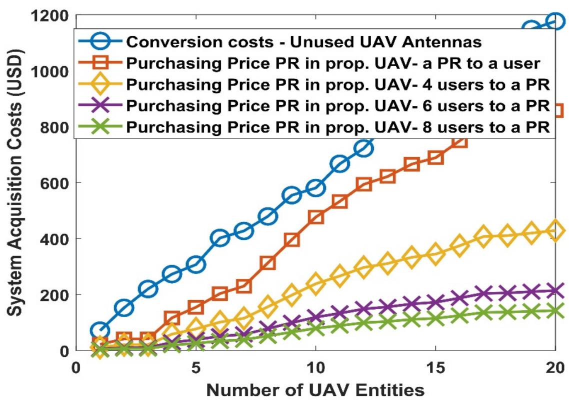

Fig. 3. System purchasing costs vs number of UAV entities.

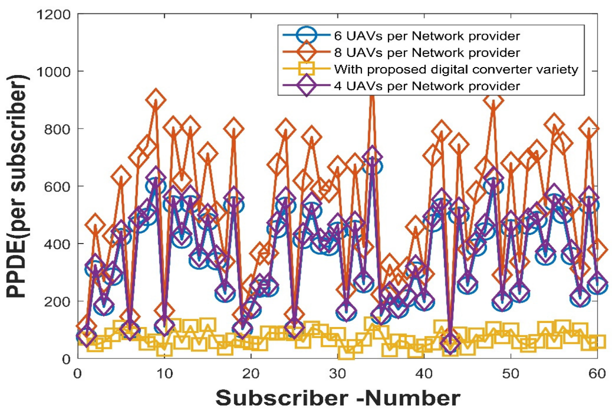

Fig. 4. Purchasing price for decoder entity per subscriber against subscriber number.

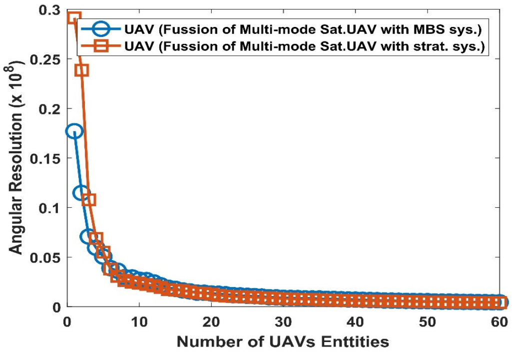

Fig. 5. Angular resolution versus the number of UAVs.

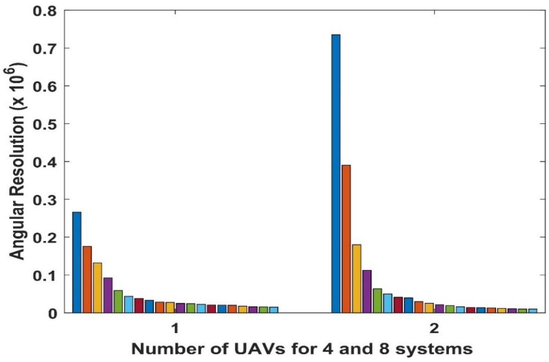

Fig. 6. The angular resolution versus the number of UAVs for 4 and 8 systems.

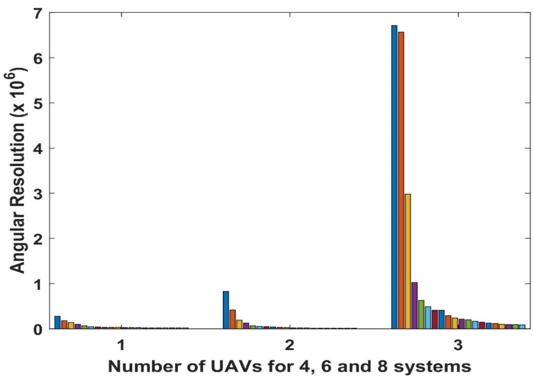

Fig. 7. Numerical result for the Purchase Price for a Decoder Entity (PPDE).

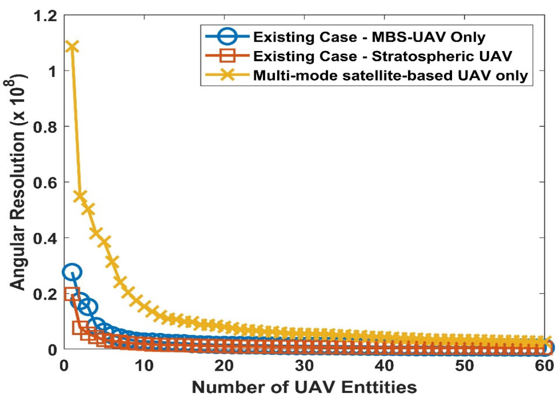

Fig. 8. Angular resolution of the existing case for UAVs vs multi-based UAV system only.

V. Conclusion

This study shows that UAVs can help astronomy institutions with tight budgets by reducing system acquisition costs and obstacles to instrument accessibility. The suggested UAV-based multimode satellite television system improves angular resolution for radio astronomy by 25.4% and drastically lowers acquisition costs by 30.2%. Furthermore, with an average savings of 81.3%, the system offers a financially viable option for multi-provider content access by minimising the purchase price for decoder entities (PPDE) by up to 79.9%. The main conclusions demonstrate how UAVs may support both satellite television reception and radio astronomy, offering a useful and cost-effective substitute for conventional terrestrial networks. These findings highlight how UAVs can improve electromagnetic astronomy observation effectiveness while increasing access to space-based television networks. Improving system performance and reducing operating costs are potential benefits of the UAV-based approach, which offers a flexible platform for consumer applications as well as scientific investigation. Follow-up studies will need to focus on enhancing strategies for pricing for next-generation non-terrestrial networks (NTNs), encompassing the creation of adaptive pricing models grounded in real-time data, such as network demand and congestion. To guarantee smooth service continuity, more research is also required on the integration of NTNs with terrestrial networks and the analysis of consumer behaviour to better customise pricing schemes. In summary, this study provides insightful information about the application of UAVs in satellite communication and astronomy, as well as a workable way to save costs and boost efficiency. The findings pave the way for future advancements in pricing strategies and network inclusion, ensuring sustainable and user-centred techniques in the ever-changing non-terrestrial network landscape.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

LAA contributed to Conceptualisation, Writing, Validation, Formal Analysis, Methodology, and Editing. MB was responsible for Supervision, Review, and Resources. EM provided supervision, Review and Resources. All authors had approved the final version.

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