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Research Article

Non-Terrestrial Network Concepts in 5G and Beyond Communication Technologies

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ABSTRACT

Mobile communication systems used in 5G and beyond will provide high-capacity, reliable and low-latency services within wide coverage areas. Currently, terrestrial networks are widely used, but it is expected that these networks will be replaced by hybrid network solutions where terrestrial and non-terrestrial networks operate together. These hybrid ones can perform cutting-edge complimentary solutions when the traditional networks have weak signal levels and geographical difficulties. The main motivation of this study can be stated as the increasing use of hybrid network structures for the solution of digital divine and access problems. In this study, design optimizations of hybrid wireless networks according to different system architectures and performance analyzes are given and various non-terrestrial network technologies are compared.

Keywords: *5G and Beyond, Non-Terrestrial Networks, Satellite Communication*

5G ve Ötesi Haberleşme Teknolojilerinde Karasal Olmayan Ağ Konseptleri

Öz

5G ve ötesinde kullanılan mobil iletişim sistemleri, geniş kapsama alanlarında yüksek kapasiteli, güvenilir ve düşük gecikmeli hizmetler sunacaktır. Şu anda mobil karasal ağlar yaygın olarak kullanılmakla birlikte, ilerleyen dönemde bu ağların yerini karasal ve karasal olmayan ağların birlikte çalıştığı hibrit ağ çözümlerinin alması beklenmektedir. Karasal ağların sinyal seviyeleri zayıf olduğunda ve coğrafi zorlukların engelleyici olduğu durumlarda; bu hibrit ağ çözümlerinin kullanıldığı en son teknolojiler tamamlayıcı çözümler olarak sunulmaktadır. Bu çalışmanın ana motivasyonu, dijital ayrılık ve erişim sorunlarının çözümü için hibrit ağ yapılarının kullanımının önerilmesi olarak belirtilebilir. Bu çalışmada hibrit kablosuz ağların farklı sistem mimarilerine göre tasarım optimizasyonları ve performans analizleri verilerek çeşitli karasal olmayan ağ teknolojileri karşılaştırılmıştır.

Anahtar Kelimeler: *5G ve Ötesi, Karasal Olmayan Ağlar, Uydu Haberleşmesi*

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I. INTRODUCTION

The Non-Terrestrial Networks (NTN) denote communication systems which work at a certain altitude above the Earth's surface. NTNs can be classified into two main groups according to their altitudes: airborne and spaceborne. Airborne networks involve drones, low altitude platforms (LAPS), high altitude platforms (HAPS) and air-to-ground networks. On the other side, spaceborne networks contain satellites operating in different orbits such as low earth orbit (LEO), medium earth orbit (MEO) and geosynchronous orbit (GEO) [1].

During the half-century period when mobile communication systems came into our lives, terrestrial wireless communication systems, from the first generation (1G) mobile networks to the fourth generation (4G) mobile networks, have operated quite successfully, considering both service quality and communication speed [2]. The mobile service, which started with 1G systems working as voice carriers, continued with multi-media and messaging applications and in the current period; it continues with the transmission of big data in broadbands, in a low latency and high reliability environment.

The transmission of broadband services to end-user devices at low latency and under high reliability conditions is provided over terrestrial networks via base stations, mostly in economically developed regions with relatively high population density compared to rural areas [3]. Fifth generation (5G) wireless communication systems, which have become widespread around the world after 2020, are similarly built on terrestrial networks and hybrid communication services have begun to be offered by integrating with non-terrestrial networks [4].

However, 6G wireless communication networks, which are planned to be put into operation by the 2030s, will focus on the communication between human-machine and machine-machine rather than the communication of people in the environment with each other [5]. The emergence of the need for communication between people, machines and objects in very large areas and the use of 6G network in many areas of life, from energy to transportation, from education to new production technologies, brings to the fore non-terrestrial network technologies that enable wide coverage areas [6, 7].

Satellite communication networks, which have an older transition and technological inheritance than terrestrial mobile communication systems, provide direct solutions in country or continent-wide areas, depending on the height of the satellite above the ground and the positioning of its antennas [8]. In the past, the use of satellite technologies for direct voice and data communication has not become widespread, especially due to the high costs of satellite production, testing and launch [9]. Although low orbit satellites are used in electronic intelligence and image retrieval applications, medium distance orbit satellites in positioning systems applications, and geostationary high orbit satellites are used for TV broadcasting and data communication in relatively limited bandwidths, large-scale satellite communication networks have not been made operational and commercial [10]. However, increasing spectrum capacity demand, creation of global coverage areas and especially disaster, earthquake etc. Since communication systems play a critical role in the management of processes such as emergencies, the development of non-terrestrial communication networks and their integration with terrestrial networks are of great importance [11].

In order to meet the increasing band capacity and high-speed communication demand for use in 5G and later communication technologies, different initiatives such as Starlink, OneWeb, Telesat, Kuiper have started to offer mobile communication services to global coverage areas via low orbits [12]. However, the fact that terrestrial networks provide effective mobile communication services at low cost and very low latency, especially in densely populated city centers and closed areas, necessitates future network solutions to be in the form of integrated use of terrestrial and non-terrestrial networks [13].

Scenarios of hybrid use of terrestrial and non-terrestrial networks have been examined in detail within the scope of the 3rd generation partnership project (3GPP) Rel-15, Rel-16 and Rel-17 studies, which were formed by seven different mobile telecom standard regulatory organizations in order to create standards for mobile communication systems [14 – 16]. In every two years a new release, which includes protocols for mobile telecommunications, is studied and mobile vendors follow the given protocols in these releases to develop their products.

Non-terrestrial networks are critical in ensuring continuous communication due to their wide coverage areas. On the other hand, especially earthquakes etc. in case of disasters, the communication systems of terrestrial networks become disabled or the high cost of installing terrestrial networks at every point in large rural areas necessitates the integration of non-terrestrial networks and terrestrial networks [16]. Considering these advantages of non-terrestrial networks and technological developments that complement terrestrial systems, integrated satellite-terrestrial network solutions appear to be the developing trend for new generation communication systems [17].

Satellite communication systems and terrestrial mobile networks, the two most important pillars of today's wireless communication systems, were developed using separate and different standards until recently [18]. After seeing the importance of hybrid structure in popularizing 5G and beyond wireless communication technologies, different studies have been put forward on how to integrate satellite and terrestrial networks and how to create a hybrid network structure through integration. For instance, the use of terrestrial relays is being discussed in response to obstacles that may arise in satellite signals reaching directly to end users [19]. On the other hand, fiber optic systems constitute the basic backbone of terrestrial networks and the current mobile communication system. In regions where there is no optical connection, it will be possible to use satellite communication systems for backhaul transmission [20]. Additionally, cognitive radio solutions are being introduced in dynamic spectrum applications to use the frequency spectrum more efficiently and effectively [21].

Both terrestrial networks and non-terrestrial network solutions have different advantages and disadvantages depending on their usage areas. Providing continuous, low-latency and high-bandwidth communication infrastructure, especially in rural areas and disasters. In cases of natural disasters, it has great importance that terrestrial networks are supported by non-terrestrial networks and hybrid solutions are applicable in order to quickly restore the communication infrastructure in the affected areas. In the second part of this study, non-terrestrial network technologies, standardization studies, and system architectures are explained. In the third section, performance analyzes are given for different application scenarios that can be used in rural areas and disaster situations. In the last section, evaluations regarding the integration of terrestrial and non-terrestrial networks are presented.

II. MOBILE NETWORK TECHNOLOGIES in 5G and BEYOND

Mobile communication technologies of the 5th generation and beyond are being developed to support basically three different application classes. Scenarios with enhanced mobile broadband (eMBB - enhanced Mobile Broad Band), massive machine type communication (mMTC - massive machine type communication) and ultra-reliable and ultra-low latency communications (URLLC - wireless communication in 5G and beyond) constitute the basic application areas for these systems [22]. As 5G becomes widespread in the field and its commercial use increases by the 2020s, technology development efforts on 6th Generation (6G) mobile communication networks have begun to accelerate. 6G systems will include technologies that have wide coverage areas, offer broadband access solutions within these coverage areas, support internet of things (IoT) applications, provide remote area coverage and enable emergency communication [23, 24]. In addition, the difference of 6th generation communication technologies from existing communication systems, especially artificial intelligence (AI), digital twins (DT), holographic communication (HC), internet of senses (IoS). There will be advances in these key technologies [25].

Figure 1 shows in detail three different application classes that will be developed using 5G and beyond communication systems. Advanced mobile broadband applications require higher data volume and spectral efficiency. Additionally, the need for wide coverage has become more prominent in this type of application. In giant machine type communication, which is another type of application, efficient use of energy and long battery times are of great importance due to high connection density and many machines distributed in large areas. In ultra-reliable and ultra-low latency applications, which are the last type of application and are mostly used in the classification of time-critical tasks, very low latency times, high reliability communication and high positioning accuracy are provided.

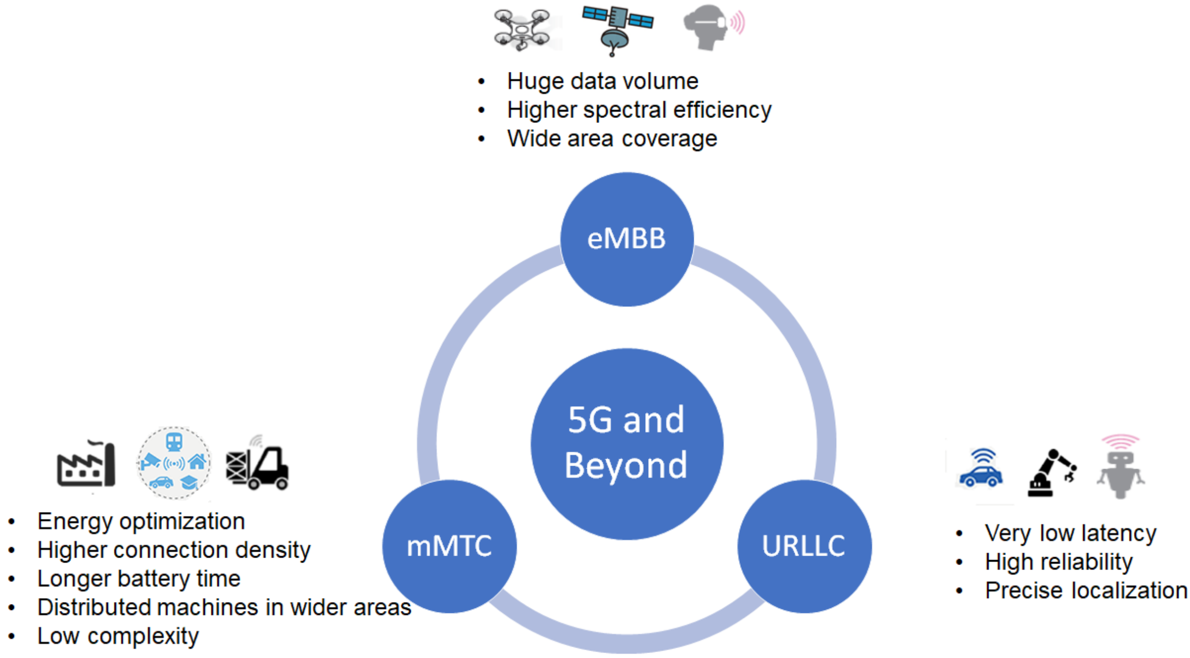

Figure 1. *Classification of 5G and Beyond Applications*

When the development of mobile communication systems is examined, it is seen that after 4G-LTE, there are great leaps in many key performance indicators in communication systems such as data speed, efficient use of communication band, delay times, network energy efficiency, and traffic capacity. As given in Table 1, in 6G communication systems that are expected to come into effect after the 2030s, these performance criteria are expected to be much higher and will cause a big leap in application-based business models.

Table 1. *Performance Evolution of 4G-5G ve 6G Communication Systems*

	4G-LTE	5G	6G
Highest Data Rate (Gbit/s)	1	20	1000
User Experience Data Rate (Mbit/s)	10	100	1000
Spectrum Efficiency	1x	3x	6x
Mobility (km/h)	350	500	1000
Latency (ms)	10	1	0,1
Network Energy Efficiency	1x	10x	20x
Traffic Capacity (Mbit/s/m^2)	0,1	10	10000

Another illustration of the development of mobile communication systems between different generations, as shown in Figure 2, is that the processing load has a more distributed structure with each passing generation. For instance, while in 4G-LTE systems there is a processing load on the core network and cloud layer, in 5G applications this processing capability is also added to the base stations. In addition to cloud, core network and base stations, many smart user equipment in distributed architecture will have processing capabilities in 6G. This will also cause the data traffic on the mobile communication architecture to increase.

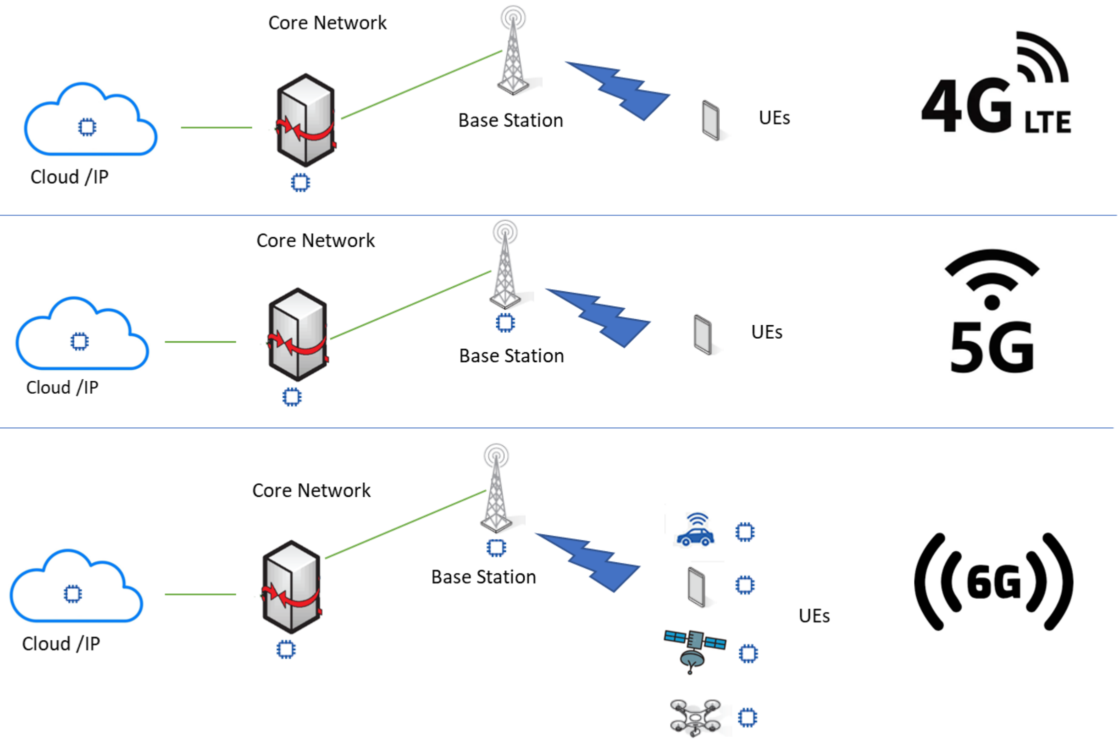

Figure 2. *System Architecture of Mobile Communication Networks*

III. NON-TERRESTRIAL NETWORKS IN 6G COMMUNICATION

A. RADIO ACCESS NETWORKS FOR NON-TERRESTRIAL NETWORKS

3GPP studies on non-terrestrial networks started in 2017 with Rel-15, and research was mostly conducted on application scenarios and channel models. Creating basic application scenarios of this technology and determining performance parameters such as architecture, orbital height and frequency bands are the first topics of study. Subsequently, by using terrestrial channel models, an attempt was made to develop channel models that can be used in different regions of non-terrestrial networks. For instance, while multipath calculations are considered an important parameter for terrestrial networks, in non-terrestrial networks, parameters such as path losses due to the distance between the satellite and the ground, line of sight probability, and angular spread are more prioritized in creating the channel model [26].

Following the studies on scenarios in Rel-15, studies on channel models for supporting non-terrestrial networks by terrestrial networks continued in Rel-16 studies. Thus, an attempt was made to determine the minimum technical specifications that terrestrial networks can work with satellite systems. Issues related to communication architecture, higher layer protocols and physical layer are discussed. Considering the central units (CU) and distributed units (DU) that form the parts of the new generation radio access networks and 5G base stations (gNB), which constitute the 5G communication architecture, studies have been carried out on numerous non-terrestrial network-based new generation radio access network architecture [27].

In Rel-16, bond level and system level evaluations were also made over S-Band and Ka-Band frequencies in terms of physical layer. In addition, studies have been carried out on transitions within cellular networks, considering the rapid movements of low-altitude satellite platforms on the earth. In these studies, it was seen that non-terrestrial networks can work hybrid with terrestrial networks, despite the problems caused by delays due to long transmission distances, Doppler shift and mobility of satellite platforms [28]. Within the scope of the currently ongoing Rel-17 studies, studies have been carried out on the development of the use of low orbit and geostationary orbit satellites, as well as the use of high-altitude aerial platforms (HAPS) in communication network systems [28].

B. HIGH ALTITUDE PLATFORM SOLUTIONS

In order to provide coverage in wide areas in 6G communication technologies, systems that provide communication via terrestrial communication, satellite communication and air platforms must work integrated. Especially for the installation of base stations, which form the skeleton of terrestrial communications in the field, roof tops or special communication poles are used. However, poles are largely high-cost structures [29].

Additionally, as seen in Figure 3, roof-top base stations are largely disabled in the event of a disaster and attract the reaction of people living in the area before and after their installation. The time it takes to build terrestrial systems, and the operational difficulties have clearly revealed the need for non-terrestrial networks.

Figure 3. *Roof-top Base Stations under Disaster Effect*

Until recently, non-terrestrial communication systems focused only on satellite communications. Satellites in low earth orbit (LEO - Low Earth Orbit) were frequently used for data communication, satellites in medium earth orbit (MEO - Medium Earth Orbit) were used for positioning systems, and satellites in geostationary geosynchronous earth orbit (GEO - Geosynchronous Earth Orbit) were frequently used for TV broadcasting and data transmission [30].

However, in recent years, especially in the space field, after it has been seen that low orbit satellites can be used for mobile communication applications, studies on positioning communication system components on many platforms in the air and space layer are increasingly continuing [31]. As shown in Figure 4, the space layer starts from approximately 400 km. Low, medium and high-altitude satellites provide services such as mobile communication, positioning, TV broadcasting and data communication to end users with different mission loads at different altitudes. In the air layer, high-altitude aerostats and unmanned aerial vehicles operate at an air altitude of approximately 20 km. In this layer, other unmanned aerial vehicles, aerostats, and small drones can also be used to provide communication services, staying below the routes of manned aircraft [32].

However, the terrestrial communication layer and the network structure, especially frequency usage, must be integrated to use the air and space layers effectively. Otherwise, mobile communication signals emitted from the air and space layer will have a disruptive effect on the terrestrial layer. To prevent this effect, when creating non-terrestrial system architectures, it should be taken into consideration that these systems are complementary technologies to terrestrial communication [33].

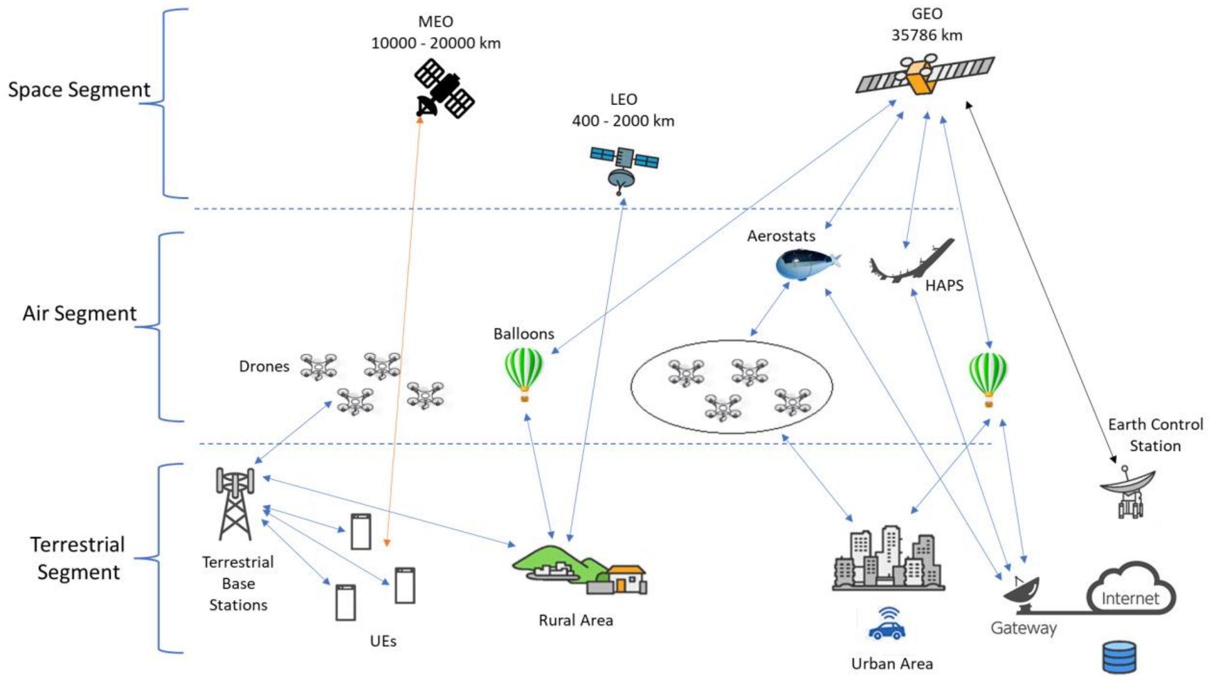

Figure 4. *System Architecture of Communication Layers*

Since LEO communication satellites are in lower orbit than GEO satellites and constantly rotate around the earth, they have less channel losses and enable the establishment of a communication network anywhere in the world. However, they must be launched as large-scale constellations for LEO satellites to provide worldwide coverage and these yields high costs in the production, testing and launch phases and in the operational phases.

Since terrestrial base stations and satellite communication systems offer high-cost solutions, establishing communication through aerial platforms at different altitudes will be one of the keystones of 6G architecture [25]. Aerial platforms can serve different missions at different altitudes, from low-altitude drone-like unmanned aerial vehicles (UAVs) to high-altitude aerostats and UAVs [34].

Table 2 gives a comparison of performance criteria for different land, air, and space platforms. Accordingly, the coverage areas of communication systems increase as the platform height increases, as expected. On the other hand, as the altitude increases, the distance between user equipment and communication platforms increases and delay times increase to very high values. Although terrestrial platforms have lower costs than air and space platforms; Air and space-based communication systems can respond more sensitively to user mobility and enable high-capacity service to be provided in large areas.

Table 2. *Performance Evolution for Various Communication Platforms*

	Terrestrial	**Non-Terrestrial**			
			Satellite		
Technical Specs.	**Terrestrial**	**HAPS**	**LEO**	**MEO**	**GEO**
Altitude	50m	1km - 20km	400km-2000km	10000km-20000km	35786 km
Coverage Area	Narrow	Wide	Regional	Regional	Country and Continent Coverage
Payload Capacity	Medium	Low	High	High	High
Power Source	Grid and generator	Solar panel/battery	Solar panel/battery	Solar panel/battery	Solar panel/battery
Flight Duration	Tethered	15 - 180 days	3-5 years	7-10 years	15-25 years
Cost	Low	Medium	High	High	Very High
Latency	Low	Low	Medium	High	Very High
Capacity	Medium	Medium	High	High	Very High
Mobility	Low	Medium	High	High	High

Aerial platforms allow solving problems such as high cost, signal delays and slow installation of systems, which determine the limits of communication in satellite and terrestrial systems. However, durability, ability to meet electricity needs, data transmission, establishment of core network connections, security and risks of collision with other aerial platforms should be taken into consideration first in communication solutions in which these platforms will be used [35].

For these reasons, it is considered that communication system solutions using air platforms and geostationary communication satellites are integrated, taking into account our country's existing platform capabilities, will be more effective. Solutions in which aerial platforms and GEO communication satellites are used hybridly appear as systems where users can receive communication services in large areas, especially in rural areas and in cases of natural disasters.

Within the scope of this study, a system architecture in which aerostat platforms will work integrated with geostationary communication satellites for situations where terrestrial mobile communication systems are insufficient has been proposed and performance analyzes of this architecture have been made. In the selection of this architecture, a cost-effective system solution was firstly taken into account, and also Türkiye’s experience in platform production and maintenance are considered.

IV. SYSTEM ARCHITECTURE AND PERFORMANCE ANALYSES

In 5G and beyond communication technologies, in order to provide coverage in large areas, terrestrial wireless communication systems must be able to work in integration with non-terrestrial communication systems consisting of space and air platforms. As a result of successful integration, it will be possible to access wide coverage areas. In addition, network solutions that can be quickly deployed, relatively low-cost, easy to maintain can be offered via non-terrestrial systems to provide communication services to rural areas, especially disaster communication. Within the scope of this study, considering that the production and maintenance of low-altitude satellite swarms for mobile communication is quite costly; in line with our Türkiye’s existing platform and communication system capabilities, a low-cost, quickly installable, and expandable system architecture is proposed in Figure 5 and basic performance analyzes of this system are presented.

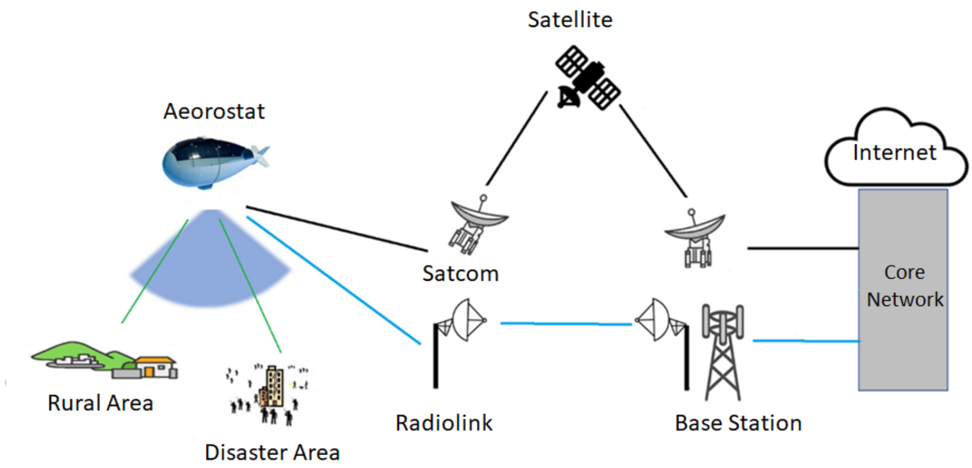

Figure 5. *System Architecture for Disaster and Rural Areas*

In the proposed system architecture, the aerial platform is aimed to provide coverage to desired points in rural areas or disaster areas. These aerial platforms can be designed as cable-connected or completely disconnected platforms. The connection feature of the platform is directly proportional to the platform height and the payload lifting capacity of the platform. Keeping the platform stable via the connected system and providing data and power lines via this connection cable, when necessary, provides flexibility in meeting the power and communication needs of the platform. However, on the other hand, any additional feature that increases the weight of the connection cable will also reduce the payload carrying capacity of the platform.

As seen in the proposed system architecture in Figure 5, geostationary communication satellite connection or ground radio link connection can be used to deliver the communication service provided via the air platform to the core network (NW). Satellite modem and antenna systems that will provide satellite connection can be located on the air platform, depending on the carrying capacity of the platform, or in the ground station in the case of a connected platform. On the other hand, since radio link systems are extremely sensitive to establishing a mutual line of sight, it is very difficult to place a radio link on the air platform and communicate with this radio link via the line of sight with the radio link on the ground. As the aerial platform rotates a few degrees due to wind, the radio link on the platform may lose communication with the radio link on the ground. For this reason, it is more suitable for the sustainability of communication if the platform to be selected is a connected aerial platform and the data line is in communication with the ground via the connection cable, as shown in Figure 6.

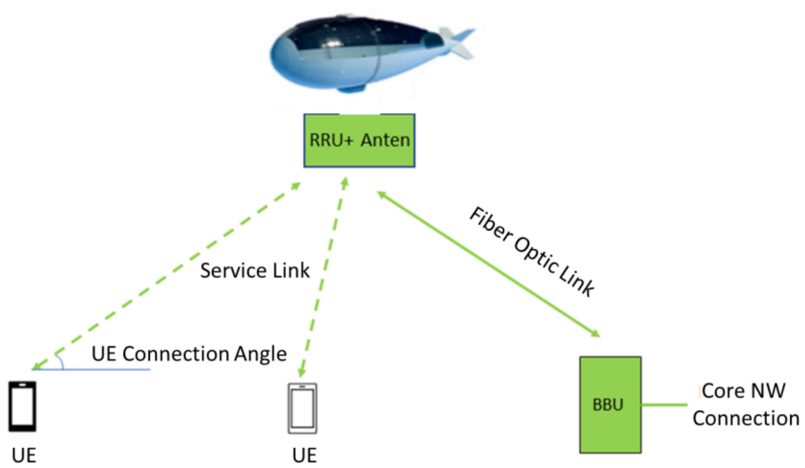

***Figure 6**. Proposed Architecture for Access Layer on Aerostat Platform*

While creating the access layer architecture, it was suggested that the remote radio unit (RRU) and the antenna that will communicate with user equipment (UE) be on the aerial platform, and the base band unit (BBU), which will process the service signals and provide connection to the core network, should be in the ground station. Thus, the equipment on the aerial platform was reduced and power and weight budgets were saved. In addition, fixed radio links located on the ground will be available to access the core network via radio link.

In selecting the altitude of the aerial platform, viewing angles of user equipment, coverage area size, number of users in the coverage area, free space loss, etc. are considered. Link budget calculations based on parameters and round-trip times of the signal will be effective. It is not possible to achieve the latency of 0.1ms, which is an important performance criterion especially for 6G communication, via geostationary satellites. For a communication satellite positioned at 35786 km, the round-trip signal delay is 238.57 ms due to the road alone. Considering this performance criterion, to maintain the delay limit and to actively use GEO satellites, it will be aimed to provide delay critical applications via air platforms, and other applications to be carried out directly via GEO satellites. As seen in Table 3, aerial platforms positioned at different altitudes will produce suitable solutions for disaster situations and rural area communication requirements with low latency and sufficient coverage areas.

***Table 3.** Comparison of Communication Parameters for Different Platform Altitudes*

Air Platform Altitude (meter)	**UE Angle (degrees)**	**Coverage Area (km^2)**	**Free Space Loss (dB)**	**Round-trip Latency (ms)**
200	10	4,04	101,98	0,0077
200	25	0,58	94,25	0,0032
200	35	0,26	91,6	0,0023
350	10	12,38	106,84	0,0134
350	25	1,77	99,11	0,0055
350	35	0,78	96,46	0,0041
500	10	25,26	109,94	0,0192
500	25	3,61	102,21	0,0079
500	35	1,6	99,56	0,0058
650	10	42,69	112,21	0,0250
650	25	6,10	104,49	0,0103
650	35	2,71	101,84	0,0076
800	10	64,67	114,02	0,0307
800	25	9,25	106,29	0,0126
800	35	4,10	103,64	0,0093
1000	10	101,04	115,96	0,0384
1000	25	14,45	108,23	0,0158
1000	35	6,41	105,58	0,0116

Since communication can be established between air and space platforms and users via direct line of sight, multipath scattering etc. is eliminated. effects have a lower impact on the vineyard budget calculation. The main determining parameter in calculating the power reaching receivers will be the free space loss. The free space loss can be calculated using the formula given in Equation 1, depending on the frequency and the distance between the receivers. Where f denotes the operating frequency, d denotes the distance between the receiver and transmitter. G_t and G_r represent the gain parameters of transmitter and receiver respectively.

$$\text{Free Space Loss} = 20log_{10}(d) + 20log_{10}(f) + 20log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r \quad (1)$$

In Figure 7, free space loss values for different air and space platforms are calculated as a function of altitude and communication frequency. As can be seen, increasing the frequency and the distance between receivers causes the free space loss to increase. On the other hand, while increasing the frequency allows the available bandwidth to increase, the higher elevation of the non-terrestrial network platform will allow the coverage area to expand and thus it will be possible to reach larger numbers of users.

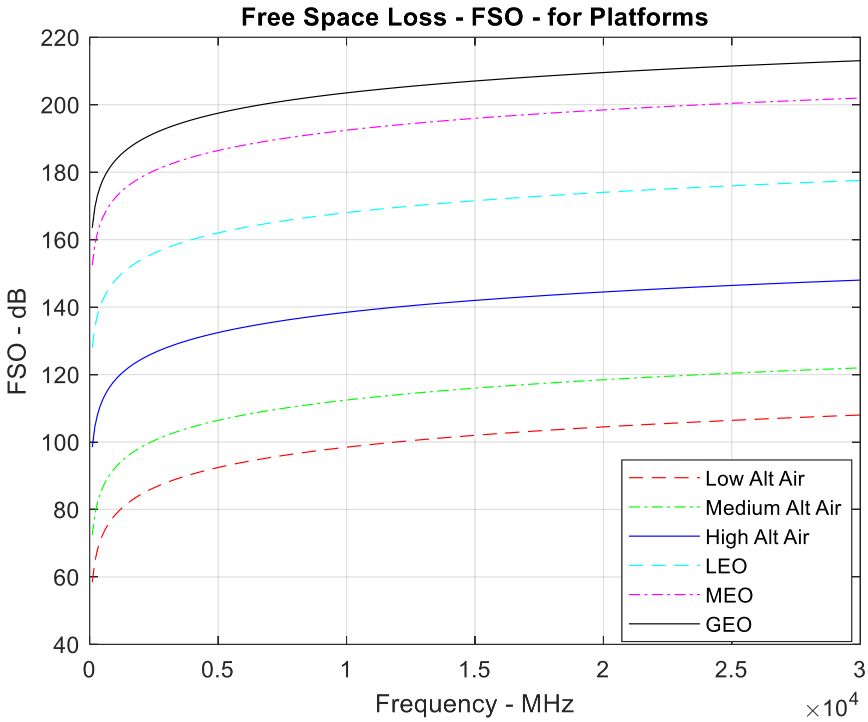

Figure 6. *Free Space Loss Variation for Platforms of Different Heights*

However, since the altitude of the platform will increase the signal delay between the receiver and transmitter, a situation will arise where the delay criterion valid for time-critical applications of 5G and beyond (1 ms for 5G; 0.1 ms for 6G) cannot be met.

V. CONCLUSION

Today, as a result of the rapid spread of non-terrestrial network systems through both air and space platforms, the use of these systems in mobile communication applications has become debatable in 3GPP standards since Rel-15. Wireless communication systems, especially those targeted to be deployed in 5G and beyond, must provide high capacity, secure and low latency services within wide coverage areas.

Currently, terrestrial networks are widely used for wireless communication, considering the prevalence of fiber optic infrastructure and its advantages in signal propagation. Non-terrestrial network solutions need to be offered via aerial platforms to cover wireless communication in remote areas such as disaster areas, rural areas, and seas, where terrestrial networks have poor access. Within the scope of this study, usable system architectures were created to solve access problems in rural areas and during disaster situations, considering Turkey's existing air and space platform capabilities. Coverage and propagation analysis of these architectures were performed, and design optimizations were presented for delay-critical applications.

Architecture and coverage area analyzes for providing satellite or radio link-based communication via connected aerial platforms that can be positioned at 1000 meters or below are presented. Within these architectures, it has been observed that up to 100 km^2 coverage area can be achieved, latency criteria of

5G and beyond can be met, necessary link budgets are maintained, and wireless communication can be established via end users' aerial platforms.

VI. REFERENCES

[1] G. Araniti, A. Iera, S. Pizzi and F. Rinaldi, "Toward 6G Non-Terrestrial Networks," *in IEEE Network*, vol. 36, no. 1, pp. 113-120, 2022.

[2] P. Rost et al., "Mobile network architecture evolution toward 5G," *IEEE Commununication Magazine*, vol. 54, no. 5, pp. 84–91, 2016.

[3] L. Kuang, X. Chen, C. Jiang, H. Zhang, and S. Wu, "Radio resource management in future terrestrial-satellite communication networks," *IEEE Wireless Commununication*, vol. 24, no. 5, pp. 81–87, 2017.

[4] X. Zhu ve C. Jiang, "Integrated Satellite-Terrestrial Networks Toward 6G: Architectures, Applications, and Challenges", *IEEE Internet of Things Journal*, vol.9, no.1, 2022.

[5] S. Zhang, J. Liu, H. Guo, M. Qi, and N. Kato, "Envisioning device-todevice communications in 6G," IEEE Netw., vol. 34, no. 3, pp. 86–91, 2020.

[6] G. Gui, M. Liu, F. Tang, N. Kato, and F. Adachi, "6G: Opening new horizons for integration of comfort, security, and intelligence," *IEEE Wireless Commununication*, vol. 27, no. 5, pp. 126–132, 2020.

[7] T. Li, J. Yuan, and M. Torlak, "Network throughput optimization for random access narrowband cognitive radio Internet of Things (NB-CRIoT)," *IEEE Internet Things Journal*, vol. 5, no. 3, pp. 1436–1448, 2018.

[8] Y. Su, Y. Liu, Y. Zhou, J. Yuan, H. Cao, and J. Shi, "Broadband LEO satellite communications: Architectures and key technologies," *IEEE Wireless Commununication*, vol. 26, no. 2, pp. 55–61, 2019.

[9] K. Maine, C. Devieux, and P. Swan, "Overview of IRIDIUM satellite network," *in Proc. IEEE WESCON*, 1995, pp. 483–490.

[10] X. Zhu and C. Jiang, "Creating Efficient Integrated Satellite-Terrestrial Networks in the 6G Era," *IEEE Wireless Communications*, vol. 29, no. 4, pp. 154-160, 2022.

[11] Fair Tech Institute, "The Role of Satellite Communications in Disaster Management", Washington, US, White Paper, 10 March 2022. [Online] Available at: https://accesspartnership.com/access-partnership-releases-the-role-of-satellite-communications-in-disaster-management-whitepaper-under-the-fair-techinstitute/

[12] I. del Portillo, B. G. Cameron, and E. F. Crawley, "A technical comparison of three low earth orbit satellite constellation systems to provide global broadband," *Acta Astronautica*, vol. 159, pp. 123–135, 2019.

[13] J. P. Choi and C. Joo, "Challenges for efficient and seamless spaceterrestrial heterogeneous networks," *IEEE Commununication Magazine*, vol. 53, no. 5, pp. 156–162, 2015.

[14] "(Release 15) study on new radio (NR) to support nonterrestrial networks," 3GPP, Sophia Antipolis, France, Rep. TR 38.811 V15.3.0. Release 15, Jul. 2020. [Online]. Available: https://www.3gpp.org/ftp/Specs/archive/38_series/38.811

[15] “(Release 16) technical specification group services and system aspects,” 3GPP, Sophia Antipolis, France, Rep. TR 21.916 V0.4.0. Release 16, Mar. 2020. [Online]. Available: https://www.3gpp.org/ftp/Specs/archive/21_series/21.916

[16] 5G Americas, “The 5G evolution: 3GPP releases 16–17,” 3GPP, Sophia Antipolis, France, Rep. TR 1, Jan. 2020. [Online]. Available: https://www.5gamericas.org/wpcontent/uploads/2020/01/5GEvolution-3GPP-R16-R17-FINAL.pdf

[17] M. Latva-aho and K. Leppanen, “Key drivers and research challenges for 6G ubiquitous wireless intelligence,” Oulu, Finland, Univ. Oulu, While Paper, 2019. [Online]. Available: http://urn.fi/urn:isbn:9789526223544.

[18] A. Guidotti et al., “Architectures and key technical challenges for 5G systems incorporating satellites,” *IEEE Transaction on Vehicular Technologies*, vol. 68, no. 3, pp. 2624–2639, 2019.

[19] M. K. Arti and M. R. Bhatnagar, “Beamforming and combining in hybrid satellite-terrestrial cooperative systems,” *IEEE Commununication Letters*, vol. 18, no. 3, pp. 483–486, 2014.

[20] X. Artiga et al., “Shared access satellite-terrestrial reconfigurable backhaul network enabled by smart antennas at mmWave band,” *IEEE Network*, vol. 32, no. 5, pp. 46–53, 2018.

[21] M. Jia, X. Gu, Q. Guo, W. Xiang, and N. Zhang, “Broadband hybrid satellite-terrestrial communication systems based on cognitive radio toward 5G,” *IEEE Wireless Commununications*, vol. 23, no. 6, pp. 96–106, 2016.

[22] W. Saad, M. Bennis, et al., “A vision of 6G wireless systems: Applications, trends, technologies, and open research problems,” *IEEE Network*, vol. 34, no. 3, pp. 134–142, 2019.

[23] E. Yaacoub and M.-S. Alouini, “A key 6G challenge and opportunity—connecting the base of the pyramid: A survey on rural connectivity,” *Proceedings of the IEEE*, vol. 108, no. 4, 2020, pp. 533–582.

[24] K. David and H. Berndt, “6G vision and requirements: Is there any need for beyond 5G?” *IEEE Vehicular Technology Magazine*, vol. 13, no. 3, pp. 72–80, 2018.

[25] S. Dang, O. Amin, et al., “What should 6G be?” *Nature Electronics*, vol. 3, no. 1, pp. 20–29, 2020.

[26] TR 38.811, “Study on New Radio (NR) to Support Non-Terrestrial Networks,” v. 15.4.0, Oct. 2020.

[27] TR 38.821, “Solutions for NR to Support Non-Terrestrial Networks (NTN),” v. 16.0.0, Jan. 2020.

[28] X. Lin, S. Rommer, S. Euler, E. A. Yavuz and R. S. Karlsson, "5G from Space: An Overview of 3GPP Non-Terrestrial Networks," *in IEEE Communications Standards Magazine*, vol. 5, no. 4, pp. 147-153, 2021.

[29] P. Chini, G. Giambene, S. Kota, “A survey on mobile satellite systems,” *International Journal of Satellite Communications*, vol. 28, pp. 29-57, 2009.

[30] M. De Sanctis, E. Cianca, G. Araniti, I. Bisio, R. Prasad, “Satellite Communications Supporting Internet of Remote Things,” *IEEE Internet of Things Journal*, vol. 3, no. 1, pp. 113-123, 2016.

[31] J. Liu, Y. Shi, Z. M. Fadlullah, N. Kato, “Space-Air-Ground Integrated Network: A Survey,” *IEEE Communications Surveys & Tutorials*, vol. 20, pp. 2714-2741, 2018.

[32] G. Araniti, A. Iera, A. Molinaro, “The Role of HAPS in Supporting Multimedia Broadcast and Multicast Services in Terrestrial-Satellite Integrated Systems,” *Wireless Personal Communications*, vol. 32, pp. 195–213,2005.

[33] B. E. Y. Belmekki and M. -S. Alouini, "Unleashing the Potential of Networked Tethered Flying Platforms: Prospects, Challenges, and Applications," *IEEE Open Journal of Vehicular Technology*, vol. 3, pp. 278-320, 2022.

[34] G. Araniti, A. Iera, S. Pizzi and F. Rinaldi, "Toward 6G non-terrestrial networks", *IEEE Networks*, vol. 36, no. 1, pp. 113-120, 2021.

[35] M. Kishk, A. Bader and M.-S. Alouini, "Aerial base station deployment in 6G cellular networks using tethered drones: The mobility and endurance tradeoff", *IEEE Vehicular Technology Magazine*, vol. 15, no. 4, pp. 103-111, 2020.