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REVIEW

Backhaul in 5G systems for developing countries: A literature review

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Abstract

The fifth-generation (5G) technology is seen to be a solution for developing countries to improve their quality of services in terms of transportation, education, health, agriculture, and other fields, thereby holding the promises of economic transformation by improving productivity and the quality of life. The paper considers some of the challenges that face operators, investors, and providers when planning to introduce 5G technology to developing countries. The main focus of this paper is the 5G transport network, in particular, the backhaul network. The 5G transport network architectural options and scenarios are discussed based on several standards and previous studies, the problems of existing infrastructures of developing countries are investigated, and new proposed technologies that may help to address those challenges are considered.

1 | INTRODUCTION

Throughout all the different generations of mobile technology, there have been major differences in network performance between countries. This is because the more developed ones have been able to use the latest releases of mobile network technology and having advanced, up-to-date infrastructures, while the less developed countries have struggled to adopt the new technology, in particular, in terms of upgrading and/or expanding their infrastructures.

Indoria [1], in his published study, listed the main challenges that developing countries could face with the implementation of 5G technologies. He particularly focused on their lack of infrastructure, which includes poor fibre construction, no proper mechanism for the rapid increase in the number of users, low rates of data speed, high costs as well as political and security issues, thus hindering the development of the telecommunications sector. He also discussed the need for 5G and its applications given its advantages over 4G and the future prospects for its implementation.

It is also important to look into the economic developments/costs associated with implementing 5G networks, for instance, Oughtona [2], in his published study, also studied the growth of data traffic of 5G infrastructure strategies for the period between 2016 and 2030. They found that there will be a 90 percentage of data growth due to technology change from 4 to 5G. They also highlighted the techno-economic problem of deploying 5G due to the cost. In this regard, they pointed to the large number of new components required to operate enhanced network infrastructure, including base station units and backhaul transmission, as well as the associated costs of site installation and operation, network optimisation and maintenance. But, Shin [3] focused on analysing the 5G users and data traffic demand and how that demand would change based on several attributes, including the content amount, additional monthly fees and additional cost of devices. The study revealed a crucial foundation for mobile service providers' investment and marketing strategies that aim to maximise profits.

In addition, Forge and Vu [4], in their published study, discussed the network performance variation between developed and developing countries. Their aim was to provide policymakers in developing countries with a clear understanding of 5G deployment in terms of demand levels, infrastructure costs, challenges of a dense deployment infrastructure, technical complexity, and the need to create effective future strategies for deploying the new generation. The authors cited an example based on a survey carried out in 2019 comparing the average download speeds rate for the existing 4G called Long Term Evaluation-Advance (LTE- A) networks. The survey showed that the download speeds were 52 Mb/s for the Republic of

Korea and 33.0 Mb/s for Japan, as an example for lead or developed countries, while this fell to 1.6 Mb/s for Iraq, as an example of a developing country.

Muluk [5], the ITU-D representative, stated in his presentation at the ITU Regional Forum on New Technologies the importance of 5G for developing countries for eliminating the number of transport accidents, which, according to the CAPMAS-Central Agency for Public Mobilization and Statistics, are high in those countries. He stated that 5G will have a good impact on improving the transport system in terms of quality and availability. Also, 5G will lead to reduction in latency to (1 ms), thus enabling remote health assistance in terms of performing surgery. The specialists could join a surgeon remotely for diagnosis and follow-up. In terms of education, 5G will offer new ways of learning in the classrooms, with students being exposed to a more visual and interactive learning experience (Augmented Reality, Virtual Reality, and Virtual Presence). Moreover, teachers will be able to deliver their classes to students not necessarily in the same room. 5G technology will assist developing countries in optimising growth and minimising the use of water and fertilisers through more targeted application in water and agriculture systems, as well as other fields.

The smart network communication environments of 5G are increasing the demand for high-speed data, and introducing new requirements of network and infrastructure, especially the transport network.

The paper aims to review the studies and research on 5G backhaul network and the proposed solutions offered to deploy 5G technology in developing countries. It is organised as follows. In Section 2, a detailed review of 5G transport networks is described. In Section 3, the backhaul network is discussed. Whilst in Section 4, the latest backhaul technologies are derived. In Section 5, the developing countries and their progress towards 5G technology are discussed. In Section 6, the role that cost plays to deploy 5G technology in developing countries is considered. The paper is concluded in Section 7.

2 | TRANSPORT NETWORK

Recent ongoing research efforts and standardisations are concerned about the crucial role of the transport network in 5G technology. For instance, the Third Generation Partnership Project (3GPP) studied the evaluations and the enhancements of the existing 4G network and how to upgrade to the new era of 5G in its standards Release (15) and then, Releases (16), (17), (18). Jaber [6] stated in her published study that the main role of the transport network is to provide connectivity between the radio base station and the core functional modules. She also discussed the determination of the preferable deployment topologies with the considerations of the cost, region type, and 5G applications that may be provided. Ericsson [7], in a published booklet, discussed the transport network infrastructures needed to handle the demands of tomorrow in terms of traffic growth, machine-centric communications, high-quality wireless video streaming, social networking, and unforeseen applications, which are included in the International Mobile Telecommunications IMT-2020 standard.

TABLE 1 The METIS scenarios and their challenges [8]

Scenario	Challenges
Amazingly fast	Very high data rate
Great service in a crowd	Very dense crowds of users
Ubiquitous things communicating	Very low energy, cost, and a massive number of devices
Best experience follows you	Mobility
Super real-time and reliable connections	Very low latency

The Europe EU project METIS [8] introduced five 5G scenarios based on five fundamental challenges relevant to set the foundation of 5G mobile and wireless networks beyond 2020 that may have a major impact on the transport network. For instance, providing very high data rates, and great services in a crowd scenario will require a transport network that needs to support huge traffic volumes and provide very high capacity on-demand to the specific geographical area, as in Table 1.

With the 4G RAN/EPC network currently in the field along with the 5G New Generation-Radio Access Network NG-RAN Core recently deployed, the migration from 4 to 5G will be a challenge. The 3GPP TR 21.915 (Release 15) standardisation [9] discussed several architectural options for migration to 5G. Not all of these options are currently fully supported, but more are expected to be available in different releases of the 5G specifications, which will provide flexibility to service providers. The two most popular options discussed are as follows.

- Non-Standalone NSA
  This option will be available without the need for network replacement of 4G. The 5G Radio Access Network NG-RAN over 4G's Evolved Packet Core EPC or over 5G's New Generation Core (NG-Core) is proposed for dual connectivity, with the 4G Evolved Packet Core EPC. The master node (MN) is the eNB, whereas the secondary node (en-gNB) is the en-gNB (SN), as in Figure 1 [9].

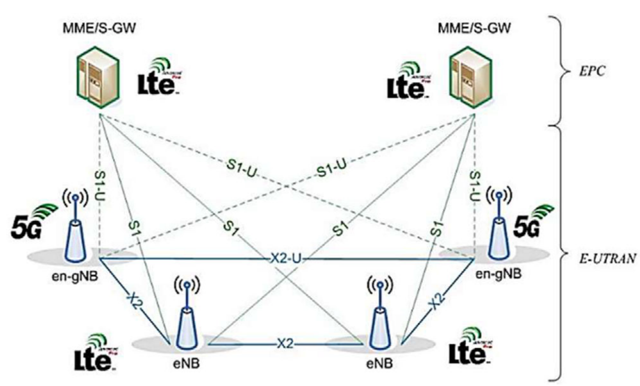

FIGURE 1 Non-standalone NSA 5G network [9]

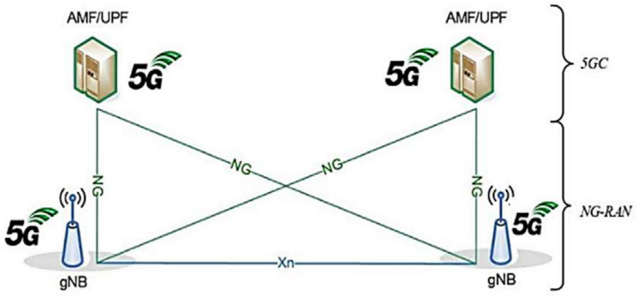

FIGURE 2 Standalone SA 5G network [9]

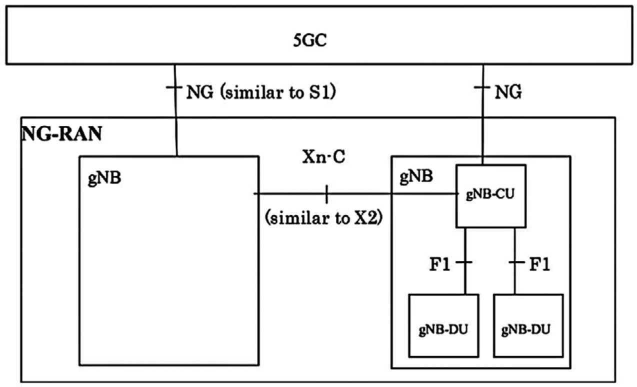

FIGURE 3 Overall architecture [10]

While the second option is:

- Standalone SA
  In this option the architecture represents full 5G deployment. The 5GC core is connected to the NG-RAN network, as in Figure 2. No 4G components are presented [7].

According to the 3GPP 5G standalone architecture specified in TS38.401 (Release 15) [8], the overall architecture of the NG-RAN network introduces new interfaces and functional modules. It describes that NG-RAN consists of the new 5G base station gNB connected to the new 5G core 5GC via new interfaces NG and connected to each other via an Xn-C interface. NG-RAN can be implemented and deployed in different ways based on the operator's requirements, as in Figure 3.

In addition, the 3GPP TR 28.807 (Release 17) standardisation [11] describes the 5G Non-public networks (NPN) scenario. NPN can be set up in a specific location for private usage, as in a business or college, to offer coverage, which is a crucial requirement for upcoming 5G applications. This type of scenario is desirable where a high quality of service is required, high security, privacy, safety, and accountability. A variety of configurations can be adopted to deploy NPN. It may involve using both virtual and physical network functions and/or being deployed as an independent, isolated network, as in Figure 4.

Several studies have focused on this scenario. For instance, Bektas [13] presented an experiment analysing the need for demand-based configuration and planning of such private 5G networks. Wen [14] provided a detailed review of 5G campus networks, focusing on implementation issues, key enabling technology, and use cases. The study highlighted the advantage of using a shared indoor small cell infrastructure, which can help in improving QoS in terms of capacity and coverage. The author added that the private 5G network is able to connect a large number of devices in a dynamic environment, where people and objects are on the move. It eliminates the need for costly and bulky wired equipment. In addition, Kulkarni [15] discussed the possible future scenarios for 5G indoor connectivity in a specific area such as university campus, where a company or an owner can start off as a local operator by collaborating with incumbent mobile network operator. The study discussed different network deployment options and focused on a Finnish telecom market. Rischke [16] studied the key performance parameters that improve the QoS and users' experiences, if 5G campus networks are to be utilised for industrial control applications with strict timing requirements. The author explained that the packet latencies need to be reduced and the consistency of the packet delay must be improved for 5G networks, especially core processing delay.

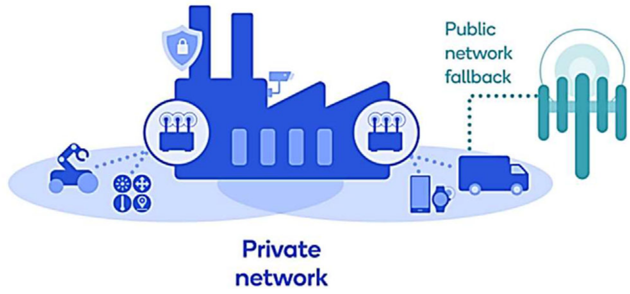

FIGURE 4 5G non-public networks NPN [12]

Eventually, operators are expected to complete the 5G migration by deploying a New Generation (NG) Core and connecting gNB base stations to work as standalone.

Based on Fujitsu's white paper [17], the NG-RAN architecture consists of three main functional modules that are mapped in the 5G base station (gNB). These are the central unit, distributed unit, and radio unit, which can be deployed in multiple topologies to provide flexibility for the 5G network. Furthermore, the International Telecommunication Union (ITU) in its Telecommunication sector (ITU-T) [18] introduced those topologies in a technical study released in February 2018. According to the study, the transport network design is made up of three logical elements: The Central Unit (CU), the Distributed Unit (DU), and the Radio Unit (RU). Those logical elements can be combined in different topologies to produce the actual physical network parts of the 5G transport network. According to these topologies, the transport network layout design will consist of fronthaul, which pointed to the connection between the DU and RU, midhaul, which pointed to the connection between the CU and DU, and backhaul that represent the connection between 5GC and DU. That mainly depends on the network requirements and operator

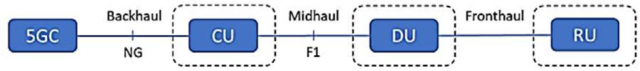

FIGURE 5 First scenario of transport network layout [19]

requirements. A 5G Americas white paper [19] has identified four Radio Access Network (RAN) deployment scenarios for designing a 5G transport network as follows.

- **First Scenario**

The layout of the transport network will consist of fronthaul, midhaul, and backhaul networks. The RU, DU, and CU are co-allocated in different sites. The CU connects to the 5GC to form the backhaul network, whilst the connection of the CU to the DU and the DU to the RU will form the midhaul and fronthaul networks, respectively, as in Figure 5

- **Second Scenario**

The layout will consist of only a fronthaul and backhaul network. The CU and DU in this scenario are co-located at the same site, while the RU is in different sites. The CU and DU connect to the 5GC to form the backhaul network and connect to the RU to form the fronthaul, as in Figure 6.

- **Third Scenario**

This layout consists of a midhaul and backhaul network. The DU and RU are co-located at the same site, while the CU is located in different sites. The CU is connected to 5GC to form the backhaul network and connected to the DU and RU to form the midhaul network, as in Figure 7.

- **Fourth Scenario**

The layout consists of just a backhaul network, with the RU, DU, and CU being co-located together. They are connected to 5GC to form a backhaul network only, as in Figure 8.

The fourth scenario allows for the adaptation of various network architectures, applications, and transport network needs. The appropriate technology depends on the individual applications, deployment scenarios, market environment, existing infrastructure, etc.

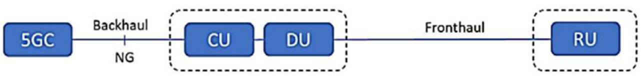

FIGURE 6 Second scenario of transport network layout [19]

FIGURE 7 Third scenario of transport network layout [19]

FIGURE 8 Fourth scenario of transport network layout [19]

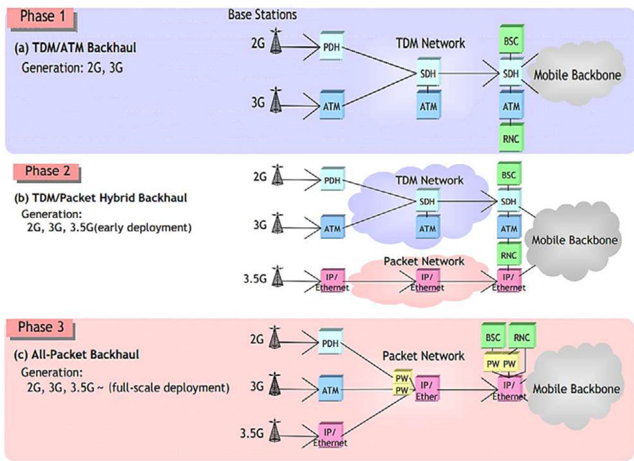

FIGURE 9 2G, 3G, and 3.5G backhaul network evolution [21]

3 | BACKHAUL NETWORK

Over the last 20 years, backhaul networks have developed with each generation of mobile networks. McClelland [20], Ericsson's expert, discussed the backhaul networks evaluation from 1 to 5G. He stated that the transport networks implemented and designed for the previous mobile generation will be insufficient for the new era of 5G. NEC [21] and Raza [22] stated that the migration from first generation (1G) and second generation (2G) mobile networks used Time Division Multiplexed (TDM) and Asynchronous Transfer Mode (ATM) technology that supported voice traffic only, to the third generation (3G) mobile network that required a new transport network with Internet Protocol (IP) technology that supported the new data applications, as shown in Figure 9, the evolution from phase 1 to phase 3.

However, based on NGOF (Next Generation Optical Network Forum) white paper [23], to migrate from 4 to 5G networks, the two-level structure of 4G that comprises a Baseband Unit (BBU) and a Remote Radio Unit (RRU) will be upgraded to a more complicated 5G transport network that comprises three-level structures. The BBU splits into a new structure called the CU, which processes L2 and L3 non-real-time protocols and services, that mainly include RRC, SDAP, and PDCP protocol and DU, which are mainly responsible for layer 1 and L2 real-time protocols and services, that mainly runs the RLC, MAC, and parts of the PHY layer. But the original

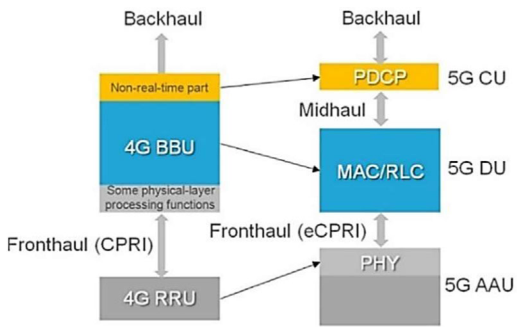

FIGURE 10 The evolution from 4 to 5G backhaul [23]

functions and some physical layer processing are moved to the Active Antenna Unit (AAU) or RU. Furthermore, a 5G Americas white paper [19] pointed out that a transport network that connects the BBU in 4G or the CU in 5G networks and beyond to the core network represents the backhaul link, as in Figure 10.

It has also been contended that when it comes to 5G backhaul, the best technology depends on the applications, deployment circumstances, market situation, existing infrastructure, and so on. Another important factor that needs to be considered is the networks that supports/connects to the 5G networks. Appropriate Internet Exchange Point (IXP) infrastructure is essential to provide sufficient quality of services and experience. The communication networking requirements for this core Internet infrastructure also need to be carefully considered when implementing 5G networks in developing countries. Studies on global Internet interdomain data traffic are limited and beyond the scope of this review paper. Some studies have looked into these requirements and Hoeschele [24] studied the impact of 5G networks on the Internet exchange point (IXP). This work looked into a method to identify the 5G use cases that will affect the traffic levels at the core Internet, in particular at interdomain infrastructures. They concluded that three use case groups, namely video in 5G, Health, and VR & AR, will likely have the strongest impact on the Internet traffic growth at interdomain infrastructures until the year 2025.

In regions where the respective infrastructures exist, new shared technology, like Hybrid Fibre-Coax (HFC) and Passive Optical Network (PON) technologies, are suitable for cost-effective and speedy 5G network deployment [19].

Several technical solutions adopted by mobile operators for backhaul vary between wireline and wireless solutions. The GSMA [25], in its published study, stated that backhaul technology mainly relies on three physical medias: copper, optical fibre, and microwave radio links. Recently, satellite links have been used to overcome coverage drawbacks present in the other mediums. Optical fibres are usually installed in densely populated urban and suburban regions with heavy traffic. On the other hand, microwave radio and satellite connections are used in places where cable backhauls are difficult to establish. Leased T1/E1 copper lines dominate backhaul systems, because they accommodate voice traffic well, with predictable Quality of Service (QoS), low latency, and low delay variation [26].

4 | NEW BACKHAUL TECHNOLOGY

Regarding the new challenges brought by 5G, particularly for developing countries, most ongoing research efforts on 5G mobile networks have been concentrated on different aspects to cope with the new requirements and to serve the high demand of the new applications. Fiorani and Monti [27] have argued that, with ongoing cell densification and the growing number of the various types of services needing to be provided, the challenges of the transport network, in particular, backhaul, will be the main focus of the present and future investigations.

According to Jaber's study [6], most of the current backhaul networks are built with microwave and fibre/copper-based links. Fibre optics backhaul is considered to be the best performing technology amongst them. However, it is economically challenging for operators to deploy compared with the other technologies, as much more civil work is required. In addition, it is not available worldwide.

A compilation of available and potential backhaul technologies is presented in this study that may allow 5G networks to cope with the demands for bandwidth, ultra-low latency applications, and other future applications. A new alternative backhaul solutions are proposed for standalone 5G networks. This study selected the most effective technology that may be considered a proper solution for backhauling 5G traffic in developing countries.

4.1 | Combining CLOS and NLOS microwave backhaul for rural areas

Nowadays, microwave backhaul is implemented using Clear Line of Sight (CLOS) technology. Because of the nature of remote rural areas, it is a challenge to guarantee Line of Sight (LOS) between settlements without using a repeater or reflector, which means extra cost. To address this, according to the Facebook study by Kusuma [28], the physics phenomenon of 'diffraction' can be used. Diffraction is well known in radio propagation modelling, it being a phenomenon that conveys signal energy into the shadow NLOS phase as in Figure 11. The main drawback is the limited spectrum resources. As GSMA [29] discussed in their published article, microwave backhaul requires a licensed frequency, which is considered to be a key challenge for this technology in terms of availability and cost. However, the V-band is unlicensed, and the E-band is only licensed with a light touch. To help solve the rural and deep-rural connectivity issues and thus, prepare their infrastructure for coping with 5G demand, several recent studies have

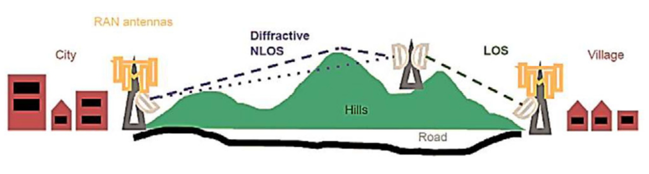

FIGURE 11 CLOS and NLOS microwave backhaul [28]

focused on using a hybrid combination of CLOS and NLOS approaches as a practical and cost-effective networking solution. For instance, there is the study 'Combining CLOS and NLOS Microwave Backhaul to Help Solve the Rural Connectivity Challenge' by Boch, Kusuma, and Park, which was published in 2021 [30], and 'Diffractive NLOS Microwave Backhaul for Rural Connectivity Network as a Service Solution Group' by Telecom Infra Project, which was published in 2021[31]. In addition, Oughton and Boch studied the evaluation of the engineering–economic implications of the diffraction NLOS backhaul in their paper 'Engineering-Economic Evaluation of Diffractive NLOS Backhaul (e3nb): A Techno-economic Model for 3D Wireless Backhaul Assessment', published in 2022 [32].

Based on the Telecom Infra Project [31], the use of this new technology will allow for the designing and building of new wireless networks in challenging environments, eliminate the need to use repeaters, and make the network design more flexible and efficient. It may also provide better coverage, with some RAN sites being better positioned or redeployed using shorter towers.

4.2 | mmWave backhaul

The millimetre-wave (mmWave) backhaul network has recently been identified as a viable technical innovation for the upcoming 5G technology that will use a higher frequency (over 6 GHz), which will significantly improve network performance. According to a study by Liang and Li [33], this new technology will overcome the obstacles of the earlier generations of 2G, 3G, and 4G, which work on a lower frequency (6 GHz and lower), with limited bandwidth and relatively low spectral efficiency. That is, this new configuration will be able to satisfy the ultra-large traffic demand and the supermassive connection required for the new generation, as in Figure 12.

A study by Zhao and Li [34] discussed the challenges that this innovation may face. These include its vulnerability to shadowing, which can become catastrophic in many scenarios, like a street to street or street to roof; however, advances in massive MIMO may be able to address this deficiency. In addition to its propagation limitation, it has a sensitivity to weather and, the legacy frequency spectrum limitation.

The work on mmWave backhaul is ongoing, with there being several pieces of research in progress. For example, 'Optimizing mmWave Wireless Backhaul Scheduling' by Arribas and Anta, published in 2020, discusses the challenges of mmWave backhaul scheduling and derives an MILP formulation for it as well as setting upper and lower bounds [35]. Further, in the research paper 'Stochastic Geometry Analysis of Hybrid Aerial Terrestrial Networks with mmWave Backhauling' by Kouzayha and ElSawy [36], published in 2020, the results of the quality of the UAVs backhaul link, which has a major role in improving the UE experience, were provided. The findings also revealed the impact of different UAV height regimes on the coverage probability. Moreover, Tang and Wen [37] discussed the use of mmWave in their published paper in 2022 'Physical layer authentication for 5G/6G millimeter wave communications by using channel sparsity', the study shows the mmWave channel perturbations that will degrade the detection performance.

According to a 5G Americas white paper [19], the mmWave is immune to other cell interference and allows for frequency reuse and maximisation of spectrum efficiency as well offering very high bandwidth. Moreover, the deployment of massive MIMO (multi-input multi-output) technology or a multi-beam system is planned for use in a 5G network. All this will present the opportunity for a new backhaul solution that is known as integrated access and backhaul (IAB), which is considered as being one of the cost-effective technologies for handling 5G traffic.

4.3 | Integrated access and backhaul (IAB)

The integrated access and backhaul (IAB) concept is defined by 3GPP TS 38.175 (Release 16) [39]. It states that the same infrastructure and spectral resources are utilised for both access and backhaul, as in Figure 13. Simsek and Narasimha [40] reported from their study that IAB nodes can operate as relay nodes or access points. With the introduction of high mmWave bandwidths, the attention to this technology has increased as a solution for meeting 5G requirements.

Teyeb and Muhammad [41] pointed out in their study that 3GPP has been working on IAB since 2017, and it was

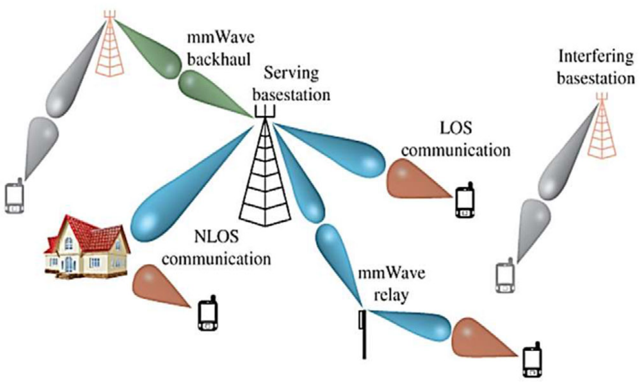

FIGURE 12 mmWave backhaul [38]

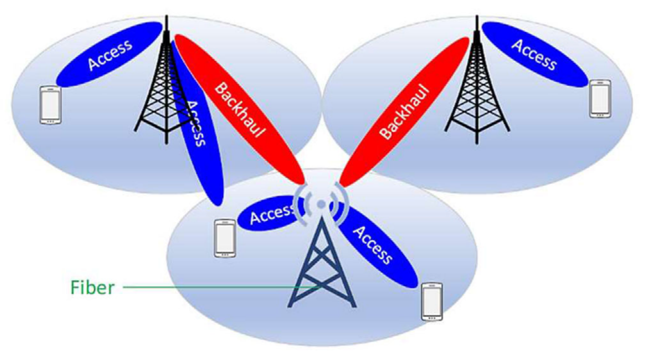

FIGURE 13 IAB layout [19]

standardised for Release (16), which was completed in mid-2020. Ronkainen and Edstam [42] stated that, in IAB, multi-hop backhauling can be provided by employing the same or different frequency bands for access and backhaul.

The proposed architecture involving the integration of backhaul and fronthaul transport network for the first time was published in a study by Antonio De La Oliva [43]. Its goal was to develop the next generation of 5G integrated backhaul and fronthaul networks that allow for flexible, software-defined reconfiguration of all networking parts in a multi-tenant and service-oriented unified management environment, thereby addressing the aforementioned challenges with 5G technology.

Key challenges that need to be addressed are the formation of an efficient IAB topology, providing topology updates, dealing with link failure or congestion, and establishing efficient topologies, in particular, the identification of the links that need to be activated to maximise the lower bound of the network capacity [40].

Several studies, such as 'Millimeter-Wave Integrated Access and Backhaul in 5G: Performance Analysis and Design Insights', by Saha and Dhillon [44], investigated the use of this technology in a 5G network. It has been argued that this new technology is crucial for facilitating better traffic flow, reducing congestion, and increasing resilience to backhaul connection failure. In addition, Sadovaya and Moltchanov [45] reviewed and characterised the system-level impact of multi-hop, multi-connectivity, and multi-beam operations on IAB performance in their study 'Integrated Access and Backhaul in Millimeter-Wave Cellular: Benefits and Challenges', which was published in 2022. Furthermore, directed communication using beamforming can minimise cross-link interference between backhaul and the access lines, thus allowing for higher densification.

4.4 | High-throughput satellites (HTS)

Satellite communications technology has progressed through different generations, resulting in substantial improvements in data transfer capacity and throughput. Ippolito, in his book [46], discussed how broadband satellite has become popular in the new generations of satellites. He stated that broadband satellites are those satellites that operate in the Ka-band Fixed Satellite Services FSS. More recently, the focus has been on those broadband satellites that can provide a significant increase in capacity. The 3GPP [39] studied and demonstrated the importance of satellites for mobile networks for the first time in Release (14), followed by TR38.811 (Release 15), TR22.822 (Release 16), and then, led by TS22.261 (Release 18) that 5G with satellite access and its requirements being outlined. All have highlighted the value that satellites will bring, particularly for industrial applications that require specific coverage and have introduced non-terrestrial networks as a new backhaul for 5G networks. The EMEA Satellite Operators Association [47] stated that Ka-band (and higher) for HTS will be a key for mobile cellular networks by the year 2025. It is anticipated that there will be over 100 HTSs in the orbits, geostationary GEOs, and non-geostationary (NGEO) satellites delivering terabits of global connectivity traffic.

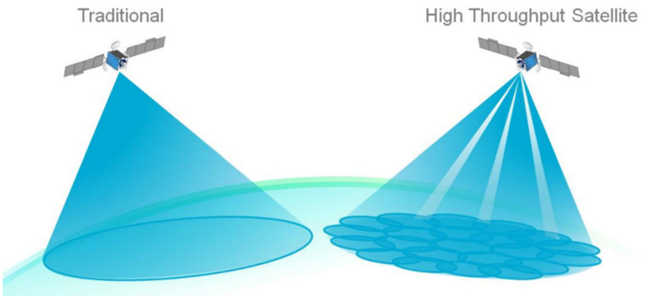

FIGURE 14 High-throughput satellite (HTS) vs traditional satellite in terms of coverage [52]

The ITU-R Resolution 174 (WCR-19) [48] was developing the roadmap for 5G networks through the International Mobile Telecommunications (IMT-2020). The document includes convergence of service delivery via multiple fixed networks (fixed-satellite service [FSS]), mobile (mobile-satellite service [MSS]), and broadcast (broadcast-satellite service [BSS]) satellites operating in new and expanded frequency bands.

Studies like 'Load balancing for 5G integrated satellite-terrestrial networks' by Shahid, Seyoum, and Won published on 17 July 2020 [49], and the 'Uplink zone-based scheduling for LEO satellite based Non-Terrestrial Networks', by Mandawaria and Sharma [50], published in 2022, investigated the challenge of integrating satellites with terrestrial 5G networks. All classes of High-Throughput Satellite (HTS) systems are expected to dramatically increase total throughput, achieve low latency, and allow for further significant reductions in bandwidth costs [51]. Figure 14 depicts the differences between traditional satellites and HTSs (14).

A comparison is made between some key performance parameters of the new backhaul technologies, as shown in Table 2, in terms of cost, coverage, latency, and capacity. From the table, it can be seen that the mm Wave is a much more cost-effective approach to backhaul the 5G traffic than the legacy cellular architectures, which connect the micro base station to the core network through fibre. In addition, the mm Wave allows the micro base stations to cooperate with each other by acting as relay nodes. It is not only a more cost-effective approach compared with fibre but also, with the other new proposed backhaul technologies, as CLOS/NLOS, and HTS due to the frequency reuse. The mm Wave also provides ultra-high-speed radio access and is ideally suited for efficient and flexible wireless backhauling for dense deployments, where a mm Wave macro base station can serve a large number of mm Wave micro base stations [35]. However, the development of the IAB approach allows for rapid and affordable mm Wave installations through self-backhauling, which uses the same wireless channel for coverage and backhaul communication to base stations. This results in better performance, efficient use of spectrum resources and lowers latency due to the simultaneous receive and transmit [53]. It is considered as being the most

TABLE 2 Comparison between the four proposed new technologies [54, 56]

Backhaul types	Cost	Coverage km	Latency	Capacity Gbps
mm Wave	Low compared with CLOS/NLOS, HTS	<1	10 us	100
IAB (mm Wave)	Cost effective than mm wave	<1 (donor coverage)	<10 us	>25
CLOS/ NLOS	High	7–150	50 us	1–5
HTS (Ka band)	Highest	50 (LEO) 400 (GEO)	<30 ms	>140

cost-effective approach among all the four proposed new backhaul technologies due to the frequency reuse and resources sharing, but still lacks a regulatory framework for spectrum rules. In comparison with mm Wave and IAB, the table shows that the usage of CLOS combined with diffractive NLOS leads to higher cost owing to the frequency licences, installation, and equipment costs. Whilst it does provide wider coverage than the mm Wave and IAB, it is still limited in terms of capacity [32].

When it comes to the HTS, this is considered as being the best approach for backhauling 5G traffic in terms of capacity and coverage, but remains challenging regarding manufacturing cost and latency. Whilst latency and cost remain an active area of research in relation to meeting 5G requirements, several studies consider the cost of the bit per second, user downlink/ uplink, and convenience of user terminals as more critical considerations for the adoption of HTS for 5G networks [54, 55].

5 | COST

In the 5G era, estimating the cost for providing the services is becoming increasingly important. Cost estimation has become a common challenge for deploying telecommunication infrastructures across national territories.

For any digital infrastructure, the expense of supply can exceed the price users are able to pay, especially in developing countries, where the annual income for the citizens is limited and governments struggle to secure financial resources for basic life infrastructure. These considerations become even more salient, with the new era of 5G technology, which is expected to require an advanced transport network, with a large number of cellular sites to provide greater capacity and coverage [57, 58].

According to GSMA's published research report [59], in 4G technology and 5G technology, the main reason as to why the cost has doubled is choosing fibre optics for backhauling the traffic, although this can meet the higher levels of user capacity demand. It has also been pointed out that, despite microwave having been considered as being more attractive for operators for over two decades compared to the high-cost fibre optics, spectrum limitation remains a key challenge for delivering communication services. Hence, the innovations in the satellite field and producing a range of cost-effective new Low Earth Orbit (LEO) satellite constellations deployed to expand the coverage to rural and remote areas will play a vital role in backhauling 5G traffic.

For some scenarios, the 5G campus network discussed in Section 2 will be beneficial when considering cost. It may be a promising solution and a first step to introduce 5G technology in developing countries [60]. The 5G campus network can provide a localised network with 5G capabilities without the requirement for a costly backhaul network. Though limited to a local area, this network can be useful in addressing specific localised needs and aid in future developments and full-scale deployment.

6 | DEVELOPING COUNTRIES MOVING TOWARDS 5G MOBILE NETWORKS

According to several studies, many developing countries lack or have a very limited 3G or 4G network. Masselos [61] discussed in his presentation that the operators prefer to concentrate only on making investments in infrastructure that is future-proof. Thus, outdated legacy infrastructures and equipment result in lack of access and backhauling infrastructure in most rural and urban areas in those countries.

To illustrate the existing infrastructure in developing countries and their steps towards obtaining 5G technology, three examples are discussed below.

In Africa, for example, fixed wireline is practically nonexistent in many regions, based on an Intelsat and Analysys Mason published article [62]. The article stated that in most circumstances, microwave connections are utilised as the equipment is widely accessible and spectrum licences are simple to obtain. Many African villages with huge populations are isolated, far away from their nearest neighbours. In these conditions, mobile operators are planning to deploy satellite as a backhaul and they have two alternatives for such connectivity, linking each base station to a single aggregation node or adopting a hybrid strategy that combines microwave and satellite technologies to expand for 5G. For instance, Gabon started testing the technology through Gabon Telecom in November 2019, but it has yet to become commercial and GEO based services are considered for 2023 [63].

In India, backhaul is also based on microwave connectivity and this will continue to be a crucial component until fibre connectivity is made generally available across the country, as Vatts from Bharti Airtel Limited stated in his published article [64]. Moreover, he stated that big investment has been made in the microwave to play a vital role as backhaul for mobile networks through all the generations. The major advantages of long-term backhaul implementation are better Quality of Service (QoS) and lower latency. According to the Indian Prime Minister, one of the most important criteria for delivering ubiquitous broadband access, is a reliable fibre backhaul network that ensures high capacity and speeds. The difficulties facing fibre penetration in India are delays due to the bureaucratic process of obtaining permission from the government authorities and cost. As a result, it remains a highly under fiberised country providing connectivity to less than 30% of the mobile towers and 7% of homes. On November 2021, Bharti Airtel telecommunication provider reported that the Airtel India had conducted a 5G trial for the first time using SA mode, with coverage of 400 km between two sites. They did test the spectrum in multiple bands for the validation of 5G use cases [65].

In Iraq, according to the latest published report on the Iraqi telecoms industry [66], the destruction and degradation of telecommunications as a result of the Gulf War in 1991 were significant and so too were the economic sanctions that followed, resulting in a drop in the infrastructure of fixed telephones density to 3.3% of that in 2002. Moreover, Iraq has struggled to cope with the technological challenges owing to lack of copper and very limited optical fibre fixed-line infrastructure. The mobile services were delivered to the Iraqi citizens for the first time after 2002. It was a rapid start from zero before 2002 to 50% penetration rate in mid-2008. Thus, because of series developments which designated by the government of Iraq through the Ministry of Communications MOC, and the Media Commission CMC in a planned development strategy for 2007–2010, to upgrade the telecommunications infrastructures [67]. In 2020, the three major operators, Zain Iraq, Asiacell, and Korek Telecom, owned 90% of the mobile infrastructure. The majority of this was based on the Global System for Mobile Communications (GSM), 3G, and 4G in most regions of the country.

To summarise, there is no one solution to 5G backhaul, that is, no unique technology to meet 5G backhaul requirements. The main point is that to build future backhaul, current transport networks must be optimised, incumbent solutions, such as HTS must be developed and new technologies, such as mmWave, sub-6 GHz, IAB, and others, must be investigated. For developing countries, there are different scenarios to be considered involving a number of factors, including the existing 3G or 4G network infrastructures, the available financial resources for deploying a 5G network and the population density in a certain geographic area.

Given most developing countries are still struggling to launch 4G technology along with the obstacles to 5G implementation discussed in this paper, it is proposed that the preferred solution should be to align with recent research that puts a strong focus on the 4th scenario in Section 2 as a cost-effective transport network layout where the backhaul represent the entire transport network, and satellite backhaul, in particular, HTS. That is, this backhaul solution is recommended in the near future for 5G deployment for developing countries, for the following reasons.

- It will enable mobile operators to provide coverage in all rural and remote areas as well as overcoming the terrestrial infrastructure obstacles, such as civil wars, which can hinder any upgrade or expansion, and some random street civil work that may damage the underground and/or overground cables or any other telecommunications infrastructures.
- It would reduce the cost of mobile coverage as many companies are planning to produce low-cost nanosatellites, high throughput LEO satellites, and also, using laser technology can be used to connect satellites and high-altitude platforms (HAPs).
- Although, considered as the highest cost approach for backhauling 5G traffic, some studies have concentrated on satellite-based quantum communications [68] when adopting HTS for 5G networks.

7 | CONCLUSION

This paper has highlighted the obstacles and challenges that providers and operators who plan to invest, deploy or develop 5G technology in developing countries may face. The 3GPP and non-3GPP standardisations have been discussed in terms of the 5G transport and backhaul networks as vital parts that will play a major role in 5G network development. Introducing the new technology proposed by several studies that can be used for the backhaul network will facilitate the deployment of 5G for developing countries. Examples of the existing infrastructures in developing countries in Africa, India, and Iraq have been presented, with proposed solutions for deploying new 5G technology being provided.

AUTHOR CONTRIBUTIONS

INAS Sawad: Conceptualization; Investigation; Visualization; Writing—original draft; Writing—review & editing. Rajagopal Nilavalan: Project administration; Supervision; Writing—review & editing. Hamed Al-Raweshidy: Supervision.

CONFLICT OF INTEREST

The authors declare they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in https://figshare.com/s/88a915b08470946610b9 at [http://doi.org/10.6084/m9.figshare.20771314], reference number [88a915b08470946610b9]

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