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Big Communications: Connect the Unconnected

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In this article, we present the analysis of the digital divide to illustrate the unfair access to the benefits brought by information and communications technology (ICT) over the globe and provide our solution termed big communications (BigCom) to close the digital divide and democratize the benefits of ICT. To facilitate the implementation of BigCom, we give a complete framework of BigCom considering both technological and non-technological factors as well as a set of suggestions for content providers, mobile network operators, and governments. By implementing BigCom, we aim to connect the last 3.7 billion unconnected people living in far-flung and underdeveloped areas and achieve the goal of global and ubiquitous connectivity for everyone in the 6G era.

Keywords: big communications, 6G, global connectivity, telecommunication imbalance, digital divide

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1 INTRODUCTION

As fifth generation (5G) communication networks are being deployed since 2019, researchers of communications science in academia and industry have started paying attention to sixth generation (6G) communications and studying the application scenarios as well as the corresponding performance goals (David and Berndt, 2018; Letaief et al., 2019; Dang et al., 2020). However, with the rapid development of 5G information and communications technology (ICT), it is even difficult to believe that there are almost 3.7 billion people on the globe who are still unconnected or under-connected (Philbeck, 2017).

Because of this surprising fact, researchers of ICT have reached a consensus that the benefits of ICT should be democratized over the world, rather than being reserved for urban and developed regions only (van Dijk, 2020). In this regard, different from 5G that is primarily dedicated to satisfying the application scenarios in populous urban areas with the dense deployment of telecommunication infrastructure, 6G aims to serve the far-flung regions with much less population, physical infrastructure, and limited financial resources and close the digital divide in the 2030s (Yaacoub and Alouini, 2020).

Accordingly, IEEE P2061, a standardization project initiated by IEEE, has been dedicated to enabling affordable broadband communications for rural areas (Khaturia et al., 2020). It is highly expected that the digital inclusion and accessibility over these underdeveloped areas will become the new economic impetus and greatly raise the levels of education, health care, and other public services (Marshall et al., 2020). As a result, democratizing the benefits of ICT is the cornerstone of Goal 1 (No Poverty), Goal 4 (Quality Education), Goal 8 (Decent Work and Economic Growth), and, of course, Goal 9 (Industry, Innovation and Infrastructure) of the United Nations' Sustainable Development Goals (SDGs).

In this article, we analyze the causes of the 3.7 billion connected/under-connected population and propose a novel solution termed *big communications* (BigCom). BigCom is anticipated to be a framework of democratizing the benefits of ICT and realizing global connectivity in the 6G era. In

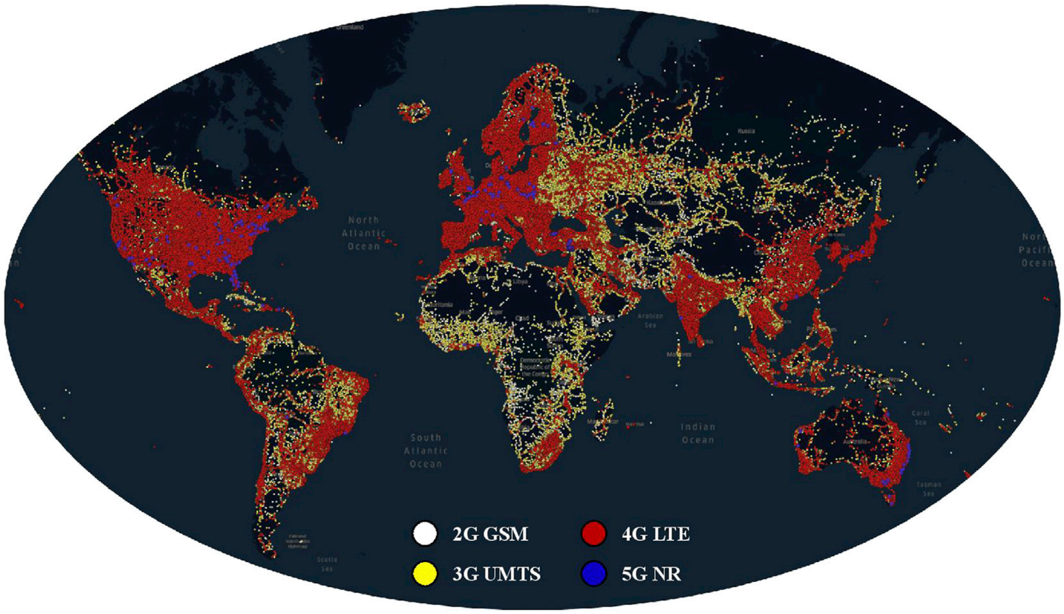

FIGURE 1 | Worldwide BS distribution between Jan. 2000 and Dec. 2020 all over the world: A visualization of the global digital divide.

particular through this perspective article, we aim to provide an inclusive framework different from existing technology-driven frameworks and provoke innovative thoughts and further investigations.

2 HUMAN-CENTRIC 6G VERSUS DIGITAL DIVIDE

As proposed in our article titled "What should 6G be?" by Nature Electronics (Dang et al., 2020), a unique trait of 6G communications compared to the previous generations is the human-centric nature. This human-centric perspective requires to pay attention to the real and heterogeneous needs of end users, rather than increasing certain performance indicators in a mindless manner.

In metropolitan areas with a dense population, providing an extremely high throughput and a vast number of simultaneous connections with much higher standards of security, secrecy, and privacy is the key mission of 6G communications (Dang et al., 2020). On the other hand, in remote areas with only a few residents, basic data and telecommunication services should also be supported by 6G communications as a fundamental social utility, regardless of the profitability (Hodge et al., 2017). This becomes another focus of 6G communications launched in the 2030s. Apart from conventional technical performance measures, it is also suggested by some researchers that the economic and sociological tools, e.g., the Gini index and the Lorenz curve, would be used to evaluate the fairness of access to the benefits of ICT among different areas (Huaizhou Shi et al., 2014).

It has been reported by the background paper to the special session of the Broadband Commission and the World Economic Forum at Davos Annual Meeting in 2017 that there was 53% of the world's population that was still offline, which was about 3.7 billion of people in absolute numbers. Most of these offline people resided in Africa and Asia-Pacific, and there was 85% of the offline population in the least developed countries, whereas the number was 22% in developed countries, forming an evident digital divide (Van Dijk, 2006; Scheerder et al., 2017; Ramsetty and Adams, 2020; Gran et al., 2021).

By obtaining the source data from (Labs Unwired, 2021) and plotting the distribution of base stations (BSs) worldwide in **Figure 1**, one can easily and intuitively observe that many areas in the map have no or limited number of BSs, especially in Africa, Central Asia, Northern and South America. Also, developed countries have better connectivity than developing and least developed countries, indicating the digital divide exists on a country-wise level. Besides, the digital divide also exists on an area-wise level inside a country. This phenomenon can be quantitatively reflected in **Figure 2**, which is also sourced from (Labs Unwired, 2021) and shows the distribution of distances from each BS to the nearest city center. Three different cities, i.e., Washington, D.C., Beijing, and Kampala, are selected and treated as representative cities. The upper-left sub-figure in **Figure 2** illustrates the cumulative probability distribution (CDF) of distances from BSs to the city center for the selected three cities, i.e., $f_X(x) = P(X \leq x)$. X denotes the distance from each BS to the city center and $P(\cdot)$ the corresponding probability. The other three sub-figures represent the histograms of BS-city center distances. From **Figure 2**, it is direct to derive the following key points:

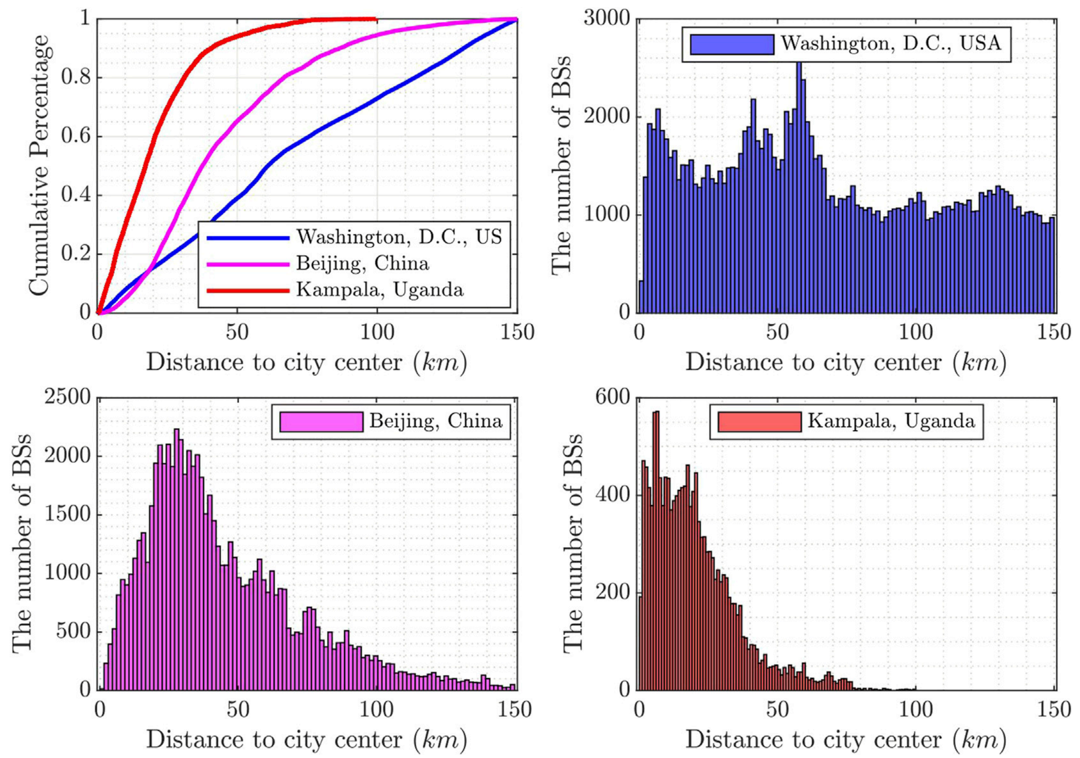

FIGURE 2 | Distribution of distances from each BS to the city center: Three case studies for representative cities.

- The more developed the city, the less BSs are located in the city center.
- The number of BSs near the city center is higher than that far away from the city center, regardless of the level of urbanization. For example, about 95% of the BSs are located less than 50 km from Kampala's city center; however, this number is only 40% for Washington, D.C.
- Though the rural-urban ratio of Kampala is larger than Beijing and Washington, which explains partly why very limited BSs are located far away from the city center. A more severe problem is lacking telecommunication infrastructures in Kampala. For example, if we only consider urban areas whose distance to the city center is less than 10 kM, the number of BSs in Kampala, Beijing and Washington DC are approximately 4,000, 5,500, 11,000, respectively. We can tell that Kampala has fewer BSs than Beijing, especially Washington, DC. These results validate the area-wise digital divide.

The obstructions causing the digital divide for the 3.7 billion of unconnected and under-connected people are sophisticated and region-specific, which can be classified into the technological and non-technological categories.

The technological obstruction mainly refers to the lack of an efficient solution to construct telecommunication infrastructure to connect those unconnected (Lavery et al., 2018). As the manufacturing cost of mobile handsets has continuously been falling over the last decade, mobile handsets are much affordable in recent years, which might not be a bottleneck problem for the connection at all (Jhunjhunwala and Rangarajan, 2011). On the other hand, the construction and deployment plans relying on optical fibers and base stations for urban and populous areas might not be economically feasible for remote and rural areas, albeit with technological feasibility (Chiha et al., 2020). Although in most countries, building infrastructure to cover the underdeveloped areas is a legal duty for telecommunication operators to run business, the lack of economic incentive dismisses their motivation, resulting in poor coverage over these underdeveloped areas (Rooksby et al., 2008). Furthermore, it is generally even more difficult and costly to build and maintain the telecommunication infrastructure by traditional techniques in underdeveloped areas, due to the lacks of legacy telecommunication infrastructure and electricity facility, adverse terrain, altitude, and other natural conditions. In the 6G era, new communication technologies and novel network architectures must be applied in conjunction with new business models to overcome the technological obstructions that prevent the 3.7 billion from global connectivity (Pirinen et al., 2019).

Apart from the technological obstruction, the non-technological obstructions are various, including the lacks of trust and content relevance, language barrier, Internet

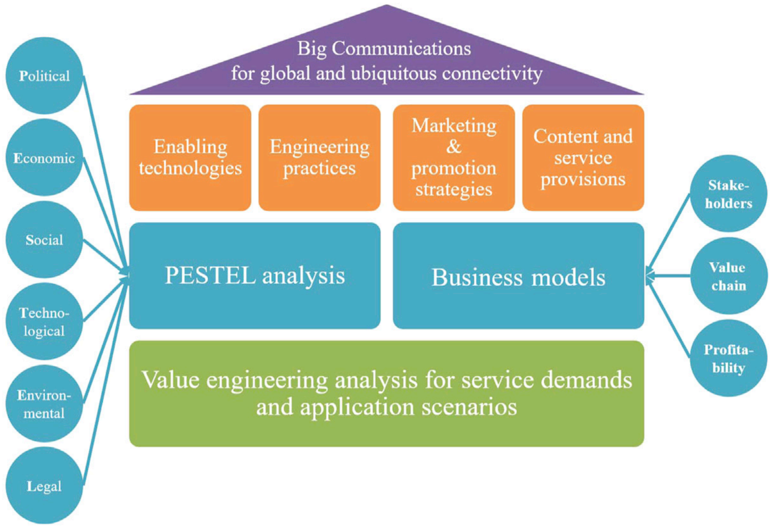

FIGURE 3 | Complete framework of BigCom for achieving global and ubiquitous connectivity and democratizing the benefits of ICT.

censorship, and low computer literacy. Apart from Internet censorship that is a supply-side issue, most non-technological obstructions are the issues with the demand side (Jhunjhunwala and Rangarajan, 2011). In other words, the residents in the remote areas have no need or motivation to be connected. Although exchanging information is one of the basic needs of human beings, exchanging information can be realized in various ways without involving telecommunications.

3 BIG COMMUNICATIONS: THE SOLUTION

To overcome the aforementioned obstructions and achieve the goal of global and ubiquitous connectivity covering the remaining 3.7 billion unconnected/under-connected people, we propose and detail a novel solution termed BigCom in this article. BigCom is proposed for achieving the following missions in the 2030s:

- Connect the unconnected population over the globe, especially those underrepresented groups with economic, geometric, and demographic disadvantages.
- Democratize the benefits of ICT over the globe and close the digital divide step by step.
- Promote the global and ubiquitous connectivity as the cornerstone of the United Nations' SDGs.

Meanwhile, it should be noted that BigCom is not only a solution dedicated to solving the technical problems but also a comprehensive framework analyzing the service demands, socio-economic feasibility, and technological enablers, as well as their long-term implications for specific areas. Based on value engineering analysis, PESTEL analysis (PESTEL: an acronym that stands for Political, Economic, Social, Technological, Environmental, and Legal factors) and various business models (Pestle, 2015), BigCom can be formed as a bottom-up framework as shown in **Figure 3** to help connect people living in underdeveloped regions with limited infrastructure and financial resources.

To provide effective and region-specific solutions under the framework of BigCom, researchers and engineers must first resort to value engineering analysis to assess the service demands and application scenarios for unconnected/under-connected people (Narayan and Nerurkar, 2006). The value engineering analysis constitutes the foundation of BigCom and is carried out to understand served groups from three perspectives:

- What are the demanded communication and data services when connected?
- What are the special needs and peculiarities for the service provisions?
- What is the minimum quality of service (QoS) that should be guaranteed?

Generally, the outcomes of the value engineering analysis are region-specific, and the corresponding actions should be taken case by case. However, there exists certain universality among the collected surveys for different far-flung, rural, and underdeveloped areas, which is summarized and briefly discussed in the following paragraphs.

First, the habitual residence of people who are unconnected or under-connected decides that most of the communication demands are confined within a local and clustered zone (Khaturia et al., 2020). The demanded contents for communication and data services are highly associated with local affairs and daily life. Occasionally, there are some data demands through national and international connections, which are generated mainly for business purposes, instead of recreational purposes.

The traits of communication and data demands of under-developed areas imply that the direct communication distance between two devices would be much closer than the case in urban and dense areas, and the node mobility in under-developed areas would be limited and even negligible. Also, considering the low-rate nature of service demands in these underdeveloped areas, the network transmission capacity does not need to be excessive. Still, the connection reliability is of paramount importance (Chiaraviglio et al., 2017).

On the other hand, some case studies have also shown that once a region has been well connected and the residents get used to the telecommunication services, they might even demand more services, rendering a much higher network throughput. This indicates that when deploying the basic telecommunication infrastructure for underdeveloped areas, one should always keep a futuristic mind and remain a high degree of flexibility and scalability (Matinmikko et al., 2017).

Apart from the aforementioned technological traits, considering the economic disadvantage of the users in underdeveloped areas, they are more sensitive to the communication cost than those living in developed areas. Affordability should be enhanced to promote the penetration of telecommunications in underdeveloped areas and connect more people so as to yield the scale effect for cost reduction (Khaturia et al., 2020). The affordability advantage in underdeveloped areas can be gained by trading customization off.

In addition, both flexibility and affordability can also be reinforced by the flexible spectrum management in far-flung areas, as the spectrum occupation is generally sparse in these areas. The richness of available spectrum allows much more flexible and inexpensive use of spectral resources, because a number of constraints for mitigating co-channel interference can be lifted and various complex techniques for enhancing spectral efficiency are not required.

Meanwhile, as a systematic project, the value engineering analyses frequently uncover the dependence of reliable connectivity on reliable power supply in underdeveloped areas. Lacking power infrastructure and intermittent power supply are two of the main causes for discontinuous communications in underdeveloped areas (Chiaraviglio et al., 2017), and higher priority should be given to the energy efficiency of telecommunication networks by a limited energy budget.

In a nutshell, abiding by the proposed BigCom framework, the service demands of the local subscribers will first be analyzed and understood, and the bottlenecks preventing local residents from being connected shall also be identified in the first place. These can be done by value engineering analysis and form the foundation of providing technological and non-technological solutions. With this primary information in mind, in-depth PESTEL analysis can be carried out to dig into the causes of these bottlenecks in the aspects of policy, economy, society, technology, environment, and legality. The rigorous and all-round outcomes will help propose improvement suggestions, formulate potential solutions, and make decisions at a high hierarchy. In the meantime, an appropriate business model can also be selected to refine the value chain, identify the corresponding stakeholders, and maintain profitability. With all this preparatory work done, researchers and engineers can dedicate themselves to developing and implementing novel communication technologies for realizing global and ubiquitous connectivity. Suitable marketing and promotion strategies, as well as relevant content disseminated over the enabled connectivity, can also be adopted by commercial bodies. With such a comprehensive framework and all-round considerations, both technological and non-technological factors are supposed to be taken into account, which considerably benefits the realization of global and ubiquitous connectivity for bridging the digital divide. Implementing BigCom is nontrivial. The main complexities lie in marketing and content and service provisions, which are complex and profit-driven issue. However, these complexities are not unsolvable as governments, content providers, as well as mobile network operators are all realizing the importance of accessing Internet.

4 ENABLING TECHNOLOGIES OF BIG COMMUNICATIONS

Depending on different service demands and application scenarios, there exist a number of techniques and approaches in the toolbox of BigCom that can be jointly applied to connect the remaining 3.7 billion unconnected/under-connected people living in underdeveloped regions. We pictorially illustrate these techniques and approaches in **Figure 4** and introduce each of them with the corresponding application scenarios in the following paragraphs. In particular, the ubiquitous connectivity in underdeveloped areas can be classified into three categories: local connectivity, terrestrial connectivity, and space connectivity, which should be enabled and supported by different communication and information technologies and paradigms.

The local connectivity aims to deliver short-distance data communications and disseminate local messages. Based on the existing telecommunication infrastructure, e.g., core networks, optical cables, machine rooms, and base stations, cooperative relaying and device-to-device (D2D) communications would be two efficient physical-layer techniques for enhancing local connectivity (Dang et al., 2018). Both techniques can work in a complementary manner to expand network coverage and enhance communication services without constructing new infrastructure. They are in particular efficient for satisfying clustered communication and data service demands in proximity.

The terrestrial connectivity relies on telecommunication infrastructures and is generally costly. Fortunately, because rich spectral resources are available in underdeveloped areas, high-quality frequency bands and large bandwidths can be employed for large and reliable coverage. Among a number of candidate frequency bands, because of the unlicensed status and a good penetration ability, television white space (TVWS) spectrum (470–790 MHz in Europe) has been regarded as a promising solution for achieving wide and frugal broadband connectivity (Khaturia et al., 2020). The coverage radius of TVWS spectrum is typically 30 km and can be easily extended to 100 km if required. Meanwhile, multiple available frequency bands also allow performing subcarrier permutation among

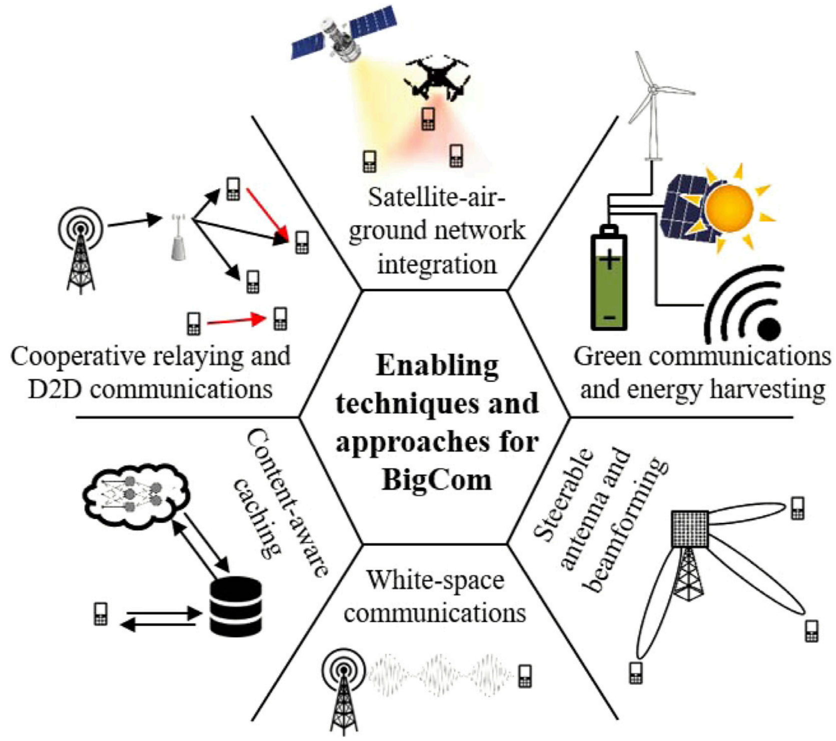

FIGURE 4 | Techniques and approaches enabling BigCom.

different cooperative hops to harvest frequency diversity gains and lead to better end-to-end communication performance.

To improve energy efficiency of terrestrial connectivity for underdeveloped areas with a limited energy budget for communications, steerable antenna arrays with beamforming functionality play a crucial role (Pirinen et al., 2019). This steerable architecture takes advantage of the low mobility of communication nodes in underdeveloped areas and can accurately track the geometric locations of nodes by a small amount of signaling overhead. To reduce the dependence on unreliable power grids, green communications and diverse energy harvesting techniques can be used to provide renewable energy for terrestrial telecommunication infrastructure and equipment in underdeveloped regions.

Apart from the terrestrial telecommunication infrastructure, the space and airborne telecommunication infrastructure should also be integrated to provide space connectivity over far-flung areas (Ye et al., 2020). In the context of beyond-5G and 6G, conventional satellite communications are expected to be greatly enhanced by drones equipped with radio transceivers and processing modules (a.k.a. aerial base stations) (Zhang et al., 2017). As a direct result of the satellite-air-ground network integration, basic communication and data services can also be provided to the dead spots that cannot be covered solely by terrestrial radios. Benefiting from the high mobility and adjustable positions of drones, such integrated networks can be deployed in a dynamical manner. Therefore, as added bonuses, networking flexibility and scalability can also be considerably improved by this integration.

In higher layers, edge computing and artificial intelligence are applicable for facilitating content-aware caching for clustered communication and data services in rural areas (Dai et al., 2019). Because of the similar and highly predictable demanded contents, when the spectral and energy resources are sufficient, edge servers can pre-load contents that would likely be requested by users. Content-aware caching provides an opportunistic optimization mechanism for allocating communication and computing resources over time. These computing technologies are expected to benefit all three types of connectivity from different aspects. All the techniques and approaches enabling BigCom can be integrated in a seamless way in future communication networks by design.

5 SUGGESTIONS FOR IMPLEMENTING BIG COMMUNICATIONS

According to the summary of service demands, application scenarios, and the enabling technologies for BigCom, we come up with several suggestions for implementing BigCom in practice in this section. To make our suggestions more specific, we first need to identify the stakeholders of the proposed BigCom framework. Different from conventional technology-driven

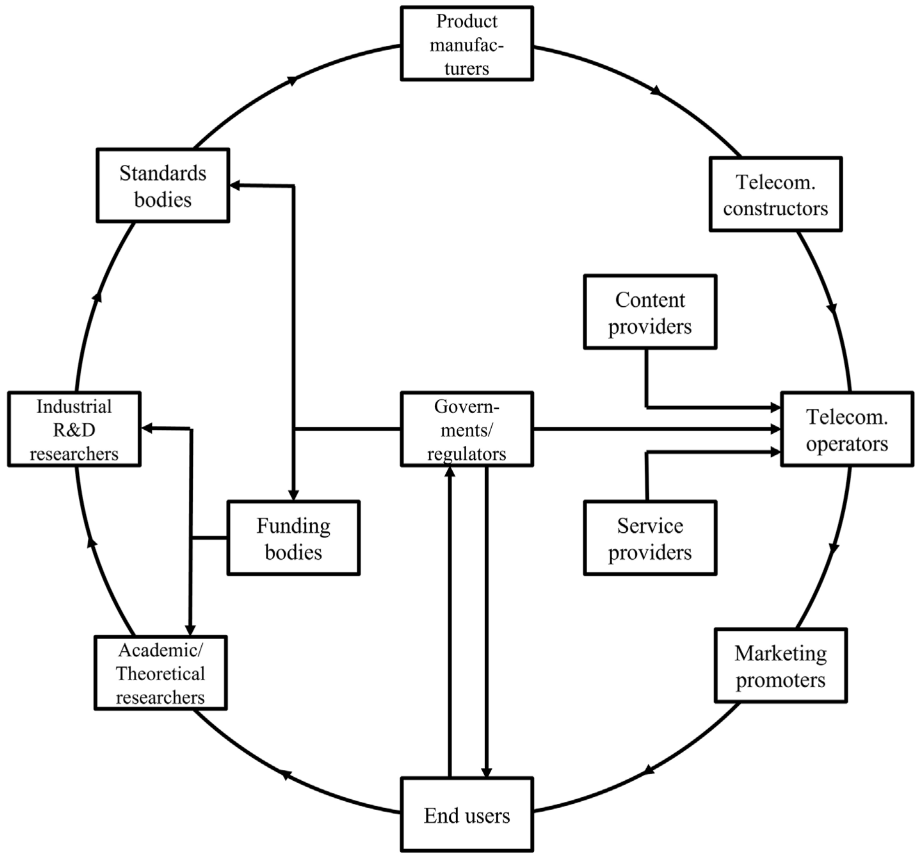

FIGURE 5 | Value loop associated with the BigCom framework and connecting stakeholders.

frameworks that can be well described by value chains, we highlight the human-centric nature of BigCom and extend the value chain to a value loop characterizing the iterative process of service improvement. From the descriptions of the proposed BigCom framework in the last section, the value loop involving multiple stakeholders is presented in **Figure 5**. From the illustrated value loop, twelve stakeholders have been identified, including academic/theoretical and industrial R&D researchers, standards bodies, product manufacturers, telecommunication constructors, telecommunication operators, content and service providers, marketing promoters, and end users as well as governments/regulators and their affiliated funding bodies.

5.1 Content Providers

Content providers are the key to solve the underlying issue of the digital divide. They should provide justifiable reasons to connect the unconnected people living in underdeveloped areas, which create motivation in technological and administrative innovations. Although somebody might argue that this is a "chicken or the egg" dilemma, it is clear that even with full-fledged telecommunication infrastructure, the implementation of BigCom will not succeed if the unconnected people living in underdeveloped areas need to pay extra but find no reason to be connected.

Thus, rather than passively waiting for new niche markets and business opportunities, content providers are supposed to actively create new demands for those living in underdeveloped areas. Some helpful experience could be learned from the rapid digitalization of China in the past decades (Zhang and Chen, 2019). The content providers in China proposed a series of innovative digital services, including e-payment, online ordering and delivery, and peer-to-peer product supply, which created a large number of profitable niche markets. Because these innovative digital services greatly facilitate daily life and benefit the locals, the penetration rates of smart phones and the relevant wireless data services in China have surged to a record high in the past decade.

5.2 Telecommunication Operators

The telecommunication operators should fully release artificial intelligence's technological advantages and detect cell coverage holes based on cross-domain data fusion. For example, as raw data obtained from (Labs Unwired, 2021, Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University, 2016), processed, and shown in **Figure 6**, by considering both the population data and the BS data, telecommunication operators can easily find out which places are less covered and quantify the degree of lack of telecommunication resources using the

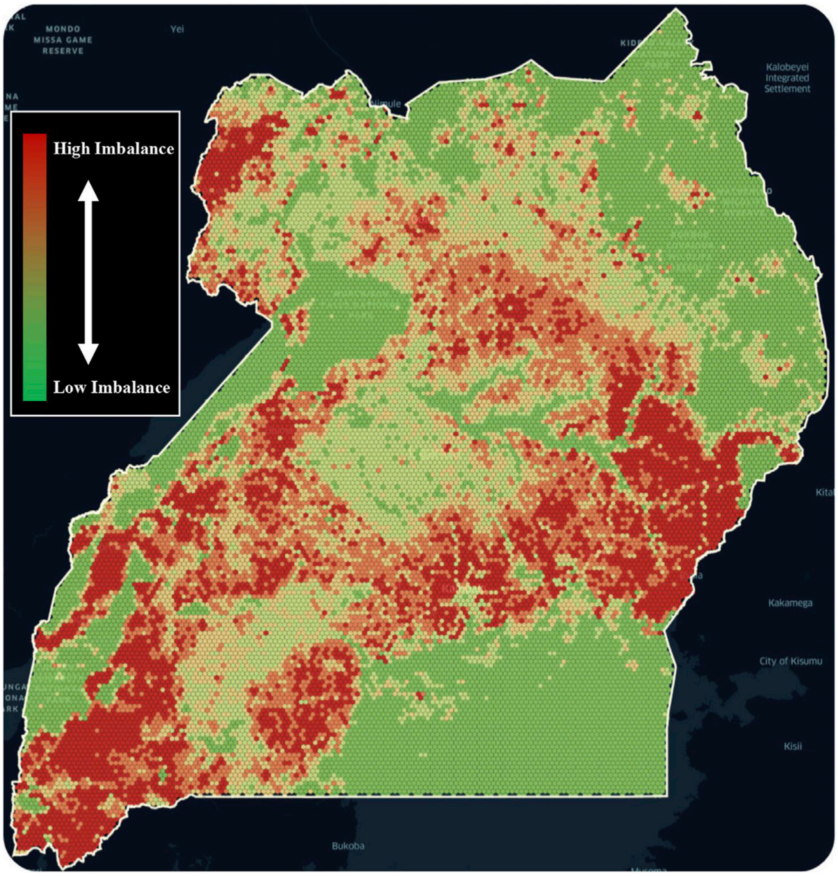

FIGURE 6 | Connectivity imbalance visualization for Uganda, a developing country in the middle of Africa. The whole country is spitted into many small areas, and each area is approximately 4 km^2, and the imbalance index calculates a ratio of population to the number of BSs for each area.

imbalance index defined in (Zhang et al., 2021). Aside from identifying coverage holes, operators should also resort to some cost-effective ways to cover rural areas, such as integrating heterogeneous telecommunication resources, including BSs, satellites, drones, and earth-orbiting balloons by considering the global acceptance and commercialization issues at the same time.

Apart from the resource integration under conventional business models, novel business models should also be found by telecommunication operators to connect the unconnected people living in far-flung and rural areas. Currently, the idea of 'who benefits who pays' has come into attention, which results in the concept of micro-operators (Matinmikko et al., 2017). A micro-operator is both the service provider and the end user. However, the self-sufficient telecommunication services supported by micro-operators will compromise the vested interest of telecommunication operators, and therefore how these novel business models can coalesce into conventional business models still remains as an open problem.

5.3 Governments/Regulators

Governments, in particular those of undeveloped countries, should recognize that accessing the Internet is the key to making innovation, improving education, and reducing poverty. Thus, governments might provide certain incentives to content providers and telecommunication operators in the initial stage of telecommunication constructions. The potential incentives include but are not limited to flexible regulations of administration, tax reduction, direct financial supports, land resources, and spectral resources. These incentives will not only attract investment for telecommunication infrastructure but also reduce the costs of construction, maintenance, and operation of telecommunication networks with a small number of users.

Besides, the government's decision-making, especially those that have important global impact, can greatly help realize BigCom. Take China's "The Belt and Road Initiative" as an example, more and more companies are participating this initiative. Among those companies, Huawei, together with the Export-Import Bank of China, have invested 1 billion dollars in Africa to help African countries improve their network connectivity. It has also deployed more than half of BSs and more than 70% of LTE high-speed mobile broadband networks in more than 50 countries in Africa.

Balancing fairness and efficiency is an eternal topic in policy sciences and policy making processes in practice (Aitken and deB, 2011); governments should, however, be aware of the fact that it is unrealistic in the short term to provide comparable data services in rural areas as in urban areas. Such temporary imbalance should be tolerated, leading to different construction objectives and telecommunication policies in rural and urban areas. Therefore, governments might not expect to close the digital divide by one attempt but reduce the divide step by step and finally close it. In this regard, flexible regulations and rich spectral resources should be leveraged as the advantages in far-flung and rural areas to facilitate basic and accessible data services for the unconnected people.

5.4 Academic and Industrial Researchers

The BigCom framework will also yield profound impacts on the research in academia and industry. Under conventional technology-driven frameworks, researchers are dedicated to proposing and developing communication systems with improved technical performance measures, e.g., throughput, peak rate, number of simultaneous connections, and latency. On the contrary, the BigCom framework requires multifaceted considerations at the research stage, incorporating technological and non-technological factors. The specific research activities shall become demand-driven, and the researchers are supposed to obtain firsthand feedback from the end users for research planning. Meanwhile, different non-technological factors need to be modeled in addition to the technological factors, which could bring new research challenges and become disruptive. Also, when considering real-world constraints and models, a tremendous amount of data will be involved—processing these data and simulating such practical application scenarios are never trivial tasks for existing simulators, which might hinder the ICT development under the BigCom framework. Far more efficient simulation approaches for incorporating non-technological factors in the modeling, analysis, and optimization would be worth studying in academia and industry.

Among all the stakeholders, we believe researchers and telecommunication operators are the main driving forces to implement BigCom. This is because the innovation of technologies and the corresponding evolutions are originated from fundamental research, and we mainly rely on telecommunication operators to implement new technologies in reality. After we have 6G technologies and the platform to implement them, end users can enjoy the benefits of 6G communications. Lastly, to put BigCom into practice, the first and foremost priority is to accelerate the research and development of 6G communication technologies such as Terahertz (THz) communications, AI-powered networking, and new security and privacy schemes. Unless mature technologies support, our society can barely enter the 6G era. Moreover, international collaborations among different countries should also be enhanced to build and/or update telecommunication infrastructure.

6 CONCLUDING REMARKS

In this article, we analyzed the obstructions preventing 3.7 billion people from proper connections and proposed a novel framework termed BigCom for the purpose of realizing global and ubiquitous connectivity in the 6G era, which we are not ready yet but will be ready in the future around 2030. BigCom is a comprehensive and hierarchical framework aiming at identifying, mitigating, and solving both technological and non-technological issues impeding linking the last remaining 3.7 billion people in far-flung, rural, and underdeveloped areas. With the support of BigCom for 6G, it is expected that the global and ubiquitous connectivity will not become the privilege of residents in dense and urban areas but also cover the 3.7 billion people living in underdeveloped areas. Though the digital divide may not be completely closed, our BigCom will accelerate urbanization and blur the boundary between urban and rural areas. As a result, the benefits of ICT would be democratized among the globe so as to help with the realizations of the United Nations' SDGs, facilitate the liberation of global economies, democratize government institutions, and eventually promote the progress of the entire human society.

Through this perspective article, we aim to propose a new alternative to the existing technology-driven frameworks and open up a new direction to move forward towards an inclusive and sustainable digital future. We also hope that the proposed framework will provoke novel thoughts on the solutions to the digital divide and ground-breaking paradigms. It should also be noted that the proposed BigCom framework is still in its infancy, and its practicality is up to further investigation and substantiation with sound empirical evidence, which form worthwhile future work. In particular, one potential future work is identifying actual coverage holes based on real-world BS datasets and comparing them with the recently proposed telecommunication service imbalance index. Besides, the security, secrecy, and privacy issues and risks related to the BigCom framework are also worth studying in depth before reaching its implementation stage.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

SD and CZ wrote the paper; BS and M-SA designed the overall structure and provided ideas and insights.

REFERENCES

Aitken, M. J., and deB, F. H. (2011). Evidence-Based Policy Making for Financial Markets: AFairness and Efficiency Framework for AssessingMarket Quality. *Jot.* 6, 22–31. doi:10.3905/jot.2011.6.3.022

Chiaraviglio, L., Blefari-Melazzi, N., Liu, W., Gutierrez, J. A., van de Beek, J., Birke, R., et al. (2017). Bringing 5G into Rural and Low-Income Areas: Is it Feasible? *IEEE Comm. Stand. Mag.* 1, 50–57. doi:10.1109/mcomstd.2017.1700023

Chiha, A., Van der Wee, M., Colle, D., and Verbrugge, S. (2020). Techno-economic Viability of Integrating Satellite Communication in 4G Networks to Bridge the Broadband Digital divide. *Telecommunications Policy.* 44, 101874. doi:10.1016/j.telpol.2019.101874

Dai, Y., Xu, D., Maharjan, S., Qiao, G., and Zhang, Y. (2019). Artificial Intelligence Empowered Edge Computing and Caching for Internet of Vehicles. *IEEE Wireless Commun.* 26, 12–18. doi:10.1109/mwc.2019.1800411

Dang, S., Amin, O., Shihada, B., and Alouini, M.-S. (2020). What Should 6G Be? *Nat. Electron.* 3, 20–29. doi:10.1038/s41928-019-0355-6

Dang, S., Chen, G., and Coon, J. P. (2018). Multicarrier Relay Selection for Full-Duplex Relay-Assisted OFDM D2D Systems. *IEEE Trans. Veh. Technol.* 67, 7204–7218. doi:10.1109/tvt.2018.2829401

David, K., and Berndt, H. (2018). 6G Vision and Requirements: Is There Any Need for Beyond 5G? *IEEE Veh. Technol. Mag.* 13, 72–80. doi:10.1109/mvt.2018.2848498

Facebook Connectivity Lab and Center for International Earth Science Information Network - Ciesin - Columbia University (2016). *High Resolution Settlement Layer (HRSL).* New York: Source imagery for HRSL 2016 DigitalGlobe (Accessed March 25, 2021).

Gran, A.-B., Booth, P., and Bucher, T. (2021). To Be or Not to Be Algorithm Aware: a Question of a New Digital divide? *Inf. Commun. Soc.* 24, 1779–1796. doi:10.1080/1369118x.2020.1736124

Hodge, H., Carson, D., Carson, D., Newman, L., and Garrett, J. (2017). Using Internet Technologies in Rural Communities to Access Services: The Views of Older People and Service Providers. *J. Rural Stud.* 54, 469–478. doi:10.1016/j.jrurstud.2016.06.016

Huaizhou Shi, H., Prasad, R. V., Onur, E., and Niemegeers, I. G. M. M. (2014). Fairness in Wireless Networks:Issues, Measures and Challenges. *IEEE Commun. Surv. Tutorials.* 16, 5–24. doi:10.1109/surv.2013.050113.00015

Jhunjhunwala, A., and Rangarajan, J. (2011). Connecting the Next Billion: Empowering Rural India. *IT Prof.* 13, 53–55. doi:10.1109/mitp.2011.58

Khaturia, M., Jha, P., and Karandikar, A. (2020). Connecting the Unconnected: Toward Frugal 5G Network Architecture and Standardization. *IEEE Comm. Stand. Mag.* 4, 64–71. doi:10.1109/mcomstd.001.1900006

Labs Unwired (2021). "The OpenCelliD Project." [Online]. Available at: https://opencellid.org/ (Accessed March 26, 2021).

Lavery, M. P. J., Abadi, M. M., Bauer, R., Brambilla, G., Cheng, L., Cox, M. A., et al. (2018). Tackling Africa's Digital divide. *Nat. Photon.* 12, 249–252. doi:10.1038/s41566-018-0162-z

Letaief, K. B., Chen, W., Shi, Y., Zhang, J., and Zhang, Y.-J. A. (2019). The Roadmap to 6G: AI Empowered Wireless Networks. *IEEE Commun. Mag.* 57, 84–90. doi:10.1109/mcom.2019.1900271

Marshall, A., Dezuanni, M., Burgess, J., Thomas, J., and Wilson, C. K. (2020). Australian Farmers Left behind in the Digital Economy - Insights from the Australian Digital Inclusion Index. *J. Rural Stud.* 80, 195–210. doi:10.1016/j.jrurstud.2020.09.001,

Matinmikko, M., Latva-Aho, M., Ahokangas, P., Yrjölä, S., and Koivumäki, T. (2017). Micro Operators to Boost Local Service Delivery in 5G. *Wireless Pers Commun.* 95, 69–82. doi:10.1007/s11277-017-4427-5

Narayan, G., and Nerurkar, A. (2006). Value-proposition of E-Governance Services: Bridging Rural-Urban Digital divide in Developing Countries. *Int. J. Educ. Dev. using ICT.* 3, 33–44.

Pestle (2015). *Analysis: Understand and Plan for Your Business Environment.* Management & Marketing. 50Minutes.com.

Philbeck, I. (2017). *Connecting the Unconnected: Working Together to Achieve Connect 2020 Agenda Targets.* Davos: Special session of the Broadband Commission and the World Economic Forum at Davos Annual Meeting.

Pirinen, P., Saarnisaari, H., van de Beek, J., Matinmikko-Blue, M., Nilsson, R., and Latva-aho, M. (2019). "Wireless Connectivity for Remote and Arctic Areas – Food for Thought. *Proc. IEEE ISWCS*, 43–47.

Ramsetty, A., and Adams, C. (2020). Impact of the Digital divide in the Age of COVID-19. *J. Am. Med. Inform. Assoc.* 27, 1147–1148. doi:10.1093/jamia/ocaa078

Rooksby, E., Wekert, J., and Lucas, R. (2008). *Glob. Inf. Tech. Concepts, Methodologies, Tools, Appl.*, 3391–3409. doi:10.4018/978-1-59904-939-7.ch242

Scheerder, A., Van Deursen, A., and Van Dijk, J. (2017). Determinants of Internet Skills, Uses and Outcomes. A Systematic Review of the Second- and Third-Level Digital divide. *Telematics Inform.* 34, 1607–1624. doi:10.1016/j.tele.2017.07.007

Van Dijk, J. A. (2006). "Digital divide Research, Achievements and Shortcomings. *Poetics* 34 (no. 4), 221–235. doi:10.1016/j.poetic.2006.05.004

van Dijk, J. (2020). *The Digital Divide.* Cambridge: Wiley.

Yaacoub, E., and Alouini, M.-S. (2020). A Key 6G Challenge and Opportunity-Connecting the Base of the Pyramid: A Survey on Rural Connectivity. *Proc. IEEE.* 108, 533–582. doi:10.1109/jproc.2020.2976703

Ye, J., Dang, S., Shihada, B., and Alouini, M.-S. (2020). Space-air-ground Integrated Networks: Outage Performance Analysis. *IEEE Trans. Wireless Commun.* 19, 7897–7912. doi:10.1109/twc.2020.3017170

Zhang, C., Dang, S., Shihada, B., and Alouini, M.-S. (2021). On Telecommunication Service Imbalance and Infrastructure Resource Deployment. *IEEE Wireless Commun. Lett.* 10, 2125–2129. doi:10.1109/lwc.2021.3094866

Zhang, L., and Chen, S. (2019). *China's Digital Economy: Opportunities and Risks.* Washington: International Monetary F.und.

Zhang, N., Zhang, S., Yang, P., Alhussein, O., Zhuang, W., and Shen, X. S. (2017). Software Defined Space-Air-Ground Integrated Vehicular Networks: Challenges and Solutions. *IEEE Commun. Mag.* 55, 101–109. doi:10.1109/mcom.2017.1601156

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