Lessons from the Commercial Failure of Project Loon for 6G Research Roadmap Design

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ABSTRACT

Currently, the sixth-generation (6G) communication research roadmap is being frequently discussed and designed, in which, undoubtedly, aerial telecommunication infrastructures play crucial roles for boosting transmission capacity, enlarging coverage, and democratizing the benefits of information and communications technology (ICT) over the globe. However, the sudden news released in January 2021 that Alphabet is shutting down Project Loon, one of the most important projects enabling communications over aerial infrastructures, surprises the academia of communications science. There is no question that the failure of Project Loon will yield profound impacts on and even shift the current 6G research roadmap design. The latent mismatch between academia and industry in communication science should also raise adequate attention. Therefore, in this article, we analyze the commercial failure of Project Loon by public information from reliable sources and summarize a series of important lessons for the 6G research roadmap design.

Keywords: 6G Research Roadmap, Loon, Aerial Communication

1 INTRODUCTION

Since the end of 2019, researchers in communication sciences have paid great attention to the design of sixth-generation (6G) communication research roadmap Dang et al. (2020); Saad et al. (2020); Yang et al. (2019). A consensus among the research community is that aerial telecommunication infrastructures will play crucial roles in 6G communications. The much higher aerial base stations (BSs) in the stratosphere than their terrestrial counterparts and the easy-to-deploy nature make stratospheric communications a promising candidate technology for boosting transmission capacity, enlarging coverage, and enhancing network reliability, as well as, finally, democratizing the benefits of information and communications technology (ICT) between urban and rural areas Yaacoub and Alouini (2020). Such aerial infrastructures can also be utilized to form supplementary networks for emergency communications and other special needs Zeng et al. (2016). Overall, communications over the aerial layer relying on unconventional infrastructures and apparatuses, e.g., floating balloons, unmanned aerial vehicles (UAVs), and airships, are advantageous compared to both classical terrestrial communications and satellite communications. The research pertaining to non-terrestrial communications has become one of the hottest topics in communications science and attracted researchers' great attention in recent years Kishk et al. (2020).

In line with the enthusiastic research activities in academia, industrial operations, practical implementations, and commercialization of aerial telecommunication infrastructures have also been carried out simultaneously by renowned companies, e.g., Project Loon by Google, Facebook Aquila, the ABSOLUTE Project, and the Matternet project Yang et al. (2019). However, when both academia and industry had high hopes for the prosperity of stratospheric communications in the 6G era, sudden news released on *The Verge* in January 2021 that Alphabet, the parent company of Google, is shutting down Project Loon casts a shadow over this high-profile technology. As one of the most important projects related to stratospheric communications and has been widely acknowledged as a firm supporter of the bright future of stratospheric communications in academic papers, the failure of Project Loon becomes ironic and has soon caused explosive controversy regarding stratospheric communications in both academia and industry.

Regardless of being constructive or destructive, the commercial failure of Project Loon will yield profound impacts on the current 6G research roadmap design and even make a great shift, which will affect the goals of 6G communications for the entire human society in the 2030s. Due to such importance, we analyze the commercial failure of Project Loon by public information from reliable sources and summarize a series of important lessons for the 6G research roadmap design. In particular, we aim to provide preliminary answers to the following questions in this article:

- What are the factors that result in the commercial failure of Project Loon?
- What should researchers learn from the commercial failure of Project Loon and how should the current 6G research roadmap be adjusted accordingly?
- Are research topics related to stratospheric communications still worth studying?

2 PROJECT LOON: PAST AND PRESENT

Connecting the unconnected is one of the core concerns in the 6G network blueprint. Although admitted as a risky venture at the launching stage, Project Loon took the responsibility to pave the way for connecting the last billion unconnected communities rather than the next billion. The project was funded in 2011 and unveiled in 2013 as one of the most hyped endeavors of X, Alphabet's incubator for lofty "moonshot" technologies. By managing a fleet of helium balloons sailing in the stratosphere and beaming Internet access to remote areas, Project Loon tried to provide a radical solution for the challenges of connecting these unconnected areas with behindhand terrestrial infrastructure and/or in poverty Yaacoub and Alouini (2020).

Different from our conventional perception, Google's balloons are made of polyethylene plastic and stand 15 meters wide by 12 meters tall when fully inflated, with built-in signal transceivers, solar panels, the global positioning system (GPS), etc. In general, the balloon flies in the stratosphere at a distance of 20 kilometers from the ground where the speed and direction of the wind are relatively stable. By implementing predefined algorithms, a number of floating balloons constitute a hierarchical communication network. Customers of the service connect to the balloon network using special Internet interfaces constructed on their buildings, which avoids using expensive fiber cables that would have to be installed underground. A transmitted signal travels through the balloon network, then to a ground-based station connected to an Internet service provider (ISP), and finally gets into the global Internet.

Table 1. Project Loon's chronology

2011	Project Loon was founded by Google Alphabet.
2013	An empirical pilot test was conducted by launching about 30 balloons in New Zealand.
2014	Tested the balloon-powered Internet in Brazil, marking its first LTE experiments and launch near the equator.
2015	Google signed an agreement with officials of Information and Communication Technology Agency (ICTA) to launch the technology on a mass scale.
2016	Achieved a stable laser communication connection between two balloons over a distance of 100 km.
2017	Supported basic communications and Internet services in Puerto Rico after Hurricane Maria.
2018	Projects Loon left the nest and became an independent company under Google's parent company Alphabet
2019	Re-directed a group of balloons serving LTE to users in Peru after an earthquake.
	Reached one million hours of stratospheric flight between the balloon fleet.
2020	Deployed Internet connectivity balloons in Kenya for the first commercial service launch.
	Claimed a record-duration flight of 312 days for a balloon.
2021	The final flight of the Loon balloon.

After nine years of exploring and exploiting, Project Loon walked into a boneyard of costly terminations but left a legacy. Indeed, Project Loon boasted several groundbreaking technical achievements over the past few years, like precisely navigating balloons in the stratosphere, creating a mesh network in the sky, and developing balloons that can withstand the harsh conditions of the stratosphere for more than a year. In the view of application launching, Project Loon provided Internet services to areas affected by natural disasters, such as Puerto Rico after Hurricane Maria in 2017 and Peru after an earthquake in 2019. Moreover, the first commercial Internet service in Kenya launched by Project Loon in 2020, comprised of a fleet of about 35 balloons that covered an area of around 50,000 square kilometers. In the view of academia, Project Loon proposed a deep reinforcement learning-based approach for autonomous navigation of stratospheric balloons Bellemare et al. (2020). From the commercial perspective, Project Loon's free-space optical communication technology is provided as a patent and has been extended as another project supported by Google X, Tarra, which aims to expand global access to a fast and affordable Internet with the support of light beams. The chronology of Project Loon is given in Table 1

3 ANALYSIS OF THE FAILURE OF PROJECT LOON

Although Project Loon has played an important role and brought a number of breakthroughs in both academia and industry. Its failure yields an even more profound impact on this field and becomes satirical, especially when a vast amount of literature refers to Project Loon as a solid proof of the technological feasibility of stratospheric communications. Therefore, it is worth investigating the failure of Project Loon and identifying the possible factors leading to this failure.

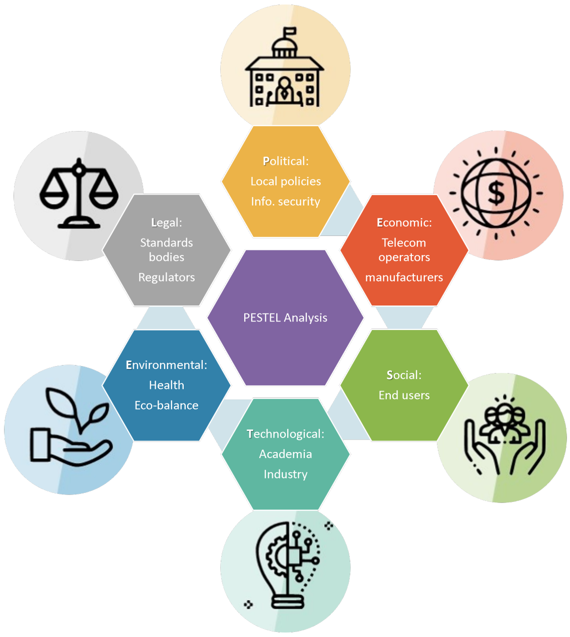

Figure 1. PESTEL framework for analyzing the failure of Project Loon.

Internet penetration and the development of a certain technology are normally beyond the technology *per se* but depend on a series of complex factors, including the average income per capita of the targeted end users as well as the country's risk (a collective measure of political, security, economic, legal, tax, and operational risk ratings) Skaletsky et al. (2016). Due to the complexity of the socio-economic nature of Project Loon, we analyze its failure by employing the PESTEL framework, which encompasses the **p**olitical, **e**conomic, **s**ocial, **t**echnological, **e**nvironmental and **l**egal aspects. In particular, the PESTEL framework is chosen herein because it can provide in-depth insights into the development of technology by different categories and has been proven effective by many practical case studies. The PESTEL framework is also widely recognized by technologists as a powerful qualitative analytical tool that helps to think out-of-the-box. For clarity, we pictorially summarize the PESTEL framework for analyzing the failure of Project Loon in Fig. 1 and expatiate on each of these aspects infra.

3.1 Political Factors

For any large-scale infrastructure construction project, political factors matter. Project Loon faced mainly two political hurdles: spectrum license limitation and information security issues. When piloting the project in India, the spectrum band required for the airwaves transmission, which is a band between 700 to 900 MHz, is occupied by telecommunication service providers and is prohibited to use by the local policy. Although the struggle to obtain clearances from civil aviation and defense ministries for approvals, impedance is still another one of the biggest concerns around the project, whether or not it will interfere with the local spectrum. In addition, an even bigger political challenge will be getting various national governments and regulators to agree to support an international broadband network, as well as getting dedicated access from multiple countries to a harmonized spectrum band or unlicensed airwaves. Information security also becomes a major political concern when deploying Project Loon, as its reliability is of high importance, and an uncontrollable airborne network can lead to catastrophic consequences when natural disasters, wars, and cyberattacks happen.

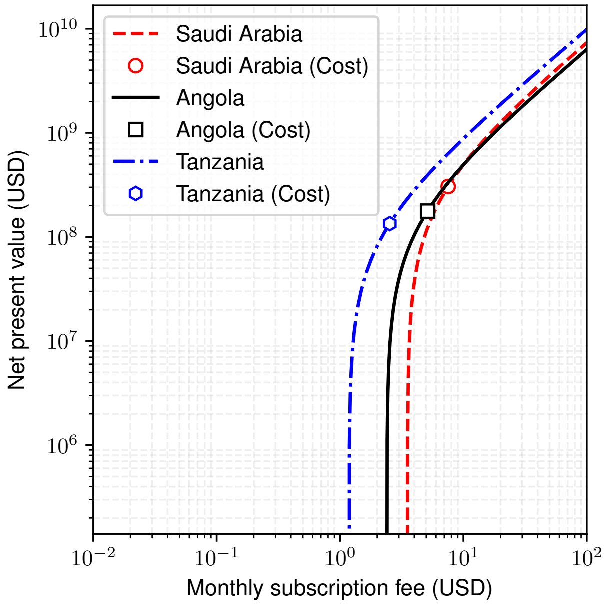

Figure 2. Net present value versus monthly subscription fee by deploying balloons over rural areas of the three considered countries: : Saudi Arabia, Angola, and Tanzania.

3.2 Economic and Social Factors

Economic and social factors are directly related to the commercial development of technology. Unfortunately, Astro Teller, the CEO of X and the Chairman of Project Loon's board said in his blog post that despite found a number of willing partners along the way and ground breaking technical achievements, the Loon team "haven't found a way to get the costs low enough to build a long-term, sustainable business."

Various costs are incurred in the balloons, such as polyethylene plastic for the envelope, solar panels, and 4G equipment. By adding up the costs of all parts, the estimated capital expenditure (CAPEX) is up to $17,870 per balloon Burr (2017). Apart from CAPEX, operating expenditure (OPEX), helium refill, for example, is also costly. Thus, Project Loon was faced with high up-front costs, and it was a great challenge to reclaim the revenue over the next several years. Our argument can be validated by Fig. 2, which depicts the net present value as a function of the user's monthly subscription fee. In Fig. 2, three countries are considered: Saudi Arabia, Angola, and Tanzania. To obtain this figure, each country's geographical information and the number of unconnected users are firstly obtained from Internet World Stats Group (Accessed: 04.20.2021). Then the number of balloons needed and the corresponding CAPEX can be calculated. Two assumptions are adopted here: 1) the OPEX mainly involves helium refill plus a surcharge; 2) a balloon can operate typically five years and needs maintenance for every 100 days. Based on these two assumptions, the net present value is obtained by subtracting the CAPEX and OPEX from the income by charging a monthly subscription fee for each user.

We can observe from Fig. 2 that the net present value increases consistently with the increase of the subscription fee. A major consideration for this project is whether to charge the public for access and if so, how much it shall be charged. To get a positive revenue, the monthly subscription fee of each user is supposed to be higher than or equal to $7.5, $5.1, $2.5, for Saudi Arabia, Angola, and Tanzania, respectively. The subscription fee for Saudi Arabia looks normal as the gross domestic product (GDP) per capita is relatively high, and most users can afford it. However, for users in Angola and Tanzania, such prices might not be affordable without proper incentives or third-party supports.

Emphasizing an idealist bent and the humanitarian potential of bringing the connection to the farthest reaches of the developing world, Project Loon was criticized by Bill Gates about whether the poor population living without sufficient basic needs, e.g., medicine and food, would require social networking and streaming videos. Some other concerns were raised that the particular radio frequencies (RF) emitted and received by the balloons in question could have detrimental effects on human, animal, and plant health, especially for the targeting area of Project Loon, where neither economy nor legislation is supportable for regular health examinations.

3.3 Technological Factors

Connectivity between aerial and terrestrial nodes is dominated by the line-of-sight (LoS) transmission link. Such a requirement brings new technological challenges. Generally, the probability that a LoS link exists for an aerial communication network is estimated based on the commonly used models which are built and refined through data-driven learning strategies or Monte Carlo methods Al-Hourani et al. (2014). On the other hand, collecting these channel related data is a nontrivial task in rural areas due to the lacking of telecommunication infrastructure. Also, the terrain and other geographical conditions in rural areas are diverse and relatively volatile compared to those in urban areas. Even with sufficient data, researchers and engineers must ponder the options of propagation models to process these data. These uncertain factors make the channel estimation and modeling even harder and complicate the aerial network planning.

Notwithstanding the technological challenges with channel modeling and network planning, the deployment of aerial nodes is also faced with meteorologic and aerodynamic difficulties. With the coverage over an area of 40 km in diameter, the balloons are designed to provide Internet penetration dynamically and seamlessly by taking the advantage of the wind currents to change the moving direction. In this regard, precisely weather prediction and self-adaptive trajectory design are indispensable. Authors in Bellemare et al. (2020) provide the solution of autonomous navigation for stratospheric balloons using reinforcement learning. However, the solution only focuses on one-agent optimization whose ability is too limited to provide large coverage of network for rural areas. Multi-agent reinforcement learning and game theory are expected to be implemented for the analysis of the balloons' cooperation but are still lacking. Even though equipped with appropriate algorithms, partial-observation, sparse-rewards, and agent-level communication stability are still remaining problems and need more efforts from academia and industry to solve.

3.4 Environmental Factors

Loon balloons are made of polyethylene, which is one of the most common plastics. A polyethylene sheet showed only partial degradation and negligible weight loss when kept in moist environments for 12–32 years Otake et al. (1995). Although promised that Project Loon employed a fairly sophisticated mission control system and the locations of all balloons were known by GPS in real time, balloon wreckage was occasionally found off the shores of New Zealand in 2013, and some of the balloons launched from Tekapo in the South Island were even lost over the sea. These occasional accidents cause environmental pollution and deteriorate the global marine ecosystem. Therefore, strict review of the impacts of deploying aerial communication nodes on the natural environment is inevitable and can become a distraction.

Power shortage would be another environmental factor resulting in Project Loon's commercial undesirability. Each Loon balloon sports four photo-voltaic panels, which provide electricity to power the on-board computers, navigation system, and communications hardware. Without a reliable power supply, energy outage is nevertheless a threat under extreme weather conditions. To reduce energy consumption, the Loon balloon uses very low-power electronics. Each of the three identical on-board computers runs on one-tenth of the power of a regular laptop, which indicates a much lower computational capability compared with standard laptops. In this manner, the algorithms requiring high-performance computing, e.g., on-line/on-policy algorithms, are not feasible for being used at the balloons, which poses a constraint on its commercial application.

In terms of consumables, each balloon devours a dozen of bottles of 5.55-cubic-meter compressed helium. As Project Loon's ambition was to launch thousands of balloons to provide global coverage around the whole world, there would not be enough helium resources to sustain such an ambitious goal. This forms another environmental obstacle for implementing Project Loon.

3.5 Legal Factors

According to the United States Code, balloons have the right-of-way if there is an encounter with any other aircraft. Unmanned aerial vehicles (UAVs), in contrast, are regulated strictly by the Federal Aviation Administration (FAA), which obliges all civilian use of UAVs subject to government exceptions. Whether the Project Loon can be cataloged as balloons is still controversial. Unmanned free balloons are usually defined as “lighter-than-air aircraft" using buoyancy instead of an engine. Regarding Google's claims about the navigability and the remote control of Loon balloons, the Loon balloons could be classified into the categories of drones or UAVs. In fact, the laws are dramatically unprepared for the vague demarcated balloons with unprecedented proprietary technologies, such as data collection, GPS augmentation, intelligence gathering, and persistent surveillance. Furthermore, the deployment of flying nodes in the stratosphere could be out of the four classes of controlled airspace in the United States. As a consequence, the right of jurisdiction with respect to Loon balloons still remains unclear, which could lead to legal risks and thereby dampen investors' confidence in Project Loon.

Not only existing at the national level but legal risks can also be raised internationally. In fact, the International Telecommunications Union (ITU) gives the discretion to the sovereign nations for legitimizing stratospheric wireless communications. As mobile nodes, aerial communication apparatuses and stations deployed closed to borders can trigger legal and diplomatic disputes or even military conflicts among countries without bilateral or multilateral treaties. Also, because of the large coverage provided by aerial BSs, it is rather difficult to strictly prohibit data services from coming across borders, which further brings about lawsuits among the telecommunication operators in neighboring countries.

4 LESSONS FOR 6G RESEARCH ROADMAP DESIGN

Although failed, Project Loon has pointed out the correct progressing directions for connecting the unconnected population and provided novel and constructive insights for all stakeholders involved in the eco-system of stratospheric communications. The closed loop from a theoretical conception to a commercialized product has been completed by Project Loon and accumulated extensive experience for researchers. To avoid a similar commercial failure for another future attempt, we summarize a series of key lessons based on the results from the PESTEL analysis for the 6G research roadmap design. These learned lessons are also of great importance for realizing global connectivity in the 2030s. Details are given as follows.

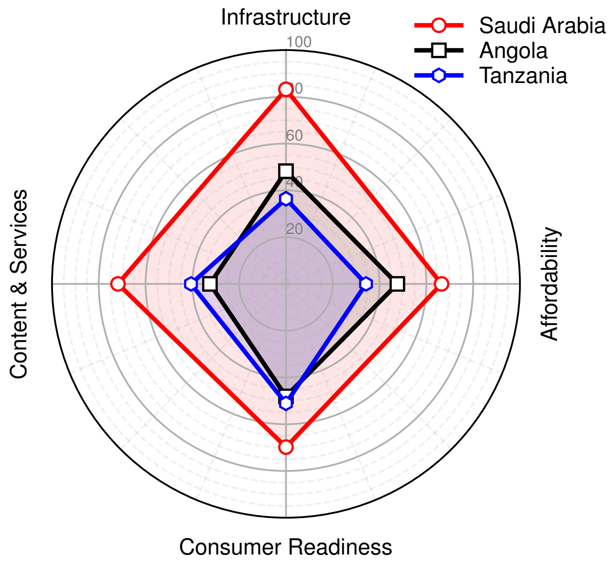

Figure 3. ICT statistics over the three considered countries: Saudi Arabia, Angola, and Tanzania.

4.1 Technology Cannot Stand Alone without Considering Non-Technological Factors

Advanced aerial communication technologies provide a premise for the future 6G communications with the requirements of reliability, global availability, and responsiveness after disasters. It naturally triggers the insight that the failure of the high-tech project is due to technological reasons. However, the non-technological factors, such as poor project management, lack of executive support, and low user involvement, indeed influence the commercial failure of the project and therefore cannot be neglected.

Wide discussions of the technological and non-technological factors including the legacy of past practices and accidents can assist academia and the industry with the development, implementation, maintenance, and continuous improvement of stratospheric communication systems. Besides technical reports, risk analysis and aversion by implementing strategic frameworks, such as PESTEL, are necessary. Additionally, different analytical tools should be adapted corresponding to specific scenarios. The classical return on investment (ROI) strategy, for example, is not viable for analyzing communication networks in rural areas since the users living in low-income areas tend to pay less for Internet connection compared to the high-income users in urban areas. Therefore, the diminishing ROI of aerial communication networks is not attractive to the private operators in rural areas where the connection of the unconnected population is the most urgent. In fact, the Internet is a primary need that could be provided by the government or the community rather than private operators.

4.2 Demand is the Key of Success

Project Loon was supposed to provide much broader network coverage to rural or low-income areas. Nevertheless, providing network access does not mean there will be network users or the users are willing to spend their limited income on accessing the network. In rural areas, particularly those of low-income countries, such as Tanzania, ICT facilities are scarce. These places do not even have electricity, let alone mobile phones. Even if Project Loon can provide network coverage, whether or not the locals need Internet access remains a question.

Fig. 3 shows the ICT statistics over three considered countries: Saudi Arabia, Angola, and Tanzania GSMA (2021.03.26). Four indicators are included in this figure, and all of them are scaled into [0, 100] for comparison purposes. The infrastructure indicator examines the quality and breadth of available infrastructure required for access and the levels of Internet usage, such as BSs, power supply, and backbone networks. The affordability indicator examines the cost of access relative to income and the level of competition in the Internet marketplace. The consumer readiness indicator examines the capacity to access the Internet, including ICT skills, cultural acceptance, and supporting policies. The content and services indicator examines the existence, availability, and extent of the content of local languages. From Fig. 3 we can see that the four indicators differ a lot among different countries and seem positively related to each country's economic development. Compared to Saudi Arabia, Angola and Tanzania have fewer infrastructure resources, lower affordability, and their people are unwilling to pay for network access and are not strongly demanding the Internet. To ensure the commercial success of future cognate projects, on-demand and personalized network deployments are suggested.

4.3 Mismatch between Academia and Industry Needs to be Bridged

The mismatch between academia and industry generally exists since both of them operate following their own rules. The academics judge a piece of work in terms of advanced technologies, rigorous theoretical derivation, and the number of punishments. On the other hand, R&D researchers and engineers in the industry are arbitrated by the stock market and the ability to maximize commercial profits. Encouraged by their own feedback and speaking their own language, academia and industry are mismatching each other with the great gap that is urgently querying bridged for long-term symbiosis.

Cooperation and communication between academia and industry are essential. The emerging open source development tools significantly facilitate the sharing of information, datasets, and even the developing progress. Obviously, Project Loon did not take the advantage of incorporating and sharing the intellectual properties with others. Rather than providing more legislative illustration, the proposed balloon communication system tried to escape the aforementioned scrutiny, inducing serious legal, diplomatic, and government tensions, which Google might not pay sufficient attention to deal with. The project is so secretive that many employees do not even know the lab's existence at the beginning. For commercial reasons, Google locked the experiments away from the research institutions, other industries, and the international community. This results in a big gap between the announced information and Project Loon's ultimate vision.

Last but not the least, the 6G network standards are appropriated to be derived together by academia and industry. Generally, academia presents results at technical conferences, while industry comes up with ideas at the standards meetings. As a result, there are fundamental communication and information sharing issues. The 6G network standards and the entire standardization process should be more accessible to researchers from both academia and industry.

4.4 Relevant Research Activities Should be Adjusted rather than Being Suppressed

Doubts and suppression of the relevant research activities of stratospheric communications are raised associated with the commercial failure of Project Loon. Without a rigorous investigation and analysis, the commercial failure of a project cannot convict the failure of technology and lead to the termination of relevant research activities. First, the extensive mathematical tools developed by the research activities help the technological incubation and guides the future launching directions. From the current analysis of the commercial failure of Project Loon as detailed above, non-technological factors play dominant roles, and therefore, the relevant research activities regarding the technological aspects should not be suppressed. However, adjustments to research strategies are imperative and should be taken into considerations by researchers when carrying out relevant research activities. First, the direct products from research activities, as tools implemented in industry, should be prospectively straightforward and user-friendly. That is, the theoretical design guidelines are not expected to be provided along with the obscure derivation but can assist the development of complex systems in practice. Second, theoretical research is supposed to involve more practical constraints and specific application scenarios. It is normally seen nowadays that to achieve generic and elegant performance, researchers do not pursue exact expressions but approximate bounds and asymptotic expressions under extreme conditions.

In the meantime, the failure of Project Loon validates the dilemmas in providing ubiquitous and pervasive communication networks. Due to the lack of terrestrial access network coverage and the economic deprivation, the challenges of connecting the unconnected population in rural areas, such as the last mile infrastructure and low affordability, indeed exist and should not be taken into consideration when carrying out research related to network integration. Consequently, instead of being suppressed, more efforts are required to reinforce the relevant research to understand and address the existing problems in rural communication networks. More importantly, with the technological advances by research, it is highly expected that the costs of stratospheric communications would be reduced and become much more affordable in the near future, which will remove the biggest obstacle to the implementation of stratospheric communications.

5 CONCLUSION

Based on the analysis and lessons summarized above, not only to those working on stratospheric communications, we would like to convey the following messages to all researchers in communication sciences:

- The determinants of the success of any communication technology are complex, which encompass both technological and non-technological factors; as no technology can be implemented without considering non-technological factors, these non-technological factors should also be integrated into the technological research in certain ways. Value engineering and the PESTEL analytic framework would be powerful tools to close the gap between technological and non-technological research.
- The commercial failure of Project Loon indicates that there indeed exists a mismatch between academia and industry. Therefore, to bridge such a mismatch, the 6G research roadmap design should be tailored to focus on more practical issues for implementing communication technologies, rather than purely mathematical derivation and optimization. More emphasis should also be placed on the justification of application scenarios of studied communication technologies. System-level prototyping and testing are going to become common and even imperative in 6G academic research, instead of being optional and supplementary to computer-based simulations.
- The technological research activities for achieving practically feasible stratospheric communications in the 6G era should be adjusted but not be suppressed just because of the demise of Project Loon. The commercial failure of Project Loon was resulted by various factors, which does not imply that such a technological conception *per se* is hyped, rather, remains researchers of the imperfection and insufficiency of the current research activities pertaining to stratospheric communications.

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