# Space Race 2.0

## Expanding Global Internet Accessibility

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***Abstract*—In this paper, we examine cyber electromagnetic activities and avenues for expanding Internet accessibility. Delivering fast and reliable Internet access to people, whose physical isolation precludes connectivity by wires and other traditional means, is challenging. In response, key industry players are racing to take on this challenge both with serious financial backing as well as their own methodologies for creating a more accessible global Internet. However, each approach must overcome its own set of technological hurdles. By way of example, satellites can deliver Internet access to sparsely populated areas, but the cost of using satellite data connections can be very high. Drones, in comparison, can reach those customers at a much lower cost. Yet, both platforms rely on the Ku-band, which is essentially saturated during the day and thereby subject to low throughput and long delays. Even if satellites and drones utilize another part of the electromagnetic spectrum, such as Ka-band, rain fade remains a persistent problem. High-altitude planes that fly above commercial airlines and the weather can utilize lasers, which are at the cutting edge of connectivity research for their incredible accuracy and high throughput; however, laser beams get scattered by clouds. Finally, the challenges of keeping a network of balloons — that are traveling on the edge of space — on course and without leaking are plentiful. The main technological challenge to the underpinning mesh network backbone is the frequency of power outages that disrupt the network. In any case, the next generation Generativity Principle holds promise not only for optimizing the flow of data throughout the Internet, but also for maximizing the primary infrastructure of Internet access.**

***Keywords-Big Data, brittleness, generativity principle, net neutrality, Internet accessibility***

## I. INTRODUCTION

With the number of networked devices surpassing the number of humans on the planet in 2008 [1], the Internet of Things (IoT) has become a ubiquitous aspect of daily life for one third of the world's population, the majority of whom live in developed countries [2]. The creation of the Internet was driven by a need to share resources, and today there is a challenge to share the Internet itself as a resource. In bringing the Internet to the remaining two thirds of the global citizenry, there is a balance to be struck between reach and resilience. On the one hand, the Internet is a valuable tool [3] for supporting the universal human right of accessing information [4], and maximizing its reach is clearly beneficial. On the other hand, the Internet must operate reliably in order to be of value, and efforts to expand its reach quickly should not come at the expense of the system's resilience. As collective reliance on Internet connectivity increases and a variety of actors endeavor to expand global Internet accessibility, the underlying communications infrastructure remains **brittle** in key areas. This brittleness is a potential **blind spot** compromising the **resilience** of essential functions such as international commerce, national defense, and disaster preparedness, which have become highly dependent on the Internet. In the effort to increase Internet accessibility, infrastructural resilience must remain a primary consideration. In this regard, much discourse has centered around smart cities [5]. Although urban centers are home to 80% of the global population and appropriately are a major focus of infrastructure improvement and protection [6], the importance of internet connectivity for rural and physically isolated areas cannot be overlooked. Indeed, for archipelagoes like Hawaii maintaining connectivity is a very real challenge, as broadband capacity is projected to run out by as early as 2017.

Therefore, we explore what options are available for expanding broadband Internet capacity for isolated populations such as those in Hawaii. We survey the current variety of endeavors being undertaken to expand access, and identify challenges related to each approach. In Section II, we begin with an overview of terrestrial and fixed broadband, including direct subscriber lines, fiber-optic cable, and mobile broadband. In Section III, we explore the capabilities and limitations of satellite broadband. In Section IV, we identify additional methods of broadband delivery being pursued by various actors, including the use of unmanned aircraft systems (UAS), high altitude platform (HAP), and balloons. In Section V, we evaluate efforts to expand internet accessibility in the context of the generativity principle and net neutrality debate, and we conclude in Section VI.

## II. A BRIEF HISTORY OF THE INTERNET AND TERRESTRIAL CONNECTIVITY

Since the inception of the four-node Advanced Research Projects Agency Network (ARPANET) was connected by terrestrial hard line with 50 kbps of bandwidth in 1969 [7], the Internet has grown into a vast web of diverse connections spanning land, air, sea, and space with over 160,000 gbps of bandwidth powering over 185 million active websites [2]. Just as ARPANET's architects envisioned a network of only a few hundred national-level resources, and had to adapt

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their operating principles to address the unforeseen growth in traffic precipitated by local area networks, today myriad stakeholders are contemplating how the Internet can be expanded to reach every individual on the planet. Although the foundational building blocks of packet switching and the attendant protocol suite (e.g., transmission control protocol (TCP), internet protocol (IP), and user datagram protocol (UDP)) remain in place and much work has been done to unite what were once fragmentary networks [8], the modern Internet is so large and complex that obtaining a clear picture of how data are flowing through it is no longer feasible [9]. Whereas it is difficult to analyze what is happening inside the Internet at any given moment, certain facts about its accessibility are clear. The Internet has fundamentally changed the nature of human communication by providing a platform for truly novel developments such as the World Wide Web, yet over four billion people in the world are living without Internet access [10]. As stylized in Figure 1, below, how to bring it to them is a key question.

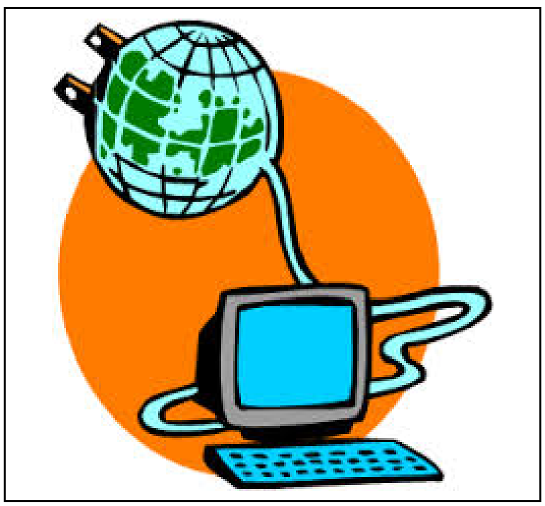

Figure 1. Artistic Rendering of Global Internet Connectivity

The first potential course of action is continued expansion of the land and subsea-based fixed connections upon which the Internet was originally built. However, as the International Telecommunications Union (ITU) notes in its most recent report [2], the growth of fixed broadband in the form of asynchronous direct subscriber line (ADSL) and fiber-optic cable is leveling off at over 700 million subscriptions, or roughly ten percent of global penetration in favor of mobile broadband, with 85% of the fixed network's 11 million km of underwater lines in the Asia Pacific region. While the worldwide average price for fixed broadband subscriptions has dropped 70% in the past eight years [2], a digital divide has persisted in that developed countries with the highest connection speeds enjoy the lowest cost subscriptions, while consumers in developing countries with less robust backbone infrastructure must pay more for slower connection speeds. By way of example, in Serbia consumers pay the highest broadband subscription rates in Europe at 3.8% of Gross National Income per capita (GNI pc) for 5 mbps of bandwidth, while in many African countries the cost of an entry-level fixed broadband subscription with speeds of 1 mbps or less can cost more than 100% of the GNI pc due to low income generation and a limited number of cables linking the continent to the international Internet [2]. Conventional fixed Internet access through fiber-to-the-premises, cable modem, and direct subscriber lines represents a large investment on the part of industry as it is expensive to lay and maintain, which translates to high subscription rates for consumers.

Such high expense is particularly cost-prohibitive for physically isolated communities who are located far from central infrastructural hubs and unable to attract investment. Submarine cable systems that provide the crucial intercontinental connections linking the global Internet are dominated largely by only three groups; Alcatel-Lucent, TE SubCom, and NEC. With such limited competition, there is little incentive to improve upon the cost or durability of undersea cable networks, as the cost of constructing new systems has remained relatively fixed at approximately $35 thousand per kilometer and designed for a 25-year lifespan, with the first cables laid in 1988 nearing the end of their service life [11]. Part of this low competition and high cost is due to the inconsistent growth of the industry, which saw a brief period of over-investment during the dotcom boom, particularly in 2001, which led to a largely dormant cable industry until recent years. Undersea cables connect all but 15 countries, providing 87 tbps in global transoceanic bandwidth. However, in light of the huge capital required for their development, cable routes cater to the world's financial hubs, as depicted below in Figure 2. At the same time, fixed Internet routed through submarine cable is not without its vulnerabilities. Indeed, shark attacks, anchor snares, fishing accidents, and other unintentional anthropogenically-induced damage accounts for as many as 150 outages per year [12]. For physically isolated locations that are unable to attract investment in the form of cable landing sites, an alternative to fixed broadband is required, which takes us back to the Internet's early days.

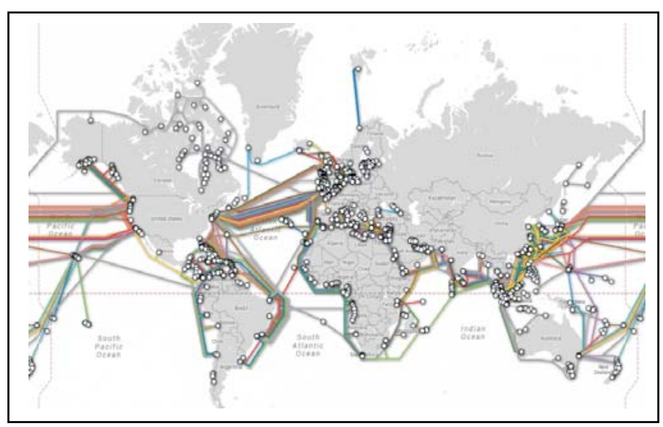

Figure 2. TeleGeography Global Submarine Cable Map

Research on wireless packet switching networks emerged simultaneously with the development of ARPANET, and since then wireless complements to the fixed Internet have continued to evolve. The ALOHANET was the first instantiation of wireless computer communication, whereby University of Hawaii computing resources dispersed over the islands exchanged data through radio channels with each other and eventually ARPANET [13][1].This concept was adapted to achieve a lightweight and mobile packet switching capability for military applications through the Packet Radio Network (PRNET) in the 1970s [14]. Advances in wireless communications capability continued through the 1980s and 90s with cellular technology, and in 2010, the number of mobile broadband subscriptions surpassed that of fixed broadband subscriptions [15].

However, broadband Internet delivered through universal mobile telecommunications systems is constrained in several fundamental ways. First, mobile broadband access consumes significantly more power per user than fixed connections [16]. Second, mobile broadband connections are more inconsistent than fixed connections and subject to increased disruptions in service [17]. Just as fixed broadband relies on the abundance of backbone infrastructure, mobile connections rely on the strength of cellular signals and the proximity of towers. Finally, and perhaps most significantly, mobile broadband networks suffer from comparatively limited bandwidth capacity due to finite spectrum availability [18], which necessitates data offloading to fixed network connections through various means, including wireless fidelity (WiFi), femtocells, and IP flow mobility [19]. In fact, in 2014 26.4 exabytes of data representing 46% of total mobile broadband traffic was offloaded to fixed connections [20], demonstrating that mobile broadband is a complementary extension of the wired Internet, not a stand-alone replacement for it. Similarly, the Worldwide Interoperability for Microwave Access (WiMAX) Forum is helping to provide broadband without the need for each user to have a fixed connection, but the networks still require a large infrastructure of base stations that would be cost-prohibitive in isolated communities [21]. Therefore, we find that without significant infrastructural investment, neither fixed nor mobile broadband are viable options for connecting isolated populations.

## III. INTERNET IN SPACE: SATELLITES

Although science fiction writer and futurist Arthur C. Clarke's first speculation about the potential for achieving a global broadcast capability through extraterrestrial relays seemed far-fetched to skeptical audiences in 1945, his vision has proved to be truly prophetic [22]. Indeed, the use of satellites for Internet connectivity is nearly as old as the Internet itself, however there are significant technical challenges associated with bringing the Internet to space. Geostationary orbiting (GSO) satellites have been used for some time to provide backbone connections for regional networks, with the Atlantic SATNET being an early example of implementing satellite communication for Internet protocols, as it provided a 64 kbps connection between the ARPANET and research networks in Europe from the late 1970s into the mid 1980s [23]. However, GSO satellites suffer from two major drawbacks; their enormous cost, and the latency of their communications. GSO satellites are located 35, 786 km from the Earth's surface, which can enable a single satellite to have broadcast coverage over a third of the planet's surface, yet also takes a signal approximately 280 milliseconds to travel each way, which amounts to over half a second in latency for roundtrips [24]. In contrast, low Earth orbiting (LEO) satellites located up to 3,000 km from the Earth's surface can overcome this latency problem, but given the proximity to the surface, their coverage area is severely limited, and therefore a network of satellites is required to relay signals. However, as depicted in Figure 3, below, early satellite Internet communications relied on a bent pipe configuration, whereby Earth uplinks were concatenated to Earth downlinks, and the satellites served as little more than signal relay points incapable of signal processing or dynamic routing [25]. Due to these limitations, early instantiations of the satellite-provided Internet were characterized by relatively high cost and low quality [26].

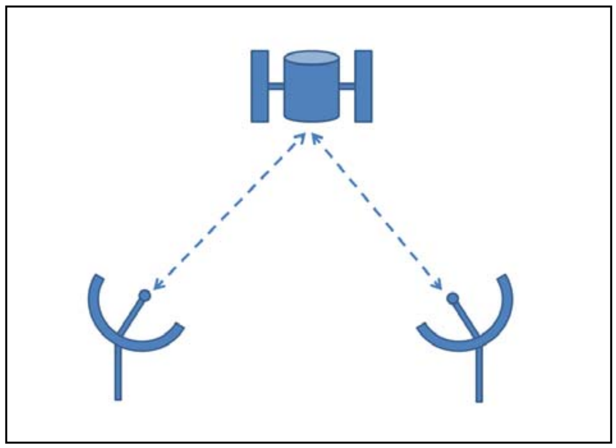

Figure 3. Bent Pipe Satellite Communications Architecture

With the explosive growth of internet users in the 1990s, demand for bandwidth appeared to be outpacing terrestrial network providers' ability to lay new wire and cable, and in response, companies endeavored to leverage satellites as an augmentation to the wired Internet. Hughes Network Systems' DirectPC Satellite System developed in 1996 enabled users to request data by phone line and modem, and download the results through 400 kbps direct link with Hughes' Galaxy GSO leveraging digital video broadcast by satellite (DVB-S) and very small aperture terminals (VSAT) [27]. Hughes expanded its services by incorporating medium Earth orbit (MEO) satellites in its Spaceway system in 2002, but was not alone in delivering broadband internet through GSO and MEO satellites on the DVB-S platform, as Cyberstar, ISky, Lockheed Martin's Astrolink, the European satellite conglomerate SES's Astra, Eutelsat's Hot Bird, Inmarsat, and Matra Marconi Space's Wideband European Satellite Telecommunications (WEST) represented some of the competition. GSO satellites using DVB-S platforms in

[1] Incidentally, this packet broadcasting technique also gave rise to Ethernet technology for local area networking.

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the Ku Band have been very effective for broadcast and non-time sensitive communication, but simply cannot facilitate the kind of broadband switched services required for the peer-to-peer networking applications that individuals and business have come to rely upon. Nevertheless, for rural and other physically isolated communities, satellite broadband is the only option. Hence, regionally-focused GSO providers such as Eutelsat's Tooway in Europe, IPSTAR in the Asia-Pacific, and North American providers Hughes, Telesat Canada, and ViaSat have all optimized their capabilities by migrating to the Ka Band and are able to deliver service with as little as a single satellite. Many of these networks having undergone recent upgrades boosting bandwidth to as high as 130 gbps, and GSO satellites will certainly remain significant components in the Internet ecosystem [28].

In the late 1990s and early 2000s, there was considerably less competition in delivering internet communication through satellites in low Earth orbit, in light of the many technological challenges associated with ensuring continuity of connections, quality of service (QoS), and achieving operational intersatellite links. However, there was great enthusiasm in the telecommunications community for leveraging LEO satellites, with the development of the Iridium and Globalstar communication systems representing over $8 billion in investment and 1000 new patents at the close of the 20th century [29].

The two early experiments in global broadband LEO networks, Teledesic and Skybridge each approached the myriad technical challenges from different angles. Teledesic, a $9Billion joint venture between Microsoft's Bill Gates, cellular technology magnate Craig McCaw, Boeing, and Motorola aimed to provide an affordable worldwide core and access broadband network with a constellation of 288[2] LEO satellites operating in the Ka Band with an equivalency to optical fiber networks. Their only competitor, Skybridge was a venture between the world's leading submarine cable manufacturer Alcatel, Loral, and Qualcomm, which utilized an 80 satellite constellation to provide a broadband access network, operating in the Ku Band frequency at a cost of $4.2Billion, and relying largely on terrestrial gateway networks for switching and routing procedures [30]. For both systems, the estimation of available resources and the dynamic allocation of resources, or bandwidth was a key technical challenge to be overcome, as the systems aimed to accommodate traffic from as many as 20 million simultaneous users [31]. However, just as Iridium and Globalstar were unable to develop a sufficient customer base amidst a burgeoning terrestrial cellular market and were forced into bankruptcy and restructuring, Teledesic and Skybridge were unable to realize a cost-effective LEO alternative to expanding ADSL and cable networks, and both folded before the systems were put in place [32].

Although the unfulfilled promise of global satellite broadband networks such as Teledesic and Skybridge stymied further investment in non-GSO platforms during the early 21st century, continued research and advances in technology have illuminated alternate pathways for extraterrestrial networking while leaving the door open for LEO platforms. With an increased focus on deep space travel, delay-tolerant networks (DTN) and bundling protocols were developed to mitigate the latency issues of disparate networks such as GSO satellites, with the ultimate intent of achieving a future interplanetary internet [33]. Historically, the U.S. National Aeronautics and Space Administration (NASA) developed unique communications systems for each of its missions, a tendency which became clearly untenable as NASA's systems were incompatible with the many emerging international, military, and commercial satellite capabilities [34]. As a result, the Consultative Committee for Space Data Systems was formed to promote shared infrastructure and develop universal Space Communications Protocol Standards (SCPS) based on Internet protocols and modified for the unique operating conditions of outer space [35]. International collaboration on the development and refinement of the SCPS has helped to facilitate rapid advances in technology that have significantly improved satellite capability. In particular, the development of onboard processing (OBP), switching (OBS), and routing (OBR), performance enhancing proxies (PEP) boosting the TCP slow start algorithm, and the integration of asynchronous transfer mode (ATM) protocols have led to improved intersatellite links, signal regeneration, error correction, and dynamic data routing [24]. Such advancements have led to renewed interest in LEO constellations for Internet connectivity, as depicted below in Figure 4.

Figure 4. Stylized Depiction of Global LEO Constellations

In light of this recent progress, a new set of actors is taking the stage to deliver global broadband Internet through satellites. First is O3B (The Other 3 Billion) Networks, which began emplacing its initial constellation of eight MEO satellites in 2010 and became commercially operational at the end of 2014. It will ultimately scale up to a network of 16 satellites, each of which deliver 10 spot beams in the Ka Band, building on the design and operating principles developed for Teledesic and Skybridge and capable of delivering a total capacity of over 160 gbps of bandwidth [36]. Orbiting at 8,000 km above the Earth, signals from O3B's satellites have a roundtrip time of 150 milliseconds, still considerably less than that of GSO counterparts. With

[2] Teledesic's system designers originally envisioned a constellation of 840 satellites, which was reduced to 288 as designs progressed, and finally down to 30 satellites before the project was cancelled.

significant financial support from investors such as the Virgin Group and Qualcomm, O3B's creators are in the process of launching OneWeb, a 648-LEO satellite constellation with aspirations that are reminiscent of Teledesic's vision to construct a satellite constellation to match the fixed Internet in terms of coverage, capacity, and reliability by 2019 [37]. While OneWeb is in the early stages of development, a critical step forward has been its ability to secure Ku Band wireless spectrum rights from the ITU [38], through which the network will interface with mobile broadband network operators and individuals with OneWeb receivers. Yet, constructing a satellite constellation is resource-intensive as a single launch costs $300 million, let alone the cost of building hundreds of satellites. Despite the resource-intensive prospect, Space Exploration Technologies (SpaceX) also recently announced plans to field an LEO satellite constellation to provide global broadband Internet access [39]. With over $1 Billion raised thus far from investors such as Google, Fidelity Investments, and Founders Fund, SpaceX plans to construct a network of roughly 4,000 satellites beginning in the next 5 years [40].

Whereas these recent developments in expanding Internet accessibility through large scale satellite networks are certainly promising, the success of such endeavors is challenged by significant technical obstacles. For systems such as OneWeb, the saturation of the Ku Band and need to develop viable spectrum sharing mechanisms among various satellite networks remains an open area of investigation [41]. In addition, although the vulnerability of both the Ku and Ka Bands to signal attenuation in moist atmospheric conditions has been well known for some time [42], effective rain fade countermeasures have yet to be developed. The details of SpaceX's LEO network design remain unclear, but one immediately apparent concern is that of how a constellation of 4,000 assets can operate sustainably and reliably in an environment characterized by significant amounts of residual orbiting debris [43], as little as 1 cm's worth of which is capable of inflicting significant damage to small assets. At the same time, the affordability and quick turn-around time in production make micro-satellites an attractive option for populating fleets of orbiting devices that number near the thousands [44].

## IV. Outside of the box: Alternate methods for expanding internet accessibility

Just as the open and collaborative spirit of the Internet Engineering Task Force has led to the achievement of a global information infrastructure through the request for comments (RFC) process and the dynamic exchange of ideas [45], the effort to expand Internet accessibility can benefit from collaboration between actors. However, the potential benefits of collaboration and rough consensus have to be balanced against the economic imperative of profit making for the investors involved. In that vein, it should come as no great surprise that some of the most innovative research with regard to increasing global Internet access are being pursued separately in parallel by two of the most influential and revenue-generating forces on the World Wide Web; the search engine Google and the social networking application Facebook.

In addition to its investment in a future satellite network, Google has pursued several equally ambitious avenues for improving and expanding Internet accessibility. First, it is constructing its own fiber-optic cable network in the United States, delivering broadband service speeds that drastically outperform existing Internet Service Providers (ISP) [46]. Second, it has conducted pilot programs to deliver 4G LTE wireless broadband access to remote areas via high-altitude superpressure envelope balloons equipped with a payload of solar panels, a battery, flight computer, altitude control system, radio, and antennae. Dubbed Project Loon, the mesh network of balloons receive and relay mobile broadband signals from telecommunications operators' cell towers and down to anyone in range with a 4G-capable device while cruising at an altitude of just over 20,000km, staying aloft for up to 100 days in the stratosphere, where temperatures can be as low as -117º Fahrenheit (-83º Celsius) [47]. Although Google has collaborated with manufacturers to produce special-purpose lithium-ion batteries for the balloons' electronic systems, such cold temperatures remain a particular challenge for sustaining power, in addition to keeping the balloons aloft for longer durations [48]. Project Loon builds on earlier concepts such as the Israeli ConSolar/Rotostar system and Sky Station stratospheric telecommunications platform, developed privately by former U.S. Secretary of State Alexander Haig in cooperation with NASA's Jet Propulsion Laboratory in the late 1990s [49]. Whereas Sky Station was unable to get off the ground, Project Loon has completed a pilot experiment with 30 balloons communicating to specialized ground antennae (pictured below in Figure 5) in 2013 over New Zealand's South Island and more recently in Brazil and Nevada [50]. Although Google is continuing to expand the project, aiming to have 100 balloons aloft by the end of 2015, a global network will have to overcome the aforementioned technical challenges as well as negotiate international over-flight rights and spectrum usage licenses in each country the system crosses over, political obstacles which ultimately proved insurmountable for Sky Station and similar platforms [51].

Figure 5. Project Loon Signal Receiver

While Google moves forward with its mesh balloon network, Facebook has announced a similar pursuit of expanded broadband access. In addition to GSO and LEO satellite options, it is exploring ways to leverage high-altitude solar powered unmanned aircraft systems (UAS) and free space optical (FSO) communication to deliver the Internet to isolated populations [52]. UAS such as Helios, Pathfinder, and Proteus have demonstrated the ability for aircraft to remain aloft for extended periods and to serve as viable high altitude platform stations (HAPS) for telecommunications, however signal attenuation and spectrum allocation have been among the greatest challenges to implementation [53]. The ITU has allocated a small section of the Ka Band for HAPS broadband services, however rain fade remains a persistent problem, particularly for systems deployed over isolated tropical areas that experience significant precipitation [54]. At the same time, FSO communication systems that utilize lasers as an alternative signal medium are attractive for their high bandwidth capacity, license-free usage, and immunity to electromagnetic interference, however they cannot effectively transmit through clouds and remain subject to atmospheric absorption, attenuation, and backscatter [55]. Although methods to mitigate atmospheric effects that include photon counting receivers and coherent reception techniques have been identified, for the moment they remain sufficiently resource-intensive so as to preclude widespread commercial application [56]. Indeed, HAPS such as Project Loon and those envisioned by Facebook hold great promise for increasing global Internet accessibility; however significant technical and political hurdles remain to be overcome.

## V. GENERATIVITY AND NET NEUTRALITY

As the Internet's vast communicative power lies in the generativity of its many diverse data pathways and content contributors, it is appropriate that a multitude of gateways exist for its accessibility. However, the openness of these gateways is an important consideration that impacts both the network's reach and resilience. In order to maximize the network's reach, barriers to entry such as identity verification are minimized. Meanwhile, to ensure the resilience of the network, access control and security protocols are needed to prevent malicious activity.

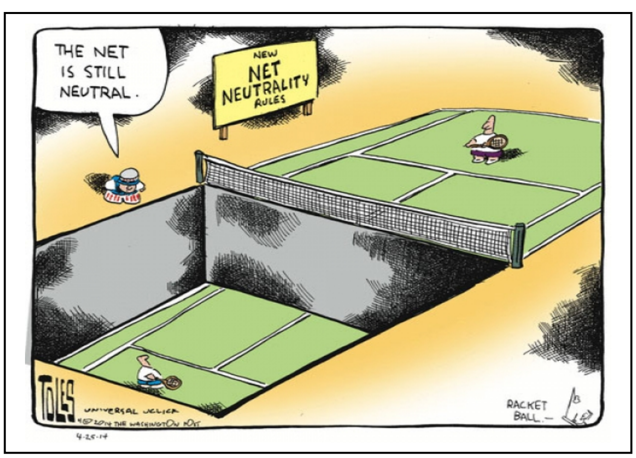


Figure 6. Satirical Commentary; Toles, The Washington Post

While any of the aforementioned methods can help increase connectivity in physically isolated areas, a separate question remains as to providing Internet access for underprivileged communities who simply cannot afford to pay. If access to information is truly a human right, then perhaps the economic principles governing the Internet's for-profit development warrant revision in light of its role in global information dissemination, and vehicles for delivering free Internet to the underprivileged bear increased consideration [57].

The business model of capitalizing on free labor in the form of user-generated content has allowed a small number of individuals to amass vast fortunes [58]. However, is there a fundamental conflict in the Internet being both a gold mine for industrious prospectors and the primary delivery mechanism for a basic human right? Whereas initiatives such as Facebook's Internet.org appear helpful for bringing the Internet to the world's underprivileged populations through negotiated access with certain regional ISPs, these efforts are facing stiff resistance for the role they play in privileging certain web sites and services [59]. Indeed, the prerogative to maintain net neutrality is in question if the aforementioned efforts to expand Internet accessibility only translate into expanding access to circumscribed pieces of the Internet. Amidst the debate over net neutrality, the Federal Communications Commission (FCC)'s Open Internet Order categorizes broadband as a Title II telecommunications service and is therefore subject to the terms of the 1934 Communications Act [60]. As a result, blocking, throttling, or paid prioritization of any content provider is illegal for the time being. However, efforts to circumvent the neutrality of the Internet ecosystem by providing free access to certain limited content undermines the technology's main function of facilitating end-to-end communication. Expanding Internet accessibility to the as-yet connected portion of the world's population will undermine the system's overall resilience if it comes at the cost of creating a two-tiered Internet for those who can afford to buy access to all information and others who can only afford free access to some information.

## VI. CONCLUSION

Although alternative means for expanding global Internet accessibility are in order, current endeavors to do so remain challenged by the same limitations that have hindered conventional Internet service delivery methods in the past. High infrastructural investment costs, signal attenuation, and efficient power generation are among the most notable obstacles to be overcome in making the Internet a truly global resource. Ambitious developments such as Project Loon, OneWeb, and Green Networking [61] all have the potential to enhance the resilience and reach of the Internet, provided they can surmount numerous remaining obstacles.

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