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The Internet in developing nations: Grand challenges

by Larry Press

Abstract

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This is a call for a "Grand Challenge" project for achieving truly global connectivity. For over a decade, we have hypothesized that the Internet could raise the quality of life in developing nations. We have conducted hundreds of studies of the state of the Internet and "e–readiness," done extensive training of technicians and policy makers, run pilot studies, and held local, regional and global conferences and workshops. After all of this activity, Internet connectivity is nearly non–existent in rural areas of developing nations, and far below that of developed nations in the urban areas of developing nations.

This is not to say the activity of the past decade has been a waste. We have demonstrated the value of the Internet and raised awareness. The United Nations and the administrations of nearly all nations have acknowledged the potential of the Internet. The way has been paved, and it is time to act on what we have learned.

After outlining the work of the last decade, we explore one possible Grand Challenge: Connecting every village in the rural developing world to the Internet using a strategy similar to that used in building the NSFNet. We speculate on wireless technologies that might play a role in working toward that goal: Terrestrial, high–altitude platform, and satellite. We conclude with a brief discussion of alternative Grand Challenges and a call for action.

The time is ripe for an audacious project. What could we achieve with US$15 billion and ten years time?

Contents

Paving the way

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to Earth." — John F. Kennedy, 1961
"That’s one small step for a man, one giant leap for mankind. — Neil Armstrong, 1969

The hypothesis that information and communication technology might raise the quality of life in developing nations pre–dates the Internet. Daniel Lerner gave us a memorable example of this in his study of the modernization of a Turkish village [1]. Lerner observed that between 1950 and 1954 the number of radios in the village grew from one to over 100, and many people moved from farming to cash–paying jobs. The people welcomed modernization, referring to a grocer who got the first radio in 1950 as a "prophet." Pioneering communication theorist Ithiel de Sola Pool pointed out that telecommunication infrastructure planning is implicit social planning.

What could we achieve with $15 billion and ten years time?

Before the spread of the Internet, the Association for Progressive Communications was using e–mail, listservers, and bulletin boards to serve NGOs in developing nations [2]. Bitnet started in 1981, and, at its peak in 1991–2, connected 1,400 research and educational organizations in 49 countries [3]. Fidonet was developed in 1984, and by 1992 it delivered news and mail to over 20,000 public nodes worldwide [4]. UUCP e–mail and news was under way by 1981 and eventually reached millions of users [5].

By September 1991, 79 political units had UUCP connectivity, 52 FidoNet, 47 BITNet, and 33 Internet. Ninety–two had some form of connectivity and 131 had none [6]. Developed nations typically had Internet connections as well as the others. Since that time, the Internet has spread rapidly, and displaced its precursors.

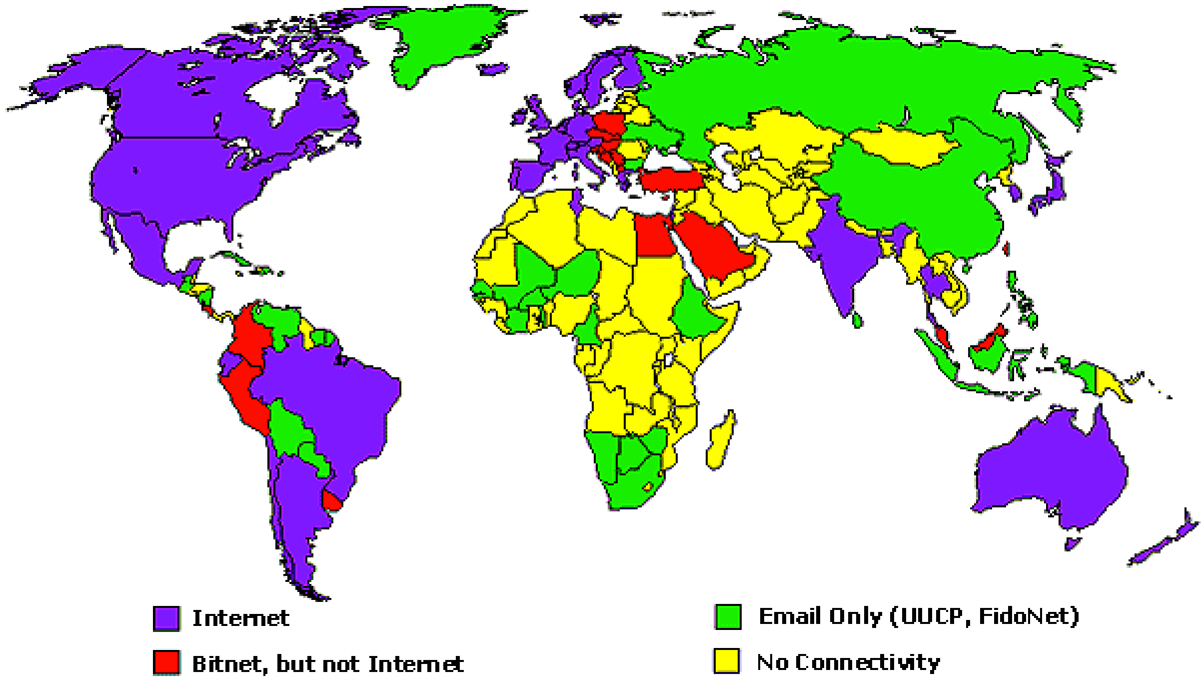

Figure 1: International Connectivity, September 1991.
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As the Internet spread, displacing the other networks, many people recognized potential applications in health, education, entertainment, business and politics in developing nations [8, 9, 10]. Recognition of that potential has led to a decade of effort aimed at bringing the Internet and its applications to developing nations. We have surveyed nations, held training workshops, done pilot projects, and held conferences.

Surveys of the state of the Internet in developing nations began in the mid–1990s [11]. By March 2001, Bridges.org found that e–readiness assessments were being done using ten different frameworks and tools [12]. One hundred and thirty seven countries had been assessed using at least one tool, fifty–five countries had been assessed at least five times and ten countries had been assessed at least eight times [13]. The E–readiness Facilitation Center is another source of methodology and results [14], and the World Economic Forum and the International Telecommunication Union (ITU) publish annual reports on Internet status [15].

As the Internet spread, displacing the other networks, many people recognized potential applications in health, education, entertainment, business and politics in developing nations.

The Internet Society (ISOC) held an important series of networking workshops to train technicians and policy makers from developing nations between 1993 and 2000 [16]. The workshops trained technicians, information providers and national network policy leaders in separate, weeklong tracks. During the week following the workshops, the participants would attend the ISOC International Conference. This afforded them the opportunity to meet and make connections with networking leaders from around the world. Graduates of these workshops seeded the Internet in many developing nations.

Organizations like the United Nations Development Programme (UNDP), the International Development Research Centre, and The World Bank have funded hundreds of pilot studies, small telecenters, ISPs, etc. Perhaps the first of these was the Sustainable Development Network Programme (SDNP), which the UNDP began in 1992 [17]. The SDNP sponsored projects in 44 countries and established a Small Island Developing States Network [18]. SDNP projects focused on both connectivity and content. They often established the first small ISP in a nation, trained technicians and users, built Web sites and portals, lobbied governments on the importance of the Internet, established public access points, etc. SDNP expected their projects to become economically self–sufficient after a subsidized startup period, and a recent independent evaluation of the program found that:

"a dozen to fifteen SDNP organizations are well established (though not to say secure) with significant capabilities in several dimensions ... A further group numbering approximately less than ten continues with a more limited range of activities and in a more uncertain environment ... A final group comprising about nine countries has evolved in directions related to, but different than SDNP" [19].

The SDNP was early, but not unique. For example, beginning in 1994, the Organization of American States, often in conjunction with the U.S. National Science Foundation, provided connectivity and technical and policy support to research and education networks in Latin America and the Caribbean [20], and the Soros Foundation began funding connectivity in Eastern Europe around the same time [21].

The UN, Internet Society, ITU and others have also held many conferences on networking in developing nations. There has been considerable consensus at these meetings: the Internet will improve the economy, education, health care, entertainment, news, etc. Privatization and competition among providers is Good. Unlicensed spectrum is Good. Intellectual property laws should be obeyed. Taxes and tariffs on IT are Bad. Government applications and support are necessary. All this is fine, but we have been saying it to each other at similar meetings for ten years.

The most recent such meeting was the ITU World Summit on the Information Society (WSIS). The WSIS meeting resulted in a Declaration of Principles [22]. The attendees declared:

"... common desire and commitment to build a people–centered, inclusive and development–oriented Information Society, where everyone can create, access, utilize and share information and knowledge, enabling individuals, communities and peoples to achieve their full potential in promoting their sustainable development and improving their quality of life, premised on the purposes and principles of the Charter of the United Nations and respecting fully and upholding the Universal Declaration of Human Rights."

That is laudable, but not novel. It is a consensus vision that has been articulated at previous global conferences.

The WSIS also published a Plan of Action with a list of goals [23]. For example, By 2015, every nation should connect their villages, universities, colleges, secondary schools and primary schools, scientific and research centers, public libraries, cultural centers, museums, post offices and archives. The Plan contains many other goals and dozens of steps nations should take to achieve them.

These are calls for action by individual nations; they are not *global.*

> Telecommunication and the Internet are now on the policy "radar screen" in every nation and multinational organization.

We have been speculating about the applications of the Internet in developing nations, doing country readiness studies, running pilot projects and attending conferences for over ten years now. I do not consider this work to have been done cynically or wastefully. The effort has been efficient and effective [24]. We have accumulated considerable evidence in support of the hypothesis that there are meaningful Internet applications in developing nations, and we have spread that word. We have built global consensus, as evidenced by the WSIS declaration. Telecommunication and the Internet are now on the policy "radar screen" in every nation and multinational organization.

We should act upon that consensus.

A grand challenge

At the July 2000 G8 Summit in Okinawa, leaders of the world's largest economies focused on information and communication technology (ICT). They expressed concern the digital divide might exacerbate existing inequalities between nations, but also held out hope that ICT could play a significant role in development. The heads of state formed the Digital Opportunity Task Force [25] (DOT Force) "to identify ways in which the digital revolution can benefit all the world's people, especially the poorest and most marginalized groups." Most notable, the Japanese government pledged a total of US$15 billion over five years in working toward that end.

The DOT Force is no more, and the $15 billion did not materialize [26], but the pledge gets one thinking — what could we do with $15 billion? Would an audacious Grand Challenge project make a difference?

There are many precedents. President Kennedy challenged the United States to send a man to the moon in ten years, and NASA met that challenge at a cost of approximately $100 billion [27]. The United States Rural Electrification and Interstate Highway programs also come to mind. The global positioning system cost roughly $5 billion between 1974 and 1995, and is expected to have cost at least $10 billion more by 2016 [28], but it has saved lives, improved operational efficiency in numerous applications, and spawned an industry. We have totally or nearly eradicated several diseases.

Let us consider one possible Grand Challenge: Connecting every rural village to the Internet by 2015.

After a decade of evangelism and work, there is virtually no connectivity in rural villages of developing nations [29]. Since a business case cannot be made to attract capital to connect them, a subsidy would be needed. There is ample precedent for subsidizing communication. Telephone franchisees and taxpayers are often required to subsidize connectivity for rural, poor or handicapped people as well as emergency response service and the ability to provide assistance to law enforcement authorities.

The NSFNet strategy

We could employ the strategy the U.S. National Science Foundation (NSF) used in subsidizing Internet connectivity for research and education institutions during the 1990s. They began by building the NSFNet backbone network in 1984 [30]. By 1988, 13 backbone nodes linked supercomputer centers and regional networks in a 1.544 Mbps network, which was later upgraded to 45 Mbps.

We could employ the strategy the U. S. National Science Foundation (NSF) used in subsidizing Internet connectivity for research and education institutions during the 1990s.

In 1990 NSF began offering grants for connecting four–year institutions of higher education. Schools could apply for US$20,000 in connection assistance, typically a router and a link to a regional NSFNet point of presence (POP). NSF also made grants to connect foreign research and education networks to the NSFNet, eventually linking 28 research and education networks in 26 nations.

NSFNet was a high–return investment. It became the first global Internet backbone at a cost of less than US$100 million (see Table 1) to the U.S. taxpayer [31].

Table 1: Cost of networking projects funded by the U.S. government [32].

Project	Funding (US$millions)
Morse telegraph: Washington to Baltimore	.03
ARPANet	25
CSNet	5
NSFNet backbone	57.9
NSFNet higher education connections	30
NSFNet international connections	6.6

The NSF strategy was to build common infrastructure — a backbone network — then offer a subsidy for connection to that infrastructure. It was a heavily leveraged investment. The aggregate cost of staff, equipment and installation of university local area networks far exceeded the cost of the NSFNet program. The NSFNet was a terrific investment.

Could a similar approach be applied to connecting villages? Could we build a network that brought a high–speed POP to every village on earth?

There is already fiber connectivity in most large urban areas, but rural backhaul is difficult in a developing nation. Villages are in remote locations, and the infrastructure that facilitates the construction of backhaul cables in developed nations — roads, railroads, pipelines — is poor or non–existent. It is clear that global backhaul to villages will require wireless as well as cable links. Let us consider three wireless technologies that could be used to supplement wired links where necessary: terrestrial wireless, high–altitude platforms and satellite.

Wireless technologies

Patrick Gelsinger, Senior Vice President and Chief Technology Officer at Intel, advises developing nations to cross the digital divide and leapfrog developed nations using terrestrial wireless technology [33]. Gelsinger urges developing nations to say "no" to more copper, and deploy fiber backbone and wireless technology aggressively. He envisions WiFi LANs with forthcoming IEEE 802.16 (WiMAX, Worldwide Interoperability for Microwave Access) for backhaul to fiber [34].

IEEE ratified the WiMAX standard in March 2003 and early chips and products are just beginning to appear. It promises non–line–of–sight (NLOS) coverage at speeds up to 70 Mbps over a distance of 50 kilometers, in both licensed and license–exempt bands. Three architectures are envisioned, point–to–point, point–to–multipoint and point–to–multipoint plus a neighborhood mesh. Intel and others have formed a WiMAX forum in the hope that interoperability certification and joint marketing will drive volume up and price down as they have for WiFi LANs [35].

Proprietary point–to–point links are currently available for backhaul to fiber, but a standard, commodity WiMAX should lower cost significantly in the long run. Still, there would be problems. WiMAX promises NLOS coverage, but even Intel's marketing department has to bow to the laws of physics. Vegetation, inclement weather, and other obstacles will degrade performance. Networks would have to be carefully planned to determine tower height and placement.

Planning might be facilitated with a program like Radio Mobile [36] which uses Shuttle Radar Topography Mission [37] from NASA and transmitter characteristics to generate predicted coverage maps like that of Figure 2. Using GIS data on roads, vegetation, and climate data along with a program like this one might facilitate network planning. Mapping and planning using tools like this would be a major activity in this Grand Challenge project.

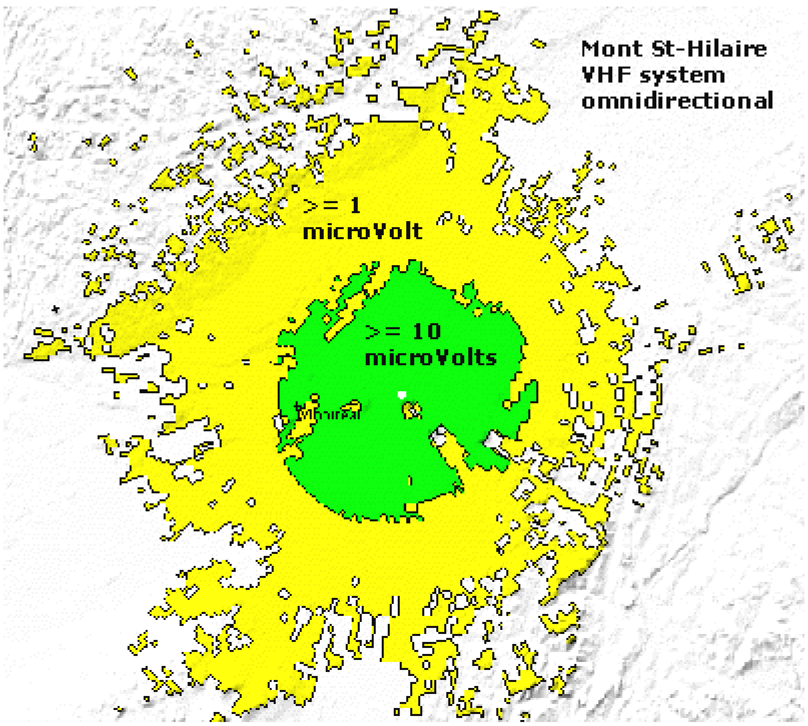

Figure 2: Radio Coverage Map.
Source: http://www.cplus.org/rmw/rme.html

Even with tools like this and commodity WiMAX equipment, there will be areas were terrestrial wireless connectivity is not practical. Another Grand Challenge activity is the design and investigation of high altitude platforms (HAPs).

HAPs are one alternative to terrestrial backhaul links. As shown in Figure 3, a typical HAP would hover between 17 and 22 km above the ground. This altitude is out of the way of aircraft, and wind speed is relatively low. A radio on a HAP would have a footprint between 60–400 kilometers in diameter depending upon platform altitude and ground antenna inclination. Altitude would be chosen to balance factors like wind speeds, attenuation due to free space distance and rain, signal latency time, and coverage. A HAP could have optical or radio links to other HAPs or to satellites in addition to communicating with ground stations.

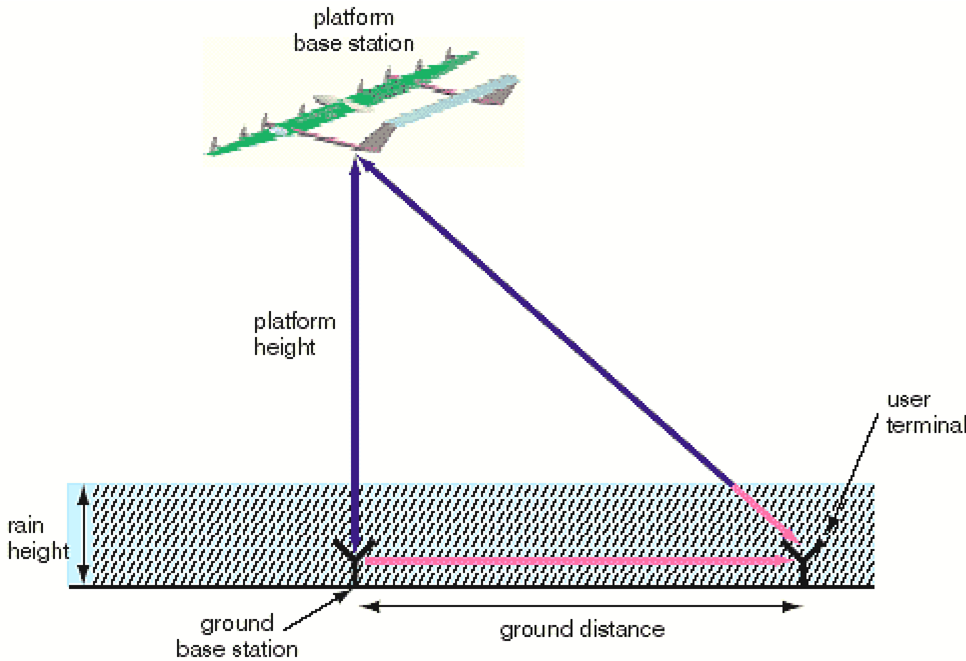

Figure 3: A High Altitude Platform (HAP).
Source: T.C. Tozer and D. Grace, "High–altitude platforms for wireless communications," *Electronics & Communication Engineering Journal* (June 2001), at http://www.elec.york.ac.uk/comms/papers/tozer01_ecej.pdf.

Research and development on a variety of system architectures is being conducted in Europe, the U.S. and Japan [38]. The platforms are generally unmanned and solar powered. They might be balloons, airships, planes, or tethered aerostats. If you are thinking "Hindenburg," bear in mind that materials and technology have improved since that disaster. For example, there are new plastic envelope materials that are strong, UV–resistant and leak–proof to helium, which is not volatile.

A practical HAP would have several advantages relative to terrestrial or satellite links or in some cases to either.

- Cost would be lower than satellite;
- Bandwidth and throughput would be greater than satellite;
- Free space attenuation would be less than with satellite;
- Platforms can have multiple uses in addition to Internet connectivity: remote sensing, weather monitoring, non–Internet communication, etc.;
- Latency times would be lower than satellite, eliminating problems with TCP [39] and with isochronous applications like telephony;

- The geometry of Figure 3 shows that rain interference would be less than with a terrestrial link;
- Foliage, rough topography and vandalism would not be issues as they are with terrestrial links;
- Faster to deploy than satellite;
- Easier to maintain than satellite;
- Incremental deployment is possible; and,
- If the HAP is tethered, the tethers may be used for power and data.

This all sounds good, but HAPs have not yet been proven practical [40]. Power and power storage systems would have to function well during summer and winter. A HAP would have to be kept in a relatively fixed location and orientation, particularly if it is desired to use fixed–position antennae, so systems to maintain orientation will have to be designed and powered. Modulation schemes, spectrum utilization, technology and standards for inter–HAP links, etc. must all be designed. Regardless of these hurdles, this technology should be watched and considered as part of a global connectivity toolbox. These engineering challenges pale beside those faced by NASA in 1961.

While HAPs are unproven, Internet traffic is traveling over geosynchronous satellite links today. According to the Global VSAT forum, very small aperture terminals (VSAT), VSATs have been in use for over ten years and there are now more than 500,000 systems operating in more than 120 countries [41]. Many of these are in developing nations, and ground stations are relatively easy to deploy.

However, geostationary satellites are limited in number, expensive, and take a long time to design and deploy. Their distance above the earth results in high latency times.

To some extent these problems will be mitigated by new technology and architectures. For example, Lloyd Wood and his colleagues argue in favor of breaking the "bent pipe" system architecture in which the satellite is seen as a relay point between two ground stations [42]. They would add inter–satellite communication links and routers to decouple the up and downlink locations. Moore’s Law will make this and processing and transmission improvements economically feasible in the future.

But geostationary satellites will always be expensive to launch, and be far away. Low earth orbit (LEO) satellites overcome the latency problem, but introduce their own. A single LEO satellite is only visible during a limited window of time from any point on the earth. That would allow store and forward applications like e–mail, but interactive applications are not possible [43]. The solution to that problem is a satellite constellation (see Figure 4) in which every point on earth is visible to at least one satellite at all times, and they are equipped with inter–satellite communication links and routers [44].

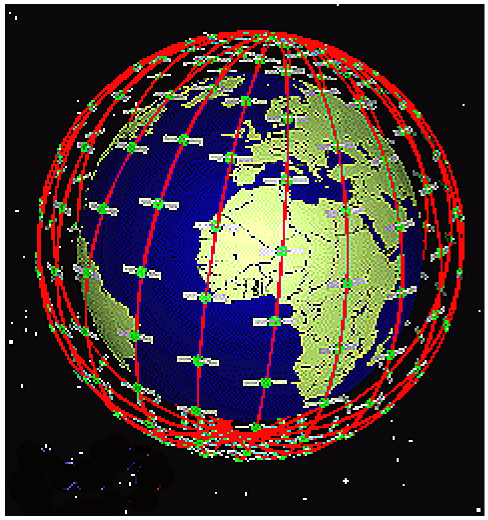

Figure 4: LEO satellite constellation.
Source: This image was generated using Satellite Constellation Visualizer, at http://sourceforge.net/projects/savi/.

Figure 4 looks good, but after several bankruptcies, it is clear that the business case for LEO constellations cannot be made today. For example, Teledesic, which is now bankrupt, had planned to offer 64k to 2 mbps IP service by connectivity by 2005. Had they succeeded, Teledesic would have had a major impact on village connectivity in developing nations and elsewhere.

Such a constellation is not economically viable in today's market with today's technology, but both of those conditions are subject to change. The technology change is certain. Advances in electronics will reduce the cost of complex, dynamic routing algorithms and radio signal processing. Vehicle and launch technology will also change with engineering advances and variety in commercial enterprises. For example, private companies are competing for the US$10 million X PRIZE offered to encourage development of reusable vehicles for space tourism [45].

But, even if technology were not to improve, we are talking about a Grand Challenge, and we can follow the NSFNet model by subsidizing the design, construction and launch of a satellite constellation and ground station acquisition and link costs. As with the NSF, the subsidies might be phased out at some point.

Conclusion

Regardless of the technology used in the link and the equipment (ground station, terrestrial radio, router, etc.) needed to terminate it, the local network within the village would remain the responsibility of local citizens. They may decide on having only a few shared computers in a community center or a wireless or cable–based network. Like the university campus LANs in the days of the NSFNet, local governments and residents would make those decisions and commitments.

Table 2 provides a back–of–the–envelope estimate of the magnitude of this Challenge. As shown there, 2,955 million people, nearly half the world population, live in rural areas in low and lower–middle income nations, and they are steadily migrating to already grossly over–crowded cities. Raising the quality of rural life through Internet connectivity would help stem that migration.

Table 2: Population (in millions), 2002. Source: World Development Indicators database, World Bank [46].

Year	1962	1972	1982	1992	2002
Low–income countries					
Urban	164	246	376	546	760
Rural	845	1,038	1,260	1,509	1,735
Percentage rural	84%	81%	77%	73%	70%
Total	1,008	1,283	1,636	2,055	2,495
Lower–middle income countries					
Urban	353	494	674	934	1,191
Rural	888	1,074	1,186	1,239	1,220
Percentage rural	72%	68%	64%	57%	51%
Total	1,240	1,567	1,859	2,173	2,411
Upper–middle income countries					
Urban	86	120	165	210	249
Rural	81	82	81	81	82
Percentage rural	48%	41%	33%	28%	25%
Total	167	203	246	291	331
High–income countries					
Urban	463	553	619	681	750
Rural	234	223	223	219	215
Percentage rural	34%	29%	27%	24%	22%
Total	697	776	842	900	965
Total world population					
Urban	1,066	1,413	1,833	2,371	2,949

Rural	2,047	2,417	2,750	3,048	3,252
Percentage rural	66%	63%	60%	56%	52%
Total	3,113	3,830	4,583	5,418	6,201

Connecting all villages is one possible Grand Challenge for developing nations, but there could be others. Could we provide free access to all scientific and technical publications, data sets and online instruments to every university in the world? [47] Doing so would require high–speed connections to all universities, hardware and systems for data storage and retrieval, and a subsidy for the cost of intellectual property [48].

Like Neil Armstrong's small step, this would be a daunting challenge, but couldn't it be achieved with a US$15 billion budget over ten years?

The connectivity portion would be most straightforward. Most universities are already in cities with wired Internet service. Subsidy along the lines of NSFNet might be all that is needed. Bandwidth for publications would not be a problem, but much higher bandwidth would be needed for access to scientific data sets in some disciplines. Efforts like the National Science Foundation Digital Libraries Initiative [49] and grid computing research would contribute understanding of storage and retrieval issues. Commercial caching companies would be involved, and would have to be tracked as part of a Grand Challenge project.

> Could we provide free access to all scientific and technical publications, data sets and online instruments to every university in the world?

Intellectual property issues may be the most difficult barriers to universal scientific access, and there would surely have to be subsidies to cover intellectual property costs.

It is difficult to estimate the impact of such a system, but it is clear that benefits would accrue in both the developed and developing nations. The story of the young mathematician Srinivasa Ramanujan rising to fame after writing Professor G.H. Hardy at Cambridge from his village in Southern India is well known [50]. How many Ramanujans might find us? We could expect many advances as a result of involving a variety of people and viewpoints in the global scientific conversation. Different problems and cultures give rise to different worldviews and lead to the asking of different questions. We would all be enriched.

The WSIS will reconvene in Tunis in 2005. Would it be possible to develop concrete proposals for Grand Challenges like connecting all villages or open access to scientific information and instruments by that time? What could we achieve with $15 billion and ten years time?

About the Author

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Notes

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3. http://www.cren.net/cren/cren-hist-fut.html, http://nethistory.dumbentia.com/bitov.html.

4. http://www.fidonet.org/inet92_Randy_Bush.txt, http://www.livinginternet.com/u/ui_fidonet.htm.

5. http://www.uucp.org/.

6. Larry Landweber, "International Connectivity list," ftp://ftp.cs.wisc.edu/connectivity_table/version_2. See ftp://ftp.cs.wisc.edu/connectivity_table/ for later versions of the list and maps. Olivier M.J. Crepin–Leblond also has tracked accessibility via Bitnet, Fidonet and the Internet since 1992, http://www.nsrc.org/oclb/.

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9. Larry Press, 1995. "Developing Networks in Less Industrialized Nations," *IEEE Computer*, volume 28, number 6 (June), at http://som.csudh.edu/fac/lpress/ieee.htm.

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21. Steve Ruth, "Reaching Out," *Internet Society Newsletter,* March 1994, http://www.nic.funet.fi/index/ISOC/pub/isoc_news/2-4/complete_issue.txt.

22. http://www.itu.int/dms_pub/itu-s/md/03/wsis/doc/S03-WSIS-DOC-0004!!MSW-E.doc.

23. http://www.itu.int/dms_pub/itu-s/md/03/wsis/doc/S03-WSIS-DOC-0005!!MSW-E.doc.

24. For example, core funding for a decade of SDNP work was only about US$9 million.

25. http://www.dotforce.org.

26. There are still many references to the pledge on the Web, but the "Okinawa Charter on Global Information Society" is no longer on the Web at http://www.g8kyushu-okinawa.go.jp/e/documents/it1.html.

27. The Artemis Project, http://www.asi.org/adb/m/02/07/apollo-cost.html.

28. These estimates are in 1995 dollars and include the satellites and launch costs, but not military user equipment or nuclear detonation detection system sensors. Pace *et al.*, *The Global Positioning System: Assessing National Policies,* Rand Corporation, 1995, http://www.rand.org/publications/MR/MR614/#contents.

29. Of course the rural and poor parts of many developed nations also have poor or no connectivity.

30. Larry Press, "Seeding networks: The federal role," *Communications of the ACM*, volume 39, number 10 (October 1996), pp 11–18, at http://som.csudh.edu/fac/lpress/articles/govt.htm.

31. Of course NSFNet could not have been built without prior federal procurement, research and development. For example, valuable lessons were learned and thousands of programmers trained in the development of the US$8 billion SAGE system for warning against the approach of bombers.

32. Larry Press, "Seeding networks: The federal role," *Communications of the ACM*, volume 39, number 10 (October 1996), pp 11–18, at http://som.csudh.edu/fac/lpress/articles/govt.htm.

33. Larry Press, "Wireless Internet connectivity for developing nations," *First Monday*, volume 8, number 9 (September 2003), at http://www.firstmonday.org/issues/issue8_9/press/index.html#note4.

34. See http://www.ieee802.org/16/ and http://www.ieee802.org/20/.

35. The WiMAX Forum, http://www.wimaxforum.org/, hopes that WiMAX benefits from the same economies of scale as its predecessor in the LAN arena, WiFi.

36. http://www.cplus.org/rmw/english1.html.

37. http://www2.jpl.nasa.gov/srtm/.

38. See, for example, the CAPANINA consortium at York University, http://www.capanina.org/welcome.php. For an overview of HAP, see T.C. Tozer and D. Grace, "High–altitude platforms for wireless communications," *Electronics & Communication Engineering Journal* (June 2001), http://www.elec.york.ac.uk/comms/papers/tozer01_ecej.pdf.

39. TCP performance suffers with the latency and asymmetry of geosynchronous satellite links. See, for example, "Documentation for Satellite Transport Protocol," by Tom Henderson, http://www.tomh.org/stp/stp_doc.pdf.

40. I believe the Cuban government used tethered HAPs to block TV Marti signals broadcast from the U.S.

41. http://www.gvf.org/.

42. Wood *et al.*, "Slot clouds: Getting more from orbital slots with networking," 54th International Astronautical Congress, Bremen, Germany, 29 September–3 October 2003, at http://www.ee.surrey.ac.uk/Personal/L.Wood/publications/lloyd-wood-iac-2003-slot-clouds.pdf.

43. VITASat, http://www.vita.org/programs/communication.htm, is the only example I know of where a LEO satellite was used for e–mail.

44. For an overview of LEO constellations, see Lloyd Wood, "Satellite constellation networks," In: Yongguang Zhang (editor). *Internetworking and Computing over Satellite Networks.* Boston: Kluwer Academic Press (March 2003), at http://www.ee.surrey.ac.uk/Personal/L.Wood/publications/zhang-book/zhang-book-wood-chapter-2.pdf.

45. See "2002 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies and Spaceports," Federal Aviation Adminstration (January 2002), at http://ast.faa.gov/files/pdf/newtech.pdf for a discussion of space development and http://www.xprize.com for the X PRIZE.

46. Economies are divided according to 2002 GNI per capita, calculated using the World Bank Atlas method. The groups are: low income, US$735 or less; lower middle income, US$736–US$2,935; upper middle income, US$2,936–US$9,075; and high income, US$9,076 or more. The urban/rural distinction is as reported by the nations to the U.N.

47. See Open Access News, http://www.earlham.edu/~peters/fos/fosblog.html, for more on this topic. The timeline posted there, http://www.earlham.edu/~peters/fos/timeline.htm, indicates considerable progress to date.

48. Other applications would also benefit from the augmented infrastructure.

49. http://www.dli2.nsf.gov/.

50. It is ironic that Kluwer publishes the *Ramanujan Journal,* which is devoted to the areas of mathematics influenced by Ramanujan, http://www.kluweronline.com/issn/1382-4090. The individual subscription price is US$123 dollars per year. No modern day Ramanujan could afford it.

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