Out of the Labs and Into the Developing World

Using Appropriate Technologies to Promote Truly Global Internet Diffusion[*]

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Abstract: One of the primary barriers to the diffusion of the Internet to the developing world is economic in nature. Mainstream Internet technologies remain too highly priced to make them accessible to the majority of people in developing countries. This paper presents and explores a range of possibly appropriate technologies which can aid local Internet diffusion. These technologies are either being developed in specialized research labs and universities, already used on a small scale within the developing world, or available in retail markets in developed countries where their applicability to the developing world is overlooked. The paper also explores technologies that in the future should aid in Internet diffusion, particularly mobile wireless Internet solutions. The paper concludes that the primary stumbling block to the provision of these technologies to developing countries stems from market failure. Private companies do not perceive the latent demand for the Internet in the developing world, thus technology is not produced with the cost and design constraints of developing nations in mind. There is an important need to create incentives for information technology development geared toward the developing world, as well as increased dialogue and awareness raising to channel market forces toward developing country needs.

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Introduction and Some Caveats

This paper attempts to broadly outline some technologies and trends in technological development that may be more appropriate for the developing world than those found in the mainstream. This appropriateness is primarily dealt with in terms of cost, as well as the more taxing physical conditions that can exist in developing countries. There are many important issues that this paper does not cover adequately. In particular, the question of designing technologies around communities, rather than individuals, is one of the most essential cutting edge trends in the development of information and communication technologies for the developing world. Of equal importance also are explorations of technologies that deal with issues of literacy (and illiteracy) and culture that can affect the usability of certain technologies. This paper only touches upon these important issues.

In terms of the specific technologies discussed in this paper, they are by no means meant to be exhaustive. Each of the Internet-enabling technologies presented is meant to indicate the potential for low cost, appropriate technologies in several different areas. Each of the technologies chosen is one that focuses on Internet diffusion at the local level. Long distance networks including national and international backbones, satellite systems, microwave relay networks and other elements which are essential for the delivery of Internet to one's home or business are mentioned but not treated in depth. Instead, this paper tries to focus on some information and communication technologies (ICTs) that are found closest to the end-user, and on how they can help alleviate the cost constraint that limits Internet use by most individuals in developing countries.

More specifically, this paper contemplates developments in three areas of Internet technologies: local communications networks, software (applications and protocols), and the hardware that make up the interface between the user and the network.

The Diffusion of the Internet

Perhaps the most talked about phenomenon during the past decade has been the Internet. There are few places in the world where the local inhabitants have not heard of the Internet, even if they do not know what it exactly is. By now, there is some Internet connectivity in every country in the world, except in the one or two nations where the last ISP routinely has either gone out of business or been banned by the national government.

The global map of Internet connectivity shows that while there may be Internet points of presence in every nation in the world, when the subnational patterns of Internet diffusion are examined, a very different picture emerges. Particularly in the developing world, the Internet has not penetrated most rural areas, and indeed, within urban areas, can be found primarily among the wealthy and privileged. The patterns of Internet diffusion are following many of the same patterns that have been etched into the global landscape of social and economic development. Internet use can very much be seen to follow lines delineated by income, gender, social standing, political power and race within most communities.

Internet diffusion can also be seen as determined by other factors. The expansion of the Internet into a particular community is directly related to its information infrastructure, skill levels relating to ICTs, telecommunications and ICT policy framework (including

taxes, tariffs and cyberlaws), business and political climate, and incorporation of ICTs by business, government and the community-at-large. Each of these determinants by itself may not be enough to ease Internet adoption, but together, they create the necessary conditions for technological diffusion.[1]

Many of these factors and determinants of Internet penetration can be seen more as barriers to diffusion than facilitators in the context of developing nations. The lack of economic resources, low levels of technical education, poor infrastructure, political instability, stagnant business community and poorly formulated policies that plague much of the developing world not only hinder economic development itself, but also retard the arrival of the Internet.

The value of the Internet

Why does this matter, and why is the Internet so important? Enough would seemingly have been written already about the Internet to obviate the need for one more attempt at describing its virtues. But it seems important, especially in light of the past decade's hype surrounding all things relating to the Internet (and the current backlash against the dot com phenomenon), to point out that when all the exaggeration and overblown fanfare associated with the Internet are stripped away, we are still left with an extremely powerful, even revolutionary, tool for economic and social development.

Never before has such a flexible, rapid and useful platform for disseminating communication and information on a global basis been so widely available. The Internet has the ability to move large (and small) pieces of information through the global communications networks in ways that have in a very period short time transformed the way that businesses, governments and individual citizens conduct their affairs, see the world, make their money, learn, teach, heal and work.

It is access to information that lies at the heart of most human activity. Information about prices and goods makes markets work. Information about diseases, their prevention, and associated remedies is the key to health care. Information about the world in which we live enables learning to take place. Information allows good governance to occur, and information is at the heart of the things that entertain us. And it is precisely information that most of the developing world lacks. The tremendous distance of developing countries from the major corridors of trade and from the major markets of the world has been a primary driver of the inequality in economic development that exists globally.[2] It is increasingly recognized that the impoverishment of information is still a serious handicap for the developing nations to overcome gaps in economic development, and educational and health levels.

There are many ways to distribute information. The written word, the telephone, the fax machine, even word of mouth all have their place in global communications. But none of these methods offers the global reach of the Internet. And none offers the multifunctionality of purpose of the Internet in terms of being able to deliver a wide range

[1] Information Technologies Group, Center for International Development at Harvard University, "Readiness for the Networked World: A Guide for Developing Countries," Cambridge, MA, 2000.
[2] Gallup, John and Jeffrey Sachs with Andrew Mellinger, "Geography and Economic Development," Presented at the Annual Bank Conference on Development Economics, World Bank, April, 1998.

of rich content. And unlike some technologies such as radio and television, which "push" information to the user, the Internet is a two-way medium in which users can not only receive information, but also disseminate their own content to the rest of the world.

While the Internet is certainly a most versatile, powerful two-way global communications medium, it remains a tool that is mostly in the hands of people and businesses in the more developed nations. Only about five percent of the world's population has been online, and of those, about 90 percent live in North America, Europe or Japan.[3] While trillions of dollars of capital move around global markets on global communications networks each day, there are billions of people who still live on less than a dollar a day and have yet to make a telephone call, let alone send an email, bank online or surf the Web. It is the premise of this paper that by encouraging the diffusion of the Internet throughout the developing world, the people and organizations in those countries will gain a powerful tool that will allow them to both access and share information, and that this will aid in raising their incomes and in improving their health and education.

Cost as a Barrier to Diffusion

One of the most pressing concerns, and fundamental obstacles to the diffusion of the Internet to the developing world, is the cost of ICTs associated with access. Given the low wage levels that prevail in most developing countries, the prices of hardware, software and of connectivity remain prohibitively expensive for the majority of people and businesses. Infrastructure providers are leery of making the required investments in networks in most communities in the developing world, and most governments lack the financial resources on their own to make the diffusion of the Internet a major priority. The international development community, particularly the multilateral and bilateral donor organizations, have also done little to-date to address the issue of cost as a barrier to Internet diffusion in the developing world.

It is important to remember that in a vacuum, information and communication technologies like the Internet have no real intrinsic value. They are merely the newest wave of tools available to humankind that fit in the same trajectory as pen and paper, smoke signals, and the telegraph. The real excitement surrounding the newest ICTs lies in their power to break down time and space in a way that was not possible before. It is the *use* of ICTs that has the potential to change the world.

Nevertheless, too often in general discussions about the impact of the Internet upon the developing world, an analysis of "ICTs" never penetrates beyond the general level; the potential of information and communication technologies as powerful tools for development is elaborated as if all ICTs were the same. The truth is, they are not. There is a wide range of information and communication technologies being developed worldwide, with great differences in philosophies of design, and ultimately, in the usefulness and cost of what, if anything, is ultimately produced. In the interest of contrasting low cost technological development with the mainstream, this paper will highlight a number of specific research and development strands relating to the Internet.

Also within the growing debate about the appropriate role of the Internet there is a growing tendency to focus on moving the discussion of ICTs and development "beyond access." Once again, it is often pointed out that access to the Internet and the global

[3] CID estimates.

telecommunications network in itself is meaningless – it is *how* this access is used that is of real import. Does access lead to job creation, higher wages, social, political and economic empowerment? However correct this view is in terms of flagging the issues that lie at the core of the use of ICTs for economic development, it does not resolve the fact that access remains a main bottleneck. Without access, we cannot begin to speak of electronic commerce, telemedicine or e-government. And cost remains a major component of Internet access that has not been adequately addressed in mainstream R&D programs or in the big ICT companies' production and sales agendas.

The cost of the Internet that a user pays reflects a number of other costs of goods and services that make Internet service provision possible: the correspondent amortized investment costs for the local, regional, national and international deployment of network infrastructure, a portion of the network's recurring costs, the hardware and software interfaces used to interact with the network, etc. On each of these levels, there are specific technology costs that contribute to the overall cost of the Internet, influenced by the regulatory framework, the intrinsic cost of the technologies themselves, and a number of other factors. In the case of users in the developing world, this total cost is often prohibitive.

Does the Developing World Really Need the Internet?

Many dismiss the argument that it is important for the developing world to have the Internet by pointing out that poor people do not need or even want the Internet if they cannot feed and clothe themselves or take care of their health. Some critics of efforts to take the Internet to developing nations also point out that people there do not have the income to spend on a luxury like the Internet. There are at least two important reasons why these criticisms are missing the point.

First, we are not speaking of a zero sum game. For some of the most rudimentary problems facing developing countries, the Internet could quite effectively ameliorate inefficiencies in markets and breakdowns in communication that contribute to poverty and stagnant development. In an environment with limited resources of course there is always a choice between one thing (food) and another (the Internet) when buying decisions are made. But the Internet is not an end in itself. The whole purpose of having the Internet is to aid in making the pursuit of food, health, income, education and entertainment more efficient and rewarding.

To illustrate this point, it is easy to talk in the abstract about the value of linking local producers to global markets, of connecting rural health clinics to better-equipped hospitals elsewhere, or of giving students greater access to the multitude of learning materials that exist on the World Wide Web. These are all potential impacts of the Internet upon a community in the developing world.

We can also consider a specific, practical example of the value of information and the potential role of the Internet. Inefficiencies in spot labor markets are one driver for high rates of employment and low productivity globally. Typically in many towns and cities around the world, each morning groups of (usually) men gather to look for day jobs. Employers who have a need for workers that day hire from this pool of available labor. The system seems fairly formalized but in reality, there is quite a bit of chance whether or not each prospective worker will get a job on any particular day. If there is a need for five workers in a particular town, yet eight men need employment, three people do not

find jobs. Unbeknownst to these men, however, there may be opportunities just around the corner in another square several blocks away, on the other side of town, or in the next village over. Meanwhile, employers whose labor needs are unfulfilled are losing productivity.

How can information or communication technologies play a role in a situation like this?[4] Obviously, some medium that can transmit the valuable employment information from one location to others would make this spot labor market work more efficiently, and allocate employment opportunities in a manner which would maximize all participants' economic interest. It can allow a farmer to have his crops picked in a timely manner, and gives the worker an extra day's pay.

An obvious criticism arises at this approach -- why does this medium have to be the Internet? It could reasonably be argued that these hypothetical towns do not need the Internet to achieve the goal of aligning their labor markets; a number of less expensive technologies could relay the essential information, including a bicycle or a burro. Perhaps all these villages need is a clever entrepreneur who can see a business opportunity and take advantage of it with whatever communication technologies exist.

But the value of a medium like the Internet is that not only could it provide a platform for making the labor markets in these towns more efficient, but it could also alleviate many or all of the other informational deficits that commonly exist in a community in the developing world. With the Internet, economic, health, education, and governance concerns can all be addressed, at least in part, all through the same information pipeline. So in answer to those who would question the relevance of the Internet in the developing world, this multifunctionality is part of the answer – the Internet can be used to alleviate a wide range of information deficits that currently impair the development process. And unlike more traditional ICTs such as the burro or the bicycle, the Internet can communicate a vast quantity of information in a much richer, more timely way.

Second, many of the people in the developing world *do* have the income to pay for information, and in fact, are already paying exorbitant prices to both transmit and receive information that is important to them. If the Internet were deployed in the developing world in a cost-effective manner, it could actually bring about cost savings in both time and money to its users. If we consider that there are certain information needs in every community in the world – needs to find out price and market information to carry out economic activities, needs for information about health care, needs to know information about the government, etc. – we can then envision how an isolated community obtains that information.

In much of the developing world, the lack of two-way communication technologies such as telephones means that people must rely upon one-way communication media such as radio, newspapers or television, or where these do not exist, upon physical travel to meet their information needs. Even when media such as the telephone or the radio do exist, in general the lack of information is a pervasive phenomenon across all levels of the economy and society in developing countries. The price that isolated people pay for information comprises the money and time they spend to obtain information, as well as the cost of not having effective and rapid means to obtain that information in a timely

[4] Without implication, I thank Dr. Robert Jensen of Harvard University for our discussions of the potential role of the Internet in the coordination of labor markets.

way (lost opportunities). This high price is further exacerbated by the low or variable quality of the information accessed.

While much more rigorous work needs to be done to evaluate this aspect of information poverty,[5] there have been some efforts to quantify the cost and willingness-to-pay associated with information in developing nations. A 1999 study analyzing the impact of pay phones in Bangladesh showed that even poor Bangladeshis living in remote villages without telephones were already paying the equivalent of US$1.34 in time and money to obtain information that could be gotten through one telephone call.[6] The key question in terms of the Internet, in light of this acknowledgement, is whether the Internet can be delivered to the developing world at a cost low enough to match up with the low income levels and willingness-to-pay.

The answer to this question is beyond the scope of this paper; however, in highlighting the technologies and technological trends in the discussion that follows, it is hoped that some insights can be gained into areas where further work could be done to provide appropriate and cost effective Internet solutions to the developing world. What is today the most common method to access the Internet, via a personal computer, is not an affordable option for most of the world. Even the lowest price of a Compaq 800 Mhz. Pentium III as of January 2001, US$699,[7] is an unthinkable luxury representing two years of income for the 1 billion people who earn only US$365 a year. But what if an Internet device could be developed that cost only US$30? And what if each email message cost only around US$0.01 to send or receive?

The Competitive Framework as a Price Driver

A major determinant of the price of Internet within a country is the prevailing competitive environment for the provision of ICT products and services. In too many developing nations, neither the existence nor observance of regulatory frameworks promote a competitive telecommunications or ICT business environment, and therefore make access to both telephony and Internet services less affordable. This paper does not address the current condition and impact of competition and regulatory issues in great detail, as this is a subject that has been treated exhaustively elsewhere in the literature. However, because of its great impact on price the topic of regulation merits mention within a discussion of cost as an obstacle to Internet diffusion.

Any basic economics textbook argues that increased competition, when properly regulated, will drive down prices. There is compelling empirical evidence that this holds true in the telecommunications market; there is a strong correlation between the appropriate level of competition, brought about through an effective regulatory regime, and lower prices of both ICT goods and services. This has held true in a range of ICT

[5] We are eagerly awaiting preliminary findings of Harvard economist Dr. Robert Jensen's work in this area. In January 2001 he launched an ambitious project to better understand the economics of information in the context of the Sustainable Access in Rural India (SARI) Project ([online] http://edevelopment.media.mit.edu/sari.html), which seeks to extend Internet connectivity to networks of rural Indian villages.

[6] Bayes, A., J. von Braun, and R. Akhter, "Village Pay Phones and Poverty Reduction: Insights from a Grameen Bank Initiative in Bangladesh, Zentrum für Entwicklungsforschung, Universität Bonn, ZEF – Discussion Papers on Development Policy No. 8, June 1999.

[7] "Yahoo! Computers shopping," search of Pentium III computers sorted by price, [online] http://www.yahoo.com.

markets, including leased telephone lines, Internet service provision, and local and long distance telephony. Historically, local telecommunication markets have been one of the most protected from competition and from the pressures to introduce new technology, which explains, in part, the increasing quality and lower prices of telephony services since the liberalization of those markets.[8] One of the most studied liberalization processes is that of the United States. The breakup of AT&T in January 1984 led to an average percentage reduction in long distance telephony rates of 40.3 percent.[9]

The last few decades have seen an explosion in telecommunication privatization throughout the world. Today, there are more private telecommunications operators than ever before. Yet there are still great inroads that need to be made in terms of promoting competition, because privatization has not necessarily translated into liberalization of services. In many countries, state-owned monopolies have been replaced by private ones. And in other countries, collusion between competing companies is not an uncommon occurrence. This of course has an important effect on cost, in that it dampens the potential impact that a liberalization process can have on making telecommunications, and the Internet, more affordable and accessible to citizens.

As can be seen in Table 1, more traditional telecommunications services (local, national long distance and international distance telephony) are still uncompetitive in most countries. Since most Internet access is still delivered over dial-up telephone connections, intuition would suggest that monopolistic and duopolistic arrangements have an adverse impact upon the price of Internet access.

In any case, there is a greater tendency towards competition in important markets such as Internet Service Provision (ISP) and cable television than in the other markets which are major drivers of Internet diffusion (i.e. local telephony, international long distance and leased lines), and in which the majority of regulatory regimes remain monopolies globally. The link between the overall regulatory landscape and Internet pricing is certainly an area in which greater research should be carried out.

[8] McNamara, John R., *The Economics of Innovation in the Telecommunications Industry*, Quorum Books, New York, 1991, p. 143.
[9] Viscusi, Kip, John Vernon and Joseph Harrington Jr., *Economics of Regulation and Antitrust, Second Edition,* MIT Press, Cambridge, MA, 1995, p. 496.

Table 1: Global Breakdown of ICT/Telecommunications Regulatory Situation

	Countries				Percentages		
	Monopoly	Duopoly	Competition	Total	Monopoly	Duopoly	Competition
Local Telephony	121	19	44	184	65.76%	10.33%	23.91%
National long distance	134	12	36	182	73.63%	6.59%	19.78%
International long distance	129	16	38	183	70.49%	8.74%	20.77%
Analog cellular	69	11	62	142	48.59%	7.75%	43.66%
Digital Cellular	47	28	79	154	30.52%	18.18%	51.30%
Leased Lines	99	11	57	167	59.28%	6.59%	34.13%
Paging	33	9	105	147	22.45%	6.12%	71.43%
Mobile Satellite Market	32	12	65	109	29.36%	11.01%	59.63%
Fixed Satellite Market	61	14	59	134	45.52%	10.45%	44.03%
Cable TV Market	22	8	83	113	19.47%	7.08%	73.45%
GMPCS Market	10	5	47	62	16.13%	8.06%	75.81%
ISP	13	3	81	97	13.40%	3.09%	83.51%

Source: CID at Harvard University analysis of 2000 ITU data.

While the remainder of this paper focuses on specific technologies, it is important to consider all technologies against the appropriate regulatory backdrops. The affordability and usefulness of most ICTs are directly impacted by the competitive environment. As the process of digital convergence deepens, this is likely to increase competition even more when cable television, local and long-distance telephony, Internet access and even other unforeseen digital services become available using the same basic technological architecture.[10] The challenge of how to regulate a rapidly converging environment will continue to be a major challenge globally, and essential in discussions of the affordability of the Internet.

The Cost of Technology

Competition, of course, can only go so far in promoting the provision of affordable technologies. The cost of the technologies themselves is obviously a major driver of Internet use and access.

What does one need to access the Internet? Connection to the Internet through a network, and some sort of hardware and software interface to interact with the Internet. The most common way to access the Internet in the developing world is through a personal computer and a dial-up telephone connection. As was pointed out previously, even the most inexpensive Pentium III computer cost US$699 in January 2001, and globally, the price of monthly Internet Service Provision rarely falls below US$20; obviously the current standard technologies associated with the typical way to access the Internet are out of reach of most people in the developing world.

Because of the extreme divergence in wage levels between developed and developing nations, observers have begun to examine how prices impact Internet diffusion. One researcher in India, Dr. Ashok Jhunjhunwala, argues that the price of Internet Service Provision remains a real barrier to more rapid diffusion of the Internet.[11] For example, in

[10] Viscusi, Vernon and Harrison; Laffont, Jean-Jacques, and Jean Tirole, *Competition in Telecommunications*, MIT Press, Cambridge, MA, 2000.
[11] Jhunjhunwala, Ashok, "Telecom and Internet in Developing Countries Bottlenecks and Solutions, IIT Madras, Chennai, February 2000.

the United States it is common to consider US$30 to be a reasonable monthly household expenditure on telecommunications services. Dr. Jhunjhunwala establishes as a benchmark that a household cannot "reasonably" spend more than 7 percent of its yearly income on telecommunications services. With this assumption, over 90 percent of U.S. households can afford this level of Internet usage. When this same benchmark is applied to the case of India, only 1.6 percent of Indian households can afford to pay US$30 a month (see Table 2). Since the average monthly Internet cost in India is even higher, at US$35/month, it is clear that the Internet is affordable for even fewer households.

Table 2: Expected Household Expenditures on Telecommunications Service

Yearly Household Income	Yearly Expenditure	% of Indian Households*
>$5,000	>$350	1.6
$2,500 – 5,000	$175-350	6.3
$1,000 – 2,500	$70 – 175	23.3
$500 – 1,000	$35 – 70	31.8

- Assuming 7% of family income for communications

Source: Jhunjhunwala, Ashok, "Telecom and Internet in Developing Countries Bottlenecks and Solutions, IIT Madras, Chennai, February 2000.

Different Models: One Device per Household vs. Shared Technologies

The previous argument seems to assume that the metric of one Internet account per household is the most reasonable model to analyze. However, one nuance that is missing is that throughout much of the developing world, computers, email accounts and Internet connections are often shared by several, tens or dozens of individuals or households. While accurate data are hard to come by to pinpoint exactly what the degree of sharing is, the community technology model is one that has exploded both organically and through sponsored efforts in the past decade. Telecenters, Internet kiosks, community learning centers and other similar endeavors focus on making the Internet, telephones and computers more accessible, and more affordable to communities of users. They have had varying degrees of success in terms of their sustainability, but are a noteworthy phenomenon that has been the subject of great discussion and focus recently.

This paper will not discuss the shared technology model in great depth. The focus of this paper is on the cost of specific technologies – whether these technologies are applied in a one device/connection per individual/household environment or in a shared setting, the overall goal of making ICTs affordable in either case is directly affected by the development of less expensive, more appropriate technologies. The combination of less expensive ICTs and a community/shared usage model makes many of the suppositions and analysis in this paper even more potent in terms of reducing the price barrier to Internet diffusion in the developing world.

Some Other Drivers of Price

Time. It should be emphasized that the best ally of the developing world in terms of making ICTs accessible in terms of price may in fact be time itself. Metcalfe's, Moore's and Gilder's respective laws[12] are cited in almost all articles dealing with the "ICT

[12] Robert Metcalfe predicted in the late 1970s that the value of a network increases with the square of the number of users. In 1965 Gordon Moore predicted that the number of transistors

Revolution," and justifiably so. The power of ICTs continues to rise exponentially, and the costs (and therefore prices) of these technologies continue to plunge over time. Consumers are able to obtain much more computing power at a lower price than in the past.

There is a sense of urgency inside many policy circles, and real worry that developing nations will be "left further behind" if they do not act immediately to incorporate ICTs into their social and economic fabric. Given the rapid change in power and price of ICTs, along with rapid convergence of different media, this sense of urgency may be unfounded. One could hypothesize that those communities that wait the longest to make the requisite changes in regulatory, taxation and import policies, foreign direct investment programs and education agendas, all of which enable faster diffusion of the Internet, may actually be best positioned in terms of being best suited to deal with cheaper, more powerful technologies that do not yet exist. This is mere supposition in the context of this paper, as well as a serious research question that merits much more rigorous analysis and study.

Entrepreneurship. One of the most influential forces pushing technological diffusion and innovation in the developing world has been the entrepreneurial initiative of individuals and companies. The cellular telephone industry in particular provides valuable lessons that are applicable to future Internet growth.

The explosion in cellular technologies throughout the developing world has come as a surprise to even the most astute observers.[13] In every region of the world, cellular telephony has become one of the fastest growing technologies, and one that penetrates perhaps deepest across all economic strata. One of the factors that has contributed to this boom has been the implementation of innovative business models and pricing practices that work within the restraints imposed by both regulatory regimes and technology costs. The "calling party pays" philosophy that can be found in much of the world has contributed to this growth (instead of billing a cellular phone user for all airtime minutes, as is the case in the United States, users only pay for calls that they have initiated, lessening inhibitions to give out one's cellular phone number or answer calls to one's cellular phone from even unknown callers). Furthermore, in many cases, cellular telephone service providers, recognizing the importance of building out a customer base in an increasingly competitive environment, have been willing to absorb profit losses. In El Salvador, for example, cellular telephones have been given away for free or priced well below cost in order to sign up new subscribers, and service agreements have been based on pre-paid calling cards that fall within the budgets of even low income Salvadorans.[14] In the well-known case of GrameenPhone in Bangladesh, the application of principles of micro-finance spawned a whole new industry around the Bangladeshi "phone ladies."[15] And in successful telecenter operations in many regions

on a silicon chip would double every two years. George Gilder in the mid-1990s predicted that total bandwidth of communication systems will triple every year for the next 25 years.

[13] There have been numerous commentaries about the unexpected rates of cellular penetration worldwide.

[14] Chacon, Richard, "In Earthquake Crisis, Desperate Salvadorans Relying on Cellphones," *The Boston Globe*, Pg. A6, January 18, 2001.

[15] Qadir, Iqbal Z., "Connecting Bangladeshi Villages," [online] at http://www.telecommons.com/villagephone/quadir.html.

of the world, local entrepreneurs have learned how to use even low bandwidth Internet connections to build sustainable micro-enterprises in low income environments.[16]

As the Internet continues to spread through the developing world, there seems to be no doubt that entrepreneurs will continue to develop creative business models that contribute to market creation and reinforce the diffusion process. In order for this to happen, it remains essential to allow a competitive environment to flourish in the Internet space, and to develop low cost technology options, because even in the most difficult environments, ingenuity and creativity allow "the invisible hand" to be a firm ally of Internet diffusion.

Design philosophies. Most Internet-related technologies are designed with consumers in the developed world in mind. These same technologies are also exported and sold to developing markets virtually unchanged. Recently, some have begun to question the appropriateness of this design philosophy for the majority of the world. There is a growing minority of respected voices that consider the prevailing global technology manufacturers as having a focus on "overdesign" rather than on "appropriate design."

There is a new generation of researchers within the developing world itself who have begun to modify existing technologies that were originally designed for developed markets to make them more appropriate for their own environments. One of the global leaders in developing locally appropriate and cost-effective Internet solutions is the Telecommunications and Computer Networks Group (TeNeT) at the Indian Institute of Technology at Madras. One of the most vocal members of TeNeT is the pre-eminent Indian scholar, Dr. Ashok Jhunjhunwala. Dr. Jhunjhunwala's and TeNeT's research is guided by a basic premise: that if copper wire were used in a major program to significantly increase the number of homes in India connected to the telephone network (say, from one percent to between 15-25 percent as China has done over the past decade), the resulting price would be exorbitant.[17] Given an installation price per telephone line of between US$900 and $1,000, each one percent increase in teledensity in India (approximately 10 million lines) would carry a price tag of US$9 to $10 billion. The multi-billion dollar investment needed for marked improvement in telephony access is a burden that neither the Indian government nor the private sector is prepared to make at this time. If seen as a purely technological question, a solution to making connectivity more affordable is to make the technology itself more affordable.

Dr. Jhunjhunwala estimates that with any mature ICT good in the developed world, there is a need for a cost reduction by a factor of between 3 and 5 for it to be useful at large in the developing world.[18] If the cost of a telephone line, in particular, can be brought down to US$300, he estimates that 30 percent of households in developing nations could then afford a connection. This is based on an infrastructure provider's need to get a return on investment. If each new telephone line costs US$1,000 to make, given the low income levels in the developing world, the market of potential customers is limited. In the case of India, between one and two percent of the population could afford to maintain such a connection (see Table 2). By bringing the per line installation cost down significantly, there is a much greater potential market for telephony and the Internet.

[16] Colle, Royal and Roman, Raul, "Communication Centers and Developing Nations: A State-of-the-Art Report, April 1999, [online] http://www.devmedia.org/documents/Banga.htm
[17] Welcome to TeNeT, [online] http://www.tenet.res.in/
[18] Email correspondence with Dr. Ashok Jhunjhunwala, January 2001.

As a partial solution to this issue, TeNeT, in conjunction with a number of spin-off companies, developed a wireless local loop technology called corDECT based initially on a European standard. Thus far, corDECT has reduced the cost per telephone installed to around US$400. The implementation of wireless local loop eliminates the need for copper wires to a home or business. One central tower or station can serve 150 different locales in line-of-sight of the tower. According to Dr. Jhunjhunwala's estimates, the result of widespread implementation of this lower cost telephony system across India would be to provide voice and data access to about 200 million people – or about 20 percent of the population, as opposed to the current two percent.

With corDECT, simultaneous voice and data (between 35 and 70 kbps) services can be deployed at less than the cost of traditional telephone mainlines. As Jhunjhunwala admits, there is still more research do be done in order to make these networks more accessible to poorer elements of the population, but as network development has continued, the price has continued to decline. The corDECT project is not limited to the research and development stage. CorDECT systems have been deployed throughout a number of sites within India, Madasgascar, Yemen, Fiji, Brazil and Kenya, and in a wide range of population densities and topographies.[19]

Dr. Jhunjhunwala also points out that technology manufacturers in the developed world focus most of their efforts on adding functionality to existing technologies at a fixed price that is affordable to most consumers, rather than on providing basically functional technology at a lower price.[20] He argues that a greater focus upon producing useful technology at a lower price is key to extending the Internet to developing countries. Similar questions are being asked about fundamental design of software, and a vibrant debate has arisen in some circles as to the appropriateness of proprietary versus open source software design for the developing world.[21]

What these debates and insights point to in the end is a major market failure on a global scale. Even with largely untapped markets of billions of potential consumers in the developing world, most major ICT corporations remain focused on building and defending their market share in developed markets. As will be seen in the discussion of technologies to follow, the most relevant work for developing countries is occurring on the fringe: in specialized academic research labs in the developed world and in a handful of their counterparts in the developing world (in countries such as Brazil and India). These are mostly small scale efforts. Where large private companies are developing low cost Internet technologies, it is more often than not destined for developed world.

What is lacking in connecting major private sector R&D efforts to the demand for Internet in the developing world is the provision of tangible incentives, as well as definitive evidence that the demand really exists and that there is a willingness-to-pay. There seems to be a real lack of understanding (and of interest) on the part of most U.S., Japanese and European ICT companies of markets in the developing world. While all of the major ICT players have a major presence in developing countries, the products that

[19] Mohapatra, N.M., "corDECT – Field Experiences", Commsphere 2000, February 2000.
[20] Jhunjhunwala, "Unleashing Telecoms and Internet in India."
[21] For example Yee, Danny, "Development, Ethical Trading and Free Software," *First Monday*, volume 4, number 12 (December 1999), [online] http://www.firstmonday.dk/issues/issue4_12/yee/

are sold there are generally identical in terms of cost and functionality as those sold in the developed world.

As follows is an overview of some of the most promising technologies that could quicken the uptake of the Internet in the developing world. In the case of each technology, there is a clear role for further research and development to adapt and expand existing efforts. In order to maximize the impact of the Internet in the developing world, the private sector will have to take the lead in commercializing low cost technologies on a large scale. No one else has the financial resources or the expertise to do so. The international donor community can also play a role in seeding these investments and in performing the due diligence needed to attract attention to these underserved markets.

In many cases, a major effort by the private sector to mass-produce appropriate technologies to developing world design and cost constraints could lead to a new round of global ICT explosion. A shift in mainstream design philosophy from "overdesign" to "appropriate design" would make a real difference in the economic and social development process.

Delivering the Internet to the End User

The method of delivery of Internet to the user is essential in terms of determining the cost and speed of service. It is becoming increasingly common to hear the view espoused that traditional telecommunications networks, based on cable landlines and copper wire last mile solutions, are no longer the best option for the developing world, given the development of wireless alternatives.[22] In general, this argument has some merits, given the high cost and logistical difficulty of implementing local wire solutions. While fiber optic cable can provide cost effective solutions under certain circumstances, wireless solutions are becoming a more and more attractive option for local deployment. Within the broad category of wireless systems, however, it is worth exploring several specific technologies that hold great potential to provide economical solutions to local connectivity in developing countries. In the context of Ashok Jhunjhunwala's research on more appropriate technologies, lower cost variations of traditional telephony were discussed. The remainder of discussion in this paper on specific technologies will focus on other less traditional and yet-to-be established methods of Internet delivery.

Bandwidth and Mobility.

Special mention should be made of two factors in Internet deployment that can greatly influence its usefulness. Until quite recently, the Internet was largely both low bandwidth and fixed, which limited its utility in many circumstances. Higher bandwidth and greater mobility are both desirable traits in Internet delivery, and these are becoming more feasible and affordable as ICTs evolve.

Bandwidth. One of the most important factors in terms of delivering the Internet is the bandwidth of the medium or network, which determines the speed at which data are transferred between devices. In general, the higher bandwidth that exists, the greater

[22] For example "Network Design Manual," *Network Computing*, [online] http://www.networkcomputing.com/netdesign/bb2.html, and "Wireless, Broadly Speaking," Wireless Week, June 5, 2000, [online] http://www.wirelessweek.com/news/Broadband/bb65a.htm

range of applications and uses are available to the end user. Most households in the world currently have dial-up connections to the Internet, which generally support bandwidth of less than 56 kilobits per second (kbps). Bandwidths of greater than 128 kpbs are sometimes loosely called "broadband" and can offer greater functionality in terms of the kinds of data that can be usefully transferred (such as streaming video, music or large data files). Internet bandwidth is not critical in an absolute sense in determining the usefulness of the Internet to the end user – there have been many examples of vital uses of the Internet in low bandwidth environments that have utilized electronic mail or World Wide Web text. However, in general, higher bandwidth solutions allow users to make more sophisticated use of the Internet in a faster and more efficient manner. In the past few years, for the first time, wireless systems offer the ability to affordably deliver higher bandwidth Internet to the end user.

Mobility. The question of mobility is becoming increasingly important when talking about the Internet, particularly as technologies are upgraded and there is convergence in both devices and networks. While use of the Internet has to date been primarily physically fixed in one place, due to its delivery through wireline systems, the migration of Internet onto mobile devices that can remain connected as they move greatly expands the repertoire of applications that the Internet can support.

Higher Bandwidth Wireline Solutions.

In the United States and Europe, digital subscriber line (DSL) technology (which allows high speed data transmission over traditional copper telephone wires in certain conditions) and cable modems (which transmit the Internet over coaxial cables that also can deliver cable television) are the primary means of deploying higher bandwidth Internet to consumers. Recent predictions by Forrester Research estimate that by 2005, DSL and cable should control about 86 percent of the high speed Internet market within the United States, and fixed wireless will only have 9 percent of the market.[23] In the developing world, however, it seems likely that fixed wireless solutions could provide a greater proportion of local connectivity than in the U.S. This is because there are a number of assumptions about existing networks that do not hold true in developing countries. For one thing, there are generally no existing networks in many parts of the developing world. And when building a local network from scratch, the difficulties of terrain and the high cost of deploying wire networks mean that fixed wireless provide an attractive alternative. While the economics of providing Internet solutions via technologies such as DSL and cable modems will make sense in the more affluent, urban areas in developing nations, there are a number of other solutions that may be more promising.

Wireless Internet

Especially as they continue to adapt and evolve, spread spectrum wireless networks would seem to offer tremendous potential for extending Internet access to the developing world. There are a number of technical advantages to spread spectrum. Spread spectrum technologies are useful in decreasing the interference from other sources, while maintaining privacy, by using a wider bandwidth of spectrum than the information being transmitted. Signals are transmitted on dozens, or even hundreds, of different frequencies to get data from one point to another. There are a number of

[23] [online] http://www.forrester.com

commercial applications of spread spectrum technologies, including digital cellular telephony, the global positioning system, digital cordless telephony, wireless Personal Communication Systems (PCS) (which provides wide area wireless voice applications) and wireless Local Area Networks (LANs) which can provide data access to a specific geographic area.

In both the developed and developing world, wireless networks have been deployed in several ways. Most traditionally in the wireless sphere, in the extension of telecommunications networks, microwave relay towers have been very effective in providing telephony and Internet access to communities that previously were isolated from communications because of difficult topography, climate conditions or lack of investment funds.

The so-called Part 15 ISM bands are spread spectrum technologies that have very relevant applications to the developing world. These pieces of the radio spectrum are currently unlicensed in many countries in the world, and therefore offer the ability to provide Internet with relatively less administrative burden and cost. There are financial and technical benefits of wireless networks in that they avoid the high costs and difficulties associated with installing wires and cables; all that is necessary is a transmitting tower that is within line-of-sight of the receivers in the surrounding area.

Fixed Wireless Networks. There are a number of examples from developing and transitional nations of successful deployment of wireless networks as cost effective solutions to providing Internet. As early as 1993, the University of Latvia installed its first citywide wireless LAN Internet access link in Riga, taking advantage of a very low cost, high speed direct sequence spread spectrum (DSSS) system.[24] Since that time more than 200 locations in the Latvian capital have been connected to the Internet through successive generations of wireless technologies. The Latvian team in 1996 helped to set up the first wireless network in Moldova. They were able to install a high speed wireless data network and satellite backbone connection (via VSAT) within three days at a cost of around US$1,000 plus the cost of a personal computer.[25] Since 1994 this group in Latvia has also assisted with or consulted on the installation of fixed wireless Internet networks in over 30 other countries.

Other groups have been active in this area as well. Over the past few years, the Soros Foundation and the United Nations Development Programme have both supported the initial deployment of fixed wireless networks.[26] Other development agencies such as Canada's International Development Research Centre have also supported wireless network rollout.[27]

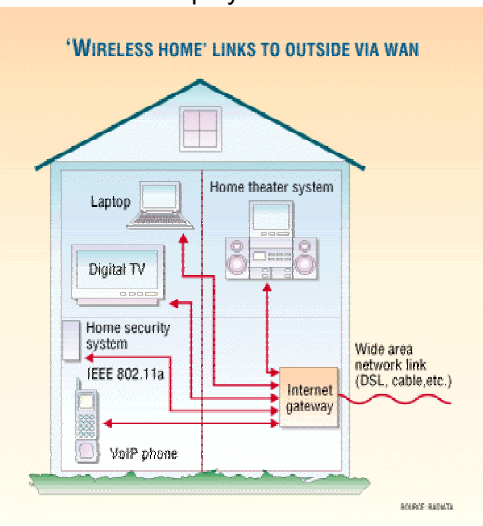
802.11. One of the most talked about wireless standards is known as IEEE 802.11, a type of wireless network architecture known by the technical moniker given it by the Institute of Electrical and Electronics Engineers. 802.11, like other spread spectrum

[24] Barzdins, Guntis, John Tully, and Arnis Riekstins; "Applications of High-Speed Wireless Solutions for Developing Countries: Lessons Learned in Latvia and Moldova," inet 1999 Proceedings, Internet Society, 1999, [online] http://www.isoc.org/inet99/proceedings.4d/4d_2.htm
[25] Ibid.
[26] Tully, John and Riekstins, Arnis, "Licence-Free Internet Wireless Technologies," [online] at http://www.terena.nl/tnnc/1B/1B3/1B3.html
[27] "The Wireless Toolbox," International Development Research Centre, [online] http://www.idrc.ca/acacia/03866/wireless/part3.htm.

technologies, offers greater immunity to interference and again, perhaps more importantly, operates in what is in many countries in the world an unlicensed band (the 2.4-2.5 GHz ISM band), which means that its deployment is not subject to governmental intervention or licensing.[28] In developed country markets like the United States, the increased competition and activity in the unlicensed microwave bands is seen as a potential pitfall because of the probability of increased spectrum clutter that could lead to interference of 802.11 and other wireless LAN systems.[29] In the developing world, however, these wireless LANs could have a more promising future in this respect, as there is generally less activity in this area of the radio spectrum.

There are several other advantages of wireless systems like 802.11 over other wireless standards. First, unlike fixed wireless systems, the standard permits roaming of users within its coverage area. Second, 802.11 allows data applications to be used. The most common deployment of wireless mobile networks has been made by private sector entities such as banks and other companies who want these LANs inside buildings. There is also a growing marketing focus on the deployment of 802.11 within homes (see Figure 1).

Figure 1: Possible Indoor Deployment of a Wireless LAN like 802.11 in the future



Source: Fisher, Chris, "Wireless home nets need 802.11," EE Times, July 28, 2000, [online] http://www.eetimes.com/story/OEG20000728S0021.

Most examples of large scale wireless network deployment provide fixed wireless services (such as in Latvia). When networks have roaming capability (users can maintain connectivity while physically moving around within the coverage area), these have usually been deployed indoors, in wireless Local Area Networks (LANs). In the last few years, however, there have been several experiments in the use of wireless LANs to provide Internet access to outdoor areas which would be extremely difficult or prohibitively costly to physically connect to the Internet with traditional wired technology.

[28] Rao, Manjuprakash Rama, "Design Challenges in 2.4 GHz ISM Band : Wireless LAN and Bluetooth," Mitel Semiconductor Asia Pacific, Commsphere 2000, Madras, India, February 2000. and Tully and Riekstins.
[29] Derfler, Frank, "Crossed Signals: 802.11b, Bluetooth and HomeRF," ZDNet, March 28, 2000, http://www.zdnet.com/pcmag/stories/opinions/0,7802,2470132,00.html

In Aspen, Colorado in the U.S., for example, several private citizens set up an outdoor wireless network that provides high bandwidth Internet to much of the town. The so-called Ultimate Taxi offers customers the opportunity to send and/or receive emails, streaming audio and video as they drive through Aspen.[30] There are also rooftop-based 802.11 systems allowing roaming that have been deployed in San Francisco in SF LAN, and plans are underway in other cities in the United States, including Boston, Seattle and Portland, Oregon.[31]

Most relevant for this paper and for the developing world, in the remote town of El Bohechio in the Dominican Republic, a group of MIT researchers led by Dr. Michael Best is currently deploying an 802.11 wireless, high bandwidth data network that will create a Village Area Network in which residents will be able to use handheld devices to access the Internet in an area of 11 square kilometers around City Hall.[32] Internet connectivity will also be extended to fixed locations that will contribute to the community's social and economic development, such as the local health center and schools.

As prices continue to fall for this technology, it seems like a more and more attractive option for larger scale deployment. As of January 2001, the cost for the installation of an 802.11 network that could cover 30 square kilometers hovered between US$20,000 and $30,000.[33] If the user base within this area numbers in the thousands or tens of thousands, the per user cost of deployment begins to look very attractive.

The lessons for other developing countries are tremendously important – at an extremely low cost, it is becoming increasingly possible to rapidly deploy a high speed Internet network that is independent of the traditional telecommunications infrastructure.

Internet on Your Cell Phone: Moving towards Third Generation (3G) Cellular.

The fulfillment of predictions of ubiquitous, low cost, mobile, high bandwidth Internet could depend upon the success in upgrading cellular technology through the next generation of cellular technology. Cellular telephony is considered to have already gone through two generations of technology. Analog cellular was the first generation, digital cellular is the second generation (2G) which is now available today, and the third generation, which is predicted to emerge in 2002, will incorporate mobile high speed data.

Before cellular networks are upgraded to full-fledged 3G capability, incorporating the Universal Mobile Telecommunications System (UMTS) protocol, there will be an intermediate stage that is referred to as 2G+. In the 3G era, there will be "always on" high bandwidth Internet capable of 144 Kbps while mobile and 2Mbps while stationary, enough to support the delivery of video, graphics, music and conferencing. UMTS will be able to do this by utilizing wider pieces of radio spectrum that will most likely include not only terrestrial radio spectrum, but also the satellite network and parts of the UHF

[30] The Ultimate Taxi, [online] http://www.ultimatetaxi.com.
[31] Churchill, Sam, "Community LANs, They Popping Up Everywhere," Computer Bits, January 2001, [online] at http://www.computerbits.com/archive/20010100/communitylan.htm.
[32] [online] at http://edevelopment.media.mit.edu/van.html.
[33] MIT Media Lab estimates.

television band.[34] 3G embodies the hope of a truly global high bandwidth Internet, as typified by the futuristic quality of 3G device prototypes such as those in Figure 2.

Figure 2: 3G device prototypes (Clockwise from upper left) Nokia 3G Terminal Concept II, Motorola Concept Handheld, Siemens SX45, Ericsson Communicator Platform.

Source: GSM Association, 2001, [online] http://www.gsmworld.com.

Currently, GSM, the cellular standard in Europe and much of the rest of the world (55 percent of global cellular subscribers) supports data speeds of 9.6Kbps. The 2G+ intermediate stage, which will add data extensions to GSM and TDMA (one of the common protocols used in the Americas) to incorporate the General Packet Radio Service (GPRS) standard, will support data speeds between 8Kbps and 115Kbps. Under GPRS, it is expected that telecom operators will be able to charge per quantity of traffic, instead of per time period.

Over 100 telecom operators worldwide have announced agreements with GPRS providers to begin the process of adapting their existing cellular networks, including many in the developing world.[35] The expected benefits of 2G+ should be a great boost for Internet use in developing countries except for a major drawback in terms of cost. It is likely that the GPRS terminal equipment will initially retail at US$350-400 and eventually cost US$200 per unit.[36] This is a price that is too high for the developing world, at least for the majority of individual users. Although many analysts point to a tremendous uptake of 2G+ systems globally (with some estimates of almost 700 million users of mobile microbrowser services by 2006),[37] the majority of these users will be in Europe, the United States, and a handful of other countries such as Korea and Singapore.

[34] "A Wap-ing dilemma," *Irish Computer*, June 2000, [online] http://www.network365.com/press/ic_June2000.htm
[35] Alcatel news. [Online] http://192.160.6.11/consumer/mobilephone/news_in_brief.htm.
[36] Gandhe, Milind, and G. Murlikrishnan, "GSM-based Wireless Internet Access Solution for Developing Countries" Mobile Communications Technologies Group, Silicon Automation Systems, February 2000.
[37] [online] http://www.ovum.com

In the past two years, several new services and standards have been introduced that have given added data capability to existing digital cellular networks, and which are bridging the transition between 2G and the expected general adoption of GPRS. Chief among those are: the Short Messaging Service (SMS) on GSM cellular phones; Wireless Access Protocol (WAP), a prevailing standard in Europe; and I-mode, most popular in Japan. SMS operates on the GSM cellular system and utilizes a channel that had previously been used for network maintenance until it was opened to allow users to send each other text messages. Both WAP and I-mode compress the standard protocol from the World Wide Web, Hyper Text Transfer Protocol (http) and the standard Web language, Hyper Text Markup Language (HTML) so that there can be faster Internet access from 2G cellular devices with their limited bandwidth and intermittent network coverage

Short Messaging Service. SMS has been called a "killer application" that has been likened to electronic mail; the use of SMS has been explosive worldwide. Growth has been tremendous for the past two years (although the first SMS was reportedly sent in 1992).[38] Already by August 2000 there were over 9 billion short messages sent each month worldwide (see Table 3), with expectations of explosive growth continuing for years to come.[39] Some analysts predict that there will be 100 billion SMS sent each month within three years.

Given the relatively high penetration rates of cellular telephony within many developing countries, the ease of use of SMS and the relatively low cost per message (subscription packages vary across countries countries), this seems a technology that is ripe for the development of applications and uses that could enhance the social and economic development process. Many of the needs for information that the Internet fulfills can be supplied by this medium.

Table 3: SMS Messages Sent (in Billions)

Region	December 1999	December 2000
EMEA	2.0	2.4
Japan	2.0	3.6
Asia-Pacific	1.0	13
North America	0.2	10
South America	0.2	17
World	**5.4**	**46**

Source: [online] http://cyberatlas.internet.com/markets/wireless/article/0,,10094_477641,00.html

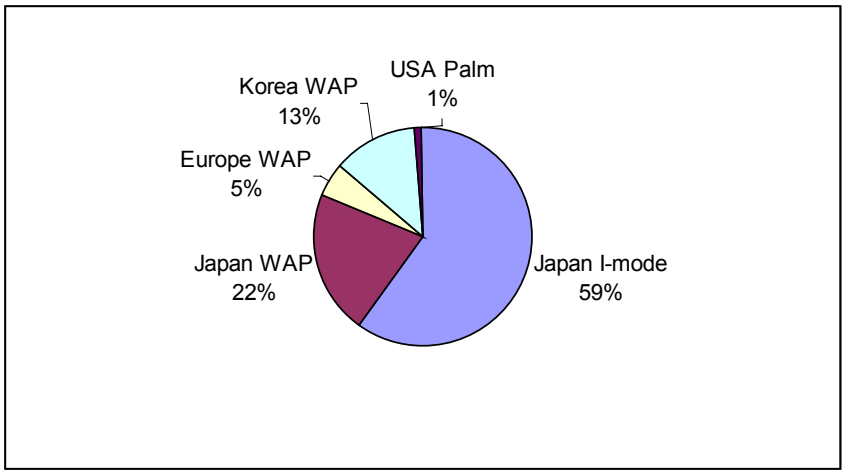
[38] "An Overview to SMS," GSM Association, [online] http://www.gsmworld.com/technology/sms.html

[39] "Variety of Uses Propels Short Messaging," *Cyberatlas*, October 5, 2000, [online] http://cyberatlas.internet.com/markets/wireless/article/0,,10094_477641,00.html

I-mode. After the launch of this network in 1999 in Japan, the success of DoCoMo's I-mode network was overwhelming, as over a million Japanese signed up each month for this service which offered Internet on their cellular phones. As of August 2000 there were over 10 million people in Japan using I-mode technology.[40] As can be seen in Figure 3, the explosion of I-mode in Japan has led to the largest wireless Internet population in the world, as simultaneously there has also been rapid growth in the WAP market.

The future of I-mode as a protocol with a truly global impact is doubtful, however. Unlike the WAP standard, I-mode is a proprietary system that until now has been developed and deployed in only one country (although AT&T recently announced that it was launching I-mode service in Seattle in the U.S.). Much of the success in Japan of I-mode has been attributed to the lack of a widespread Internet boom previously, as well as to the Japanese cultural proclivity for gadgets. It remains to be seen how DoCoMo's significant investments in both North America and Europe will influence the growth of wireless Internet there. As far as the spread of I-mode to the developing world, it seems unlikely that this standard will become a dominant protocol, given the emphasis upon gaining market share in the developed markets, the commitment of so many countries to the open WAP standard, and the high cost of building a microcellular network.

Figure 3: Breakdown of Mobile Internet Users, Worldwide (November 2000)



Source: Eurotechnology Japan, [online] http://www.eurotechnology.com

Wireless Access Protocol (WAP). In Europe, the launch of WAP technology was seemingly less successful than I-mode's explosion, as consumers reacted badly to the seemingly slow bandwidth, small screen size, cramped keyboard, and poor security, as well as the initial marketing failures of the WAP campaign.[41] Although WAP has come under serious criticism, particularly since its slower uptake has been compared to the rapid diffusion of I-mode phones, the significance of WAP should not be underestimated. WAP represents a global open standard protocol that was developed by a number of large multinational companies (including Ericsson, Nokia, Motorola, and Phone.com), with commitments by telecommunications carriers throughout the world to work on WAP

[40] NTT DoCoMo Press Release, August 7, 2000.
[41] Nielsen, Jakob, "Killing Time is the Killer App," *The Feature*, December 4, 2000, [online] http://www.thefeature.com/article.jsp?pageid=8183.

deployment.[42] Until 2G+ is deployed at the end of 2001 or in 2002, WAP could represent the most likely global opportunity for mobile wireless Internet.

The future success of WAP depends on whether current and future WAP operators and content providers are able to maintain the protocol's relevance as 2G+ systems are deployed.[43] Because it is an open standard that can be applied to any technological platform, WAP could successfully evolve into an important protocol in the GPRS system.

Within the developing world, WAP faces the same difficulty that is foreseen under GPRS. The cost of WAP telephones remains quite high, particularly in comparison to the 2G cellular technologies that are currently being deployed throughout the world. Users who have already invested in a digital cellular handset are unlikely to upgrade to a costly WAP device, particularly if they understand that WAP may be a temporary technology that disappears over the next few years with the onset of GPRS and then 3G.

The future of all of these mobile Internet standards is far from clear. Some analysts argue that 3G itself will not be successful. Given the exorbitant prices that were paid in last year's 3G auctions in Europe (US$43.7 billion in Germany and US$36 billion in the United Kingdom for the rights to the UMTS spectrum, not including the future costs of building out the network), many observers feel that the 3G system is not financially viable. In the case of several European countries, UMTS providers have sunk costs that equal US$1,000 per possible subscriber, figures that would extremely hard to recoup. Others feel that consumers will be content with the 2G+ standard and will not see the need to upgrade again to costly 3G handsets and service.[44]

Given the problems that are expected under both 2G+ and 3G systems, and as hard as it is to predict consumer patterns globally, WAP technology could have a significant impact on Internet diffusion in developing countries. If there are doubts about the cost effectiveness of 3G solutions even in a developed world context, then it seems unlikely that third generation cellular will provide a widespread answer for the developing world. While it is true that much of the high price in the developed world comes from what is generally agreed to have been overbidding in the 2000 European 3G auctions, if 3G were to fail in developed markets, it would have a slim chance of success in developing nations. Even if 3G is to succeed, without dedicated research to make 3G, or even 2G+ technologies cheaper for the developing world, wireless high bandwidth Internet will be accessible by only small, wealthy portions of the developing world population. Of course, time will have a deflationary effect upon 3G prices, but this is not likely to happen in a significant way until later in this decade, unless there is a concerted effort by the ICT community to develop low cost 2G+ and 3G telephones specifically for developing countries. If this is the case, then one possible hope for the developing world is to fully embrace WAP cellular technology.

[42] "Understanding WAP," *Financial Times*, Summer 2000, [online] http://specials.ft.com/ln/wap/.
[43] "WAP Market Strategies," OVUM, [online] http:www.ovum.com.
[44] "Negroponte: 3G will not see the light of day," ZDNet, September 16, 2000, [online] http://www.zdnet.co.uk/news/2000/36/ns-17861.html.

Table 4: Projected number of WAP users worldwide (in millions)

Geographic area	2000	2002	2003	2005
Africa, Middle East	0	2.1	6.7	23.1
Central and South America and the Caribbean	0	0.2	9.5	35.1
Asia – Pacific	5.9	35.0	67.4	159.0
Europe	0.07	25	68.4	171.6
North America	0,2	14	37.5	95.6
TOTAL	6	77	190	484

Source: Ovum, [online] http://www.ovum.com.

This conclusion is borne out by some analysts' predictions such as those in Table 4, which shows significant growth of WAP markets in Africa, Latin America and Asia. With the WAP protocol's open standard, the widespread existing commitment to its rollout that already exists, and the energy and momentum that cellular telephony already has in the developing world, the main obstacle for more rapid WAP deployment lies in the cost of the handset. However, given the similarities between the I-mode and WAP standards, it does not seem unreasonable that the low cost research tradition embodied in certain Japanese handheld interfaces (that will be discussed later on the paper) could be incorporated into the WAP system, thus producing low cost devices that operate on a global open standard for mobile wireless Internet access. While it would not provide high bandwidth Internet, the success of short messages services and email over both the I-mode and WAP systems seem to point to a model that is replicable in the developing world. A WAP device would certainly offer enough bandwidth to overcome many issues of information scarcity such as the spot labor market scenario described at the outset of this paper.

Satellite solutions. The advent of true global roaming came with the launch of the Iridium satellite system in 1999. There had been great hope that Low Earth Orbit Satellites (LEOs) would provide a low cost remedy for the developing world, at least for voice communications. Unfortunately, the per handset (US$1,000 to $3,000) and connectivity charges (~US$3/minute) remained too high, particularly with increased competition from roaming GSM cellular telephones, to make Iridium a feasible solution for large scale deployment within communities in developing countries, and the ensuing financial difficulties of the system keep Iridium as a niche product suitable only for users in the developing world with ample budgets (such as employees of international organizations and military personnel). There are still a number of other planned LEO satellite systems, some of which will offer data solutions, but they have yet to prove that their cost structures will make them reasonable alternatives for Internet deployment at-large in the developing world.

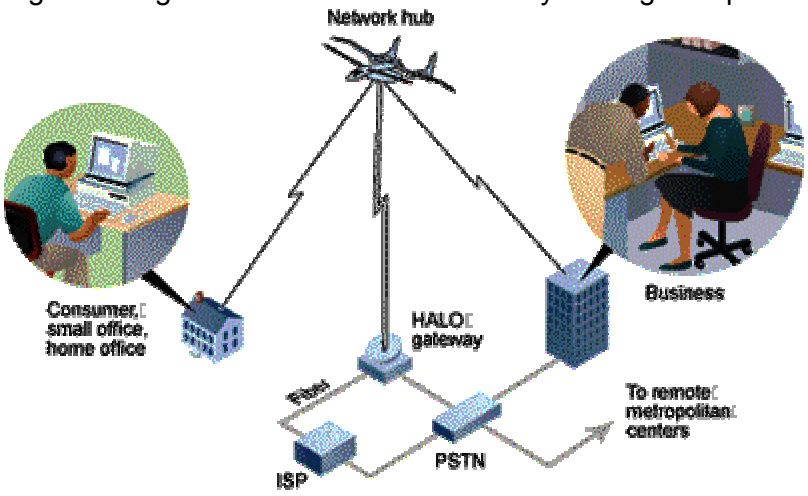
The use of VSAT (Very Small Aperture Terminal) to deliver two-way voice and data communications, through either a small or large earth station, is fairly common in developing countries, particularly by organizations wishing to create private networks where issues of terrain prohibit either microwave or landline solutions from an international gateway. VSAT will continue to be a viable alternative for connectivity in many areas. Much has been written in the literature on ICTs and Development on the use of VSAT in the field, so this topic will not be covered in great detail within this paper.

Internet Delivered by Aircraft. In the last year or two, a number of groups have begun to explore aircraft, dirigibles and other airborne vehicles as a potential alternative to

satellites to deliver Internet in a cost effective manner. Citing reduced financial risk due to the smaller investment than is necessary to launch a satellite system, easier software and hardware upgrades and more dependable technologies, these ventures have yet to prove that they are commercially viable, but some of their ideas are intriguing.

One such company, Angel Technologies, is exploring how to provide high bandwidth Internet to metropolitan areas between 50 and 75 miles in diameter from extremely high altitude airplanes that would hover at about 10 miles above the Earth (see Figure 4).

Figure 4: High Bandwidth Internet Delivery Through Proposed HALO Aircraft System



Source: http://www.angeltechnologies.com/techpaper3.htm

Another initative called AeroVironment, which has funding from NASA, is researching the possibility of deploying ultralightweight solar-powered high altitude aircraft (Helios) that will be capable of staying aloft for six months at 60,000 feet above the Earth, providing high bandwidth Internet services to a wide terrestrial customer base.[45] While it seems likely that this initiative is between 5 and 10 years from a possible launch, the potential for both the developing and developed nations is exciting.

Figure 5: Possible Future Internet Delivery by Ultralight Solar-Powered Aircraft

[45] Aeroenvironment, [online] at http://www.aerovironment.com/area-telecom/telecom.html

Source: [online] at http://www.aerovironment.com/area-telecom/telecom.html

Perhaps the most relevant for the developing world of these alternative visions of wireless Internet delivery over a large area was the announcement in March 2001 by Platforms Wireless International that it would be launching in June 2001 its first unmanned 15 foot long zeppelin that would provide cellular connections across difficult terrain in Goias, Brazil.[46] This company claims that its airship costs less than half than the cost of a cellular tower and has tremendous cost benefits over satellite systems such as Iridium. The Aerostat would be tethered at 15,000 feet above sea level, carry 1,500 pounds of antennae and communications equipment and support a variety of cellular protocols for 125,000 cellular customers in an area that is 140 miles in diameter. This commercial venture is specifically targeting the developing world, noting that "you won't see cellular towers in the Amazon, in Africa or in China."

Outside the Local Network. The delivery of Internet to the local network is not considered in detail in this paper. However, the various modes of delivery deserve a mention, as they certainly influence the final cost of Internet services. Over the mid and long range, the most cost effective solution for Internet delivery depends upon the local and regional conditions, and the most appropriate mix of satellite, fiber-optic cable and mid to long range microwave transmission.

Devices and Interfaces

A less expensive telecommunications network can significantly lower the total cost of deploying Internet-enabling ICTs by impacting the price of Internet Service Provision, but the major cost that the end-user faces related to Internet access is the hardware interface to the network. While the personal computer (PC) continues to be the predominant device used to access the Internet worldwide, there are clear limitations of the PC in terms of continued Internet diffusion in the developing world. Apart from issues of how PCs handle power outages and unreliable electricity supply and the

[46] Cohn, Michael, "Zeppelins Take Wireless Access Aloft," Internet Everywhere, March 9, 2001, [online] at http://www.infoworld.com/IE.

fragility of PCs in many developing country environments where heat, dust or humidity greatly deteriorate their performance, the high cost of personal computers remains the most serious hurdle to a more rapid spread of the Internet.

There is, however, an increasing array of alternative, lower cost, hardware interfaces that offer new diffusion channels for the developing world. These options include the new and next generations of Internet appliances, game consoles and handheld devices.

Personal Computers. While prices for PCs continue to plummet, given the primary overdesign philosophy and the continued focus on developed markets by PC vendors, it seems unlikely that prices can drop to levels that could appeal to broad swaths of the developing world. That said, however, the flattening of demand as PC markets especially in the United States become saturated may push PC manufacturers to begin to tailor their products to developing countries. The personal computer will likely remain the main hardware interface globally for years to come, especially in shared hardware environments such as schools, telecenters and offices. However, there is sure to be some erosion as other devices, like the ones discussed below, become established in the market.

Another low cost personal computer option is the supply of refurbished, used PCs that is increasingly becoming available to developing nations through Non Governmental Organizations (NGOs) and small private companies. Organizations like the World Computer Exchange (the Exchange),[47] based in the U.S., which works with the Sustainable Development Networking Programme (SDNP) of the United Nations and a global network of 87 NGOs, distributes working, Internet-ready computers. The Exchange not only ensures that these computers actually work, but also helps its NGO partners formulate plans that contemplate maintenance, electricity, wiring, installation and connection of the equipment in the schools, orphanages and learning centers that are the final destination. Each month the Exchange plans to ship containers with almost 400 computers and monitors to different sites in 33 developing nations. Although in some areas of the developing world there is a stigma associated with used machines, the Exchange has created a low cost transfer mechanism through the economies of scale of shipping (it costs around US$20,000, or around US$50 per computer and monitor to ship a container of computers). Its partnership with the SDNP allows the total cost to the Exchange to drop to US$15,000. The Exchange and other organizations like it offer a useful remedy for the millions of computers that are annually discarded in the more developed nations.

Desktop appliances

There is a whole new generation of “Internet appliances” that have come onto the market during the past few years which are primarily marketed within the developed world. These appliances are billed as low-cost alternatives to the PC and are geared towards developed world users who do not need the full-fledged functionality of a personal computer, but only wish to access the Internet. As the PC market has become saturated, a number of manufacturers have entered this niche market (see Table 3), hoping to capture a hitherto untapped group of consumers who have not been drawn into the PC market because of either higher prices or “computer phobia.” The lower price and ease of use are the main selling points. An examination of the range of

[47] See [online] http://www.worldcomputerexchange.org.

appliances in Table 5 reveals that there is a range in price of several hundred dollars, with the high end of the spectrum being in the same price category as low end personal computers or wireless handhelds (see Table 7), and the low end being close in price to lower end handhelds without Internet access. The appliances reflect the growing convergence of digital media, as some are oriented around the television, some around Ethernet and dial-up telephony for their network access.

Interestingly enough, although there looks to be quite a bit of competition in this niche developed world market, there seems to be no attempt to market these products to the much larger potential markets of users in developing countries for whom net appliances would be a much more affordable option than personal computers. Two notable exceptions to this manufacturing and marketing philosophy can be found in India and Brazil.

In Bangalore, India a group of computer scientists joined together to form the Simputer Trust, a non-profit organization devoted to designing the Simputer, a low cost computing appliance that will cost less than US$200, be loaded with localized open source software applications running over the Linux operating system, and offer Internet connectivity through a 30kbps modem.[48] An effort will be made to create Simputer applications relevant to the Indian context, such as microbanking and agricultural information. There

[48] The Simputer Project," [online] http://www.simputer.org.

Table 5: Selected Desktop Appliances available in U.S. Market, 2001

Manufacturer/ Model	Processor Speed	Installed Memory	Modem Speed	Operating System/ Interface	Price (US$)	Included/Comments
Emachines MSN Companion	200MHz	32MB SDRAM	56K	Microsoft Windows	349.99 (199.99 on sale)	Monitor, wireless keyboard
Netpliance I-opener	200 Mhz	32MB RAM, 16 MB Flash	56k	N/A	199.99	10" flat screen, wireless keyboard, printer port, PS/2 port, 1 USB port, 2 phone jacks, speakers
COMPAQ IPAQ Home Internet Appliance IA-2	N/A	32MB SDRAM	56K	Microsoft Companion	599.00 (499.00 on sale)	Monitor, wireless keyboard, 4 USB Ports
Cidco Mailstation	N/A	512 KB flash	33.6K	N/A	99.99	N/A
3com Ergo Audrey Home Internet Appliance	N/A	N/A	56K	N/A	499	Wireless keyboard, stylus touch screen, 2USB Ports, 2 phone jacks, 1 serial port
COMPAQ Internet Appliance 1A-1	N/A	32 MB RAM; 16 MB Compact Flash	56K V.90	N/A	399.99	10"flat screen, 4USB Ports
PIA (Personal Internet Appliance)	Celron 366 MHz (upgradable to Pentium III 500)	32MB PC100 SDRAM (upgradable to over 700MB)	56K V.91	Linux	349.95	Keyboard, no monitor, 2.5 GBIDE harddrive; 8MB shared AGP video, 16 bit sound; 10/100 interface card; 1 PCI/ISA Expansion Slot
AOL/Philips Electronics America Online TV	N/A	N/A	56K v.89	N/A	249.95 plus service (14.95 for AOL TV, plus 21.95 standard monthly AOL membership)	Set top box for cable or satelite (later in 2001)
Gateway Connected Touch Pad	N/A	N/A	56K V.89	N/A	499 (plus 21.95 monthly aol membership fee)	Keyboard, 10" touch screen, 2 USB Ports; Ethernet option
NadaPC Surfboard	32bit RISC Processor 129 MHz	32 MB RAM; 32MB ROM;8MB Flash (expandable)	56K V.90	Windows CE	Free plus service charge (21.95 per month with 36 month contract)	2.2lbs; 2 USB ports; serial port; 2 infrared; PCMCIA type II slots; compact flash card slot; 8.2' diagonal display
Vestel Internet Terminal	N/A	N/A	56K V.91	Microsoft CE	N/A	15"monitor or wireless web pad
Vestel Internet TV	N/A	N/A	56K V.92	Microsoft CE	N/A	Wireless key board, printer port, 16 bit sound jack
WebTV Classic Internet	150 Mhz, R5230	8 MB RAM, 2 MB ROM, 4 MB Flash	56K V.90	N/A	Receiver 99 to 129. 9.95/month, 21.95/month, depending on TV model	Wireless keyboard
New Internet Computer	VIA Cyrex MII PR266 Processor	N/A	56K v.89	N/A	319.95 with free ISP (199 without monitor)	24x CD-ROM, 10/100 base T Ethernet, 2 USB ports, Keyboard, Mouse, Speakers

Source: Author's compilation from public information on World Wide Web, January 2001.

are also plans to address issues of illiteracy through the development of speech to text translators. The Simputer is expected to be launched in 2001 to the Indian market.

Just as the corDECT wireless local loop technology designed by IIT Madras is an excellent example of the redesign of technology developed in the U.S. and Europe, the Simputer combines two elements that will be essential to spur greater Internet adoption: lower cost and localization of design and content. It remains to be seen whether the other network appliance manufacturers will shift their marketing focus to developing countries, but in the meantime, efforts like the Simputer have the potential to radically change the trajectory of Internet access in India.

An even larger scale program in this vein was recently launched by the government of Brazil to mass produce a personal computer[49] that would retail for about US$300. The program will be backed by a US$500 million government fund, and would also provide consumers with a special line of credit that would allow payment for the machine over a 24 month period with monthly payments of around US$10.[50] The technology to be used in this program was developed in the Federal University of Minas Gerais, and would be available to hardware manufacturers who wish to participate in the program. It remains to be seen how this program develops, but this is an example of an extremely forward-thinking initiative by the Brazilian government that incorporates cutting edge research within a university laboratory in an extremely innovative way.

Game Consoles. The video game console market should be ripe for further exploration for Internet access in the developing world. Game consoles have a lower retail cost than personal computers, are more powerful computational machines in several respects, and their physical design makes them well-suited for a range of environmental conditions. Game consoles are designed to be more rugged than PCs, as they are meant to withstand the rougher handling of children. This makes them good candidates for use in school environments or other places where conditions are less easily controlled.

The current design of devices such as the Sony Playstation II and the Sega Dreamcast show further evidence of convergence and the blurring of more traditional functions such as computer or game console. For example, the Playstation II comes with a DVD player, capable of playing both audio and video discs, and the Dreamcast has a built-in CD-ROM. The Dreamcast is also packaged with a keyboard, a modem, and its US$21.99 Seganet Internet Service Provision package comes with four connections to the Internet that can be used on separate PCs or other Dreamcast machines.

At a retail price of around US$300, the Sony Playstation II is price-competitive with the lower end of the PC market, and its Emotion Machine processor is actually more powerful than most desktop PCs at any price. The Sega Dreamcast has a retail price for US$149.95, but with the purchase of a two year ISP contract, the Sega Dreamcast hardware for a time was being given away for free (when rebates are factored in). Both consoles are ready for the Internet, and come with storage capacity in DVD or CD-

[49] With 500 Mhz, 64 MB of RAM, 16 MB of flash disk instead of a hard disk, Etnernet board, 56 kbps modem, 14" monitor and soundboard.

[50] Rich, Jennifer, "Compressed Data: Brazilians Think Basic to Bridge the Digital Divide," *The New York Times*, February 12, 2001.

ROMs.[51] With other manufacturers such as Microsoft and Nintendo also competing in this market, it is likely that game consoles will continue to become more powerful and to remain competitive with their market prices.

Table 6: Features of Sony Playstation 2 and Sega Dreamcast

Manufacturer/ Model	Processor Speed	Installed Memory	Modem Speed	Operating System/ Interface	Price (US$)	Included/Comments
Sega Dreamcast	Hitachi SH4 200 Mhz	128 bit architecture, VMS Memory card	56K	Windows CE	149.95. Free with 2 year Seganet ISP at 21.99/month	64 bit audio output, Modified CD-ROM (GD-ROM)
Sony Playstation 2	Sony Emotion Engine, 300 Mhz	128 bit architecture	Cable Modem	Sony OS	300	Dolby surround sound, Dolby Theater System, DVD-ROM, IEEE1394 and USB ports

Source: Author's compilation of public information from World Wide Web, January 2001.

The low cost, rugged design and speed and power of game consoles like the Sony and Sega products make them very attractive for developing world markets. With the addition of a hard drive and some minor alterations that allow them to run software applications that are not only games, any of the major game manufacturers could enter quite competitively into markets in developing countries, which until now have been dominated by the PC manufacturers. As a marketing strategy, given the extremely competitive nature of the world video game market, such an entrance would seemingly be quite attractive from a public relations standpoint. The developing world would certainly gain from the provision of such powerful computational machines at a low price.

Handheld Devices

Great hope is being placed on handheld devices as the most cost effective means to extend Internet access to the developing world. Their size, mobility and potential lower cost than desktop appliances make them a very likely vehicle for more rapid Internet buildout. There are a number of iterations of these appliances that are worth exploring in this light.

Personal Digital Assistants (PDAs). Future offshoots of today's PDAs could be prevalent Internet access points for users in developing nations. Designed to manage daily needs such as address books, accounting, calendars and other tasks, the rapid development of greater memory capacity and wireless capability has led to a proliferation of software applications. Some devices including more advanced standard applications such as e-mail, short text messaging and limited Internet access. In the U.S. and European mainstream retail markets, there are currently no personal digital assistants which are cost-appropriate for developing countries. The industry standard in the United States for a wireless handheld personal digital assistant was the Palm VIIx as of January 2001. This device comes with 8 MB of memory, a number of software applications, and allows mobile wireless access at speeds up to 50 Kbps to the Internet wherever the Palm network is deployed within the U.S. The Palm VIIx as of January 2001 was selling for

[51] "Playstation 2," [online] http://www.playstation2.com and "Sega Dreamcast," [online] http://www.dreamcast.com

around US$400. The closest competitor to this device was the RIM Blackberry Wireless Handheld (see Table 7), while the Motorola Talkabout represents a lower end of the PDA market, offering a bare minimum standard of connectivity with email and web browsing.

Table 7: Features of Selected Wireless PDAs

Manufacturer	Processor Speed	Installed Memory	Modem Speed	Operating System/ Interface	Connectivity	Price
Toshiba/Tomy Tegacky PM-T101 Character Phone	N/A	N/A	64 Kbps	N/A	email and short messages	US$33 for device and US$2.87 per month. Data is transferred at ¥0.3 ($0.003) per packet (128 bytes
Palm VIIx	N/A	8 MB, 512 KB SRAM	50 Kbps	Palm OS	Palm Net Web Access and email	US$399 for device 9.99/month Palmnet access
Rim Blackberry 957 Wireless Handheld	32 bit, 386 Intel processor	5 MB Flex Memory & Flash	N/A	N/A	Email	US$499
Cybiko	32 bit, 11 MHz Hitachi H8S/2246	N/A	30 channels, 19200 bps each channel	CyOS v.1.2	Email, short messages	US$85
Motorola Talkabout T-900	N/A	N/A	N/A	N/A	text based email and web browsing	US$179 for device US$9.95-19.95/month service plans

Source: Author's compilation of public information from World Wide Web, January 2001.

In Japan, there is a different design tradition which has led to more likely candidates for adoption by the developing world in terms of cost. In February 1999, for example, the toy maker Tomy, together with Toshiba and DDI-Pocket's, released a "Character Phone" called the Tegacky. This PDA was initially marketed primarily to Japanese schoolchildren as a way for them to pass messages back and forth with one another. Retailing for about US$33 (the units are sold very near cost) with a cost of about US$0.01 per message, the Tegacky operates on the Japanese I-mode microcellular network, and provides its users with the ability to send messages, maps, and other pictures to other users, using a stylus and touch screen. Its extremely small size (see Figure 6) also makes it very useable and convenient to carry. With enough memory to hold up to 1,000 characters and the ability to check e-mail, young Japanese professionals and other adults began to use the Tegacky as a wireless personal digital assistant.

In questions of price, the design philosophy embodied in the Tegacky would seem to offer a realistic option for low income consumers in developing markets, when compared with the price of handhelds such as the Palm VIIx.

Figure 6: Tomy's Tegacky PDA with stylus shown to scale with U.S. penny

Photo: CID at Harvard University, January 2001.

Another low cost PDA that merits attention is the Cybiko, which carried retail price of US$85 in March 2001. The Cybiko uses a stylus and a miniature keyboard to manipulate its functions such as wireless communication, electronic mail, game-playing, a scientific calculator, spell checker, Spanish-English dictionary, multilingual phrasebook, organizer/address book, alarm clock and an MP3 Player.[52] Most significantly, the Cybiko communicates with other Cybiko devices without the need for a central tower through a decentralized network, and does not have any subscription, message or monthly fee. With a manufacturers' cost that is most likely below US$50,[53] the Cybiko would also seem to signal the kind of trend in technology development that would be beneficial for the developing world.

Scientists who keep abreast of global trends in information technologies and who think about the implications for developing nations are optimistic about Tegacky and Cybiko-like technologies as harbingers of more inexpensive developments to come. According to Dr. Alex Pentland, Academic Head of the Media Laboratory at the Massachusetts Institute of Technology, within the next four years it will be possible to manufacture a handheld device at approximately the same price as the Tegacky with much greater capability. For about US$30, Dr. Pentland foresees a handheld device with voice and Internet access, relatively high speed processor, sufficient memory for complex operations, global positioning capability, and a platform that would support the addition of a digital camera and sensors that can monitor health and environmental data. The implications of this trend for the developing world are tremendous in terms of being able to offer inexpensive means to get Internet access and address serious development needs.

The Software Side of Things

Without the accompanying software, it is impossible to access the Internet with hardware and a network alone. A constellation of software, that includes an operating system, as

[52] Cybiko, [online] at http://www.cybiko.com
[53] Based on conversations with Dr. Alex Pentland of the MIT Media Lab.

well as applications and communication protocols, is generally necessary for a user to communicate across the Internet.

In the developing world, there are certain constraints that make many developed world software models inappropriate. In terms of economics, proprietary software that carries costs for purchase and licensing can make it too expensive for much of the developing world. And in computing environments that are already unstable because of older computer equipment with less memory and power, difficult weather and physical conditions, low bandwidth, high latency, frequent power outages and other challenges, software that has been developed for developed nation conditions can be inappropriate in operational terms and expensive.

Finally, there is growing skepticism as to the appropriateness of many software solutions for the developing world because they do not take into account literacy and language issues, the cultural environment and the difficulty of translating U.S. and European metaphors to other cultures.[54] Software development that is geared to specific local needs should be appropriate in terms of usability and culture.

There are a number of trends in software development that may be more appropriate for the developing world than what is represented by the current mainstream solutions. Open source software, alternative communication protocols, software designed for the needs of local communities and for older machines all could make a real difference in offering more reasonable software options, both in lower cost and enhanced operational capacity.

Linux

Since the introduction of version 0.01 of the Linux operating system by Finnish programmer Linus Torvalds in September 1991, more and more attention has been paid to open source software (OSS) as a serious competitor to proprietary software systems (such as that produced by Microsoft). There is a growing debate about whether OSS is a more appropriate model for a developing nation context. In several instances, major efforts have been launched that explicitly endorse the open source approach. In 1998, the Mexican government decided to run only Linux in 140,000 computer laboratories in its elementary and secondary schools[55]. For several years, UNESCO has promoted Linux in the developing world, particularly in the health care informatics context.[56]

There are at least two major benefits that are usually pointed out with regard to Linux. First, although there is some controversy surrounding the issue, open source software such as Linux is considered by some to be much more stable from an operational and administrative standpoint because of the predominant OSS design philosophy. Advocates of OSS believe that a collaborative approach, in which large numbers of programmers contribute to make a piece of software bug-free, is a superior evolutionary design model to the closed model of software development. In one of the definitive

[54] For example, "Community Knowledge Sharing," [online] http://edevelopment.media.mit.edu/comm_knowledge_sharing.html.
[55] Kahnev, Leander, "Mexican Schools Embrace Linux," *Wired*, November 6, 1998, [online] http://www.wired.com/news/technology/0,1282,16107,00.html.
[56] For example see "Unesco Net D@ys 2000 America Latina y Caribe," [online] http://www.unesco.org/general/eng/events/latin/.

works regarding the philosophy of open source, *The Cathedral and the Bazaar*, OSS leader Eric Raymond affirms that "the closed-source world cannot win an evolutionary arms race with open-source communities that can put orders of magnitude more skilled time into a problem."[57] Through a primarily volunteer, collaborative approach, the Linux effort has created an extremely stable computer platform. This stability makes open source software a desirable alternative, particularly in the developing world, where software instability only exacerbates other reliability issues implicit in older hardware and unstable electrical environments.

The underlying software code for Linux is openly available and distributed, and the global community of software programmers is encouraged to make its own additions and alteration to the code. In this way, through a distributed work approach, defects or "bugs" in the codes are identified and can be fixed by a much larger community of coders. Outside the mainstream software manufacturers, the global community of "hackers" is extremely decentralized; it was historically extremely difficult for this community to collaborate on large projects. With a truly global distribution platform such as the Internet, and the boost given to the OSS movement by Linux, a new method of distributed work has arisen. By some estimates, there are tens of thousands of programmers who have contributed to making Linux an extremely stable, reliable operating system. Financially speaking, not to mention administratively, organizing a workforce of this size behind a programming problem would be difficult.

The second important aspect of Linux that could make it extremely attractive to developing countries is that it can be less expensive. Unlike proprietary software vendors, which typically charge royalty fees for both the initial software and then for each additional user, most open source software is available for distribution free-of-charge. OSS such as Linux is technically not shareware (software in the public domain) because it is legally covered by the Gnu General Public License (GPL). This means that while Linux and other similar OSS are freely available and distributable, vendors who sell this software cannot restrict the rights of those users who have purchased the software. Any user of GPL covered software has the right to sell the software to others or alter the underlying software code, or distributed the software to others for free. These actions are typically not allowed under proprietary software license agreements.

This of course begs the question of why someone would purchase open source software when it is available for free. The answer to this is that while the software itself is free, there is typically no service or support available from the software vendor in the event of technical problems, aside from online resources or the benevolence of the global hacker community. Red Hat, for example, has been the leading commercial vendor of Linux, and earns its revenue not through selling the software but by providing technical support to its customers.[58]

Advocates of Linux and open source software point out that the total cost of ownership of OSS is much less than that of proprietary systems. One of the leaders of the open source movement in India, Prakash Advani, uses a comparison of Linux and Windows NT to provide print and file server needs in a small business environment to show how much more cost effective Linux can be. Advani points out that a five person license for

[57] Raymond, Eric S., *The Cathedral and the Bazaar*, [online] http://www.tuxedo.org/~esr/writings/cathedral-bazaar/cathedral-bazaar/index.html#CATB.
[58] Redhat, [online] http://www.redhat.com.

Windows NT costs 30,000 Rupees (about US$667), with another 1,500 Rupees (about US$33) for each additional user. To run a server with email capability and as an Internet gateway for 50 users, Windows NT would cost about 275,000 Rupees (about US$6,111) more than Linux per year. These are significant savings for a small business. In addition to the lack of a cost per user, client and server, Advani cites the stability and efficiency of the Linux system as leading to further cost savings for the life of the technology.[59] Finally, cost issues aside, the open source aspect of Linux, and the ability to rewrite the code in languages other than English, has enormous benefits in terms of making software more accessible to the majority of people in the developing world who do not speak English.[60]

So is open source software the best alternative for developing countries? The answer is not clear. In questions of reliability and initial cost, it seems more beneficial. It seems unlikely that most of the world can afford to, or would, pay for licenses to use software when there are good options available for free.

However, proprietary systems such as those sold by Microsoft have their own advantages. Microsoft represents the global standard for many software needs, and there is a comfort level with the Microsoft brand name that OSS does not have. There are also many more software applications available for Microsoft operating system environments, even though many of these are also proprietary software systems that must be purchased. Because of the enthusiasm and commitment of the global community of open source programmers, there is a growing library of applications for Linux, and many applications written for Macintosh and DOS environments can now be run in Linux environments through the use of emulators. Linux also is known to be more technically challenging to both install and to resolve any problems that do arise, in spite of its greater stability. Finally, there is much more written and online literature, as well as opportunity for technical support, for most proprietary systems than there is for open source software in the developing world.

There is quite a bit of disagreement, even within the open source movement, as to whether open source solutions are the most appropriate in all circumstances in the developing world. Some open source supporters advocate that governments and multilateral institutions only purchase and consider open source technologies. At the same time, even some of these more skeptical supporters push open source systems as generally more reliable for servers in a developing country context.[61]

In the end, therefore, it is not clear if the initial cost and stability benefits of open source software outweigh the possible downsides represented by the lack of customer service and potential technical challenges. As Linux and other open source software become more well-established, they will no doubt continue to become more prevalent in developing nations. Based on cost considerations alone, open source solutions are

[59] Advani, Prakash, “Why Does Linux Make Sense for India?” September 27, 2000, [online] http://www.freeos.com/articles/2345/2/3/.
[60] Hariharan, Venkatesh, “Why Linux Makes Sense for India,” [online] http://slashdot.org/features/00/01/30/1042201.shtml
[61] Bezroukov, Nikolai, “Internet and Open Source in Developing Countries and Webliography,” Softpanorama: (slightly skeptical) Open Source Software Educational Society, [online] http://www.softpanorama.org/Social/oss_in_developing_countries.shtml.

certainly worth exploration and deserve a more detailed cost-benefit analysis for each particular situation.

Much of this discussion is rather academic, however, in light of the day-to-day reality reality in much of the developing world; it is possible to purchase a pirated copy of Windows or virtually any other proprietary software, from countless vendors on the street between US$1 and $3. A significant portion of software that is sold and distributed in the developing world is pirated. This widespread piracy falls under the radar screen of most major multinational creators of content, if not in acknowledgement, at least on the more practical level of enforcement. What this means for open source software is that even as it makes gains and converts throughout the world, most potential software users will continue to opt to obtain pirated versions of established products such as those made by Microsoft. In fact, it has been pointed out that in the developing world, Microsoft products are most often considered to be "shareware," and that "copyright" is many times taken to mean "right to copy."

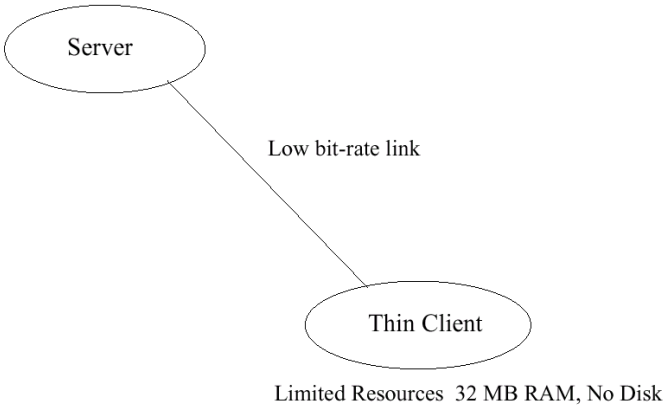
Appropriate Communications Protocols

The transport of data over the Internet takes place through the Transmission Control Protocol/Internet Protocol (TCP/IP). TCP/IP is an extremely hardy and robust system that tolerates poor infrastructure and low bandwidth conditions quite well. Even with this in mind, however, some researchers in the developing world have begun to explore other protocols that may be even more appropriate for some of the more extreme conditions that exist in developing countries. These researchers are trying, among other things, to make the Internet even more efficient under conditions such as low bandwidth, high packet loss and high latency (delay that can come from satellites or other delivery mechanisms).

This software development is also taking place in the context of wanting to make certain lower cost hardware solutions work. In one case in India, researchers at the Indian Institute of Science in Bangalore have investigated the software requirements of low cost network interfaces and the potential for "thin client" devices. These generally are devices that have no hard disk, and that draw upon the network for their resources, rather than upon local software and file systems.[62] These thin client devices would cost less than traditional computers since they do not have a hard drive, and would typically have less memory (around 32 MB) and a relatively fast computer processing unit (CPU) (see Figure 7). Applications (office suites and browsers, in particular) would run on main servers, therefore reducing the need for local storage and computational capability. The goal of a well-designed thin client system would be to use network bandwidth efficiently in order to maximize the functionality of available applications. This includes the development of new software solutions.

[62] Gopinath, K., T.S. Ajai, N.P. Singh, and K.S.R. Murty, "On the Design of a Low Cost Access Terminal" Department of Computer Science & Automation, Indian Institute of Science, Bangalore, India, February 2000.

Figure 7: The typical configuration of a "thin client" in India



Source: Gopinath, Ajai, Singh, and Murty.

These researchers at Indian Institute of Science are currently exploring the relative benefits of alternative communication protocols to TCP/IP such as Wireless Application Protocol and Wireless Transaction Protocol (WTP) to determine the optimal design that would take into account the conditions of higher packet loss and lower bandwidth that are more prevalent in India. WAP and WTP are communications protocols that were designed with lower power and memory environments in mind, and are used on the generation of WAP telephones (that were discussed earlier in the paper).

While these Indian researchers and others work to develop appropriate software code for the conditions that exist in the developing world, in the developed world, one example of this type of research is geared toward a market that does not even exist yet and which has no human dimension at this time – the exploration of space. It is ironic that in this case space is considered a market with greater potential than the developing world. In the United States, the National Aeronautics and Space Administration (NASA) together with the U.S. Defense Department and the National Security Agency are working on developing software protocols that are appropriate for the conditions envisioned for future space exploration projects.[63]

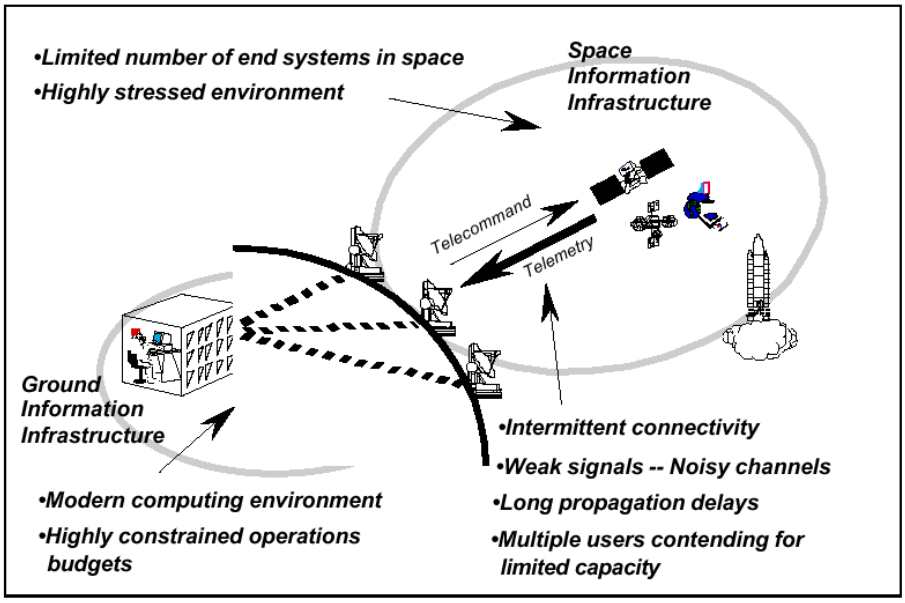
The rationale for such research is remarkably similar to some explanations of the need for new software solutions for the developing world.

> Today's internet protocols were developed for terrestrial networks and assume that connectivity is maintained, that data loss due to corruption is rare, that balanced bi-directional links are available, and that most data loss is due to congestion. Further, vendors of commercial communications products that implement these protocols use these assumptions to maximize performance and economy in this environment, making the treatment of retransmission, recovery, and time-outs inappropriate for space operations. For the large majority of space programs, the space mission environment makes performance of these protocols unacceptable.
>
> NASA, "Space Communication Protocol Standards – Extending the Internet Into Space," Page 2.2, August 1998.

[63] Zukoski, Mary Jo and Rafols Ramirez, Rafols; "A Transport Protocol for Space Communications" *The Edge Newsletter*, November 1998.

When one compares the relative constraints and challenges of designing software protocols for space and for the developing world, there are a number of parallels in terms of the conditions that programmers must consider, as is illustrated in Figure 8.

Figure 8: Extension of the Internet into Space



Source: NASA, "Draft Report: SCPS Rationale, Requirements and Application Notes," p. 13.

Given the military dimension of the NASA project, it is unlikely that the U.S. researchers could collaborate with their colleagues at the Indian Institute of Science; however, this kind of cross-national cooperation is the kind of activity that could lead to a more appropriate software design for the developing world, and aid in the diffusion of the Internet there. Especially given that most efforts to create localized technological solutions for developing nations are small scale programs well out of the mainstream, any degree of mutual support that can be given among similar research strands should be encouraged.

Lightweight Software Applications for Old Computers

Like these previous computer scientists, other researchers have investigated how to create slimmed-down versions of office suite and Internet browser software that require less memory yet lose little in functionality from more standard products such as Microsoft Office, Internet Explorer or Netscape Navigator. The goal of such research and development is to be able to run fully functional software not only on thin client devices or network appliances, but also on the older generation computers that are commonly found throughout the developing world. An example of this software movement is New Deal Inc., a U.S.-based company that has developed a suite of word processing software and a World Wide Web browser that are able to run on personal computers with as little memory and processing power as a typical 286 PC.[64]

[64] "Welcome! New Deal Inc.", [online] http://www.newdealinc.com

One issue surrounding alternative software providers that has been observed by some IT practitioners is that many developing world consumers are unwilling to forgo the brand name cache of products by global leaders such as Microsoft, and feel that they are somehow receiving a sub-par product. This is certainly not a phenomenon unique to the developing world; however, for smaller companies such as New Deal Inc. which have created low cost software applications that are well designed to work within hardware constraints more common in developing countries, this attitude works against the diffusion of their products, and in the end, this negatively affects the diffusion of information technologies and the Internet.

Shifting Technological Paradigms – Glimpses of Technologies to Come

There are numerous tracks of technological development that show tremendous promise in bringing down the price of technology even more precipitously in the future by radically changing the assumptions of how networks work and how technological components are manufactured. At the Media Laboratory at the Massachusetts Institute of Technology in the United States, for example, researchers are questioning the way that technology is developed and deployed.

In the Penny PC Special Interest Group at the Media Lab, researchers are focusing on new manufacturing processes for all the elements that make up a computational device, including chips, conductors, insulators, semiconductors, memories, sensors, actuators and display elements.[65] One idea behind this research is to obviate the need for multi-billion manufacturing environments and instead be able to use relatively low cost processes that literally "print" electronics onto paper-like substances. The economic ramifications for developing countries to be able to produce their own ICT building blocks for a cost of tens of thousands of dollars would be revolutionary. Thus far, these MIT researchers have made progress towards their eventual goal by successfully developing "electronic inks" that can be printed and programmed to change according to the needs of the designer.

Distributed computing and decentralized networks offer another research track that brings with it tremendous promise in lowering the cost and the administrative and managerial burdens in running information and communication networks. Again, researchers at the Media Lab are exploring the creation of wireless networks of devices that self-organize and communicate with one another without the need for a centralized authority.[66] Such low cost digital networks would be extremely easy to deploy, need little power and employ new routing systems, but would be extremely advantageous in avoiding the high investment costs in both setting up and administering packet-switched networks such as mobile wireless Internet.

Within the context of the Digital Nations research consortium, other researchers at the Media Lab are questioning the appropriateness of current mainstream ICTs not only in terms of cost but also in light of specific differences in language, literacy and electricity that are frequent in the developing world.[67] An emphasis upon designing technology

[65] "MIT Media Lab SIG - Penny PC," [online] http://www.media.mit.edu/pennypc/.
[66] "Project Summary: Embedded Networks," [online] http://www.media.mit.edu/~r/projects/embedded/.
[67] Digital Nations, [online] http://www.media.mit.edu/dn

with the end users in developing countries in mind is at the core of the philosophy of this research.

Unfortunately, while numerous research trends such as these exist within academia or specialized R&D labs, very few of them find their way out of the lab and into mainstream commercial space, let alone into the developing world context where they could be so valuable in eliminating or lessening obstacles to technological diffusion.

Addressing the Sources of Market Failure

Among the many barriers to greater diffusion of information and communication technologies into the developing world, cost remains a significant obstacle that stems not only from regulatory shortcomings and the high price of prevailing technologies, but also from a structural failure that currently exists in the global marketplace.

There is a great need for low cost, appropriate technologies in developing nations. At the same time, on the fringes of mainstream ICT development, there are research tracks which hold great promise for the development of those appropriate technologies. What can be done to better align the supply of technological expertise with the pressing demand that exists in the developing world?

When the actions of the leading global ICT companies are examined, gleaned through observation of their R&D activities, production processes, and sales and marketing channels, it becomes clear that the majority of them, whether they are software companies, hardware manufacturers, networking specialists or content producers, are focused on protecting and expanding their market share within the developed world. This is not unnatural behavior, since the lion's share of global wealth and consumer buying power is concentrated in the developed world. However, given the tremendous numbers of potential consumers that exist in the developing world, and the latent demand for products and services relating to information and communication, it seems that there must be a way to address the global misalignment of supply and demand. When the importance of information within the economic development process is also considered, the need to correct this market failure becomes a prerogative for those in the international development profession.

One of the few companies which has recently indicated that it understands the importance of the developing world and the potential for the development of appropriate technologies to spur economic growth is Hewlett Packard. The establishment of the HP World e-Inclusion Program is at least a signal of greater commitment on the part of one global ICT leader to help address the tremendous demand for information that exists in developing nations.[68] Unfortunately, there are very few other major initiatives underway in the private sector at-large, which suggests that real solutions need to be developed that will engage the private sector in the issue of low cost, appropriate technology development.

Some Recommendations for Action

[68] Hewlett Packard world e-inclusion – broaden access to the opportunities to the internet in developing countries [online] http://www.hp.com/e-inclusion/.

There are a number of solutions that could help develop, produce and distribute ICTs that are more appropriate to the needs of the developing world:

1. **Provide Incentives**. Compelling incentives need to be developed to attract private sector investment in appropriate technologies for developing nations. One mechanism which could be developed follows the logic established by the recent discussions around a global Vaccine Purchase Fund that would provide a significant monetary reward to pharmaceutical companies that successfully developed vaccine that were specifically geared toward disease strains found in Africa and elsewhere in the developing world.[69] The idea of Development ICT Funds is not new – similar ideas have been proposed after seminars and conferences on the subject of ICT and Development,[70] and organizations such as the Economic and Social Council of the United Nations have recently been exploring the prospect of establishing funds that would aid in the diffusion of ICTs to developing countries. If the international donor, G8 governmental and foundation communities are serious about their commitment to incorporating the Internet into the development process (as they each have expressed quite forcefully over the past several years), the establishment of a Fund would be a good way to leverage their respective funds while leaving the development and rollout of appropriate technologies to the private sector, which has the requisite expertise and finances to launch and sustain major R&D efforts. The design of such a Fund would be extremely important to identify the most important research agenda. By guaranteeing a market through the establishment of such a Fund, some progress could be made in addressing the current market failure.

2. **Market Research**. More explicit efforts should be made to show that there is indeed tremendous latent demand in developing nations for the Internet and other ICTs. There is a big role that governments in developing countries, academics, the international donor community and foundations can play in carrying out and funding the due diligence and market studies necessary to attract greater private sector interest in developing countries. If it is shown that there is certifiable demand for more Internet even among the poor, the global ICT private sector would surely pursue these new markets.

3. **Enhance Communication**. There is a real need to establish greater channels of communication and of education among ICT researchers, policy-makers and decision-makers in the developing world. As has been shown in this paper, there are numerous ongoing research activities globally that hold great promise for the development of low cost, appropriate technologies that could spur the adoption of the Internet in the developing world. Most of these activities, however, are taking place outside of the mainstream, and are truly niche programs that come to the attention of policy-makers and developing

[69] Sachs, Jeffrey, Michael Kremer, and Amar Hamoudi, "The Case for a Vaccine Purchase Fund," Center for International Development at Harvard University, 1999, [online] http://www.cid.harvard.edu/malaria/malaria.htm.

[70] For instance see recommendation for Global Service Trust Fund coming out of the Emerging Global Distance Learning Conference in Tampere, Finland, August 1999, [online] http://www.uta.fi/EGEDL/.

country leaders only with great difficulty. The process of awareness raising is not easy, especially because of the widely dispersed nature of the research programs and nations under consideration. However, it would be appropriate again for the international donor and foundation communities to take the lead in creating a bridge between relevant academic and R&D pursuits and the real world challenges in the developing world which ICTs could help remedy.

4. **Educate the Policy-Makers**. The decision-makers in the developing world need to better understand how technologies are changing, in order to plan ahead for likely (and unlikely) contingencies in technological development and to design appropriate policies. Just as the designers need to understand the problems for which they are developing technology, the policy-makers need to understand the technologies for which they are developing policy. As in the preceding item, educational and communication processes need to be put in place that encourage and channel greater collaboration between the ends of the policy design continuum.

5. **Look for Opportunity/Take Risks**. The private sector should not forget the global experience with cellular telephony and the value of entrepreneurship and ingenuity in creating new markets around the new technologies. Even without firm knowledge that there was indeed demand for cellular services in the developing world, cellular providers from developed countries invested heavily in networks and cellular initiatives throughout the developing world. The explosion so far has been something that not many observers saw coming. If any private sector business believes that there is latent demand for Internet in developing countries, with the cellular telephony experience to-date as a model, and the idea that innovative business models can create opportunity where none may appear to exist, investments into the Internet in developing nations would seem to have the possibility of high reward. This may mean utterly changing established business models to work with lower income levels – marketing ICT products to groups rather than to individual consumers, or creating loss leaders in products to build out market share, but the combination of the latent demand for Internet and the conduciveness of the Internet medium to entrepreneurship would suggest a potent opportunity for business.

6. **Social Entrepreneurship**. There is a noteworthy affinity between the global ICT community, made up of engineers, software programmers, designers and hackers, and the issues that developing nations face. Greater effort could be made to directly involve this community in the design of appropriate and low cost technologies. Part of this solution would be remedied by greater private sector commitment to developing world problems, for this would lead to more widespread deployment of ICT professionals toward these issues. But there are many other creative ways in which the ICT community could be engaged. There is a strong “liberal” bent to much of the hacker culture, which combined with the engineering mentality of wanting to solve challenging problems, could bring potent resources to bear upon the issues of the developing world.

7. **Use the Brain Drain**. Diaspora networks of immigrants are a great resource of expertise and funds to address ICT issues in the developing world. The success of Indians, Chinese, Africans and Latin Americans who have been

educated in the United States or Europe and who stayed because of the lack of opportunity in their homelands has been well documented. Many of these individuals are wealthy and looking for opportunities to give back to their native communities Networks such as The Indus Entrepreneur (TIE)[71] are great leaders and allies of efforts to spur economic development with ICTs in their countries of origin.

8. **Use the Internet Itself**. The medium of the Internet itself can be used with much greater effect in bringing together the right stakeholders and interest groups who together could make a difference in determining what technologies should be developed for what purpose. Online mechanisms could be utilized to more directly communicate the needs of the eventual users of the technologies to the designers, developers and engineers who will implement the ICT solutions.

9. **It's Not the Technology That's the Problem**. Throughout the entire process of designing and redesigning more appropriate technologies, all stakeholders should not lose sight of the fact that most difficulties in the implementation of ICT projects in developing countries stem not from the technologies, but from the social components – from the managerial, administrative and cultural tensions that new technologies inevitably bring with them. The ultimate success of these efforts will depend upon adequate preparation of these non-technological factors as well.

[71] The Indus Entrepreneurs [online] http://www.tie.org.

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