Presented at 34th TPRC, 2006

Connectivity and the Digital Divide – Technology, Policy, and Design tradeoffs for Developing Regions

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ABSTRACT

This paper examines some of the causes of poor connectivity in developing countries, and suggests options for overcoming the so-termed digital divide. Based on a techno-economic analysis of connectivity technologies and design, I show that technical limitations per se are not the bottleneck for widespread connectivity; rather, design, policy, and regulatory challenges are the reasons for high costs (which determines penetration to a large extent).

The first part of this paper deals with the “digital divide” and a brief look at existing measures and difficulties with such measures, such as issues of granularity. I present a starting point for a new framework for the digital divide, based on what we call the 4Cs of Information and Communications Technology (ICT): Computers, Connectivity, Content, and (human) Capacity.

The next section focuses on the Connectivity aspect of ICT, and examines cost components of different technologies. While there are obvious differences between technologies in terms of speeds, reach, and infrastructure, there are non-technical implications of such choices, such as legacy requirements, competition, leapfrogging, etc. Once we formulate a basic, indicative, network design for broadband, using estimated costs and some limited real-world emerging economy data, we can see what reasons there are for higher costs (and prices) than the model would indicate. We identify over a dozen policy add-ons (such as ISP licensing, spectrum fees, taxes, limits on applications such as VoIP, etc.) that raise the costs to end-users.

Expanding from the idealized model, I also present a new design for broadband across Africa (“FiberAfrica”) based on GIS modeling and a bottom-up design. This is not an idealized model but a first attempt at a hypothetical continental network based on available data. It not only includes appropriate technologies (optical fibers and fixed broadband wireless) but also innovative business models such as open access networks. The analysis shows such a design could bring affordable, accessible broadband to the majority of Africans, for a one-time capital cost of only a little over $1/capita.

KEYWORDS

Digital Divide, Broadband, Internet and Telecom Access, Wireless, Optical Fibers, Techno-economics, Open Access, Africa

A poster presentation of portions of this analysis were made at ACM’s www2006 conference

1. INTRODUCTION – DIGITAL DIVIDE

The recently held second phase of the World Summit on the Information Society (WSIS), November 16-18, 2005, was meant to focus attention on the digital divide, but much of the deliberations and negotiations focused on Internet Governance issues. While there remains a status quo on that front, slow but steady steps were taken towards addressing the digital divide.

What the digital divide is depends on whom you ask. Is it the ability to make a phone call? Get on the Internet? Through personal means (e.g., in-home) or in a shared (kiosk) mode? If the latter, how near must that be? Unfortunately, almost all studies on the digital divide suffer from methodological flaws, especially related to granularity. E.g., [1] finds correlations between incomes and penetration, or [2] between competition and penetration. While indicative in terms of overall trends, specifics should not be drawn from these because national data, suspect or outdated in many cases, never apply across wide segments of the population. The average income is based heavily on a small subset of the population, often in the capital or a few urban areas. Similarly, while there may be 2 or 3 mobile providers with licensees, they may not all have footprints in the same areas, especially rural areas. Our ongoing analysis on new methodologies indicates granular, spatial, and multi-dimensional Lorenz Curves and Gini Coefficients[1] may be a useful exercise in digital divide analysis, but it is beyond the scope of this paper to delve into such issues.

If we accept that access to information is a primary goal of connectivity,[2] entirely new mechanisms are required to understand the causes of and possible solutions to the digital divide. As increasingly recognized, the digital divide is not a cause but a symptom of other divides, spanning economic, gender, age, geographic, and other divides [4, 5]. A useful model for thinking about the digital divide is given below [4]:

1) *Awareness*: People must know what can be done with ICT (information and communications technology); they must also be open to using ICT
2) *Availability:* ICT must be offered within reasonable proximity, with appropriate hardware/software
3) *Accessibility*: relates to the *ability* to use the ICT (spanning literacy, e-literacy, language, interfaces, etc.)
4) *Affordability*: All ICT usage together should, ideally, be only a few percent of one's income (under 10% maximum); this involves life-cycle costs (total costs of ownership—TCO), spanning hardware, software, connectivity, education, etc.

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[1] Lorenz curves plot cumulative wealth (or other metric) by population, and help measure distribution (in)equality; Gini coefficients are a numeric measure of such inequality.

[2] Jaime Carbonnell [3] posited in the mid 1990s a Bill of Rights for the Information Age: "Getting the right information to the right people in the right language in the right timeframe in the right level of detail." To this, we can add "for the right value."

Reducing the divide requires improvements across all the dimensions of ICT [dubbed the 4C Framework]: Computing, Connectivity, Content, and (human) Capacity.

1) *Computing*: PCs are prohibitively expensive for most people, and shared access (e.g., community centers or cybercafes) becomes inevitable. PCs today are very difficult to use, and even "experts" spend a lot of time maintaining their machines, worrying about upgrades, security, compatibility of hardware, etc. As a complementary technology, non-PC devices are an important option, e.g., mobile phones.
2) *Connectivity*: While mobile telephony is improving worldwide (witness in Africa it is now almost triple the number of landlines), it remains expensive, limited in rural areas, and poor at providing data connectivity.
3) *Content*: Meaningful content is lacking in many languages, and most content is not locally relevant. Today's systems tend to make people passive consumers of information, instead of enabling generation of local information. In addition, rich content demands multimedia (useful to overcome literacy issues), which, in turn, requires broadband connectivity.
4) (human) *Capacity*: Users need to be aware, literate, and innovative to hardness the power of ICT. They also should be empowered to use ICT, societally and governmentally.

Of course, ICT usage does not occur within a vacuum, rather within social and cultural norms that also shape the divide. In addition, ICT usage is based on policy and business models, especially regulation. In the long run, ICT must provide value and be sustainable from both a user and a provider perspective.

If we consider the desired end-goals of empowerment and opportunities, access leads to information, which can lead to knowledge, leading to empowerment and opportunities [6]. Of course, it is not linear, and one requires complementary capabilities, especially to interpret information into usable knowledge.

Access → Information → Knowledge → Opportunities/Empowerment

Thus, access is a fundamental step in the Knowledge Economy.

2. ACCESS TECHNOLOGIES

2.1 Developing Region Issues

Digital divide statistics abound, such as by the ITU or the World Bank. As well known, the majority of users, hosts, PCs, internet connections etc. are in developed countries. At a deeper level, developing countries themselves show great variance, with China accounting for much of the growth in the last 15 years. Focusing on Africa,[3] we find teledensity as low as 5.3 per 100 population in 2002 (fixed plus

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[3] Multilateral agencies often separate Northern Africa, focusing on Sub-Saharan Africa.

mobile), growing to over 11 by 2005-end, mainly from mobiles. Investments are large, estimated around $30 billion between 1995-2002 [2].[4] Indeed, telecoms, mainly mobile telephony, have been termed the only bright spot in African industry, and the six largest (private) strategic investors in mobile had total revenues in 2003 estimated at US$7 billion, with profits of US$800 million [2].

Studies have shown that the majority (~70%) of ICT differentials can be shown by income levels, with additional variation explained by urbanization, regulatory regime, literacy, and age [2]. Thus, costs of access matter. The ITU"s Digital Access Index is one composite metric that factors in affordability when comparing ICT (in addition to quality, infrastructure, and knowledge). However, it only studies basic (20 hours) dial-up, and uses average numbers across nations.

2.2 Broadband, mobiles, and connectivity

Before we examine the feasibility and costs, we must first consider if the Internet is relevant to developing countries, let alone broadband. ICT is widely recognized as a powerful enabler towards development. The old argument of bread vs. computers has moved from competition towards complementarity.[5] While development requires large investments, ICT investments are relatively modest, e.g., an order of magnitude lower than those required in electricity [4].

A fundamental question is whether a little connectivity is good enough, e.g., mobile phones or narrowband. Some have argued that developing countries don't need broadband [8], given high costs vis-à-vis other ICT. If this is the case, backbone requirements can be done via wireless quite easily, e.g., innovative designs for low-cost modified WiFi as developed by Brewer, et. al under the TIER (Technology and Infrastructure for Emerging Regions) project at University of California, Berkeley, or even commercial microwave backbones used by cellular providers in much of Africa. E-Commerce can certainly be transacted over mobile phones. But much of the value-addition here is in terms of financial transactions and credit systems, which are limited in much of the world.

Limited backbones inevitably become saturated, as users grow and applications drift upwards in bandwidth. Quality of Service (QoS) mechanisms do not help significantly, and there are indications these create more costs than benefits for many providers [9]. This is part of the moving target phenomenon. Those who are online via dial-up then face a new divide between those who have broadband, e.g., rural America.

If one is investing in infrastructure, it makes sense to deploy solutions that will last not a few years, but a generation. Interim solutions may cost less up front, and, through cherry-picking profitable users, may

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[4] Only a fraction of investments went into new infrastructure; the remainder went into buying existing stakes through privatization, or licensing/regulatory fees.

[5] "The issue is whether we accept that the poor should, in addition to the existing deprivation of income, food and health service, etc., also be further deprived of new opportunities to improve their livelihood." [7].

even be highly profitable, but societal penetration, and hence, benefits, will be low. There is also evidence that many complementary efforts (and costs) are relatively constant, regardless of the speed of the linkages being considered, e.g., the permits and construction times for erecting a wireless tower or digging a duct. This is further reason to optimize for higher speed connectivity, something only looking at capital costs would not indicate.

Why build a network if you are not sure there will be users? If people don't have or cannot afford PCs, then this is a serious challenge. However, not only are there an increasing number of PCs for end-users, but many schools, hospitals, government offices, institutions of higher learning, etc. have computers, but find connectivity expensive.

2.2.1 Mobiles – Competitive or Complementary?

Mobile telephones operate as a proprietary, closed (but profitable) network. Add-on communications (e.g., SMS, m-Commerce, etc.) require working with the operator, unlike open networks like the Internet where the innovation can occur at the edge, independent of carrier.

Mobile telephony is now on the order of 10% penetration in Africa, and the footprint of providers in Sub-Saharan Africa is estimated as high as 57% of the population [2]. Are mobiles the solution to the digital divide, as claimed in the Economist March 10, 2005 cover story [5]?

Mobiles have been successful for many reasons beyond the need for people to communicate. Most initial providers were private, who operated more efficiently (and with much less delay) then the incumbents. Mobiles are also not an interim solution, in that the solutions deployed in developing regions are similar (if not superior) to those deployed in developed countries. Why would we consider interim solutions for data connectivity?

Mobiles fall short on several grounds when it comes to data needs.[6] For starters, it is just too expensive for much of the population; ITU data from 2003-04 [10] show average monthly costs more than double those in India, though the ratio is improving. In addition, mobile devices are such that users find it difficult to *produce* information, except in a one-to-one mode (voice *or* data, as SMS), making them *consumers* of information at best. Claims of the third-generation (3G) cellular systems providing a relevant data solution ignore the very high costs carriers hope to, rather, need to charge to recoup their investments. The total bandwidth is also relatively limited, especially if we want real broadband for many simultaneous users. The use of wireless backbones by many cellular networks across Africa further limits their ability to offer broadband.

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[6] There is significant value to mobile phones for some applications, such as use of SMS messages for agricultural price discovery, or mobile-commerce (m-Commerce), but these are subsets of the overall use of data connectivity.

Under scenarios of bandwidth scarcity, which would a provider rather supply: voice or data? As Odlyzko [11] and others point out, voice bits are worth multiple times more on average than data bits, so data again takes a back seat.

Questions about “enough” bandwidth may also be patronizing. Few people who have used (affordable) broadband would ever want to go back to narrow-band. Duncombe and Heeks [12] say telephones are what people in many developing regions need most to reduce costs – the network with whom people communicate is often known or proximate. This is a useful first step, but there are indications it may not be enough. Once gains have been culled from the voice telephony system (or, when it approaches ubiquity and thus provides no relative competitive edge), improvements will only come from data connectivity, in appropriate formats and form factors. There are undeniably higher learning curves and barriers to adoption, but these should be addressed through improved designs and technology. Consider the US or Europe (or even parts of China) – many people find more financial value (savings, new opportunities, etc.) from the web than from the phone. This may be a chicken and egg problem, however, that without the right consumer *access* to e-government or e-commerce, providers or suppliers will not build out the content to spur connectivity demand.

2.3 Techno-economic framework

Tongia [13] presents a generalized model for analyzing broadband connectivity, which includes stochastic or parametric elements for many of the variables. The four major components of the monthly costs are, along with the components or factors that matter in [brackets]:

1) *Capital expenditure* (amortized into monthly payments) [turnover or churn rate, interest rate, financing period (which is linked to churn and market competitiveness)]
2) *Operating Expenses* [customer relations, billing, maintenance]
3) *Uplinking costs* [transit or backbone fees, rated or advertised speeds, oversubscription ratio, applications allowed (e.g., peer-to-peer, voice, etc.) and topology (where does contention and sharing occur)?]
4) *One-time costs* [installation, activation, customer premises equipment (if bundled with service, else is a capital or subscriber cost), marketing, rights of way charges or spectrum, as applicable].

Importantly, this model focuses only on costs, and not price. Retail prices often have very little to do with costs, for various market, competitive, and social reasons.

Naturally, this generalized model requires adaptation for different scenarios. Not only are technologies different and not always comparable, but different locations and regulatory environments lead to different costing models and even technology choices. In a simplified model, there is an access (“last-mile”) solution that operates over the first hop between end-user and edge of the provider’s network. At the other end, the retail provider must connect to the overall Internet ("cloud connectivity"), paying uplinking fees. In between, depending on the technology and business rollout, there may or may not be an intermediate network segment or provider linking the two. Alternatively, one of these two (core or retail) providers may do this function themselves. E.g., DSL uses voice-copper over the last-mile, all the way to the central office (CO). From here, the voice and the data are separated, and data uplinks to the cloud. Cable networks typically include a metro ring to interconnect the head-ends, end points for where the hybrid fiber-coax network ends. In developed markets with competitive national backbones, this metropolitan link is often a bottleneck; upgrading this local loop can be as time-consuming and expensive as uplinking inter-city connectivity. For the middle link, collocation designs have some advantages, but don't obviate the physical need to go from a central office, headend, or base station to the point where the core is available.

Under the generalized framework as above, how does one reduce the digital divide? The first step is determining which services (and thus, technologies) apply. Availability of existing infrastructure is vital to low costs. Cable modems and DSL utilize copper that was laid to carry other, revenue-bearing services, something missing across much of Africa (wireline penetrations are a little over 3% only, mainly in urban areas [10]).[7] Mobile telephony, by its very success, limits migration paths for broadband.

Let's say the backbone is competitive. The US would qualify under that metric. Does that do enough? Rural areas may still not be competitive, and the US often sees uplink charges 5 or more times higher in rural areas. It is important to recognize that total charges for a high-speed link (e.g., a T-1) are the sum of the transit fees (at the Point of Presence) plus the local loop, and the latter can dominate.

Limited backbone connectivity in developing regions (that too only at exorbitant prices) is a major issue, esp. in Africa. Megabit speeds across Africa are rare, and largely available through satellite only (except urban niches). Costs are *at least* $2/kbps/month for special (educational) cases—with uploads much slower than downloads—and typical costs per mbps are closer to $4-5,000/month or higher, plus high upfront costs.

Backbone ("transit") prices are very different from retail connections. The latter are often advertised for tens of $/month per mbps, sometimes lower. This is because retail connectivity is shared by multiple users across an access segment, regardless of the technology. (It is inherently practical to do so, since the bursty nature of packet transmissions means average utilizations are much lower than peak.) The main differences are the levels of oversubscription, or statistical multiplexing. Business connections are usually less shared in the uplink. If uplinking can be had for as low as $100/mbps/month (this is available but cheap, strongly depending on geography, competition, etc.), then oversubscribing it by a

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[7] This means 3 phones per 100 population.

factor of 100—considered overly shared—implies per user costs of only $1/month. Personal conversations with DSL analysts indicate US providers only pay ~$2-3/month per consumer for uplinking. High oversubscription ratios lead to low performance for users, and these can be 200 or worse in Africa [14]. In addition, increasing use of peer-to-peer and rich media applications is also pressurizing uplinking speeds.

Given different design options and commercial choices providers can make, comparing technologies and providers is difficult at best, and meaningless in many cases. Table 1 attempts this through indicative numbers only. Dial-up is not shown in the table, though advertised speeds are upto 53 kbps. In reality, many connections are 28.8 kbps or lower, and effective throughput is far worse because of massive oversubscription.

Table 1: Broadband access technologies and costs for consumers (residential) (US$). The capital costs are estimates based on public data, and are per subscriber (typical deployment), not per home passed. One difficulty is cost allocation, e.g., advanced cable systems can share infrastructure for Video-on-Demand functionality. For DSL, cable, and BPL, we assume availability of existing copper. There are a few exceptions to these numbers, e.g., community, municipal, or even free WiFi and other networks being considered in some cities.

	Typical speeds (mbps) [Down/up]	**First hop ends**	**Capital expenditure /subscriber excluding CPE**	**Customer premises equipment (CPE) Costs**	**Operating costs per subscriber/ month**	**Uplinking costs /subscriber /month**	**One-time costs**	**Typical monthly prices seen in developed countries**	**Typical monthly prices in developing regions**	**Tech. Maturity or deployment**
DSL	0.64-100 both	Central Office (CO)	40	10	Operating costs are assumed to be comparable across technologies, differentiated more by business model and location than technology. Costs range from 1-6 typically.	Uplinking costs are strongly a function of location and of rated consumer speed, instead of technology. Ranges from 2-10 typically, but higher in some locations.	Low (assuming existing copper)	15-50	5-100 (for lower speeds)	High
Cable	.1-10/lower	Head-end	~100	10			Medium	30-60	5-100	High
Broadband over Powerlines (BPL)	1-4/lower	Distribution Transformer	~300	20			High	30-40	NA	Low
Fiber to the Home	100/100	Access cabinet or CO	~1000 (western figure)				Highest	30-70	NA	Low
Satellite	0.64-45/lower	Satellite	~500-1000	300-500			High	70-90	200+	High
3G cellular	0.384-2/lower	Base Station	~300+	~200			High-medium	60+	40+ (limited throughput)	Low
Fixed wireless										
WiFi (mesh)	1-11 (raw, lower in practice)	Neighboring node	~100	10			Low	20+	??	Medium
WiFi (access point)	1-11	Access point	~100 (no tower)	10			Low	20+	??	High
WiMax (802.16)	.5-10	Base station	100-200	250			Medium	30+	NA	Low

Given the numbers above, we see that capital expenses are only a fraction of total monthly costs, especially for reasonable costs of capital (10-15%). Tongia [13] goes through the above exercise in detail for a particular technology (broadband over powerlines).

The 4C Framework for the digital divide on page 3 is more important than first glance when considering costs of connectivity. Where does content sit that users want? Today, much of the global content is in select locations, especially N. America, Europe, or East Asia.[8] This implies heavy usage of international connectivity, typically submarine fibers. In contrast, a domestic-centric network not only improves performance, it also reduces costs significantly (if we assume, as seen worldwide, terrestrial links are much less expensive than submarine). This is also a reason measuring the digital divide based on international connectivity per capita, such as [15], is problematic. China, Korea, and Japan have low values because of domestic content, and the US lags Europe given much of the content is within.

2.3.1 Policy and Add-on Distortions

Cost per user clearly depends on chosen technology, penetration level, user distribution, as well as factors outside the broadband domain, including availability of complementary infrastructure. A further distortion in access costs occurs when we consider how policies (especially governmental) lead to artificial increases in the cost of connectivity (or other ICT). If one starts with the equipment (hardware, software, and installation) for an ideal network (optimized for user conditions), there is an associated cost to end-users. Any policy decisions on top, for whatever reason, create additional costs, distortions, or rents. Below is a list of policies that make connectivity such as broadband more expensive for the end-user (not in any particular order):

Table 2: Policy and regulatory add-ons raising costs of technology. This is compared to an optimized techno-economic framework, which is the bare minimum any deployment would cost based on technology, subscriber profile, applications, etc.

	Distortion	Financial Impact	Other Impacts	Underlying Issues	Suggestions (beyond eliminating the policy)
1	*ISP licensing fees*	Upfront costs (often), which become higher for low user base, or revenue-sharing (sometimes 10-15%)	Even non-financial regulations pose compliance burdens	Government revenues; Regulatory mindset	Move to revenue share, if at all; Create new licensing norms including penetration requirements instead

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[8] Caching and content delivery networks aim to mitigate this issue, but are ultimately limited.

2	*Spectrum*	Cellular licenses in Africa have reportedly sold for as high as hundreds of millions of dollars	Limited unlicensed spectrum[9]	Spectrum considered a scarce resource (which may no longer be true due to improved technology); Key frequency bands poorly utilized [16], or unavailable for broadband	Open new bands for licensed and unlicensed broadband, especially UHF bands; Allow higher power levels, incl. through antennae gain
3	*Rights of Way charges*	Can be as high as tens of thousands of dollars/mile	Limits barriers to entry	Major issues of public vs. private (both of land usage and of ICT services)	Open access solutions; Transparency
4	*Import Duties*	Can be 10s of percent on capital equipment	Impacts tech. choices	Government revenues; Domestic market protection	Revenue share models (if net revenue neutrality is desired)
5	*User Taxes and Surcharges*	Fraction of revenues, order of 10% in many places	Cross-subsidy implications	Ostensibly for universal service, many surcharges are diverted to general accounts of the govt. (or worse)	Transparency; "Escrow" accounts outside general govt. budgets
6	*Uplinking and interconnection restrictions*	Artificially enhances market power of backbone		Incumbents are powerful, and often government entities; Security rationale is often given	Non-discriminatory regulation
7	*Limits on applications and services*	Limits convergence and new revenue stream		Control over information flows; Voice over IP (VoIP) is the most visible restriction, driven by profits (often monopoly rents) from voice services	Allow full competition across services, applications, modes of delivery, etc.
8	*Limits on sharing connectivity*	Cannot share costs		Poor acceptance of low marginal costs to allow new models of deployment	New deployment models for high levels of deployment, incl. community networks
10	*Lack of clarity / consistency on "affiliate transactions"*[10]	Some charges are passed through to different classes of users	Barriers to entry (helps incumbents, often)	Regulatory immaturity; Incumbency power	Create level playing field, inter- and intra-modally
11	*Low density of target users*	Implications of lower penetration can be almost (but not quite) linear	Equity issues (exacerbating existing divides)	This is an issue of design, not natural consequence of markets.	Develop new deployment models for high levels of deployment instead of niche
12	*Design without scalability or upgrading possibilities*	Limits economies of scale	Can favor traditional or established technologies	Conservatism; Limited purview of market	Use optical fibers rather than copper, and IP-centric designs over circuit-switched
13	*Proprietary or National-only standards*	Poorer price-performance (usually, but not always)	Less global competitiveness by local industry	Domestic market protection; Leapfrogging (e.g., China or Korea)	Harmonize standards globally to reap economies of scale
14	*High costs of regulatory*	Raises start-up and ongoing costs	Potential for corruption or poor	Security bogey;	Standardize; Create single-window

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[9] Some countries allow for "fee-free licensing" which can be burdensome, or only allow for "in-campus" usage, (e.g., India), which obviates Wireless ISPs.

[10] These are the charges passed on to sister or partnering entities; e.g., a power utility offering broadband over powerlines, how are they to pay for the copper, rights of way, poles, etc.?

	compliance		enforcement	Bureaucracy	clearance mechanisms
15	*Higher failure rates and/or maintenance*	More spares are required Shorter equipment lifespan	Cutting edge solutions are often avoided until proven robust	Poor standards or enforcement Ancillary infrastructure limitations, e.g., electricity	Improve quality of service(s)
16	*High costs of capital*	Can double/triple ongoing costs of capital expenditure	Modifies optimal technology choice	Many market failures (beyond expected risk premium)	Better regulatory environment and rule of law

It is very difficult to produce specific ranges for the absolute (or even relative) impact of these add-ons due to case-to-case variations. A back of the envelope calculation shows that given capital costs are only a minority of monthly costs (Table 1), policy and additional costs as above can dominate “unencumbered” system costs as optimized per Table 1.

Looking at spectrum fees, license fees, and retail taxes/surcharges only, Indian regulatory authority data [17] indicate these are ~25% of *gross* telecom revenues on average, and would be higher for low-usage consumers. Looking just at spectrum and operator licenses, Egypt recently awarded a third license for mobile phone operations to a consortium headed by the UAE operator Etisalat, who paid approximately $2.9 billion, along with 6% revenue share to the government [18]. To put this in perspective, Egypt's population is roughly 78 million people, and the 2006 mobile phone subscriptions are about 15 million, of which nearly half is with the first operator, MobiNil (jointly owned by Orascom and France Telecom). Projections by operators for the future market are that within 4-5 years there may be up to 35 million net subscribers; such a growth could only be achieved through price cuts. Etisalat stated that they hope to gain ~25+% of the market. Newspaper reports also indicate that the company would spend almost $1 billion in capital investments to roll out their network. (In mobile phone deployments in most of the world, the end-user or pays for their mobile handset independently, and this would be a similar scale of capital investment.)

Applying a range of parameters for both the discount rate (nominal cost of capital) as well as the number of subscribers, we can see that the cost per subscriber just from the upfront license fee might be on the order of 5-7 dollars per month, depending on assumptions. While this may be affordable, it is certainly nontrivial, and governments usually obtain further revenues by taxing the airtime (usage) as well. Given that in this case the provider’s capital costs are three times lower, we can quickly see how this policy add-on raises the costs to the end-user. In these calculations, we assume a 10 year lifespan for the license, for which we have no exact data. However, in 10 years, alternative technologies may supersede the present ones. Etisalat’s license actually includes 3G services, but the two incumbent mobile operators have to pay 20% of the $2.9 billion each to allow them to offer 3G services in their respective spectrum.

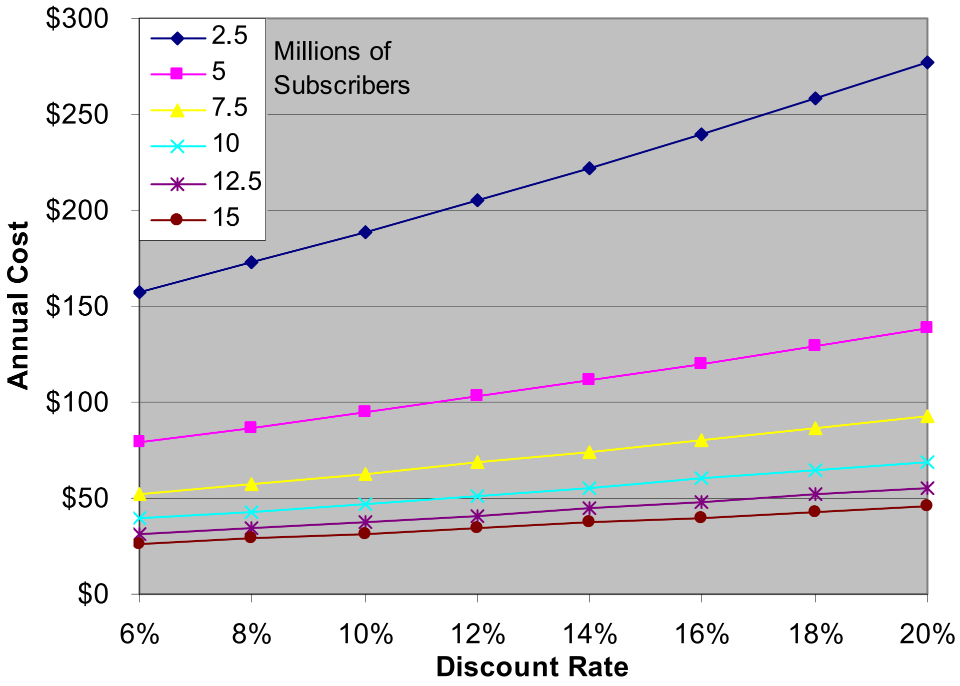

Figure 1: Projected License Fee for 3rd Egyptian Mobile Operator, with varying subscriber levels (millions). Etisalat paid ~$2.9 billion (excluding 6% revenue share), and this assumes a 10 year license. The number of subscribers over the period will grow from zero to several million, but a reasonable time-weighted average may be ~7.5 million, or lower.

Mobile phones are just one example where data is readily available, and similar calculations can be done for alternative technologies and four the other policy add-ons mentioned in Table 2. If one wanted to reduce costs to the end-users by simply removing the spectrum license fees, one would still be left with the difficult decision how to allocate spectrum to operators, which conventional wisdom claims is a scarce resource. (This also reduces government revenues, always problematic, but preliminary research suggests that lower costs/prices raise penetrations, and the subsequent higher economic activity, combined with elasticity greater than one during growth phases, leaves the government better off.) Alternatives to up-front license fees include bidding based on the highest revenue share offered, but the corresponding percentages might be high as well. An alternative mechanism might have parallels to the Chilean reverse subsidy auction model [19], where the operators guaranteeing the widest (rural) penetration would be granted licenses, and having at least three competitors would ensure they are not able to rake in monopoly rents.

3. LEAPFROG NETWORK DESIGNS (E.G., “FIBERAFRICA” PROPOSAL)

If we accept the limitations of trickle down, market-driven broadband deployment in Africa (especially rural areas),

Table 2 presents a useful starting point for thinking of new designs for connectivity. I present details on a leapfrog design network for broadband across Africa, dubbed "FiberAfrica".[11]

3.1 FiberAfrica Design

The high-level design requirements include:

1) Core network of 10+ Gbps across all major population centers
2) Easy access to the core, without which (1) is meaningless
3) Affordable access costs (free or nearly free)
4) Public and private partnership, with competition

Gigabit speeds are only practical with optical fibers, and analysis indicated access was best achieved through fixed (or perhaps portable) wireless. Reasons for the latter include (1) relatively low densities of users, and wireless is a shared medium; (2) continuing innovation in price-performance; (3) scalability with costs distributed with growth; (4) *mobile* wireless is complementary, competitive (with vested interests) and sometimes burdened with regulations.[12]

3.1.1 Need for new designs

There is a philosophy held by many across various fields, amplified in the networking world: *incremental changes lead to incremental benefits*. FiberAfrica (FA) is presented as a continental scale network based on optical fiber and (fixed) broadband wireless that gives the majority of Africans virtually free basic broadband connectivity within walking or cycling distance. The network is sustained by small-scale payments and by commercial users who still benefit by dramatically lower costs for connectivity than not only today but also alternative designs as proposed elsewhere.

The rationale for the FA model as proposed is based on several realizations:

1) *Small "Internet Size" of most countries requires unique scaling and design.* Most countries in Sub-Saharan Africa are very small in terms of "Internet Size,"[13] and even the obvious exceptions are themselves modest in the scheme of the Internet overall. Today, most countries are attempting to "reinvent the wheel" with their individual international fiber connected gateways, data centers, security centers, etc. Instead, they could save significant costs by sharing many of these features (with appropriate security mechanisms and sovereign control, of course). A single large-scale core

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[11] More details on FiberAfrica are available at http://tinyurl.com/dttga

[12] Mobile wireless typically lacks enough spectrum for broadband (channels often being 1.25 MHz wide, compared to, say, 20 MHz for WiFi). The spectral efficiency is also lower, even in 3G systems. In addition, mobility imposes unnecessary costs on system technology, perhaps as high as 30-50% for the soft handoffs.

[13] Internet size is our metric for capturing population, density, applications (and hence, bandwidth), etc. as well as secondary measures such as literacy, age, language, etc.

router could handle all the traffic going in or out of Africa today with ease. But, we have countries with a few million people, and less bandwidth than a small city in the US, building out their own networks without optimizing them for the size or scale possible under a transnational network.

2) *Domestic content and connectivity are required.* Without meaningful penetration within the country, building out international connectivity doesn't achieve much. Meaningful penetration will only be driven by content that meets domestic (local) needs, and such content is unlikely to be made available from abroad, especially not in local languages. Using international connectivity as the backbone for interconnections is poor and expensive design[14] – domestic fibers will be much less expensive and easier to scale. We already have significant global fiber capacity (potentially, hundreds of Gbps) landing at multiple points in Africa (in multiple countries). However, has this done much for bringing down connectivity/uplinking costs in those countries?[15]

3) *Big bang approaches can sometimes be more acceptable than small interventions that keep the underlying system (and divides) in place*. A continental level playing field can mitigate neighboring rivalries. In addition, the vision of FA ensures that a new divide between African countries is not created – market-driven solutions would otherwise only connect a subset of countries in a meaningful manner. This also makes it more likely for donors to consider investing in such infrastructure. There are certainly interim solutions and technologies that may be less expensive upfront, but they are less scalable and more expensive in the long run. Of course, FA will not be built out at once, rather beginning in certain regions first.

4) *There is no lower barrier to entry than free.* In addition to innovations in technology, FiberAfrica has a unique business model, whereby public users (schools, hospitals, libraries, etc.) can get free or nearly free broadband access, and end-users can also get free basic connectivity in community access points, distributed throughout Africa. Such access points would themselves receive either free or virtually free connectivity, and could charge for value-added services or assistance with transactions and fulfillment. Affordability is a key aspect of the digital divide. Mobile telephony could, in theory, be availed by almost 2/3 of Africans, even a non-trivial fraction of rural populations. However, they choose not, based on the value proposition (or lack thereof).

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[14] Even India had segments until the late 1990s where e-mail from one city to the other would go through the US!

[15] SAT3 is the most visible example of such an expensive submarine cable landing in many countries in W. Africa. There is a proposal by NEPAD to build a similar fiber-optic backbone for multiple countries in the Eastern portion of Africa based on submarine cables – EASSY – Eastern Africa Submarine Cable System. This is a positive step in bringing countries together, but FA might be a better design for the same stakeholders to consider. In addition to the much higher cost for EASSY—estimated ~10 times higher per km for the submarine fiber (based on limited public data) than the low-cost terrestrial figure of $3,000/km inclusive of initial equipment—"bringing the Internet to more countries," even at high speeds, does very little for increasing access and penetration, especially in rural areas. Also, this network has not been envisaged with innovations in business plans or true open access, rather, is currently set up as a "closed club" like SAT3. A number of analysts have expressed concerns about such a model [20], and there are recent indications the World Bank and others are insisting on Open Access rules to receive support.

5) *The best model is one of public and private partnerships, on an Open Access model.* Treating connectivity as a utility but with a combination of shared core and competitive edges and/or retail services appears to be the most cost-effective solution.

The suggested use of donors for one-time costs is only one option, and private funds could also be used (leveraged through multilateral agencies, perhaps, who help reduce risks). It is worth emphasizing that donors need only pay for the lowest level of open infrastructure; the actual retail services would be provided by other public or private providers, whose total investment would be much larger in the long run.

3.1.1.1 Open Access Networking

Optical fibers are a preferred technology for connectivity, but can we expect 3 or more independent fiber networks being deployed across Africa in the near term (a minimum number of players as per economics analysis)? If we treat optical fibers like a utility, built everywhere (or deeply enough) just once, then different players could compete to provide *services* on top of this infrastructure.[16] For rural or underserved areas, free or nearly free connectivity could be given for community access points. In urban areas, this could provide much cheaper uplinking bandwidth for service providers.

Open access networking is a concept that represents a fundamental shift in regulation and business. This is more than "net neutrality," whereby a service provider should allow all packets through the network, and especially not favor (rather, disallow) some types of packets on commercial grounds. Open access networking is based on a rethink of how different layers in telecommunications and connectivity operate, especially in an integrated or converged world, and is an extension of structural separation (between bulk and retail services). Instead of regulating integrated providers ("vertical silos") who provide applications over underlying infrastructure they own, the Internet offers a layered approach, whereby different services can be provided over different technologies and layers, owned by different providers [21]. Simplified, a bit is just a bit, and a provider is, say, either carrying it in the core, or providing an end-user (retail) service. Voice can be carried as a packet (VoIP) or over mobile phones, or traditional circuit-switched lines.

Open access networking has been recognized as especially important for developing countries, where incumbents do not have near universal deployment and where capital is scarce. A recent report [22] highlighted that open access can help overcome historical obstacles present in Africa. Additional reasons for such a design include: (1) Economies of scale; (2) Competition, especially for broadband, is hard to achieve in practice (merely allowing it is necessary but rarely sufficient); (3) Given the extra costs that policies and regulations impose (

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[16] This has parallels to the Utopia network model in the state of Utah, USA, and projects in Sweden.

Table 2), any waivers from these should only be given for the greatest public good, instead of enriching select providers; (4) Competition can be enhanced at the edge and in retail services, who all benefit from very inexpensive uplinking; this also allows more content/application innovation instead of mere connectivity; (5) Donors are likely to fund only public projects, and not help private companies reap more profits.

Economies of scale are more than issues of larger market share. Optical fibers last for decades, while the electronics upon these last much shorter, and must typically be amortized within just a few years when considering access solutions. This fundamental disconnect today raises the costs to end-users if amortized across the least common denominator (shorter timeframe) [23]. However, open access networks can separate the two, reducing costs for providers (and thus, endusers).

A number of analysts have advocated treating bulk connectivity like a utility, and the Utopia network in Utah is just one example of a community network.[17] Critics have questioned many municipal or similar open access networks on commercial grounds, and there are event attempts to restrict such networks—in favor of private networks—especially in several states in the US. While there are certainly some fiscal shortcomings in some deployments (along with successes), part of the challenge is when incumbents lower their prices dramatically just in the regions where such competition is emerging [24]. This is either predatory pricing (easy to achieve given very low marginal costs of providing services), or proof they were overcharging before! Competition, or the threat of competition is key to improving connectivity (especially in Africa) [1]), and this so-termed "Walmart effect"[18] undoubtedly helps consumers.

Roads are a good example of an analogous system that allows open access on top of public infrastructure – we don't want ten highways in parallel under the aim of competition. But, there remains significant competition and private participation, ranging from hardware (e.g., cars) to maintenance (e.g., outsourcing or tendering for toll-booth operations or even building the roads) to services riding on the infrastructure (e.g., courier and delivery companies). But roads can cost 2 orders of magnitude higher per km than FA.

3.1.2 FiberAfrica Technology

FA design has 3 components: core backbone, using Dense Wavelength Division Multiplexing (DWDM) optical networking, core wireless from the backbone ("hubs"), and secondary access wireless to end-users.

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[17] Community provision of utility services is common in much of the developed world, especially for rural power service in the US; over 25% of power utilities in the US are cooperatives, as per US Dept. of Energy data (though they supply smaller users than investor or publicly owned utilities, and thus supply only ~10% of the power).

[18] Walmart, as a dominant retailer, lowers prices on products significantly, and the competition must lower prices to match, or go out of business [25].

Core network: A GIS-based analysis showed that 70,000 km of fibers can link all 400+ cities over 250,000 in size, and 30,000 km spur fiber bundles to help extend the network into deeper regions as well as connect to wireless hubs. Even if these cities are not all "lit" in the first phase of the network, it becomes much easier to connect them over time as demand warrants. This design offers almost limitless capacity, scalability and "future-proofness."

Access solutions: A backbone network is of limited value without users accessing the network, and this is where new wireless technologies are expected to play a major role, such as the emerging WiMax (IEEE 802.16) standard. Not only is the core network routed along population centers, but the locations for optical amplifiers along the core are ideal points for core wireless hubs (every 60-70 km). Regional optical fiber spurs would extend the wireless footprint and satellite-based connectivity would be useful for remote locations where extending optical fiber connectivity is not cost effective.

There are alternative designs based on WiFi and modified WiFi (including meshing) and such solutions remain complementary. Our experience in building out real-world solutions shows that the radio chipset costs are only a small fraction of the total installed costs in a mult-point scenario, where a large tower can cost ~$10,000, and electricity, security, uplinking, etc. are major barriers. For a single point-to-point pairing, instead of blanket deployment, WiFi remains a competitive solution. Calculations show the proposed hybrid optical-wireless solution is optimal for greenfield developing region deployments.

End users: End-users would access the network through entrepreneurial or community-based telecenters (kiosks), important given very low PC penetrations. Such providers would receive free uplinking, in return for which they would have to offer free or nearly free basic connectivity for basic (limited) usage.

3.1.3 Business Model

Using today's numbers for costs of components and installation, which will decrease over time, we found the total costs to be a little under $1 billion one-time capital costs. This includes laying optical fibers, opto-electronics, routers, core wireless hubs and towers, and primary wireless (WiMax) receivers.[19] This represents a little over $1/capita only!

How are costs so low? The primary realization is that optical fibers in developing countries (for intercity routes especially) are not nearly as inexpensive as conventional wisdom due to cheap labor. In India,

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[19] This excludes end-user radio modems, designed to be WiFi, handlehelds, or computers. These are non-zero costs per user, but scale nicely with growing deployment.

the upcoming Andhra Pradesh state network, which will bring Fiber to every village, was realized for only a few thousand dollars per km cost for the fiber including installation.[20]

Annualized, this figure comes to under $100 million/year. Operating costs, including uplinking (via submarine cables), maintenance, R&D at multiple percent of revenues, power,[21] insurance, rentals, etc. comes to a similar amount. While $200m may appear large, it is a small fraction of the billions spent on telecoms in Africa every year, most on mobiles.

How are costs to be recovered? The model envisages several thousand core wireless hubs, distributed across Africa, each of which can be linked to multiple primary receivers (one per town or village cluster). These would then provide last hop wireless links to user sites (such as the telecenters, schools, etc.). Using such a hierarchy, we estimate that 10% of the population could ultimately access the network. Based on effective usage costs of only a few dollars per user (not per capita) per year, the network is sustainable. The costs towards connectivity are only a small fraction of the overall target expenditure on ICT; given a crude average per capita GDP of $200 (conservative), 6% of this (close to the global average ICT expenditure) is $12/year. Government support or cross-subsidy mechanisms could ensure public users such as schools, hospitals, etc. could avail free megabit speed connectivity.

In addition, by designing the network to offer last hop services using standard WiFi, non-PC classes of devices could access the network at low cost, including PDAs and upcoming Voice-over-Wireless LAN (VOWLAN) phones, if allowed.[22]

The estimated <1.5$/capita capital costs may appear low, but it is actually expensive at some levels, not merely based on normalization by average GDP. For starters, only 10% of the population are users (per the business model), so capital costs are closer to $15/user, and this figure excludes CPE costs (low on a per-user basis, however). Advanced (multi-megabit) DSL is being deployed in placed like China for $50/household, including CPE, DSL Access Multiplexer, (DSLAM), port, etc. This comes to $15/user (assuming three users per home), for much higher speeds, in the home.

3.2 Challenges

There are a number of issues and concerns beyond financing. One of the main sources of potential failure would be fewer people connecting than planned, but even then the cost-benefit calculus should remain positive. The optical fiber infrastructure, a large fraction of the capital costs, will be usable well into the future (especially with ducted construction). In comparison, other grand schemes like Teledesic

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[20] In addition to governmental usage commitments (highlighted in [20] as important to create viable demand), competitive bidding, and creation of e-Governance content, the scale and ubiquity of services are a key factor for the low costs, in essence, a design similar to FiberAfrica.

[21] This includes backup power at all optic fiber and wireless hubs.

[22] Voice communications are not considered part of the cost-benefit analysis, though the potential is immense, because of regulatory conflicts and resistance from traditional (mobile and land-line) providers.

were more capital intensive, had shorter timeframes for amortization, and had lower richness in terms of value-addition.

The main challenge is one of mindset, one difficult to change for several reasons. If it were really that simple, wouldn't everyone be doing it? Vested interests and conventional wisdom are difficult obstacles. Incumbents and those with enshrined or de-facto monopolies are loathe to accept competition. In addition, there is a conventional wisdom, often projected by the West and the World Bank, that competition is the answer (sometimes confused with privatization). Competition is certainly helpful, especially for mobile telephony [2] but there is less evidence for broadband. Appropriate regulatory frameworks for such public-private partnerships as proposed are few and far-between, and there is the visible success of private competition for mobile telephony purporting to fill the void (or at least draw investments).

Other issues include:

Cooperation: This vision requires cooperation between all the countries in Africa, potentially through the New Partnership for Africa's Development (NEPAD). While there are some regional cooperative networks, such as COMESA and WAEMU, etc., FA, being Pan-African, reduces local and regional rivalry issues.

Security: Physical and data security are paramount in this network, with extensive redundancy and robustness in the design to counter issues such as inter- and intra-nation conflict. To ameliorate vandalism and theft concerns through greater participation of local communities in the network, local participation is important. For example, at every site that requires equipment housing (every 60 to 80 kilometers, say), a local entrepreneur would be given concessional connectivity for Value Added Services. He or she would help secure and physically maintain some of the equipment. By providing local connectivity, it is possible not only to spread access around the routing of the backbone, but also reduce local opposition and mischief. Experience from India also suggests several techniques for reducing theft of optical fiber and cables. While copper is often dug out from access networks due to its resale value, optical fiber has very little resale value, something would-be-thieves quickly learned after superfluous bundles were purposely left behind at construction sites.

National Policies: Countries need to commit to investments to help spread penetration, and develop the applications for harnessing the power of the network, such as e-governance initiatives. Member countries must also enact enabling legislation/regulations that allow FA to be built, e.g., allowing appropriate spectrum availability and disruptive technologies such as Voice over IP. At the same time, FA must work within the bounds of sovereign decision-making. Countries must also allow appropriate cost reductions such as duty import waivers or free rights of way – without these the costs to the consumers will increase. The network should be built such that access is non-discriminatory and largely free. Otherwise, there remain concerns that incumbents and alternative players would object. Here, experience from rural development initiatives in other countries have shown that urban utilities and service providers often do not oppose networks that have a rural focus, as they consider such areas unattractive commercially. ISPs and other providers today would also benefit from FA, especially if regulators allow it to be used for complementary services (such as aggregated voice transport). However, such calculations are not part of the focus of FA, nor included in the business model.

3.2.1 Experimentation and Next Steps

No single segment of the network as proposed is unique, and the technologies as designed are available today (even though they'll improve over time). In fact, there is significant hype over WiMax, and how it will "level the playing field." However, these are thought of as extensions of today's designs, lacking integrated design or changes to business models.[23]

What is required is to prove the concept, picking a country or region to demonstrate the technology and price-performance.[24] Enlightened and supportive government and regulators are a must, and additional support could be had from development agencies, NGOs, academic institutions, etc. (In India, the software industry is a major supporter of connectivity, and in other countries, exporters could play such a role). Another option is to begin deployment of this network as a research and educational network, which should minimize political and incumbent opposition.

A reasonable scale deployment (beyond a small pilot) might cost on the order of ~10 million dollars or more, which typically means donor or grant support. However, this is still affordable, and low by telecom investment standards. In addition, technology companies have significant incentives to provide in-kind if not equipment donations as the long-term market depends on such experiments. While standardization is part of the reason for the low costs, optimal designs will require iteration and testing, and technology continues to improve.

Why should anyone build any such network in Africa, instead of such networks being built first in more well-to-do nations? This represents a leapfrog opportunity, with less legacy needs, and less regulatory hurdles (esp. compared to the US!) It might even be the one of the best methods for developing ICT in the continent—a combination of innovations in technology and in regulation/business models. There are also opportunities to test new technologies in scale, such as use of UHF bands for broadband.

In addition, the imperative for intervention in Africa is much higher given the stark differences in human development versus the rest of the world. Critics might believe that Africa's limited development is due

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[23] In discussions with a senior African government official, he mentioned they were going to auction 3.5 GHz spectrum for WiMax soon, and based on earnings for cellular, hoped to earn on the order of $100m! When I pointed out that even with one million broadband subscribers (difficult but possible in the large country), that implies a $100/user "capital cost," he had no comment.

[24] There is actually a fair amount of optical fiber already drawn in Africa, but un- or under-utilized, often in the hands of the power company. Synergies are possible, but there is extreme regulatory confusion over access to and use of such fibers.

to poor governance and corruption. The truth is that Africa, only recently emerging from colonialization, has been burdened with several debilitating challenges. The rains are seasonal and erratic, and the overwhelming majority of agriculture is rain-based, instead of based on irrigation. The soil is also highly depleted, reducing productivity dramatically. On top of this, Africa also bears the burden of a triad of endemic diseases – HIV/AIDS, malaria, and tuberculosis. While ICT will not directly help with these, it can play a powerful supportive role in improving the efficiency and transparency of all development efforts.

4. CONCLUSION

New technologies continue to evolve, and this will help push deployment of Internet access across the world. Not only will costs fall, but capabilities will continue to expand, especially in wireless technologies where innovations in smart antennae (multi-input multi-output technology), mesh networking, software defined radios, and cognitive radios can change the landscape within the next five years. Even then, the generalized techno-economic model shows that equipment costs are only a fraction of the total costs, and new designs must be considered that integrate innovations in policy and business models. Without this, even with an impressive 15% annual growth of the Internet in Sub-Saharan Africa,[25] given increasing population, it would take roughly 25 years for basic Internet penetration to cross 20%. Higher growth rates have been seen in mobile telephony, but *broadband* has a <u>much</u> lower base than the roughly 1% of population online using mostly dial-up as of 2002 [1]. New designs and business models must be explored, and the open access model with new technical and business models (FiberAfrica) is one worthwhile experiment. Otherwise, the digital divide will not only persist, but divides between and within developing countries will grow. Enlightened or determined pockets of growth will emerge (e.g., China, Estonia, Chile, parts of India, etc.) but in a globalized economy, communities that deploy advanced ICT will see increasing economic growth, further widening the digital divide.

5. ACKNOWLEDGMENTS

This work was based on seminal ideas by Dr. Raj Reddy (CMU), and benefited from discussions with Dr. V. S. Arunachalam (CMU/CSTEP) and Dr. G. Gongireddy (WorldBank). Many others have given useful feedback on the FiberAfrica Model, including colleagues associated with the UN ICT Task Force and UN Millennium Project, notably Dr. Jeffrey Sachs, Ambassador Astrid Dufborg, Anders Comstedt, and Samuel Danofsky. Section 1 draws from previous work [4], supported by the US National Science Foundation, UN, and World Bank.

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[25] Excluding South Africa.

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