Information Technologies for Development: Reliable Networks in an Unreliable Environment

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Abstract

Information and Telecommunication Technologies (ICT) are tools that could boost development in emerging nations. Services such as e-post, remote education and tele-jobscan be important opportunities for the growth of isolated communities. In this work we introduce some technical solutions and an analysis methodology, which we used to introduce a reliable Internet connection in an unreliable environment, characterized by limited or no electric power, and limited or no telephone lines. The methodology is applied to develop a solution for the country of Bhutan, in the context of its Education IT Master Plan.

The tools here introduced can be used to install an Internet workstation in a isolated village, as part of a student project. With limited financing and human resources, an independent, self-powered work-station can give access to the Internet and manifold opportunities for development. A rich partnership between the student group's university and the local community can enrich the cultural experience of both.

1 Introduction

Information and Telecommunication Technologies (ICT) are tools that could boost development in emerging nations. In a developing country, ICTs can give access to information resources that are difficult or expensive to reach otherwise. Besides the relevant governments, developmental agencies such as the UNDP and ITU-U are working to bring forth the best technologies to give developing countries a boost in their development and to narrow the *digital divide*. Nonetheless, the lack of cheap Internet connection, or of electric power, can prevent the implementation of digital services in rural and isolated communities.

In this work, we describe the result of a three-month effort[1] to develop a solution for the country of Bhutan, with the goal of offering the students the opportunity to connect to the information available on the Internet, even from villages with limited or no electricity, and limited or no Internet connection. The suggested ideas can be applied in a similar way to other circumstances. In particular, a group of students with limited financing could bring the Internet to an isolated community, so to boost its development opportunities.

In the next section, we give some comments on opportunities to create digital services. Then we describe briefly the country of Bhutan, initially chosen as a test-bed for our strategy, with some details about the goals of the Education Master Plan. In the fourth section, about technical solutions, we introduce briefly TeK, as a mean to reduce connection costs, and we suggest a way to connect isolated villages. Then, we give a survey of our analysis methodology, and a quantitative summary of our results. Finally, we conclude, with some suggestions for a possible student project. An appendix collects further data about our methodology and results.

2 Opportunities for Development

As said, ICTs can be important in reducing the cost of access to information, and in offering new means of development. In this section, we want to enumerate a few examples of opportunities offered by ICTs to isolated communities, some of which already existent and working in some countries.

Tele-education. The wealth of knowledge available on the Internet can be an important element to support education in small communities. High-quality syllabi and class materials are cheaply available on the Internet.[2] Educational partnership can be set up: good schools in rich areas can offer educational support to smaller schools and communities, by offering remotely assistance to grading and teaching.[3]

Tele-jobs. In the globalized world economy, many opportunities for tele-jobs are present. The availability of cheap, English-speaking, skilled labor, can be exploited by international companies to reduce costs. Customers' data can be sent digitally from abroad to the workers in the community, be processed, and sent back. A small isolated village with some computing capabilities could boost its economy this way.

Assisted health care. Data about an isolated population could be analyzed by a remote staff of doctors in a large hospital. The presence of epidemic problems or rare diseases could be observed by expert

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[1] Diego Puppin, Ezequiel Hart, Atsumasa Sakai, Mark Sin, *Reliable Networks in an Unreliable Environment*, final report for the MIT/Tufts class *Internet Modeling and Policy Analysis*, Spring 2002. Hereinafter cited as *Reliable Networks*. To be published. Available at request from the authors.

[2] See for instance the MIT initiative *OpenCourseWare*, which made available on-line the materials for all classes in the Institute.

[3] In some examples, video-conferencing has been set up to do the teaching. Clearly, this solution is more costly than just retrieving class material on-line, but can give the full experience of high-quality education in developing countries.

doctors, who can warn the local health facilities. Good results have been observed in India for a similar project, focused on eye-care.

E-post. The opportunities of cheap and reliable communication are important even for small communities, where a piece of mail can save one day otherwise spent traveling. Mail messages can be scanned, sent digitally and printed at the destination, with big savings in time, money and energy.

3 The Kingdom of Bhutan

Bhutan is a small country of 47,000 Km^2, almost entirely mountainous. Over 90% of Bhutan's official population – approximately 650,000 people – lives in rural areas.[4] The 1999 GDP was $0.4 billion, or $1.0 billion according to the purchasing power parity method of calculation. The economy is based on agriculture and forestry, which provide the livelihood for 93% of the population.

Development Goals. Bhutan's King Wangchuck has officially established as the country's "guiding principle" for development the concept of "Gross National Happiness," which goes beyond economic development to include cultural and spiritual values. Bhutan has identified four "essential constituents of happiness": economic development, environmental preservation, cultural preservation and promotion, and good governance.[5]

As we will see below, several of these challenges relate directly to our project: ICTs can play an important role in addressing them. Particularly relevant are the related challenges of meeting the needs of a new generation of more educated youth and of encouraging private sector growth. Generation of employment for educated youth has been identified as a "major human resources management concern."[6]

Internet Connection. Telecommunications services were introduced in Bhutan in the early 1960's, with further development of the network in the late 1980's and early 1990's. Construction of the current National Telecommunications Network began in 1991, with grant assistance from the Japan, and digitalization of the network was completed in 1998.[7]

Nonetheless, as of October 2001, Bhutan had only 15,193 main telephone lines.[8] The teledensity in rural areas is extremely low, and it is estimated that even today over 80% of the population has never used a telephone.[9] As of June 2001, basic dial-up connectivity was available throughout Bhutan at the price of a local call, and 64 and 128 KB leased lines were available to businesses. The national Internet Service Provider, DrukNet, estimates that the number of Internet users was as high as 2,500.

Education. Today the literacy is still low, but has risen to near 50%, and the educational system represents one of the most wide-spread public networks in the country. Free education is provided from primary school through college.[10] All high schools have power and telephone connections, while it is estimated that 30% of primary schools have telephone connections, though nearly all of them have power.[11] Also, it should be noted that English, along with Dzongkha, the Bhutanese language, is an official language of Bhutan.[12]

Our proposal for the deployment of Internet in schools and colleges fits the goal of the *Education IT Master Plan*, promoted by the Ministry of Education. This plan, budgeted at $24.1 million, includes future programs to develop IT facilities in public schools.[13] As mentioned above, the Ministry of Education intends to provide IT training in all schools, with the goals being to "provide computer access to all schools and produce computer literate high school graduates by 2010."[14] Our project can be integrated into the current plan, and will provide both increased levels of reliability and cost savings.

4 Technical Solutions

Our team has considered various solutions to improve reliability, bandwidth and up-time, including peer-to-peer communication, network redundancy, different network topologies and other back-up systems. The limited space allows us to speak only of TeK and our plan to connect isolated villages.

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[4] The United Nations' July 2001 population estimate for Bhutan was 2.05 million. The reason for the large disparity between the UN estimate and Bhutan's own count seems to lie at least partly in the status of Bhutanese residents of Nepalese ethnic origin. Another explanation for the disparity is that the UN is using projections of outdated estimates of Bhutan's population. See, for example http://www.asianinfo.org/asianinfo/bhutan/bhutan.htm and http://www.undp.org.bt/unfpa/Revised_BhutanCP4-may.pdf.

[5] The Planning Commission Secretariat, *Bhutan National Human Development Report 2000: Gross National Happiness and Human Development, Searching for Human Ground*. (Thimphu: Royal Government of Bhutan, 2000), 4, 18-20. Hereinafter cited as *BNHDR 2000*. Available from http://www.pcs.gov.bt/publications/nhdr2000/nhdr2000.pdf.

[6] Planning Commission, *Eighth Five Year Plan Mid-Term Review Report*. (Thimphu: Royal Government of Bhutan, Dec 1999), 17. Available from http://www.pcs.gov.bt/publications/8th_mtr/8fypmtr_rep.pdf.

[7] ITU, *Kingdom of Bhutan: Country Report* (2001). Hereinafter "*Country Report*." Available from http://www.itu.int/ITU-D/gender/documents/Asia-PacificlWrkshopKorea/CntryReportBhutan.pdf.

[8] *Country Report*. The ITU's 2000 figures for Bhutan were 13.3 thousand main lines, for a teledensity of 1.97.

[9] *Country Report;* Siok Sian Pek, "Bhutan Joins the Digital Age." *Choices* (UNDP, June 2001). Available from http://www.undp.org/dpa/choices/2001/june/j18e.pdf.

[10] *BNHDR 2000*; Bhutan Education Department Website (www.education.gov.bt).

[11] Estimate provided by Sonam Leki Dorji.

[12] *Briefing Report.*

[13] *Education IT Master Plan: A Summary*. (PowerPoint presentation.) Available from http://www.dit.gov.bt/training/workshops/march30-2001/education-masterplan.pps.

[14] *ICT Development Master Plan*, 24.

4.1 Software Caching: TeK

The access to the Internet can be very costly. Various strategies to reduce the required bandwidth or the on-line time have been developed. Offline Internet is a very promising approach, explored, among others, by the TeK (Time equal to Knowledge) group at MIT[15]. The idea is simple: when browsing the Internet, a user will have access only to pages locally stored in a big cache in the local disk. If a page is not locally stored, a request for the page will be queued, and sent the first time the machine goes online. At that time, the page is retrieved, stored to the disk, and made accessible to the user.

But a second way is offered by TeK. When a user is looking for some data on the Net, s/he will fill a form with the necessary keyword describing his/her interest, the same way s/he would with a common search engine. This information will be sent to a TeK server when the machine goes online. Later on, when the machine goes online again, the TeK system will retrieve the relevant data, and will let the user navigate them, as s/he would do from the result page of any search engine. All the results of previous queries, and queries from other users, are kept stored, and they are available to all the users. Over time, TeK will build a local library with knowledge interesting to the community.

A typical TeK workstation will connect to the TeK server once or more times a day, scheduled in a way to be as cheap and convenient as possible. For instance, the TeK workstation can connect to the server in the night, when connection fees are cheaper and the telephone line is idle. During the connection, users' query are sent via email to a TeK server and processed.

At the same time, results for previous queries are retrieved from the TeK server, in a compressed format, which strips out redundant HTML, reduces the volume of big pictures and excludes results known to be already in the user's server. In TeK developers' estimations, the compression is about 50% of the original size. Also, 50% of the pages are estimated to be already present in the cache, and not re-sent. This latter figure clearly averages the initial phase, when the local cache is still empty, and a later phase, when the local cache is rich of relevant information.

This system offers a series of clear advantages. First, when connected, the line is used to carry on a sustained transfer of data: there is no idle time in the connection due to user's input. Second, there is no duplicate transfer of data: if some page was already accessed, the system will not download it twice. Nonetheless, the system is configured to verify if some stored page has become obsolete due to an update in the original document. Third, HTML pages are stripped out of advertising, applets and other types of contents that do not contribute to the information value of the page. Fourth, as pages are locally stored: users do not experience slow downloading of the information they need. This can be really important when the connection is slow and pages can take some minutes to be downloaded. Last, the total daily movement of data is, as just shown, dramatically reduced. This means that, with the same type of connection (e.g. modem, radio, DSL), a better service can be offered to more users.

The usage of a TeK server to access the Internet can be expedient in enforcing policy choices. For instance, it can be used to filter out some information, such as pornography or gambling sites, which are not deemed suitable to the recipients. If the TeK server is accessed by students, the school director could enforce his/her policies by configuring the TeK server. If it is accessed by the whole country, the server could be set up to implement central Government choices, such as the principles of the "Gross National Happiness".

Presently, a TeK server is present at MIT, but it is possible to relocate it in any location with high bandwidth. We suggest Thimphu, or some city at the border with India, be selected to host a TeK server for Bhutan.

The TeK group at MIT showed that this approach can reduce the cost per megabyte of Internet information of up to 3 order of magnitudes. Instead of a costly connection to the Internet, users can take advantage of the cheaper technology of large hard disks.

This system will be used as the main tool to offer a reliable connection in the presence of unreliable power supply or Internet connectivity.

4.2 How to Connect Isolated Villages

In order to reach the largest part of the population, we have to consider the problems given by the lack of electric power and Internet connection in rural areas. With TeK, we need only a limited on-line time to perform the communication needed to serve a community. So, we studied the implementation of an Internet workstation by using solar power and radio connection.

A photovoltaic module with a battery can offer about ten hours' power supply daily. The reliability of the components is good. The offered power is used to supply a PC, a printer, and a communication system. Its approximate total installation cost is around $500 in 1994.[16] Its operation cost is low because the solar energy is free and abundant in Bhutan.

To perform the connection, the necessary components are a short wave transceiver, a Terminal Node Controller (TNC), and an antenna, which can be purchased for about $920.[17] The communication protocol, called *packet radio*, was established in 1982 by the Amateur Radio Relay League of America and thoroughly tested. We assume the presence of an Internet provider with antenna within reach. We estimated that every village is within ten miles from a school

[15] William Thies et al., *Searching the World Wide Web in Low-Connectivity Communities*, 2001

[16] Richard Perez, *"Photovoltaic Power for the Permanently Portable,"* Home Power #38, pp32, December 1993/ January 1994, http://www.humboldt1.com/~michael.welch/extras/laptoppv.pdf

[17] Martin Diggens, *Enhancing Distance Education through Radio-Computer Communication,* 1990, http://cleo.murdoch.edu.au/aset/confs/olnt90/diggens.html

equipped with power and telephone line: this could be the needed partner in this protocol.

We offer limited Internet services to the inhabitants of isolated villages. We estimated that, with this configuration, the active Internet users (estimated to be 40% of the population, average 20 people out of 50), can send or receive 30 short emails, and browse Internet one hour every week.

5 Analysis Methodology

In our analysis, we consider what a cost-feasible network installation can be for each situation (city college, rural school...). Then, we determine the reliability and availability of the system. This constraints the maximum performance that, according to the number and type of users, can yield a different level of satisfaction, measured by our performance index. In this section, we summarize the concept that are explained in more detail in our original work.[18]

Availability and Reliability. Different network configuration offer a different quality of service, which is measured by the complementary metrics of availability and reliability. Availability is the percentage of up-time in the life-time of a component, and is determined by the time between failures and the time needed for repairs. Reliability is an absolute index that builds on the availability of the components of a system, and gives an indication of the different quality of two installations.

Maximum Performance. Given the reliability of the system, it is straightforward to compute its expected throughput and bandwidth, as the highest possible bandwidth, weighted with the reliability of the connection. The system offers a satisfactory behavior if the connection bandwidth required by the users is within its reach.

Performance Index. In our analysis, we needed a quick way to compare different systems and the services they could deliver to users. The *Performance Index* (PI) is a metric we develop to quantify the daily productivity of the Internet connection offered by a specific installation. It is computed as a function of the number of pages browsed, email sent and files downloaded, weighted with the probability of a successful connection (availability). *PI* is an absolute value, and it is used only for comparison. More detail about this index can be found in the appendix.

The index is used to develop the best service profile that can be offered with a given system bandwidth. We can tune the *service quota* offered to each user, to maximize his/her productivity and satisfy the performance constraint. The cost/performance trade-off shown in the appendix gives an example of this methodology.

Limitations. In most of this work, we compare TeK and legacy systems. We are aware of the different service that a legacy system can offer with respect to a system featuring TeK. Even if a TeK user has to wait to retrieve the results asked for, on the other side the latency of online browsing is totally avoided, resulting in a faster work once the results are back. We estimated that in 80 minutes, a modem user can retrieve 15 pages when on-line (about 11 queries a hour). Splitting the same time over two sessions, one to query TeK and one to analyze the results, the user can access to 28 useful pages. Our *PI* simply rewards the higher number of pages: we cannot estimate numerically the time-sensitivity of information.

[18] *Reliable Networks.*

6 Results

Our team proposes a school computer network for the Kingdom of Bhutan. Students, teachers, and the local community will benefit from greater access to information and faster communication to their neighbors and the world. Starting from the students, a generation of *Internet-educated* people will grow in the country.

Our integrated approach, combining models of reliability, performance and cost allow our analysis to specifically address concerns including disruptions from power and communication link failures, before recommending a set of options to implement in Bhutan over a time span of seven years.

6.1 Phase I and II – High and Junior High Schools

In the first implementation phase, high schools will be addressed. Our plan aims to give a good Internet connection to all the high schools students in Bhutan. To do this, our model plans to install a large number of computers, and to give the students a package of services that can give them the opportunity to communicate with other students in the world, and to access academic information on the Internet.

The first expenses will be the installation of a computer every 10 students. Every other day, a student will be allowed to send up to 20 emails, and to browse 40 pages on the Internet. Also, every week s/he will be able to download a couple of papers for his/her research. A big part of the student community (students with ongoing projects, involved in student activities) will be given access to the Internet. The appendix shows an example of a cost/performance trade-off for this phase, with a significant comparison between TeK and legacy systems. All the 26 High schools of Bhutan have electric power and telephone lines. In our opinion, the installation of two dedicated phone lines with modem offers the best cost-effective configuration.

Phase II should start one year later than Phase I. Similar costs and solutions will be used for the 59 Bhutanese Junior High Schools. Performance Index will be a bit lower, and one shared telephone line should satisfy the needs of the student community.

6.2 Phase III and IV – Primary and Community Schools

Phases III and IV focus on the 151 primary schools and the 110 community schools, many of which without electrical power and telephone. In this case, the connection will be carried on via radio to the nearest wired facility, which will offer the usage of its telephone line at market price (included in the costs). The measure is appropriate for the mountainous profile of Bhutan, and the offered bandwidth can satisfy the limited connection needs of the users in phases III and IV. Also, we propose to use solar panels as a power supply because of its limited cost and simple set-up.

The needs of Phase III (primary schools) can be satisfied with two radio lines: 40% of the population will be allowed to send/receive 30 emails a week, and browse 1 hour a week (15 pages). The two radio lines will connect each school with two different schools equipped with telephone facility, for increased reliability. The strategy for Phase IV (community schools) is similar to Phase III. The same Performance Index can be offered to the smaller student communities with one radio line.

6.3 Costs

The cost of the whole operation is within the budget of the Education IT Master Plan. The installation costs are high especially for Phase II, about $3 million, but are much smaller fort Phase III and IV. For Phase IV, a basic installation costs less than $3500, and maintenance costs can be kept very small if telephone fees are discounted. In the Appendix, the reader can find a plan of expenses and a summary of our cost analysis.

7 Conclusions – A Students' Project

In this paper, we summarized a proposal for a country-wide Internet introduction project for Bhutan. The solution aims to offer advanced IT facilities to high schools students, and to bring essential Internet services to the local communities. We showed briefly some technical solutions that can face problems related to isolation, lack of power and lack of telephone lines. In particular, we highlighted the effectiveness of TeK in reducing on-line time and connection costs. Also, we proposed a methodology that allows us to specify the level of service offered to the user, and to satisfy the network constraints by using the *Performance Index*.

The proposal of Phase IV – connection through a radio antenna, powered with solar panels – can be adapted with limited effort to other situations in the world, and could be used to *connect* remote villages, and to offer them the advantages of some digital services: remote education, remote health services, telejobs. A small group of students, with limited funding (a few thousand dollars) could install an Internet workstation in a village, which would be used to launch a set of initiatives for the development of the village.

When the connection is on, a deep partnership can be started for the benefit of the local community. We list here a few examples.

Educational partnership. Students in the local community can be involved in project hosted by the university of the student group. Also, problems from the local community can be submitted as class projects in the university. Exchanges and field trips can be promoted between the two communities.

Job creation. Administration work can be farmed out from the university to the local community. For instance, in Bhutan, young people speak English fluently and can work with information in that language. The university could exploit this source of cheap, skilled labor to reduce student tuition.

Computer recycling. The WSC-SD project for computer recycling could be re-routed to the project of connecting isolated communities. De-activated technology (old computers, out-dated software…) could be used to build Internet workstations in rural areas.

These are just a few examples. We strongly believe in the potential of this idea: ICTs can lead to a way of development that is not material- and energy-intensive, that prevents disruption of communities and migrations, that promotes local enterprise, that gives an advantage to youth. The hope of the author is that WSC-SD will invest energy and skills to promote the growth of Information Technologies, in order to support local development.

8 Acknowledgements

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Appendix

Performance Index

In our work, PI is computed as follows. The square root describes the decreasing marginal utility of more connection. The weights are chosen to allow a comparison of apples with oranges, that is emailing, web browsing and other data download and upload. We estimated that a 2-page email is worth as much information as a small web page (50 kb). For other services (PDF, MP3…) we considered a smaller weight of 0.3. *p* measures the availability of the service.

$$PI = \sqrt{\text{daily 1-page email} * 10 + \text{web kB} * 0.4 + \text{other service kB} * 0.3} * \sqrt{p}$$

Comparing TeK with a legacy system

Here we compare the different performance offered by TeK and a legacy system. For three different configurations (one or two dedicated telephone lines, one shared line), we compute the top performance index that can be reached. It can be seen that the PI reached by TeK is unavailable with a legacy system: the bandwidth offered by TeK is higher because it can exploit the night hours. Also, one shared line with TeK reaches a similar performance of two dedicated lines with the legacy system.

	EXPLOITING TEK			ONLY LEGACY		
	2 ded. lines	1 ded. line	shared	2 ded.lines	1 ded. line	shared
Performance Index	56.9	42.2	26.8	27.8	18.9	9.2
Need daily bw	3,238	1,780	718	772	359	84
Feasible legacy?	XXXXX	XXXXX	XXXX	OK	OK	OK
Feasible tek?	OK	OK	OK	OK	OK	OK
Max b.width w/legacy	619,200	309,600	77,400	619,200	309,600	77,400
Max b.width w/TeK	928,800	464,400	232,200	928,800	464,400	232,200

Table 1. Performance Index comparisons between TeK and Legacy connection systems

On the other side, costs grow faster with the legacy system is we want to reach very high performance, because more resources are needed.

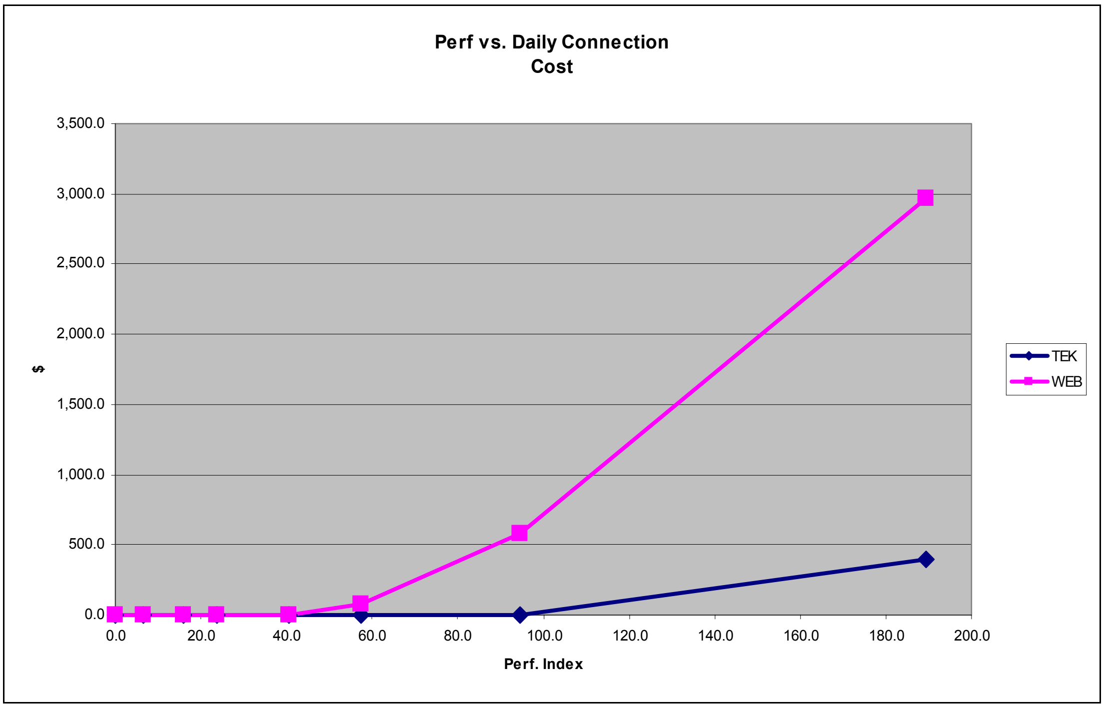

Figure 1. Graph of Performance Index vs. Cost (in dollars) with TeK and Legacy (labeled Web).

Deployment Costs

Year	Phase I	Phase II	Phase III	Phase IV	Total
0	1,730,750				1,730,750
1	1,646,926	2,967,000			4,613,926
2	1,482,233	1,172,534	854,000		3,508,767
3	1,334,010	1,055,281	871,075	494,760	3,755,126
4	1,200,609	949,753	783,968	896,718	3,831,047
5	1,080,548	854,777	705,571	807,046	3,447,942
6	972,493	769,300	635,014	726,341	3,103,148
7	875,244	692,370	571,512	653,707	2,792,833

Table 2. Deployment cost of all phases over 7 years.

The table describes the cost (installation and maintenance) of the four phases, in dollars. It can be seen that the largest costs come to offer connection to the advanced schools. If we want to limit our reach to offer connectivity to the local schools and isolated villages, the costs are much smaller. Each installation costs less than 3500$, including PC, radio and solar panel. Phases are scheduled to start one after another, at one year of distance.

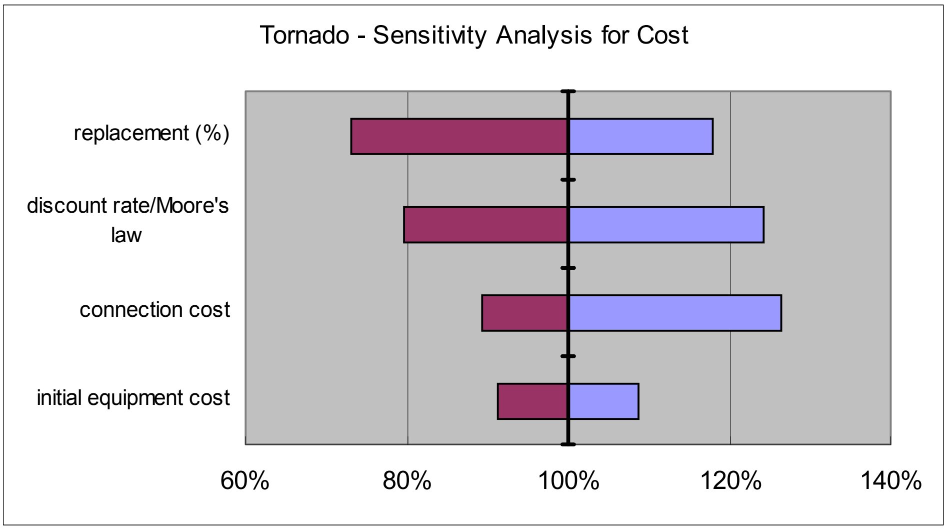

Figure 2. Tornado sensitivity chart.

In this picture, a summary of our cost analysis is presented. For every major parameter of our model, we changed the value between the minimum and the maximum in our estimated ranges (values reported above are for the average value). It can be observed that connection costs have a strong impact on final costs: high fees can increase significantly the total costs. If replacement costs of equipment is smaller (components are more reliable and cheaper to maintain), costs can be significantly reduced.