



# Cloud computing: Opportunities and issues for developing countries

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## Abstract

Cloud computing offers a range of new opportunities for developing countries to do what they could not do earlier with computers and the Internet. Cloud computing infrastructure and applications are able to interact with users who have mobile phones, Tablet PCs, OLPC [one-laptop-per-child], and other mobile devices. This paper looks at how cloud computing will surpass the Internet in adoption and usage as this technology's users are on the other side of the digital divide. Mobile phones and other devices have penetrated and saturated developing countries where the Internet has failed. This paper looks at the diffusion of mobile phones and devices in developing countries and its continuous dramatic rise. \$15 Mobile Phones and \$20 Tablet PCs are now in the hands of those technology-connectivity-deprived billions. This paper will look at how cloud computing and mobile devices combine present new opportunities for developing countries. Because the mobile phone and devices user market is too big to be ignored, cloud service providers, in collaboration, with mobile service providers have deployed hundreds of cloud-enabled applications and are continuing in their endeavour to provide an endless range of products. This paper looks at some popular mobile applications that are helping development efforts, such as m-Banking, m-Education, m-Health, m-Agriculture, and others that already exist and are popular within developing countries. Each technology has its good [opportunities], bad [challenges], and ugly [issues] side. There is an attempt to address the issues and challenges in deploying mobile applications via cloud computing in developing countries when compared to developed countries. For example, issues such as connectivity to remote regions and the challenges faced by service providers and governments to subsidise and provide mobile applications to those who are already struggling with sustenance.

**Keywords:** cloud computing; mobile computing; m-applications for developing countries; ICT4D

## Cloud computing opportunities

Cloud computing technology, advances in information technology (IT) infrastructure and scalable sophisticated applications enable individuals, students, and businesses around the world to connect to data, information and computing resources anywhere and anytime. In this section, this research will look at how individuals, students, and businesses no longer need memory intensive, processor dependant, location constrained computing resources and broadband connections because they can access data, information, and computing resources from their light-weight mobile phones.

According to Dikaiakos *et al.*, (2009), the vision of the twenty-first century is accessing Internet services from lightweight port-

able devices, instead of accessing them from a traditional desktop PC. Cloud computing is a technology which will facilitate companies or organisations to host their services without worrying about IT infrastructure, let alone invest in it and other supporting services.

The cloud concept draws on the existing technologies which are not new, such as virtual computing, cluster computing, utility computing, distributed computing and Software-as-a-Service (SaaS). It is new in the way it integrates all of the above and shifts them from a localised processing unit to a globalised network (Weiss, 2007).

Users of mobile phones and devices are not required to store data and information on their devices. Whatever data and information they need are stored with their cloud service providers.

When the need arises to use that data or reference that information, access is obtained via their mobile service provider as long as they are within the network connectivity range. Access to data and information is not confined to any location, and that is the essence of cloud computing.

Access to applications and services via mobile phone applications addresses the digital divide of the 'have-nots' to some extent. For example, a Fijian sending an SMS (short message service) to a friend in New Zealand has the potential of conveying the same message that a Canadian could have done via email. It provides a level playing field for the Fijian in terms of being able to keep in touch. This was not possible for the Fijian last year. Early this year, a number of mobile phone providers entered the market after deregulation and, as part of their promotion to sign new customers, gave away mobile phones for free.

Many industry pundits are predicting that the cloud will surpass the Internet (Subramaniam, 2008; Bourne, 2010; Nichols, 2010). What we are seeing is the evolution of the cloud as a central nervous system for a new universal communications infrastructure that is more important than the Internet. One of the reasons behind the Internet's demise would be its dependence on web browsers and computers for connectivity and service. The evolution of mobile phones from 2G to 3G has enabled the mobile phone providers to build simple interfaces into mobile phones for such connectivity. Once connected, the cloud service provider's processing power, storage capacity, computing resources, data and information is yours to exploit.

With cloud computing, instead of connecting to the network server, a mobile phone or device connects to the cloud service provider. All services are available from wherever we are, as long as there is a connection to the network. Armed with such portability and flexibility in the computing environment, businesses can reach their customers 24/7 anywhere in the world. Students can study online courses from anywhere in the world, and individuals can socialise on their mobile phones, SMS and do whatever they want from wherever they are, whenever they want.

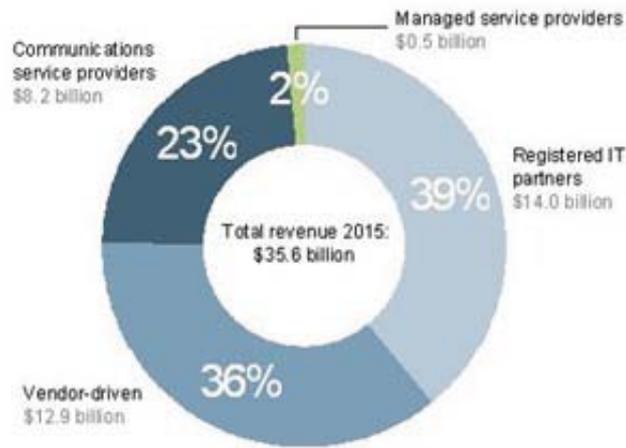
Cloud computing is a trend with enormous implications. 'Cloud computing provides access to large-scale remote resources in a very efficient and quick manner,' explains Karsten Schwan, Director of the Center for Experimental Research in Computing Systems at Georgia Tech University. 'It has the potential to dramatically change business models and the way people interact with one another.' (Greengard, 2010). We have already witnessed the change in communication etiquette from posting letters to sending emails through the Internet, and now there will be a transition to texting.

There are many statistics regarding cloud computing for businesses: IDC estimates the market for public cloud products and services was at USD\$16 billion in 2010 and will grow to USD\$56 billion by 2014. Gartner more optimistically estimates the cloud market at USD\$150 billion by 2013 while Merrill Lynch estimates the market at USD\$160 billion by 2011. AMI Research estimates that cloud spending alone will reach USD\$100 billion by 2014 (Nichols, 2010). Regardless of the exact numbers or estimates of cloud computing that each of these companies used, the conclusion is that the public cloud infrastructure, platforms and applications market is large and growing much more quickly than any other type of IT market (Nichols, 2010).

By now sceptics of cloud computing are probably convinced that cloud computing is not a fad, given the amount of spending it is attracting. Figure 1 shows that the global market for enterprise cloud-based services will grow from USD\$12.1 billion in 2010 to USD\$35.6 billion in 2015.

A recent survey by international research firm Vanson Bourne of IT and business decision-makers found that 70% of respondents think cloud computing will help their businesses. There is now an emerging consensus that cloud computing will play an increasing role in IT operations. This will fundamentally change the delivery model for services (Vanson Bourne, 2010).

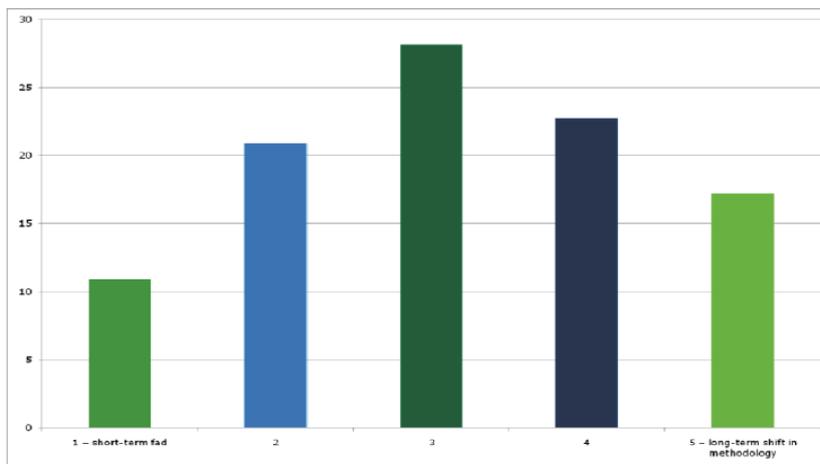
*'Nowhere is this more obvious than in developing nations, where the ability to access resources has often been limited and build-*



The year-on-year growth rate will be 43% in 2011 but will decrease to 13% over the next five years. SaaS will account for 70% of revenue in 2010, while 30% will be related to Infrastructure-as-a-Service (IaaS).

(Analysys Mason, 2010)

Figure 1. Enterprise cloud-based service revenue by sales channel, worldwide, 2015 (Analysys Mason, 2010).



A survey conducted by Vanson Bourne on behalf of One CA Plaza asked IT decision-makers if they see cloud computing as a short-term fad or as a long-term shift. As evident from Figure 2, many think cloud computing is here to stay.

Figure 2. Survey: Do you see cloud computing as a short-term fad or lng-term shift? (Vanson Bourne, 2010).

ing out a robust IT infrastructure can be daunting. The emergence of cloud computing changes the stakes for: entrepreneurs, small and large businesses alike, researchers, and governments. “It has the potential to level the playing field because it breaks down barriers to entry”, says Steve Bratt, CEO of the non-profit World Wide Web Foundation. ... In addition, they open up new markets – including vast numbers of mobile phone users – that previously weren’t reachable. ...’ (Greengard, 2010).

‘Clouds provide a powerful – and often otherwise unattainable – IT infrastructure at a modest cost. In addition, they free individuals and small businesses from worries about quick obsolescence and lack of flexibility. Yet, at the same time, large organisations can consolidate their IT infrastructure across distributed locations, Sinha points out. Even government entities can benefit by enabling services to consumers on a shared basis. In some cases, cloud-based

computing grids enable research that simply wasn’t possible in the past’ (Greengard, 2010).

Every time there is a major advancement in IT, there is usually a corresponding change in the competitive edge. With cloud computing as a new type of IT platform, there is potential for a significant narrowing of the IT competitive edge gap between developed countries and developing countries. The rise of mobile phone technology in Asian and African countries is one example of how countries in one part of the world took advantage of emerging technology to leapfrog countries in other parts of the world. Developing countries appear to be thinking about more strategic approaches to cloud computing in order to narrow competitive enterprise IT edges with global rivals.

3Tera, for example, delivers a comprehensive platform that companies can deploy to create a cloud computing platform. The company has

noticed that shortly after it added IPv6 support for its platform, the number of companies adding support for the platform using IPv6 shifted significantly towards Asia. The potential advantages of cloud computing have not been lost on smaller companies either, as more of them appear to be moving to embrace cloud computing at a faster rate. Naturally, there is a lot more to IT enterprise than just the platform. But the fact remains that IT infrastructure until recently was a significant barrier to the cost of entry, and that might not be so relevant anymore (Vizzard, 2010).

### Cloud computing with mobile phones

In this section we look at how cloud computing has been enabled via mobile phones. For many developing countries, phones and Internet connections have reached its populace through fixed line (wired) infrastructure. Those countries that had rough geographic terrains, mountains, scattered islands, and tribes living in pockets of isolated villages everywhere were almost impossible to wire (connect). Cellular networks infrastructure has become a saviour for these physically and technologically isolated people.

Mobile cellular technology has been the most rapidly adopted technology in history. Today it is the most popular and widespread personal technology on the planet, with an estimated 4.6 billion subscriptions globally by the end of 2009 (ITU World Telecommunication/ICT Indicators Database). Developing countries sur-

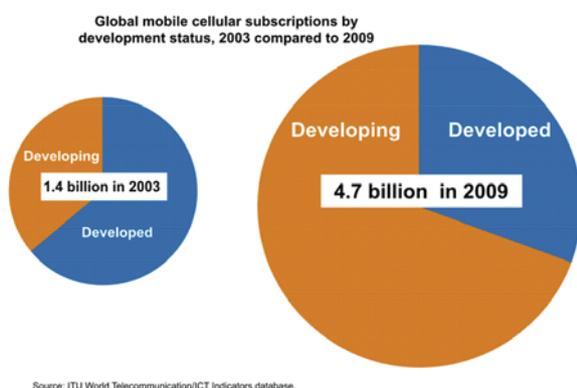
passed the 50% penetration mark in 2008, and by 2009 over 70 economies had surpassed the magical 100% penetration mark, including a number of developing nations. Given this trend, it seems that eventually most countries will attain a penetration of 100% (Motorola Solutions, 2011).

As evident in Figure 3, there was a dramatic increase in mobile cellular subscriptions in developing countries between 2003 and 2009, as compared to that of Internet subscriptions in developing countries in the same period (Figure 4).

There is no indication of the mobile phone usage trend going downwards for developing countries. As mobile phones converge and provide banking, education, health, agriculture and entertainment services, no one can predict what we will be doing with them in another five years.

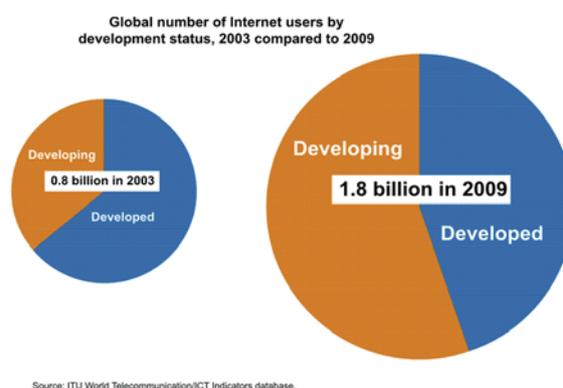
An analysis of Internet penetration in developing countries when compared to mobile phone penetration in developing countries can be described as follows:

Internet: The global broadband usage has increased from 17 million in 2001 to quarter of a billion today. India, in comparison, had a meagre 2.43 million users by April 2007 (Bindal, 2007). In Africa, 4 out of every 100 users use the Internet, and it has 1% penetration in the population (Subramaniam, 2010). This could be due to lack of or unaffordable electricity and broadband connections in the remote regions of developing countries.



Source: ITU World Telecommunication/ICT Indicators database.

**Figure 3.** Cellular phone subscriptions in developing countries (ITU World Telecommunication/ICT Indicators Database).



Source: ITU World Telecommunication/ICT Indicators database.

**Figure 4.** Internet users subscriptions in developing countries (ITU World Telecommunication/ICT Indicators Database).

More than 85% of small businesses surveyed in South Africa rely solely on mobile phones for telecommunications. 62% of businesses in South Africa and 59% in Egypt said mobile use was linked to an increase in profits. 97% of people surveyed in Tanzania said they could access a mobile phone while just 28% could access a land line phone. There was a 5000% mobile growth in Africa between 1998 and 2003. Currently, there are more than 82 million mobile phone users in Africa (Subramanian, 2010). The mobile phone revolution has been sweeping through developing countries and will continue to do so.

Mobile phones are used by reporters to report news from potentially any corner of Africa. Mobile phone financing is the hottest trend in Zimbabwe and many other Asian and African countries. Money is transferred through SMS at ease in these developing countries. Countries like Rwanda use mobile phones extensively in the health care sector. I have seen many Indian farmers using mobile phones exclusively in their agricultural trade. It is the same case in many other countries in Asia and Africa too. There are several other examples of mobile data usage in the developing economies. In Africa, wireless operators are not only providing an opportunity for banking and commodity exchange, they are also providing them at a much lower cost leading to drastic proliferation of mobile data usage. Similarly, in India the number of mobile data users are four times that of PC based internet users. In Thailand, mobile TV is being offered by 2.5 G infrastructure. Today, we see the release of 3.75 G supported Eee PC from Taiwan. Such netbooks have a good market in many Asian countries (Subramanian, 2008).

The comfort level of mobile phone usage in these countries – combined with the lack of power and broadband infrastructure – offers a unique opening that cloud computing can fill. The SaaS offers give businesses in the developing world a free or low cost alternative to traditional desktop based productivity applications. They need not buy expensive bloated office suite or accounting software. These businesses now have the option to use CRM applications, which were prohibitively expensive in the traditional software world. By moving their data to the clouds, these businesses are not held hostage to frequent power failures

and broadband disruptions. Their data is always available for easy access through their mobile devices. With the advent of low cost smartphones and netbooks with mobile data capabilities, they can now have IT infrastructure that can parallel even those of developed countries (Subramanian, 2008; Greengard, 2010; Nunn, 2010).

Cloud computing is a boon to this world. It offers an opportunity for individuals and businesses in developing countries to compete with those in advanced nations on an equal footing. Such an opportunity will create tremendous growth in these countries and help in our fight against global poverty (Subramanian, 2008).

Chong, who is involved with the cloud computing project at the (NATL) Sugar Factory in Vietnam, writes:

‘As many of you may already know, the number of mobile phone subscribers in emerging markets is growing at astounding rate, and Vietnam is one of such developing countries. Another interesting data point is that mobile phone communication and applications play key roles in driving the economic development agenda in these nations. Here we are not talking about mobile applications that use high speed 2G/3G/4G mobile networks for sending and receiving data. Instead, we are referring to content services that use plain old SMS text messaging for transmitting information’ (Chong, 2010).

PCs are still not as affordable as basic phones. As power blackouts occur very frequently in rural areas, mobile phone batteries are able to yield longer service cycles. Compared to PCs, portable phones are more convenient and better suited for roaming and rugged agriculture lifestyles. Huge proportions of the population live in rural areas where basic cellular network is almost available everywhere, and signal coverage often reaches remote farming sites as well (Chong, 2010).

## Cloud computing enabled mobile applications

Cloud computing has enabled an array of applications to be deployed via mobile phones. While 3G mobile applications are ubiquitous in devel-

oped countries across the globe, the majority of the world's mobile users live in developing countries with access to only 2G cellular networks and phones with little more than voice and SMS capabilities. In this section, we look at how users of 2G mobile phones in developing countries are making the most of what they have and the applications that they use. While 2G applications as an emerging media channel may sound like an oxymoron to those in developed countries, this cloud computing technology has the potential to change the way people live, interact, trade and consume media in developing countries.

The creation of useful 2G data applications for expanded access to media in developing countries relies on cloud computing to handle the heavy calculations that a data application requires, using SMS as a conduit for the information and simple application interfaces to handle user interaction. Applications running on such a stripped down platform could be as simple as a local news aggregator and as complex as a medical data repository. Because calculations, data storage and other advanced features are handled by servers 'in the cloud' and sent via SMS, the 2G application only needs to handle basic text presentation.

Another way in which 2G applications will act as an emerging channel in developing countries involves the same concept of connecting cloud computing to 2G handsets. However, it relies on a new generation of cheap mobile phones that are capable of running more advanced applications and not just SMS interfaces. Vodafone is the major driving force behind this application of 2G as it owns a number of cellular networks in developing countries. Vodafone recently released a 2G phone capable of running applications at an extremely low price. To expand the availability of 2G media, Vodafone teamed up with Opera Software in 2009 to develop a custom-made version of mobile browser Opera Mini, designed to give customers a high-quality mobile Internet experience on affordable 2G mobile handsets. The Opera Mini browser uses cloud computing to compress Internet pages by over 90% before transmitting them to mobile phones over the 2G network.

According to the World Bank, in 2009 three-quarters of the world's estimated 4 billion handsets were used in developing nations on 2G networks (Weinberg, 2010).

## M-Banking

Mobile banking (also known as M-Banking, mbanking, SMS Banking, etc.) is a term used for performing balance checks, account transactions, payments etc., via a mobile device such as a mobile phone or Personal Digital Assistant (PDA). Mobile banking today is most often performed via SMS or the mobile Internet but can also use special programs, called clients, downloaded to the mobile device (Wikipedia, 2010).

An Afghan police officer gets his salary in a text message on his mobile phone. A Kenyan worker dials a few numbers to send money to his family. The rise of banking transactions through mobile phones is giving a whole new meaning to pocket money in parts of the developing world that lack banks or cash machines. Mobile money applications are emerging as potent financial tools in rural and remote areas of the globe, allowing people with no bank accounts to get paid, send remittances or settle their bills. 'One billion consumers in the world have a mobile phone but no access to a bank account,' said Gavin Krugel, of GSM Association. (Cornu, 2010)

M-PESA (Swahili for M-Money) is a branch-less banking service, meaning that it is designed to enable users to complete basic banking transactions. In Kenya, the continuing success of M-PESA has been due to the creation of a highly popular, affordable payment service with only limited involvement of a bank. The system was developed and run by Sagentia from the initial development to the six million customer mark. The service has now been transitioned to be operationally run by IBM Global Services on behalf of Vodafone, the initial three markets (Kenya, Tanzania and Afghanistan) are hosted by Rackspace (Wikipedia, 2011).

## M-Education

The term M-Learning (or 'mobile learning' or M-Education) has different meanings for different communities. Although related to e-learning and distance education, it is distinct in its focus on learning across contexts and learning with mobile devices. One definition of mobile learning is: any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies. In other words mobile learning decreases limitation of learning location with the mobility of general portable devices (Wikipedia, 2011).

There is also clearly great promise for the use of mobile phones in education in Africa. As a DE delivery mode, SMS has already proved to be cost-effective and efficient. Visser and West noted that the next generation of mobile phones 'have started to include full Internet access and introduce an 'always on' cellular technology which enables the cellular telephone user to access the Internet directly' (2005, p. 120). Two of the driving forces for mobile phone technology in developing countries will be the development of the USD\$20 handset and 3G network expansion (Motlik, 2008). With increasing cell-phone penetration, the use of SMS in both formal and non-formal education can benefit learners at a fraction of the cost of other methods in developing countries (Motlik, 2008).

millee is an m-Education Project. The acronym stands for *mobile* and *immersive learning* for *literacy* in *emerging economies*. It states:

**Problem:** formal schooling has limited impact on children in developing countries due to child labour, inadequate teacher training, etc. Literacy levels in several underdeveloped regions can be shockingly low, sometimes under 50%. Sub-Saharan Africa has highest rate of children out of school (36.2%), followed by South Asia (20%).

**Opportunity:** mobile phones enable access to quality learning resources - anytime, anywhere. UN estimates that half of all residents in remote areas will have mobile phones by 2012. With mobile technology, we have an opportunity to significantly increase the reach of education

**Solution:** Brings education to learners who cannot attend school on regular basis. Game-like learning experiences that are engaging. Compatible with public schooling and other educational delivery models. Target learners: (i) rural children, (ii) urban slums children, and (iii) other near-poverty children whose families cannot afford education (Carnegie Mellon University Human Development Lab, 2011).

## M-Health

Rural populations account for 56% of developing countries' 5.3 billion people. The combination of geography, isolation, and poverty conspires with dramatic urban-rural disparities in resource allocation to create unique and often intractable health care challenges. Health care needs among rural populations are largely, though not entirely, aggravated by remoteness. Rural concerns include: distance from health centres limits pre-natal and maternal care, distance from specialty



M-Pesa Statistics:

Customers: 2007 April = 52, 543

Customers: 2009 August = 55, 425, 515

3 Million Transactions a Day – Rackspace

407 Million Users Predicted by 2015

(PC World)

*M-Pesa inspired 60 copycat companies  
(oreignpolicy!)*

Figure 5. M-Pesa of Kenya is now in other developing countries.

services, lack of good health education, susceptibility to climatic crises, nutrition, dietary issues, and greater frequency of work-related injuries (Vodafone and United Nations Report, 2008).



**Figure 6.** Efficiency and impact of m-health for development in developing countries (Vital Health Consulting, 2009).

In the developing world, lack of infrastructure prevents health workers from delivering efficient healthcare to rural areas. As health workers travel from clinics to reach isolated patients, they are often as disconnected from central clinics as the patients they are trying to serve. The mission of FrontlineSMS Medic is to advance healthcare networks in underserved communities using innovative, appropriate mobile technologies. 'The centrepiece of our system is FrontlineSMS, a free, open-source software platform that enables large-scale, two-way text messaging, using only a laptop, a GSM modem, and inexpensive cell phones. We are also extending the FrontlineSMS platform to enable better patient management, electronic medical records via the cell phone, cheap mobile diagnostics, and mapping of health services' (FrontlineSMS:Medic, 2010).

m-Health is now fast becoming the future face of healthcare management systems and will significantly re-engineer the healthcare delivery system worldwide on the personal, collective and system levels. United Nations and Vodafone's mHealth Alliance have banded together to advance the use of mobile phones to better aid those in need of healthcare in developing countries.

## M-Agriculture

As an affordable and accessible means of communication, rural communities are realizing the potential of mobile phones to create economic opportunities and strengthen social networks. Mobile phones effectively reduce the 'distance' between individuals and institutions, making the sharing of information and knowledge easier and more effective. The mobile phone is no longer just an audio communication tool but capable of providing additional integrated functions.

Mobile telephones have been a 'dream come true' for rural areas. Connectivity to the outside world has been made easy. Unnecessary commuting to urban centres has been tremendously reduced. At a meeting with farmers, one of the key discussions was: *How ICT can help rural farmers get access to required agriculture-related information?* Interestingly, many of the farmers never heard of computer technology but tried to relate ICT with mobile phone. They clearly understand the value and benefits of mobile phones; in the past they had to travel long ways to give or collect any information, but now they get information and can connect to people effortlessly (Shahid Uddin Akbar, Bangladesh Institute of ICT in Development, e-Agriculture.org, 2009)

Farmers use SMS in relation to market access, interacting with traders and middlemen to distribute and receive information about products, prices, and availability. Other examples of mobile phones used in the agricultural sector of developing countries are:

**Bangladesh's CellBazaar** is a service from Grameenphone that allows people to buy or sell over their mobile phones. Customers looking to sell something, post the information on CellBazaar through Grameenphone, and buyers get in contact.

**Ghana's TradeNet** is an Internet application that enables you to provide market information via the web, email and SMS quickly and affordably. The application has been designed and developed by an international team based in Accra, Ghana.

**Jamaica's Jamaica Agriculture Market Information System (JAMIS)** is a proj-

ect by the Ministry of Agriculture and Fisheries aimed at establishing the first electronic market system focused on the publication of weekly prices at the farmgate, at municipal markets, at retail, and wholesale.

There are several mobile phone applications that have been deployed using the cloud computing infrastructure. There is a strong indication of e(electronic)-applications of developed countries being replaced by m(mobile)-applications in developing countries. Internet banking in developed countries is now m-Banking in developing countries, as is: e-Learning to m-Education, e-Health to m-Health, and e-Agriculture to m-Agriculture. This list could be endless, considering the number of mobile phones continuously being subscribed to in developing countries.

Cloud computing applications will also supplement existing traditional establishments like tertiary institutes and universities. Google just announced its Google University Access Program that aims to address the underlying cause – the high cost of Internet bandwidth and access to experienced engineers. The program offers Internet bandwidth, Google Apps for Education, training and integration grants and the support of Google engineering. This is in return for the university committing to invest in their campus infrastructure; ultimately Internet bandwidth will reach faculty and students (Google University Access Program, 2011).

Governments have the potential to be model users of Cloud computing. As the largest economic entity in most countries, government has the leverage to set standards and requirements that can influence actions throughout the economy. Just as US federal government websites demonstrated the power of the Internet and inspired state and local governments and companies to create an online presence, national governments can be early adopters of cloud computing, which would demonstrate and publicise the technology. However, if governments are going to become early adopters of cloud services, they must overcome bureaucratic, regulatory, and cultural barriers to resource sharing that could slow the adoption of cloud comput-

ing. Government IT procurement rules covering hardware and software purchases must be updated to enable the purchasing of cloud services. Cloud computing could provide huge benefits to governments – m-Government.

Cloud computing has some attractive qualities for scientific researchers. It delivers data storage and processing as a service, rather than software that is loaded onto a hard drive or something that sits on a desk somewhere. Information is held in massive data centres spread all over the world and available upon request. In the cloud, the ‘supercomputer’ exists virtually, meaning: no clunky hardware, software interfaces that are easy to use, and scientists who have access to their data and simulations from just about anywhere by simply logging in.

### Cloud computing’s issues and challenges

By now, it is evident that in this research paper on cloud computing, the focus has mainly been on mobile applications enabled via cloud computing. Cloud computing in essence as applied to the developed countries within the context of broadband Internet is not only a challenge; it is not viable for many developing countries considering its economy, existing infrastructure, and affordability. The reason why mobile phones and mobile applications have an influx within developing countries is because they are affordable and are able to make use of existing radio broadcast infrastructure and emerging wireless cellular network architecture.

Many mobile phone service providers have invested substantial capital into infrastructure development to provide mobile phone networks in remote regions, forfeiting their profit margins. Others have been subsidised by the developing country’s government or donor agencies like the World Bank. Working in emerging markets presents challenges, sometimes with marked differences in approaches to risk around issues such as customer loyalty and revenue, when compared to developed countries. Users of mobile phone services in developing countries do not make the volume of calls required to give the mobile service provider the required profit.

We are expanding our networks to extend access and tailoring products and services to make them affordable for more people. At the same time, we are finding many areas where we can learn how to be more cost and time efficient – a prerequisite of operating in lower-margin markets. First, we aim to bridge the digital divide in emerging markets. We believe that improving access to communications can be a springboard to alleviating poverty and enabling sustainable development. Many of the benefits our services can bring are very visible in emerging economies. (Colao, 2010)

Providers and users of the mobile applications enabled via cloud computing face additional challenges in developing economies, due to unfavourable institutional environment. In many developing countries, factors such as corruption, the lack of transparency, and a weak legal system can exacerbate security risks. These factors combined with famine, civil strife, political upheaval, and natural disasters make mobile service providers more reluctant to move into the markets of developing countries. Lack of return on investment and business continuity is not guaranteed.

Cloud computing's lifeline is connectivity. All the services, benefits, and goodies that it is envisaged to deliver only exist when we are connected to the network. No network = no services. How consistent is network connectivity? Different readers from different parts of the world will have different answers. Based on connectivity, some readers might read this online and others, who are not sure of their connectivity, will download or print it out to read. Some readers might even read this paper on their mobile phones, Tablet PCs, PDAs, or Blackberry.

Readers can recall times when they were disconnected, or when their network service provider was down, or the service that they wanted in the cloud was down. Some still remember their frustrations when trying to contact their families and friends while on holiday somewhere remote where the connection was intermittent. If this diminishes the value of cloud computing, then it certainly does. For businesses that rely on mobile phones, connectivity downtimes translate into huge losses. For individuals, they miss out on that important call for a job interview.

The mobile revolution is a primary driving force behind the quick ascent of cloud computing. 70% of mobile phone users are from developing countries, engaging in mobile cloud computing from anywhere, at anytime, and need secure data access, access to applications and services. Security and privacy issues are even more challenging than they were before. How do we reach a balance in security and usability? Will service providers segregate users according to the digital divide?

In the future, there might not be a choice because some of the applications might only be mobile applications. They might not be offered within the traditional desktop computing platform. To use the application, you will need a mobile phone because that is the only means of access. However, if the application is only developed and delivered through the cloud environment, and – if it is the only way you can use that service – you will have to find a way to connect to the cloud.

Strategies need to be employed to manage not only risk but also those situations when a cloud service provider suddenly and unexpectedly stops delivering services. There might be several reasons why this could happen. Reputable sites like Google, Amazon, and Microsoft have been known to have been down and unable to provide services for some time. The other issue to be considered is that in moving services to the cloud, the organisation or individual no longer retains direct access and control (Bristow *et al.*, 2010).

Mobile cloud services are largely dominated by vendor specific walled gardens and debate is not as intense as one would expect, given the number of cell phone users. This is probably due to the fact that not only are free software powered mobile phones still a minority, but installing new software on phones was not an option for the mass market until recently. After the iPhone and Android, with more and more 'application stores' emerging, the issue of mobile users' freedom is coming up. Users of one handset, for example, may want to get their email from one provider, sync pictures with another, and use the international services of yet another (Capobianco, 2009).

Network operators do not want users to be too free, so most of them prevent users from running applications that are not digitally signed. RIM, Apple, and, to some extent, Symbian devices are locked down, which renders users' freedom in the mobile cloud a balancing act: on one hand a developer needs to obey the rules dictated by network operators and device manufacturers, and on the other hand the same developer needs to find ways to deliver freedom to users.

Many of the most successful and most visible applications of cloud computing today are consumer services such as email services (Google Mail, Hotmail, and Yahoo Mail), social networks (Facebook and MySpace), and virtual worlds such as Second Life. The companies providing these services collect terabytes of data, much of it sensitive personal information, which are then stored in data centres in countries around the world. How these companies, and the countries in which they operate, address privacy issues will be a critical factor affecting the development and acceptance of cloud computing (Nelson, 2010).

With the Internet, strong economic benefits and customer demand both pushed network service providers to link their different networks and create a network of networks. The situation may not be as clear-cut with the cloud, and some companies building the infrastructure of the Cloud may be able to use economies of scale, ownership of key intellectual property, and first-mover advantage to block or slow competitors. Governments will need to watch carefully to see that companies do not use their dominant position in one sector of the IT or telecommunications market to gain an unfair advantage in the market for Cloud services. A Cloud built by only one or two companies and supporting only a limited set of applications would not be in the best interest of either individuals or corporate customers (Nelson, 2010).

One of the thorniest issues related to the Cloud may be electronic surveillance, particularly when it spans international borders. In most cases, the police must get a search warrant to examine data on someone's home computer. It is not at all clear whether the same data is protected if backed

up in a data centre in the Cloud, particularly if that data centre is in another country. If users believe that governments will be monitoring their activities, their willingness to use the Cloud for important functions will surely decrease.

Will cloud computing give rise to online piracy? Would governments try to enforce laws against this in ways that limit or slow the development of cloud services? By giving customers access to almost unlimited computing power and storage, cloud services could make it even easier to share copyrighted material over the Internet. Will cloud service providers be required to take special measures to prevent this? Will they be liable for illegal activities of their customers? Would doing so make it impractical for companies to provide cloud services to the general public?

The biggest challenges are vendor lock-in and proprietary technologies. If data gets locked in, then the flow of data will be disrupted, disrupting the very nature of the cloud itself. Other challenges include the clamp down on content by media giants, who, in the name of privacy, can have a tendency to inhibit expression and, as a consequence, the free flow of information. The government may play its own part as it seeks to regulate, which in turn may create an onerous environment for the development of the cloud. Cloud computing also means that companies may shed their IT resources, saving on capital expenses. That may mean a loss of jobs but it is clear the upsides may be considerable as to the cloud scales (Nelson, 2010).

A study has found that popular mobile phone applications are sharing sensitive information about users, including their location, with advertising companies. A group of computer engineers wrote a computer program called TaintDroid and installed it on a Smartphone to monitor how 30 applications – mobile phone programs for the likes of social networking and downloadable games – were using sensitive information. Of the 30 applications, 15 sent sensitive information, including the phone's location, to several advertising companies' servers. Two also shared mobile phone number and SIM card identifiers with random servers, whose owners could not be identified (Phillips, 2010).

## Discussion and conclusion

The cloud computing technology has been around since industry started using main-frame computers for distributed computing. The distributed computing technology has been labelled as cluster computing, virtual computing, and other names. Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centres that provide those services. The services themselves have long been referred to as Software-as-a-Service (SaaS). The data centre hardware and software is what we will call a cloud. When a cloud is made available in a pay-as-you-go manner to the general public, we call it a Public cloud. We use the term Private cloud to refer to internal data centres of a business or other organisation, not made available to the general public.

The evolution of mobile applications enabled via cloud computing technology for use in developing countries clearly unfolds at a much greater speed than the evolution and adoption of personal computing and the Internet. ICT4Ds are also not developing in isolation from technological and business model solutions for developing countries. ICT4D clouds will greatly enhance and bring dramatic improvements to existing development efforts. Cloud computing has interesting implications and potential for developing countries. There is an initiative to use cloud computing to help universities and public libraries in Africa adopt open source integrated library systems, a transition they are struggling with as they lack local technical support. Using cloud computing might reduce incentives for developing ICT capacity at the local level.

In today's academic environment, the value of a computer lab not connected to the Internet is negligible. Faculty and students must be connected with the research community in order to contribute to and benefit from it. Much of the due diligence in Sub-Saharan universities has uncovered no shortage of computers but rather a severe lack of connectivity. The Google University Access Program aims to address the underlying cause of the high cost of Internet bandwidth and access to experienced engineers. The program offers Internet

bandwidth, Google Apps for Education, training and integration grants, and the support of Google engineering. This is in return for the university committing to invest in their campus infrastructure – ultimately the Internet bandwidth will reach faculty and students.

According to several presentations at Digital Africa, there is strong evidence that with each 10% of any population in Africa having access to mobile or Internet technologies, there is a corresponding 1.8% increase in that nation's GDP. There is strong evidence that simply bringing mobile education to the rural and unwired population will increase the national wealth and quality of life by an annual increase of 1.8%. Computing has long been recognized as a means of ensuring that people from developing countries have a pathway to bettering their lives and joining the rest of the international community. Computing has been at the heart of many developmental programs in both the urban centres and rural centres.

Cloud computing will play a big role in enabling the IT revolution in the developing nations to help companies market products and services to four billion consumers at the bottom of the pyramid. At the end of 2009, there were four billion mobile phones. By 2013, that number is projected to grow to six billion. That is many times the number of personal computers. When we start including other Internet capable devices into the mobile world, like ebook readers, photo frames, printers, photo and video cameras, personal navigators, the numbers go way up. Small portable devices that can access information are already part of everyday life for hundreds of millions of people in the developed world. Also, much points to the fact that developing countries will be using the mobile cloud before they get to the 'regular' one (Capobianco, 2009).

The popular uptake of ICT devices for personal use in developing countries only started around 2003-2004 with the development of the pay-as-you-go business model for mobile services and the lowering of the cost of mobile phone devices. Currently, there is an intense competition among device manufacturers for the establishment of an ultimate and pervasive platform for mobile devices. The competition among

Nokia's Symbian, Google's FOSS Android, Apple's iPhone, RIM's BlackBerry, Microsoft's Windows Mobile, and others is similar to the early days of the personal computer and the struggle between Windows and Apple. Mobile phone technology in developing countries is in Phase 1 (the emerging phase) with 2G phones, while the developed countries are using 3G and 4G phones for entertainment. With the innovative use of 2G phone technology by developing countries' users, one can wonder if they will ever embrace computers and the Internet like the developed countries when 3G and 4G phones get into their hands. They might not have the need for processing power and storage capacity like others.

Cloud computing makes new classes of applications possible and delivers services that were not possible before. Examples include (i) mobile interactive applications that are location, environment, and context-aware and that respond in real time to information provided by human users, nonhuman sensors (e.g. humidity and stress sensors within a shipping container) or even from independent information services (e.g. worldwide weather data); (ii) parallel batch processing, which allows users to take advantage of huge amounts of processing power, to analyse terabytes of data for relatively small periods of time, while programming abstractions like Google's MapReduce or its open-source counterpart Hadoop, which performs the complex process of parallel execution of an application over hundreds of servers, transparent to programmers; (iii) business analytics that can use the vast amount of computer resources to understand customers, buying habits, supply chains, and so on from voluminous amounts of data; and (iv) extensions of compute-intensive desktop applications that can offload the data crunching to the cloud, leaving only the rendering of the processed data at the front-end with the availability of network bandwidth, reducing the latency involved (Bandyopadhyay *et al.*, 2009).

Cloud computing has some attractive qualities for scientific researchers. It delivers data storage and processing as a service, rather than software that is loaded onto a hard drive or something that sits on a desk somewhere. Information is held in massive data centres spread all over the world and available upon request. In the cloud,

the 'supercomputer' exists virtually, meaning no clunky hardware; the software interface is easy to use, and scientists have access to their data and simulations from just about anywhere by simply logging in. Amazon has been leading the way in on-demand computing for the past decade, invaluable for organizations with large databases that do not necessarily want to hire an IT department. The service is flexible and pay-as-you-go. An hour will set you back 80 cents, or as little as 10 cents per gigabyte. Subscribers buy only what they use, which is ideal for research departments that face periodic peaks in the computational power they require (Werth, 2009).

Another opportunity provided by cloud services is to support researchers in reducing the costs involved with computation. Only a small number of researchers need capability computing – high-performance computing (HPC) systems with large numbers of cores. The majority of researchers are well served with capacity computing – systems that share their computing power with several and up to many users. This capacity computing is exactly where cloud computing excels. Recently, Microsoft and the National Science Foundation announced an agreement that will offer selected individual researchers and research groups free access to the Windows Azure cloud computing resources. This initiative opens up a whole new spectrum of opportunities for both researchers and institutions (Bristow *et al.*, 2010).

Cloud services offer higher education and research institutions the power to choose: the opportunity to rethink which services are needed to support education and research and what will be the best way to deliver those services. Many services are readily available in the public cloud. Some services need to be procured through the institution's IT department. Only a few services will require custom development, either alone or in partnership with other institutions. The final result will most likely be a loosely coupled, customised arrangement, consisting of off-the-shelf systems and services based on proven technology.

One specific use of the cloud for research is e-Science Central in the United Kingdom, developed by Professor Paul Watson and his team at Newcastle University. Building on experience

gained through projects by the Joint Information Systems Committee, such as myExperiment, e-Science Central delivers cloud-enabled e-science capability to researchers across many disciplines. Researchers build workflows in a drag-and-drop interface from pre-existing shared modules, or they write and contribute their own workflows using Java, .net, or Python. The system utilizes a collaborative model inspired by Facebook, with users having the ability to form groups and share data and processes. The security model of e-Science Central works with this element of the system: allowing researchers to permit collaborators to see their workflows and to comment on them. The system also has a built-in blogging tool. Once an experimenter has set up the workflow, he or she initiates the process, at which time the system sends the computational work either to Newcastle's own servers or to the cloud, as appropriate. Although e-Science Central currently uses Microsoft's Azure platform, the system can also be configured to use Amazon EC2. It has about 50 regular users across a range of scientific disciplines, but Watson sees the system as scalable to thousands in due course. He also sees the potential for applications like e-Science Central to open up for those who at present are excluded, by geography or cost, from access to HPC (Bristow *et al.*, 2010).

The mobile phone revolution in developing countries has changed the way people communicate in their daily lives and conduct business. Many people never had a landline and in some cases no electricity. Some of them charged their mobile phones using a charger that generates electricity from a bike. As the cellular data networks become more and more mature and reliable, the same consumers will have access to the Internet on their mobile phones without having a computer or broadband at home. This will enable a range of applications for computing in the cloud.

The costs associated with cloud computing facing early adopters include the potential costs of service disruptions, data security concerns, potential regulatory compliance issues arising out of sensitive data being transferred and processed or stored beyond defined borders, limitations in the variety and capabilities of the development and deployment platforms cur-

rently available, difficulties in moving proprietary data and software from one cloud service provider to another, integration of cloud services with legacy systems, cost and availability of programming skills needed to modify legacy application to function in the cloud environment, legacy software CPU-based licensing costs increasing when moved to a cloud platform, etc.,

Developing countries have their highly skilled IT people working in developed countries. These people are skilled to write new kinds of software that will fuel the cloud computing growth back home. This has the potential and is already causing a reverse immigration trend amongst highly skilled IT workers who have chosen to return back to their home countries to pursue such existing opportunities. These skilled people are likely to bring in their experience of the western world to build new generations of tools and applications and innovative ways to serve their people.

It is encouraging to see that there is an increasing amount of ongoing research on cloud computing. Most of the current researches are focused on cloud computing within the context of the Internet and broadband and how it is changing the computing landscape in developed countries. Cloud computing will offer more opportunities to developing countries. More research is necessary in order to make individuals, businesses, and their governments in developing countries realise how they can benefit from mobile applications enabled via cloud computing. Understanding the challenges and issues in using cloud computing and overcoming them will provide the necessary fuel to the development efforts of the various stakeholders in the developing economies.

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