IT Infrastructure in Emerging Markets: Arguing for an End-to-End Perspective

To help sustain large-scale pervasive computing in emerging markets, researchers must address unique challenges in the delivery fabric and enterprise backbone. Such challenges present opportunities for high-impact innovation.

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Emerging economies, including the so-called BRIC countries (Brazil, Russia, India, and China), are growing at phenomenal rates. China and India are the world's seventh and tenth largest economies, with a combined gross domestic product of US$2.3 trillion ($10.3 trillion including purchasing-power parity).[1] With projected GDP growth rates from 5 to 8 percent, these economies are poised to be an even greater fraction of the global economy. For example, the BRIC countries' combined GDP will likely overtake that of the G6 countries (the US, the UK, France, Germany, Italy, and Japan) in the next few decades (see figure 1). Dominic Wilson and Roopa Purushothaman estimate that the BRIC countries' spending will be twice that of the G6 countries by 2025, and they project that the BRIC countries will have a larger share of the demand generation for computing products.[2]

Although several of these countries dominate vertical domains such as IT outsourcing or hardware manufacturing, domestic consumption of computing technologies is just starting to ramp up.[3] India and China's middle-class populations are the largest customer base for home computing solutions, and this group's buying power continues to increase. For example, a study by India's National Council of Applied Economic Research predicts that India's "consuming class" will likely grow from 25 percent of the total population to over 45 percent by 2007.[4] Correspondingly, in the year 2010, PC shipments in India and China are likely to be an order of magnitude higher than in the US.[1] China already boasts nearly 100 million Internet users and 350 million cell phone subscribers, and analysts expect it to have the most Internet users and broadband adoption in the world in the next five years.[5]

At the enterprise side, analysts estimate that Chinese and Indian corporations' IT infrastructure spending will outpace spending by American firms. In the last year, 69 percent of Indian corporations had an increase in their IT budgets, compared to just 39 percent in North America.[1] Forrester Research estimates that India and China alone will spend close to $1.1 trillion in the coming decade on new infrastructure.[1] All these trends create the need to focus on new products and solutions targeted at new pervasive information and communication technologies (ICTs) for emerging markets.

Although most research organizations have focused on developing consumer-facing solutions (see the "Previous Approaches in Emerging Economies" sidebar), we posit that future research must take an *end-to-end perspective*. That is, researchers must not only consider the front end (such as consumer devices) but also the medium to reach the consumer (for example, the delivery fabric) and the back end (for example, the enterprise backbone) to create an economically sustainable, scalable solution.

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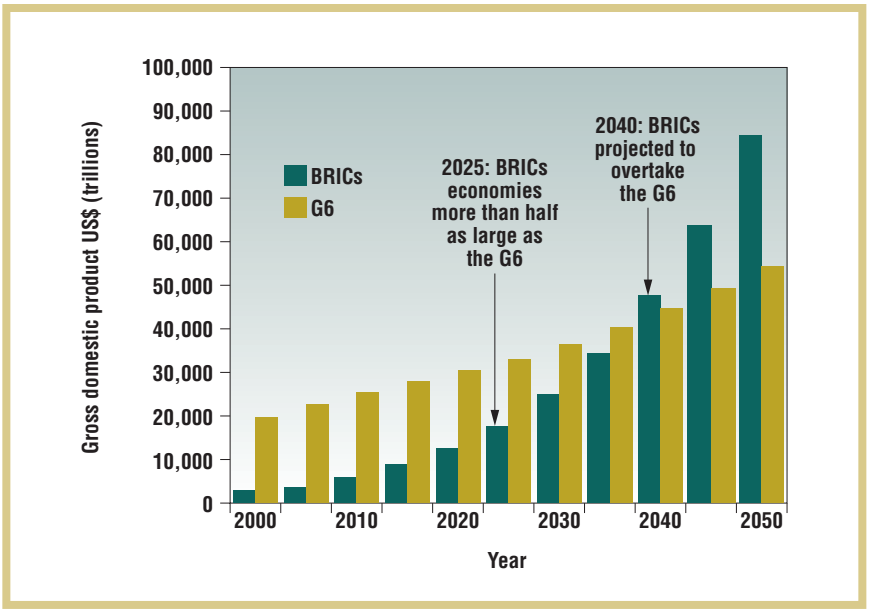

Figure 1. Projections of economic growth show that the BRIC countries' combined gross domestic product will likely be significantly higher than that of the G6 countries in the next few decades.[2]

An end-to-end perspective

Numerous consumer-centric projects have improved social and financial conditions in small-scale scenarios. Examples of several such projects highlight the need for an end-to-end perspective.

Some motivating examples

aAQUA, a multilingual question-answering and knowledge-retrieval system, is a newsgroup patrolled by agricultural and medical experts (http://aaqua.persistent.co.in/aaqua/forum/index). The question posting and searching facility conveniently and automatically translates into multiple Indian vernaculars. aAQUA has helped farmers improve their crop yields.

With a similar goal, eSAGU takes a more direct approach. It distributes agricultural experts' knowledge to numerous independent farmers (http://agriculture.iiit.net/esagu). A semiskilled agricultural expert, a coordinator, visits farms weekly, collects data, and photographs potential problems in the field. Couriers manually deliver the photographs and other farm data to a central site where the data is deposited into a database for experts to peruse. Experts examine each case and email farmers with advice on applying fertilizers or pesticides. Farmers receive the recommendations through local kiosks or from coordinators.

Tapan Parikh's CAM system leverages mobile phones' ubiquity to let computer-naive users interact with computing services.[6] The main innovation is the user interface, which integrates specialized forms and a camera phone through which users can query and enter data into a back-end server. The phone communicates with the server through the cellular network or an intermediate host connected to the Internet. CAM has enabled pilot applications for verifiable record keeping and electronic transactions in remote rural areas.

Although these systems have all succeeded at small-scale deployment, it's unclear whether they can be economically viable on a larger scale, when the back-end database infrastructure grows to populations larger than just a few districts. Thus, such projects need research that focuses on the back-end infrastructure in addition to user-centric research.

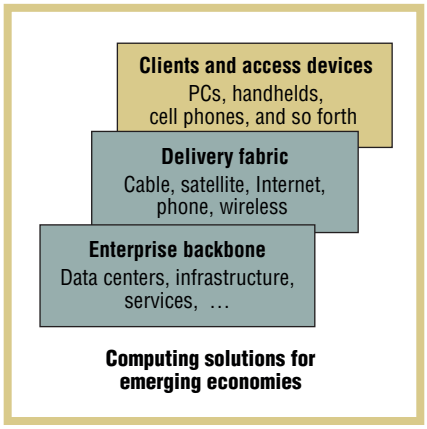

Figure 2. A high-level view of emerging-markets research. Future emerging-economies research must look beyond front-end solutions to a complete end-to-end perspective.

Opportunities

Emerging markets will likely offer many opportunities for innovation in the delivery fabric and back-end enterprise backbone (see figure 2). Understanding the challenges unique to these markets will give researchers greater opportunities to increase ICTs' pervasiveness and extend their reach to larger populations. For example, focusing on the delivery fabric, a key characteristic of emerging markets is the huge amount of existing infrastructure. Unlike developed countries, where many computing solutions are delivered through the computing network fabric, emerging markets have a huge existing user base linked to cable and satellite networks. For example, Internet penetration in developing countries is as low as 7 percent compared to 53 percent for developed countries.[7] Cable reaches a much larger fraction of the population than the Internet.[5]

Similarly, several emerging communications markets, such as India's, have greater wireless growth and penetration compared to conventional phone networks due to broader adoption of wireless networking. According to the United Nations Conference on Trade and Development Information Economy Report, in 2004, developing nations had 895 million mobile subscribers—20 percent

Previous Approaches in Emerging Economies

Spurred by a common belief that emerging economies will generate the next wave of growth, many international firms have established centers in these markets to tap their relatively high-skilled, low-cost talent. Multinational corporations have set up more than 250 R&D labs in China and India since 1997.[1] Although many labs initially operated as lower-cost subsidiaries for consumer demand in more developed countries, the focus has increasingly broadened to the development of technologies specific to the local economies.[2] Specifically, several studies have cited increased demand combined with a lower per-capita income as a motivation for higher-volume, lower-cost solutions specifically targeted at emerging markets.[3,4] As an initial step, R&D centers have worked on characterizing emerging economies' cultural uniqueness and their implications for computing environments. Several resulting solutions have focused mainly on front-end solutions, targeting client systems to potentially reach a larger fraction of end-consumers. For example, much research addresses emerging economies' cultural differences, such as the multiplicity of languages, cultural diversity, low literacy rates, price sensitivity, and low computer usage.

This trend toward focusing on local customers in emerging markets by developing affordable, relevant solutions is a noteworthy departure from the past. However, these research organizations' experience working in situ over the past few years, especially HP Labs India, has led to several salient realizations. Emerging markets have a large, distributed customer base with highly variable incomes. This diversity makes it much easier for IT firms to reach the customer base through existing distribution channels via value-added intermediaries rather than create their own channels. Typically, these intermediaries are large existing entities, government or private, to which customers are already accustomed. Targeting these intermediaries not only lets IT firms focus on their core competency of technology innovation, but also enables the intermediaries to serve their customers better (see figure A). This approach lets IT firms effectively leverage existing organizations to reach end consumers.

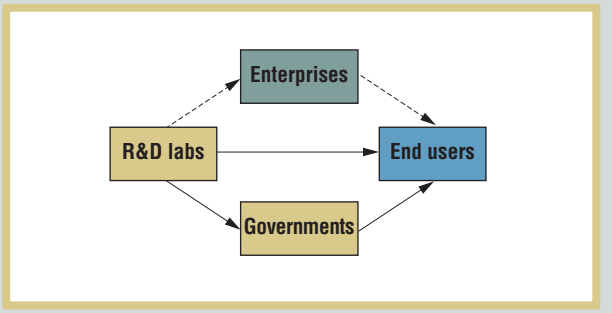

Figure A. Opportunities for R&D labs in the enterprise segment.

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higher than developed countries' subscriber base of 740 million.[7] Figure 3 presents illustrative data for various delivery fabrics at a broad region level across North America, Europe, Asia (excluding Japan), and Latin America. These delivery fabrics, such as cable and wireless, present several unique challenges for deploying the bidirectional and high-bandwidth computing solutions we associate with developed markets. Thus, we must rethink solutions specific to delivery fabrics in developing countries.

Examining the enterprise backbone reveals similar opportunities (see figure 4). For instance, developed countries' increased outsourcing of IT functions (and often higher-level business functions) to emerging markets has caused enterprises to make large, continuous investments in emerging economies to augment their IT infrastructure. The increased infrastructure enables the outsourcing and replaces equivalent (higher-cost) deployments in the US. Countries such as India and China have growth rates of close to 20 percent in the outsourcing segment, significantly higher than those in developed countries. The reasons behind this growth are twofold. The revenues from business-process outsourcing to India increased from $300 million in 1999 to $1.5 billion in 2002.[8] Also, opportunities to provide other basic infrastructure services beyond IT outsourcing are also tremendous in these economies. One such example is the Indian financial sector's introduction of *anywhere banking*, which lets customers access their accounts and perform transactions through various channels, including branches and extension counters, automatic teller machines, call centers, and the Internet. In this case, the banks require increased investment in both IT back-end and front-end infrastructure. Another opportunity on the enterprise side lies in addressing the small-and-medium business (SMB) market in emerging economies. These smaller enterprises are plentiful and have signif-

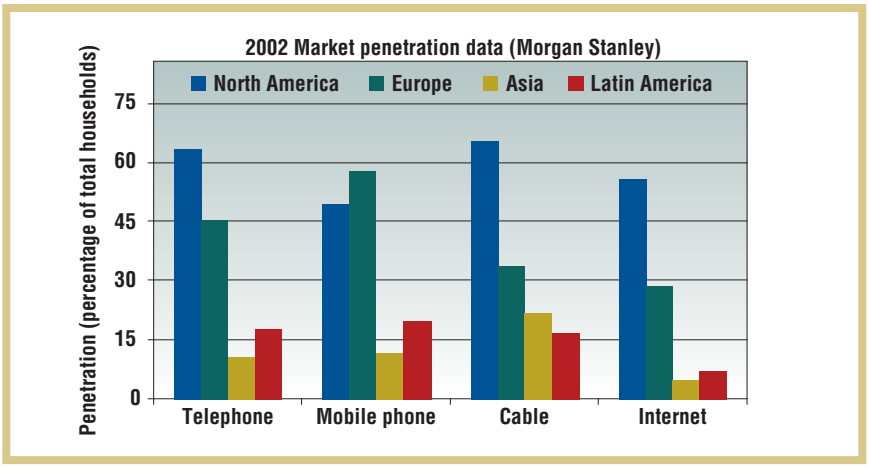

Figure 3. Comparing different delivery fabrics' penetration in developed and developing countries.[5]

icantly different constraints than their counterparts in the US. Another key challenge is in providing a transition path for current manual processes to work seamlessly with future automations in the enterprise backbone.

Although our end-to-end perspective generalizes to all emerging markets, in this article, we mainly discuss the Indian market from which we based our observations.

Leveraging the delivery fabric

To reach the largest fraction of consumers in emerging markets, we must consider not only consumer-centric devices but also the most prevalent communication fabrics to reach those devices. For example, in India, the two most ubiquitous delivery mediums are television broadcast and the mobile phone network. In 2005, India had 500 million television viewers—far outweighing the Internet's penetration of only 18.5 million users.[9] By November 2004, the number of mobile phone subscribers (44.9 million) overtook the number of landline phone subscribers (43.9 million).[10] Moreover, mobile phone subscriptions have doubled roughly every year.

Television broadcast network

One strategy is to leverage broadcast networks, combining them with high-function end user devices to enhance the consumer experience. For example, HP Labs India has developed a technology to convert passive television viewing into a rich mixed-media experience. The PrintCast system augments television programs with print-related information to give end-users additional material that they can retain on paper.

The PrintCast approach (see figure 5) augments a television signal with electronic data to enhance the viewing experience. Electronic data is embedded in the Vertical Blanking Interval, part of the television signal. (Parts of the VBI have been used for teletext in Europe and closed-captioning in the US.) On the transmitting end, this scheme requires no change to existing broadcast technology. PrintCast combines print data from a PC with the program AV signal using a standard device called an inserter. After insertion, the system encodes the signal and transmits it with traditional broadcast equipment. On the receiving side, viewers use a PrintCast decoder to decode the data from an analog television signal. Once decoded, the PrintCast box relays the data to a printer, which prints the context.

PrintCast applications include voter information guides for elections, coupons associated with advertisements, homework exercises for distance learning, and printing recipes for cooking shows. With appropriate identification in the device, the PrintCast decoders can become addressable to allow personalization. Such a feature enables broadcasters to deliver targeted advertising (for example, based on region or user profiles) at low cost. A working prototype of PrintCast is complete.[12] (For a discussion of an interesting extension to this approach, see the "Reverse Migration" sidebar.)

Mobile phone network

Indian and Chinese markets' rapid adoption of cell phones indicates that future research should target this platform as a data and financial services portal. Indeed, prior approaches in developed countries using cell phones for financial transactions provide proof points on this approach's viability. A key obstacle in such a scenario is the presence of a security barrier, which must be overcome so

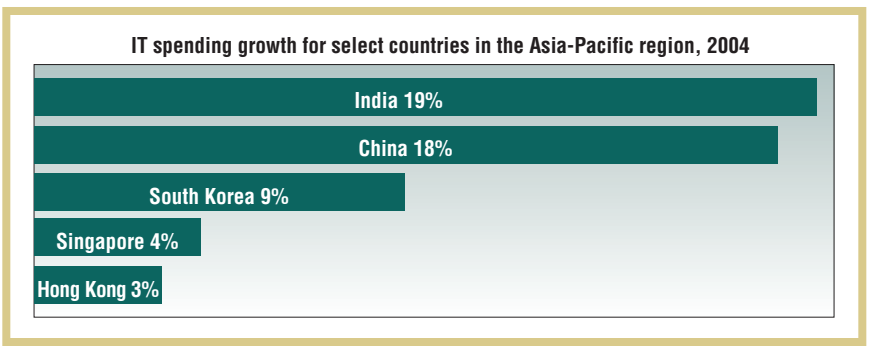

Figure 4. Data on IT spending in emerging markets.[11] The data indicates a much larger investment in the enterprise backbone to support broader computing solutions, compared to developed nations.

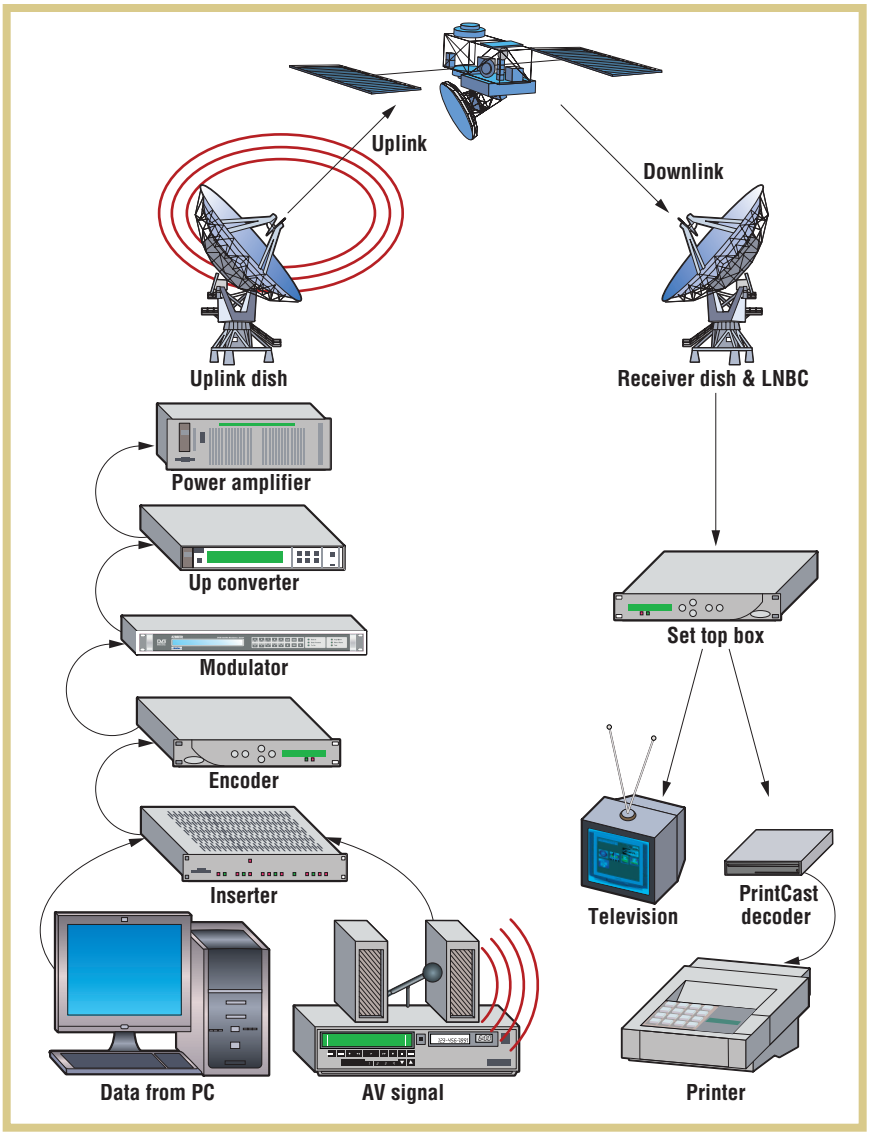

Figure 5. PrintCast overview diagram—leveraging the television broadcast medium to enrich the viewing experience. (Figure courtesy of Krishnan Ramanathan, HP Labs India.)

that businesses offering these services can trust the devices initiating the transactions. Researchers at HP Labs India are investigating opportunities for using cell phones for microtransactions in everyday life, and we believe that is another promising research area in the delivery fabric.

Planning for the enterprise backbone

Beyond the delivery fabric, we must consider the back-end infrastructure for executing the high-volume processing necessary for supporting the large-scale consumer base. One constraint of the Indian and Chinese contexts is that the transaction volume demand is two orders of magnitude higher than in developed countries. Another constraint is that back-end solutions must be extremely low cost, often an order of magnitude cheaper per transaction than those in the US. To achieve these cost benefits, we can leverage the ubiquity of cheap labor and the ability to tolerate high latencies in certain scenarios. Moreover, the lack of legacy hardware and software provides opportunities for quickly delivering solutions tuned to the emerging markets' specific constraints. We speculate on possible areas of innovation in data centers for large enterprises, shared utility-computing services for SMBs, managed services for the home consumer, and other solutions specific to the outsourcing industry that support the developed markets.

Large enterprises

Emerging economies present a unique green-field opportunity in data-center services and data-center differentiated sales. Several differences exist from equivalent opportunities in developed nations:

- Data centers are simpler and smaller (1,500 square feet on average) and less likely to be as overprovisioned.
- White-box and low-cost vendors have a larger fraction of the market, increasing the pressure to add differentiation at the data-center level.
- Power and cooling are a larger fraction of total operational costs, due to limitations in delivery of utility grid power and water for cooling towers, ambient weather conditions, and lower labor costs (particularly in high-performance and supercomputing installations).
- Existing data centers' expansion rate and the creation of new data centers are much higher than that in the US. (We know several large multinationals that will build new data centers in the next few years.)

These trends pose interesting challenges for research in enterprise data-center environments. There's a compelling need for a turnkey-datacenter solution—something that, to our knowledge, no one in the industry offers. This could, for example, involve a data-center synthesis environment that addresses all aspects of the data-center design (including the physical design) as well as the compute, storage, and networking elements. Designing modular data centers that are cost efficient at all points of

the data center's growth while providing the required performance reliability guarantees is a challenge.

Additionally, data-center services hold a lot of value. Cooling and power hold interesting opportunities, such as a service that dynamically manages cooling and power to reduce electricity costs or, alternatively, a service that performs detailed thermodynamic modeling to determine provisioning for failure. Another key challenge is in the provisioning and costs of network bandwidth across continents, particularly given the high costs of linking the domestic Internet to the Internet backbone.

SMBs

Table 1 summarizes the total IT market in India.[11] SMB segments constitute a dominant fraction of the total IT market. India's SMBs, in particular, need enterprise-level IT operations but at an order-of-magnitude reduced cost.

Consider the case study of a small-sized brokerage, a member of the Bombay and National Stock Exchange. Such a business—typically 30 or more employees—has revenues of two orders of magnitude smaller than a US brokerage but some of the same needs. A US firm can afford to hire professional IT staff and developers and can build high-end IT infrastructure in-house. The Indian firm also performs all IT functions in-house but with untrained employees and commodity PCs. As a result, it copes with limited availability and reliability.

All the IT concerns for this small business are customer-facing. The brokerage reconciles accounts only at the end of the business day, and customers still request orders over the telephone. Moreover, the brokerage doesn't perform consistent backups. Given its cost structure, there's little wiggle room for additional IT expenditures, although the brokerage demands certain functionality for operations to run smoothly. For example, the brokerage needs automatic backup and replication. But because labor is cheap, the brokerage executives prefer manual reconstruction upon failure rather than spending $2,000 for the current replication software. The brokerage needs automatic updates and patches because viruses are a concern, yet no such service exists. Moreover, there's constant pressure to go online, but an Internet-based trading solution that provides real-time customer account reconciliation is only affordable to a few very large brokerage houses.

The main obstacles aren't in the ongoing IT costs but in initial investments to purchase infrastructure. Since most Mumbai brokerages are similar, all using basically the same software with predictable workloads, outsourcing many of these brokerage functions to a shared-utility computing-based infrastructure appears feasible. US firms place stringent availability and performance requirements on their IT infrastructure, making it difficult to outsource to flexible shared-utility computing-based solutions at

Reverse Migration

Technologies developed for the Indian markets are likely to be equally useful in the future for developed countries. HP Labs' Simulcast project is one such extension of PrintCast (see the main text). Simulcast ties together multiple, growing delivery channels (such as the Internet and mobile phone networks to the television broadcast network) to provide a richer, more interactive media viewing experience. Instead of downloading data onto a printer, Simulcast discovers nearby devices such as cell phones, PDAs, and PCs and lets users download content appropriate for the respective end host. For example, through Simulcast, users can download mobile phone ring tones, a growing business in both developed and emerging markets, without involving the mobile phone provider. This is one noteworthy example, especially because the current business model lets telecom companies appropriate 70 percent of the revenue. New technologies like these now have the potential to disrupt conventional business models in emerging markets—and can later be transferred to mature markets as well.

A key advantage of Simulcast is that broadcasters can use it to solicit audience feedback on specific television programs, which would help boost the program's interactivity. A TV program that asks viewers to vote for their favorite contestant (for example, *American Idol*) can send the list of options to a cell phone via Simulcast. A viewer could then select a result using the cell phone interface and return results over the mobile phone network. Alternatively, if a PDA or PC with a browser is available, viewers could automatically be directed to a Web site. Finally, Simulcast's delivery fabric from broadcasters to consumers need not be only via the TV broadcast medium. HP Labs India is developing techniques to provide a Simulcast-like experience over Flash-based programs delivered via CD or the Internet through IPTV. Although Simulcast isn't yet a product, it provides a powerful example of how technologies intended for emerging markets can evolve and transfer back to developed regions.

TABLE 1
Segment and market share for an Indian IT market.[11]

Segment	Market share
Large businesses	4,700 crore* (15.5%)
Small-and-medium businesses	18,200 crore (60.2%)
Home	3,550 crore (11.8%)
Government and education	3,800 crore (12.5%)

* One crore (Indian rupees) equals US$200,000.

cheaper costs. Indian firms, on the other hand, are willing to tolerate high latencies in many situations to obtain the protections currently needed (such as backups and maintenance of patches) but unaffordable owing to extreme cost pressures. In such cases, shared-utility solutions might provide sufficient functionality at low-enough costs to make that solution profitable in the emerging-market scenario.

Also, unlike for US firms, the availability and functionality benefits might outweigh the risks of trusting a third party with business assets. In countries like India and China, several legitimate businesses have processes that the business owners prefer not to have a third party store their paper (or electronic) trail. The challenge will be to provide a utility service that can mollify upfront costs, handle highly correlated workloads, and appease privacy concerns.

On the other hand, a managed services approach could also prove effective because labor is cheap. The brokerage in our case study currently employs one technician on an on-call basis. The challenge will be finding trained labor at reduced costs to make regular visits worthwhile. Another interesting open question is the use of open-source software. Given the availability of cheap labor to offset some of the trade-offs in functionality with such software, broader adoption of open source is potentially more likely.

Home consumer

From the home consumer perspective, the huge market of first-time computer (and, more broadly, compute-technology) users offers a correspondingly huge potential for additional attached services "with the box" (for example, patch management, data backup, format conversion, and component upgrades). The low cost of unskilled labor and the lack of perpetual connectivity leads to interesting possibilities in managed services deployment. This market's low cost requirement, coupled with the cultural acceptances of franchise retailers in some segments, also leads to interesting possibilities for shared services (for example, printing a photo from home for pickup at nearby Internet cafe).

Beyond a compute backbone that addresses the needs of a large technology-literate population, a challenge exists in enabling these technologies' reach to equally large technology-challenged populations. For example, a mobile data center that provides compute-intensive services (such as on-the-fly medical imaging or customized book publishing) could be valuable in villages that don't have consistent electricity but can benefit from solutions that provide a large amount of computational power locally. Researchers have already deployed some of these technologies in niche applications in developed markets, but emerging markets offer conditions that enable deploying these solutions in volume and in different contexts.

Technology for services

Countries such as India—which have emerged as powerhouses for services such as business-process outsourcing and call centers—have the unique opportunity of understanding the challenges faced by the service industry. Services research is interdisciplinary in nature and can be characterized by the lack of a tangible product that's exchanged for money. The customer usually co-invents the service being delivered, so continuous exchange and an ongoing evolution is necessary. Fast delivery of a service is important, so modeling and reuse are crucial. Some challenges also relate to remote delivery of services. Understanding the problems and challenges in this area and developing technology solutions to make services delivery more efficient has a huge potential in emerging markets.

The back-end infrastructure opportunities we've discussed in this article not only complement other work on front-end solutions that target the specific end consumer but also are inevitable for the future. For computing technologies to be economically sustainable and truly pervasive in these markets, they must begin to address delivery fabric and enterprise backbone challenges. Though most of the solutions we've discussed leverage constraints specific to emerging markets and target the problems of highest impact in those markets, many of these solutions are likely to be relevant even in the context of developed economies. An interesting problem we're likely to face in the future is in "reverse-migrating" these technologies back to developed countries and redesigning them for those markets (see the "Reverse Migration" sidebar). The solutions we've discussed here only scratch the surface of what's possible, and our hope is that this article encourages more innovation in these areas by the broader systems community. P

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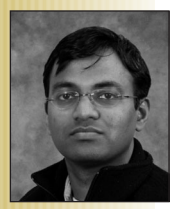

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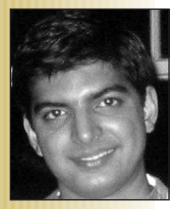

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