# TELEDENSITY GROWTH IN THE DEVELOPING WORLD THROUGH SDR

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## ABSTRACT

Vanu, Inc. has exploited software defined radio (SDR) technology in its Anywave™ and MultiRAN™ cellular radio access network products to help bring low-cost cellular telephone and wireless data access to rural areas in developing countries. This is a counterintuitive application of SDR, which is normally regarded as a way of designing high-end devices. We explain this application of SDR from both technical and business perspectives. We discuss India as a case study.

## 1. INTRODUCTION

Access to telecommunications is considered essential for development in rural and impoverished regions worldwide. Lack of telecommunications hinders progress in diverse areas including business development, health care, humanitarian issues, and quality of life. Many governments have made growth in teledensity—the fraction of the population with effective access to telecommunications—a cornerstone of their development policy. However, it has proven difficult to rapidly increase teledensity in rural areas of developing nations.

Early strategies to increase teledensity focused on providing wireline telephone and data communications. In the 1990s these programs were largely supplanted by cellular telephone based approaches, due to the significant reduction in infrastructure and maintenance cost provided by wireless last-mile access. Despite the reduction in cost compared to wireline, cellular service has not yet become available in most impoverished rural areas.

This paper explains why software defined radio (SDR) technology is a key enabler for increasing rural teledensity. SDR technology overcomes the critical economic barriers that have hindered deployment of cellular systems in rural areas. It significantly improves return on investment (ROI) for telecommunications providers and reduces the amount of government subsidy required.

The paper explains the benefits of SDR for teledensity using India as a case study, and considers related technical, business, and regulatory policy issues. We identify two primary benefits of SDR.

1. SDR enables a single hardware platform to support multiple different cellular standards.

This is important in many markets to increase revenues for cellular operators without increasing costs. For example, an operator can use this capability to earn roaming revenues from overseas tourists from multiple regions, or to provide both mobile service and fixed wireless service, while only investing in a single network deployment. Vanu, Inc. has developed its Anywave™ RAN product line to provide this benefit of SDR to cellular operators.

2. SDR enables multiple cellular operators to share a single network effectively.

When traditional radio designs are shared, operators are constrained to use the same cellular standard and features. The resulting loss of independence reduces business flexibility and creates regulatory concerns due to reduced competition and differentiation. With SDR, the costs of the infrastructure can be shared across operators while preserving full competitive differentiation and operational independence. Vanu, Inc. has developed its MultiRAN™ product line to provide this benefit of SDR to cellular operators.

## 2. BENEFITS OF TELECOMMUNICATIONS

We start with a brief review of some of the benefits that make telecommunications critical for economic and social development. Both voice and data services provide benefits in all these areas, although their relative importance changes depending on the application.

1. Education

The information access provided by telecommunications is a fundamental requirement for effective education, which in turn underlies nearly all development goals.

2. Business Development

Better selling prices for products—Small farmers or producers can increase their returns by bypassing traditional middlemen and selling directly to the downstream buyers of their goods.

Information on market conditions—Access to real-time market information enables rural business owners to make

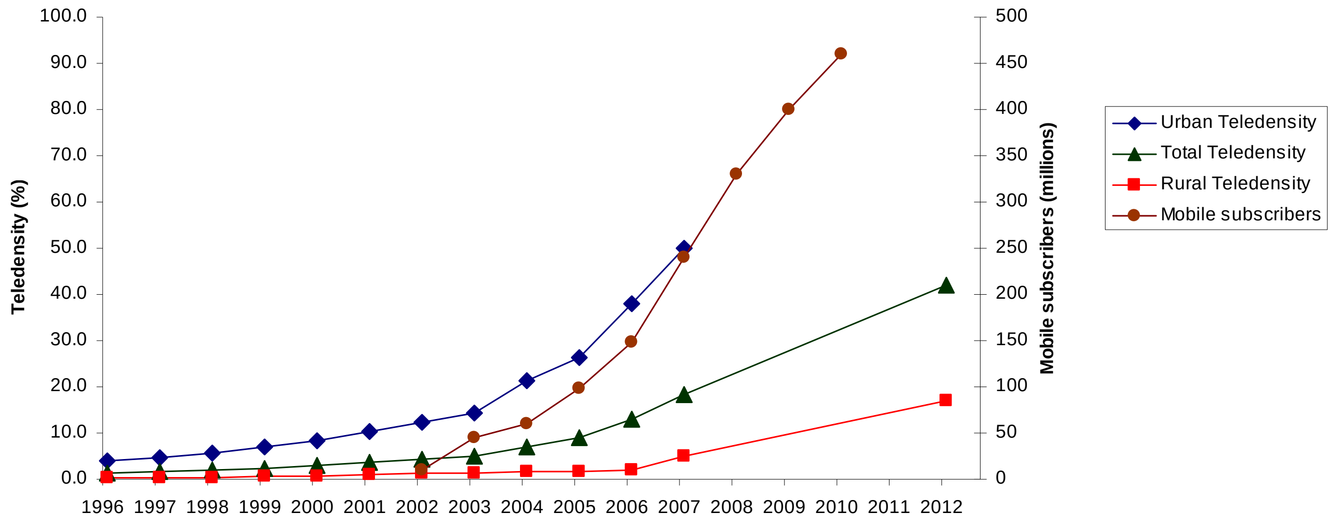


Figure 1. Teledensity growth history and predictions. Information through 2010 from [2]; 2012 is from [3].

better decisions on critical questions such as what to produce and when to sell.

New customers and suppliers—Businesses can expand to new customers and reduce input costs through interacting in wider markets.

Better access to credit—Lenders are more willing to extend credit, even micro-credit, if they have effective means of keeping in contact with the borrower to monitor progress and protect their investment.

3. Health care

Support for health providers—Health care effectiveness is improved if providers have better ongoing communications with patients, with each other, and with regional and national facilities.

Remote diagnosis—Health care effectiveness is improved and costs reduced when providers can interact remotely with a sick person or caregiver to determine appropriate primary care, and to determine whether travel to a health care facility is necessary.

Epidemiology—Authorities trying to measure or slow the spread of a disease benefit from the ability to quickly interact with responsible individuals such as village leaders across a wide region.

4. Humanitarian Issues

Disaster management—Effective response to natural disasters requires real-time coordination among responders and the civilian population.

Journalism—Telecommunications strengthens local information gathering by journalists and access to that information by citizens, thereby promoting improvement of social institutions and government.

Human rights—Broad access to telecommunications makes it significantly more difficult to cover up human rights abuses.

5. Quality of life

Migrant worker connectivity—Workers separated from their families for weeks or months can stay in touch and can be recalled if an emergency arises.

International culture—Telecommunications provides access to highly desired entertainment and cultural products, global news and opinion.

## 3. BARRIERS TO TELEDENSITY GROWTH

Teledensity is regarded as such an important contributor to rural development that it is rigorously measured and regularly reported by member states of the United Nations. This activity is coordinated by the ITU-D (the International Telecommunications Union, Telecommunication Development Sector) whose website provides access to the data [1]. Figure 1 shows an Indian government summary of teledensity history and predictions for India.

Over a 10 year measurement period, March 1996 to September 2006, urban teledensity increased from 4% of the population to almost 33%. In the same period, rural teledensity increased from 0.3% to only 2%. In India the population considered as rural represents over 700 million people. Even in 2006, therefore, there were well over half a billion people in India without effective and affordable access to telecommunications.

Providing communications services to such a huge number of people is a major business opportunity. Why has teledensity grown so slowly? The answer is of course that it has been uneconomic to provide service. Multiple factors contribute to this.

### 3.1. Revenues are low in rural areas

Average Revenue Per User—Most of the 700 million people in rural India have little or no disposable income. 86% of the total population lived under US$2 per day in the most recent World Bank Poverty Assessment, conducted in 2002 [4]. Estimated average revenue per user (ARPU) for cellular voice service in 2008 is below $3.75/month, for a prepaid user in the low usage category [5]. Other South Asian countries face even greater challenges. The ARPU for similar users in Pakistan is currently $3.30/month and in Bangladesh $2.50/month. For comparison, ARPU in the US and Europe is roughly $40/month.

Geography—Much of India's rural population lives and works in small village clusters, each of which has on the order of 1000 estimated potential cellular subscribers. Furthermore, it is a priority of the government to assure competition in telecommunications services, so the available subscriber base will likely be partitioned among multiple providers. As a result, each cellular base station (BTS) serves many fewer subscribers than are served by the urban and suburban sites that dominate the industrialized world. This means that the expected revenue per BTS is even lower relative to the revenue per BTS in the developed world than is indicated by the ARPU.

### 3.2. Costs are high in rural areas

Backhaul—The village clusters where cellular coverage is needed are often remote. This makes reliable connections to the core network expensive to deploy and maintain.

Power—Electrical supply from the grid is unreliable, with outages often occuring daily. Therefore cellular sites must be provisioned with substantially greater autonomous power generation capability, and larger fuel supplies, than sites in industrialized nations.

Site access—Road conditions are poor, so travel times to remote sites are high. This reduces the efficiency of deployment and sustainment activities.

Interestingly, handset subsidies are not a significant cost in rural India, in contrast to urban areas and developed nations where they significantly impact ROI. The dominant user base is prepaid and customers purchase their own phones.

## 4. GOVERNMENT SUBSIDIES

Since telecommunications is vital for development, most governments provide subsidies to overcome the economic barriers just listed. In the USA, subsidies historically were provided with government grants and loans through the Rural Utilities Service of the Department of Agriculture, and through granting a monopoly to AT&T so high long distance rates could cross-subsidize local service. Currently, the USA operates a Universal Service Fund which taxes telecommunications providers to fund subsidies in high-cost areas and for low-income users.

In India, the subsidy mechanism is called the Universal Service Obligation Fund (USOF). It is a 5% tax on the revenues of cellular operators who choose not to build out a nationwide footprint. The fund value now exceeds US$3.5 billion (May 2008 value and currency conversion). The government has been using the fund for cellular tower construction and has completed the first steps towards funding network deployments.

There was fierce competition among vendors in 2007 for participation in the first round of USOF-subsidized network deployment. Because of the competition, the subsidy per base station was bid down to zero or even negative. That is, vendors offered to pay the government for the right to install their base stations on the rural towers. The bidding may have gone this far due to vendor belief that participation at this stage is necessary in order to compete in the very large market that will someday emerge in rural India. Cooler heads soon prevailed, with the government unable to find takers for many of the sites on offer (at the price established by the winning bidder, as per the auction rules). A future auction will likely establish a more rational subsidy level for rural deployments.

## 5. LIMITATIONS OF TRADITIONAL RADIOS

Even with government subsidies to support network buildout and operation, substantial challenges remain if traditional radio technology is used for the base stations (BTS or Node B) in a rural cellular network.

### 5.1. Obsolete communications services

With traditional radio technology, the communications standard supported by the base station is fixed in the initial system design. Upgrading to a newer standard requires a substantial investment in new equipment.

The frequent upgrades needed to keep up with the rapidly evolving cellular marketplace are not affordable in rural deployments. Government subsidies typically increase revenues (or reduce costs) just enough to reach the minimum operating margin necessary to close the initial business case. The business cases that we have seen for rural coverage do not plan for hardware upgrades at the pace that is common in the developed world.

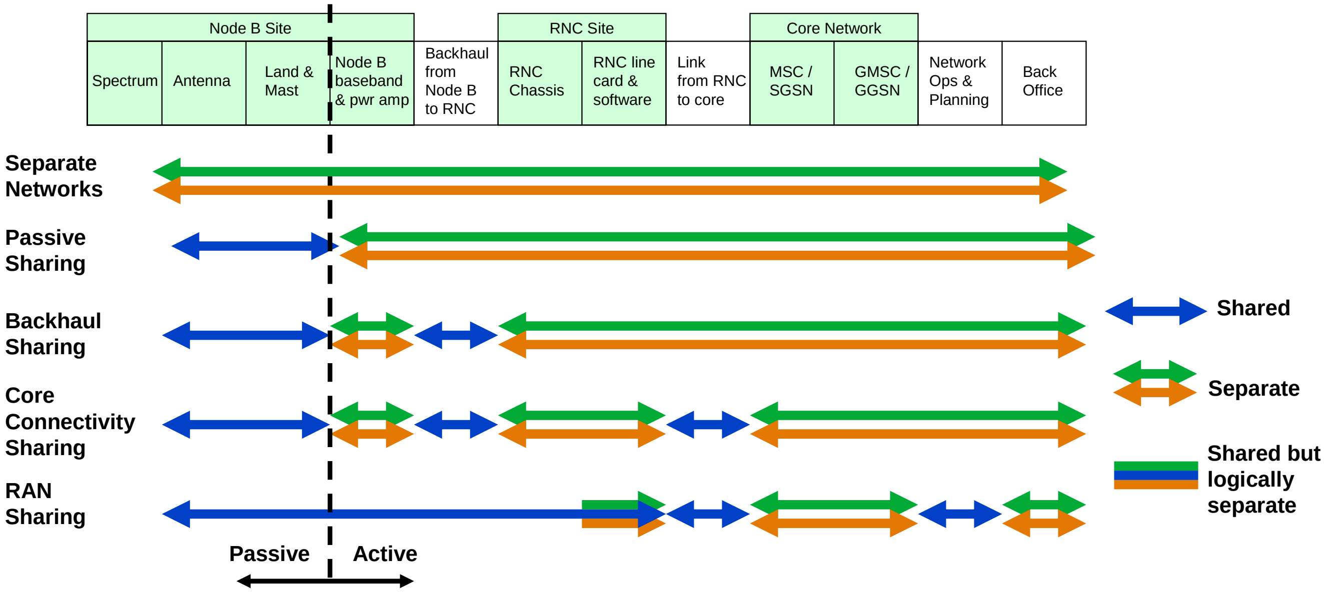


Figure 2. Infrastructure sharing possible with traditional radios. Source: UK Office of Communications (OFCOM).

As a result, communications services offered in these rural areas will inexorably become obsolete if traditional radio technology is used. This rapidly erodes many of the hoped-for development benefits of the investment in telecommunications. Organizations find it harder to do business in the areas with obsolete cellular services. One might consider the impact today of a business person traveling to an area that provides only analog cell-phone coverage. Most phones no longer support analog mode, even though just a few years ago the capability was universal. Similarly, individuals in areas with obsolete services are cut off from many of the advantages of telecommunications. As an example, users without SMS capability cannot participate in the new online classified ad marketplaces built around SMS, e.g. [6][7].

### 5.2. Lack of competition

Given the low revenues and high costs of rural cellular deployments, it is difficult enough to support a single network. Supporting multiple cellular networks is even less economically feasible, with the available gross margin and subsidy resources split among multiple organizations. The result is a natural tendency towards monopoly, with one dominant operator outcompeting the others even if the government chose to subsidize multiple deployments.

To avoid monopoly-based excessive tarriffs that would stunt the benefits of telecommunications, governments have two options. One is to regulate prices closely—an approach that is likely to backfire for the usual reasons (politicization, poor selection of rates due to incomplete or incorrect information, inability to respond quickly to changes in market or economic conditions). The other option is to push for infrastructure sharing among multiple operators, to preserve competition at the retail level despite the natural tendency towards monopoly at the network level.

Figure 2 is a valuable chart from OFCOM categorizing the infrastructure sharing models possible with traditional BTS radios.[1] The greatest savings are offered with the greatest amount of sharing, in which the BTS/Node B equipment is shared. In RAN sharing each operator controls one or more of the transmit/receive carrier pairs of the shared BTS units. An analysis by BT Ireland based on their actual network costs reported an expected 30% cost savings if RAN sharing were adopted [8].

Although RAN sharing is desirable for operators looking to reduce costs, and for governments looking to maximize the coverage benefits provided by a given level of subsidy, it has not been adopted except in rare instances. The reason is that RAN sharing with traditional radios leads to loss of operator independence. This is undesirable for the operators and also substantially reduces the level of competition which governments seek in promoting sharing.

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[1] One model not shown in OFCOM's figure is a mandated mutual roaming agreement among operators. Each operator builds out one geographic area, then customers roam freely to other operator's networks in other areas, even living permanently in those areas without cost penalty. Market power and size differences among operators make the low-cost roaming arrangements required in this model difficult to sustain without close government regulation of inter-operator tariffs and fees, which is unlikely to produce good results in the long run.

Specifically, operators in a RAN-sharing arrangement with traditional radio technology must agree on the precise communications standards and services to be provided. They must agree on the technology roadmap for which new services to offer in the future, and on the dates when the upgrades to provide those services will occur. All of these contraints derive from the use of radio technology that supports only a fixed and closely related set of communications standards, and that requires hardware modifications for upgrades.

Moreover, traditional BTSs are not designed for RAN sharing, so there are significant operational constraints. Operators cannot control the configuration and behavior of their transmit/receive carrier pairs independently of the choices made by sharing partners. It is also difficult to prevent disclosure of sensitive information to others sharing the BTS. As a result, the operators sharing a RAN need to reach close agreement on many day-to-day operational issues and also need to achieve a high level of mutual trust—even though the operators are fierce competitors.

These challenges are significant enough that, as far as we know, no RAN-sharing agreement is active in the world today that involves more than two operators. India's regulatory authorities have decided to aim for at least three operators competing at the retail level in rural areas. Perhaps as a result, or perhaps because the lack of operator independence reduces the level of competition too significantly, India has focused on passive infrastructure sharing rather than seeking to capitalize on the greater economic benefits of full RAN sharing.

## 6. SDR FOR TELEDENSITY GROWTH

Software defined radio technology provides a solution to the challenges that have limited teledensity growth.

### 6.1. Multistandard networks

SDR can be used to provide multiple communications standards on a single network, increasing operator revenues.

This is particularly valuable in conjunction with the development of tourism. Tourists can normally afford substantially higher tarriffs than the local population. However tourists from different parts of the world require the cellular system to support different communications standards. A network built out with traditional radio technology can only provide part of the necessary services and can only earn part of the potential roaming revenue. Multistandard SDR therefore supports tourism development at the same time as it increases operator revenue.

The other major application for SDR of this type is to provide mobile and fixed wireless services using a single network. In India, the dominant standard for mobile voice services is GSM, while the dominant standard for fixed wireless is CDMA. Recently India changed its licensing regime to permit operators who had historically been limited to one of these offerings to compete in both areas. (The first Universal Access Service Licenses were issued January 10, 2008.) SDR is vital for cost reduction when an operator wants to provide services in the same geographic area from both the GSM family (GSM/GPRS/EDGE/3G) and the CDMA family (IS-95/1xRTT/EVDO).

The Vanu Anywave Radio Access Network is in commercial operation today using SDR to cost-effectively support both GSM-family standards and CDMA-family standards on a single network [9].

### 6.2. Upgradeable networks

SDR enables BTS designs that are upgradeable to add new communications standards, dramatically reducing the cost of keeping up with the evolving cellular market. This aspect of SDR is widely understood and its benefits for networks deployed in impoverished regions are clear.

New cellular standards are invariably more computationally challenging than older ones. While sufficient processing capacity can be deployed to support future major upgrades, it normally does not make sense to pay for all that capacity up front. Instead, an SDR BTS can be designed to minimize the cost of adding the capacity for new standards, in several ways. The previous processors should continue to operate in the upgraded system, helping to support the new standard. There should be enough spare processing capacity so standards upgrades within the selected generation (e.g. 3G or 4G) can be deployed without hardware change. Upgrades should not require modification of the analog equipment (transceiver, power amplifiers, etc.), which normally represents 60% or more of the hardware cost.

The Vanu Anywave Radio Access Network provides these necessary attributes through a combination of design features. The processing hardware is modular and exploits off-the-shelf high-volume commercial components. This approach offers high processing densities and ongoing performance improvements at the lowest possible cost. The system uses standards-neutral analog equipment, which leads to unique design approaches compared to traditional radios and other SDRs. There are multiple papers on the company web site explaining these aspects of the Anywave RAN [9].

### 6.3. RAN sharing with operator independence

SDR permits operators sharing a BTS to run different cellular standards and to upgrade their offerings on independent timetables, while isolating the BTS configuration and monitoring functions of the operators. This facilitates RAN sharing while improving competition, reducing costs for both operators and consumers.

Effective RAN sharing requires what we call a *Virtualized Radio Access Network* (Figure 3). Just as an operating system virtualizes the underlying hardware of a PC or

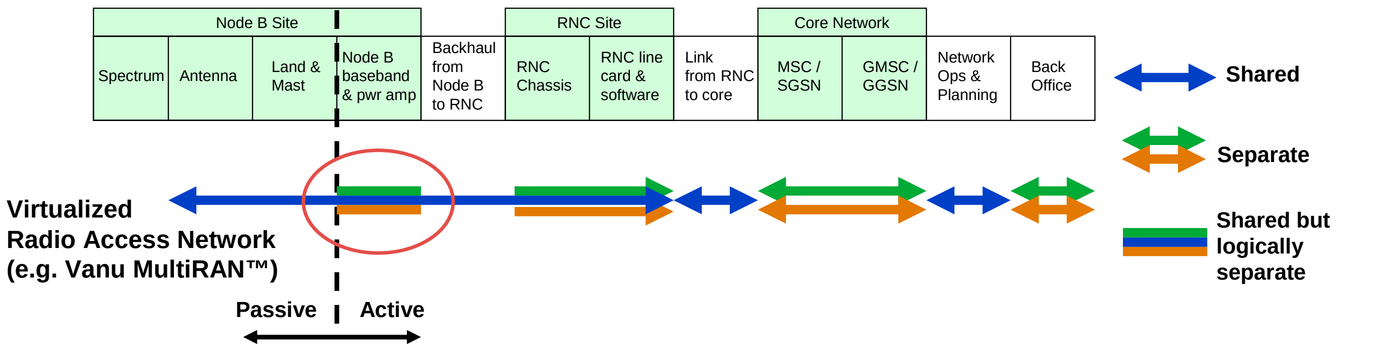


Figure 3. Infrastructure sharing possible with SDR. The red circle highlights the key change from traditional radios.

server, enabling multiple applications to share the hardware without interfering with each other, a virtualized RAN enables operators to share network infrastructure without interfering with each other. Each operator can select its own cellular standards, which is analogous to different users running different applications on a shared server. The virtualized RAN isolates the operators, which is analogous to one user on a server not being able to see another's private data or modify the other's application behavior. The specific requirements for a virtualized RAN are:

- Multiple *Virtual BTSs* run on one hardware BTS.
- Operators have independent choice of communications standards and upgrades.
- Externally the behavior is indistinguishable from multiple separate BTS devices, one per operator.
- Each virtual BTS uses only that operator's spectrum. (In countries that permit spectrum pooling, spectrum sharing is supported among virtual BTSs.)
- Each virtual BTS connects only to that operator's BSC/RNC and OSS systems.
- One virtual BTS's configuration and behavior does not affect other's performance.

SDR technology makes it possible to implement a virtualized radio access network. Vanu, Inc. has done this with its MultiRAN product. Our experience has been that the Vanu SDR design based on standard platforms and operating systems was a key enabler for the implementation. There are mature "virtual machine" technologies that make a single server appear as multiple servers to multiple users, while isolating the users from each other's behavior. This is exactly what is required for virtual BTSs. These features would be very expensive and time-consuming to implement from scratch in a SDR design centered on DSPs or FPGAs.

## 7. FREQUENCY AGILITY

The SDR benefits just described are limited by the low frequency agility of current cost-effective RF equipment. RAN sharing and upgrades are affordable today only if all the operators and communications standards are in the same band. We eagerly await new RF hardware designs that provide increased frequency agility at competitive cost and power consumption. In parallel, we join with the SDR Forum in advocating technology neutral spectrum regulation that allows multiple standards to operate in the same frequency band, as this significantly increases the near-term benefits of SDR for teledensity growth.

## 8. CONCLUSION

Software defined radio technology is a key enabler for increasing access to telecommunications in rural areas of developing nations. Policy-makers and developers should consider its application in this area when considering teledensity growth strategies and system designs.

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