

# Potential of CDMA450 for Rural Network Connectivity

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## ABSTRACT

*This paper evaluates CDMA450 as a potential solution for rural data and voice connectivity. We begin by analyzing the main strengths of CDMA450, but also some of the potential limitations for rural coverage, both from a technical and an economic standpoint.*

*We argue that CDMA450 is a promising technology, competitive in both capacity-centric urban environments and in coverage-centric rural environments. Consequently, we discuss the opportunities of providing universal coverage by adopting a business model targeting both urban and rural deployments, and utilizing urban to rural cross-subsidization.*

*We then explore the advantages of deploying CDMA450 using a fixed wireless (WLL) model. To this end, we explore the effective range of WLL CDMA450, and the impact of using directional antennas and receive antenna diversity in real-world commercial CDMA450 deployment in Romania. If used properly, these techniques can aid us in increasing cell radii and thus lead to substantial cost benefits.*

## I. INTRODUCTION

It is widely accepted that communication technology is one of the most important enablers to increase access to information and thus the standard of living. Recent advances have greatly reduced the cost of telecommunications infrastructure and worldwide mobile phone penetration has increased from 8.24 (per 100 inhabitants) in 1999 to 34 (per 100 inhabitants) in 2005 ([1]). However, most of the gains of the telecommunications revolution has been restricted to the industrialized countries.

In particular, extending network coverage to rural regions of the world remains a big challenge because of a combination of limited purchasing power and low density of rural users (mobile phone penetration in rural India is 2% as opposed to 33% in urban areas in 2006). Since, typically 70% of the capital cost of cellular networks is in the access network as opposed to the backbone, these networks depend on a certain user density for profitability. Hence urban areas tend to be covered by multiple carriers, while rural areas typically have one or none.

For example, even the best known “rural” cellular system, Grameen Telecom [2] in Bangladesh, avoids rural only base stations. Instead, by exploiting the high population density of Bangladesh, Grameen places base stations such that they cover both urban, higher income users as well as lower income users in the rural areas; typically, there is no coverage for rural areas that are not near an urban base station [3].

CDMA450 is an promising technology to consider for rural connectivity in emerging regions. It combines an established, competitive cellular standard (CDMA2000) with an unconventional yet promising frequency spectrum (450MHz). Thus, in addition to sharing the same evolutionary path and advantages provided by the spectrally-efficient, high capacity CDMA2000 family of technologies, the use of a low frequency carrier in CDMA450 can dramatically reduce the cost of coverage.

We start by giving an overview of the CDMA450 technology (section II). Section III presents the most important advantages of CDMA450 as an appropriate technology for rural connectivity. We continue by discussing some of the potential limitations, both technical and economic (section IV). We then proceed by analyzing the use of a fixed wireless model in combination with directional antennas, receive diversity and high-powered fixed terminals to increase cell radius, and thus make rural deployments more cost-efficient (section V). We continue by discussing the choice of providing voice services, data services or both in section VI, and we conclude in section VII.

## II. OVERVIEW OF CDMA450

*CDMA2000* [4] is a family of third-generation CDMA cellular communications standards that supports voice and data traffic. *CDMA20001x* (also known as *1x*, *1xRTT* or *IS-2000*) is the core air interface standard of CDMA 2000 and it uses a single pair of radio channels (1.25MHz each for forward and reverse links) to transmit both voice and data with a peak data rate of 153 Kbps in each direction.

The newer data standard called *CDMA 1xEVDO (Evolution Data Optimized)* [5] adds capabilities of high speed data services to CDMA 2000 by devoting a second pair of channels for packet switched data transmission. The first version called Release 0 offers peak data rates of 2.44 Mbps on the forward link (base station to handset) and 153 Kbps on the reverse link (handset to base station). The newer version known as Revision A will offer higher speeds (3.1 Mbps for downlink and 1.8 Mbps for uplink).

The technology that is most interesting for rural emerging regions is *CDMA450* that uses the same air interface as CDMA2000 1x but operates at 450MHz. As a result CDMA450 can offer the same basket of high speed data technologies such as 1x EVDO but at a potentially lower cost by using a lower carrier frequency.

Starting from the first deployments in 2001, CDMA2000 has about 264 million subscribers in 58 countries now (in 2006 [6]). In addition to that, high speed data services of 1xEVDO are now availed by about 42 million subscribers in 24 countries. CDMA450 however is a relatively young technology; the first commercial CDMA 450 deployment was launched in Romania by Zapp Telemobil [7] in December 2001. Since then, its popularity has increased rapidly. Zapp estimates that currently there are about seven million CDMA 450 subscribers worldwide, and as of June 2006 the CDMA Development Group (CDG) [8] reported that commercial CDMA450 networks have been deployed in 18 countries around the world and an additional 27 networks will soon be launched or are undergoing trials.

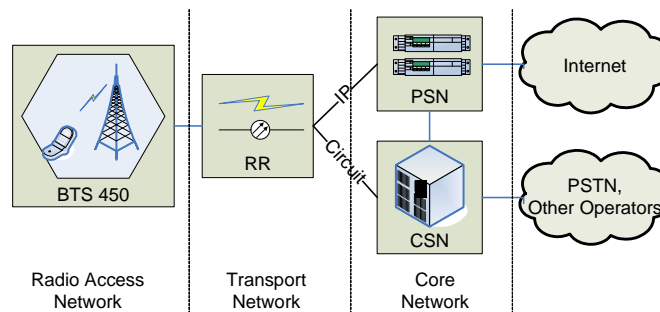


Fig. 1. Structure of a CDMA450 network

The architecture of a generic CDMA450 network offering both voice and data service is presented in figure 1. The network structure and hardware/software components are identical with the ones of any CDMA2000 network, with the exception of the air interfaces at the base-stations, and the mobile terminals, which operate in the 450MHz band.

The main components of such a network are:

- **The Radio Access Network.** The access network is composed of all the base-stations (BTS) deployed on the field. These are responsible for communicating with the terminals through the radio air interface. A BTS contains both the hardware and software performing the signal processing necessary to run the radio interface and to communicate with the servers and routers from the core network. It also contains all the radio components sending and receiving the RF signal to and from the terminals (cell phones).
- **The Transport Network.** These are long distance communication lines connecting various components of the system. The transport network can be further divided into:
  - The Backbone Network, which connects various circuit switching nodes(CSN) and packets switching nodes(PSN).
  - The Access Network, which delivers the traffic from each base-station to its corresponding switching node.
- **The Core Network.** The core network contains the necessary circuit and packet switching equipment, the gateways connecting to other networks, as well as other server responsible for network administration, monitoring, providing value added services, etc. The core network usually consists of several circuit switching nodes(CSN) and packet switching nodes(PSN), as well as one network management system (NMS).
  - The Circuit Switching Nodes(CSN) enable circuit switching for the voice circuits, are responsible for signaling, and ensure the connection with other fixed or mobile telecom networks, as well as with other switching nodes. These nodes only serve 1xRTT voice traffic.

- The Packet Switching Nodes(PSN) are similarly responsible for the packet switching part of the network, and ensure the IP connection with the Internet. These nodes serve both 1xRTT and 1xEV-DO data traffic.
- The Network Management System preforms the network management, configuration and monitoring.

### III. ADVANTAGES OF CDMA450

There are several well known reasons why CDMA450 is an appropriate connectivity solution for rural areas. Some of these reasons arise from the advantages in using CDMA technology regardless of the frequency, while others arise from the particular characteristics of the 450MHz frequency spectrum.

In this section we present the main CDMA450 strengths, and the resulting implications for providing rural connectivity. In the next section, we revisit some of these strengths by also considering the practical limitations that can prevent real deployments from reaching peak performance capabilities.

**Large cell size:** The main advantages of using 450MHz are its superior propagation characteristics and better penetration compared to commonly used frequencies (800/900/1800/1900MHz), leading to longer ranges; the resulting larger cell sizes reduce the number of base stations required to cover a given area. Table I shows typical cell radii for various frequencies according to an International Telecommunication Union (ITU) study cited in a CDG white paper [9]. The general rule of thumb is that doubling the frequency quadruples the number of base stations required. Thus, using 450MHz has the potential to provide significant savings in upfront capital expenditure (CapEx), ideal for rural areas where carriers are more cost sensitive given the low purchasing power and low subscriber density. Additionally, the savings can be passed on to customers to encourage technology adoption.

Frequency (MHz)	Cell radius (km)	Cell area (km <sup>2</sup> )	Relative Cell Count
450	48.9	7521	1
850	29.4	2712	2.8
950	26.9	2269	3.3
1800	14.0	618	12.2
1900	13.3	553	13.6
2500	10.0	312	24.1

TABLE I  
CELL RADIUS VS. FREQUENCY

**Flexible cell size:** CDMA technology manages the trade-off between capacity and coverage by leveraging its embedded power control mechanism and adapting the cell size dynamically to either serve very large ranges (when top capacity is not needed), or to deliver high capacity (where top coverage ranges are not needed). The effect of dynamically shrinking the cell range, also called "cell breathing", happens when, as more users connect to the base station, the effective cell range decreases. As described by Veeravalli and Sendonaris [10], an increase in the number of active users in the cell causes the total interference seen at the receiver to increase. This requires an increase in received power seen at the base station for each user, since each user has to maintain a certain signal-to-interference ratio at the base station for satisfactory performance. However as there is a maximum limit on the transmit power from the terminals, an increase in the number of users results in a decrease in the maximum distance a handset can be placed from the base station.

While cell breathing can preclude the system from simultaneously achieving maximum capacity and maximum coverage, in practice the scenarios where both high capacity and large cell size are simultaneously needed are very rare. In rural environments with sparse users, coverage is the determining factor, and the system is never used to capacity; on the other hand, in urban morphologies, capacity is the driving factor, and cell sizes can be very small, with each of them being used to capacity.

The ability to have flexible cell sizes relaxes a number of constraints related to cell placement planning, and offers a way to enable cost-effective deployments in both rural and urban environments, essential for the successful adoption of the technology.

**Good performance in both urban and rural morphologies:** Targeting rural-only deployments can be challenging, given the possibly small customer base, low user density and lower disposable income. These issues may make it challenging for operators to target rural-only deployments, especially when much more attractive opportunities are present in the denser, more affluent urban market.

But fortunately, CDMA450 is competitive for both rural and urban environments; operators can use the same technology to simultaneously target both urban and rural markets.

*Low density rural deployment:* We already know that CDMA450 is well suited for rural areas given that it enables a larger range per base station, ideal for covering low density subscriber regions.

*High-capacity urban deployment:* It is also known that CDMA450 can provide high capacity in an efficient manner. One misconception is that spectrum frequencies determine the effective cell size of the base station and that consequently only higher frequency carriers (e.g. 1800 MHz) are useful in dense environments. In practice, this is not true; CDMA450 can efficiently achieve smaller cell sizes in urban environments. Firstly, the size of the cell reduces dynamically as load increases, which is the case in urban environments with high user density. Secondly, the CDMA soft-handoff mechanism allows the signals of several adjacent base stations to overlap producing a higher quality signal rather than interference.

In terms of spectral efficiency, CDMA450 has the same characteristics as standard CDMA2000. While a direct “apples to apples” comparison is difficult (and very controversial) to make between competing cell phone standards, most studies have shown the CDMA2000 technology to be among the most spectrally efficient; one study by Deutsche Bank cited in a 2003 industry briefing [11] ranks it the best with respect to spectral efficiency. In general, CDMA450 can deliver high capacity efficiently, saving on spectrum licensing cost.

*Combining rural and urban markets:* The applicability of CDMA450 in both rural and urban markets is an important consideration because of spectrum licensing and operator incentives. Given that spectrum for both urban and rural areas is usually licensed together, the ideal situation for an operator is to be cost-competitive in both capacity-centric urban areas and coverage-centric rural areas using the same common technology. This facilitates a more viable business model by which operators can use the more profitable urban operations to subsidize their rural expansion on the way to universal coverage.

**Simpler spectrum licensing:** Another advantage of using 450MHz arises from historical reasons. In many countries, the 450MHz spectrum was previously allocated to cellular carriers using analog standards, of which the most commonly known is NMT450, and which are now all obsolete. As these carriers went out of operation, the spectrum was left unused, and has been less expensive to license compared to competing in auctions for newer spectrum. This provides additional savings in CapEx.

**Established technology:** CDMA is a well-established technology with several large industry players such as Qualcomm, Huawei, ZTE, Lucent, Nortel, and others providing economies of scale and support. This means that most of the expensive network components, with the exception of RF air interface cards, are common between regular CDMA and CDMA450 deployments and can benefit from existing economies of scale.

#### IV. POTENTIAL LIMITATIONS

In the previous section, we have looked at several advantages that make CDMA450 appealing as a rural connectivity solution. However, there are a number of practical limitations that make CDMA450 challenging to deploy in such scenarios.

**Less than maximum cell range:** An important advantage of CDMA450 in rural settings is the extended cell range, sometimes exceeding 50 Km. Our own experiments verifying this are presented in section V. However, most range experiments, including ours, are only performed with a single active user.

However, as explained in the previous section, CDMA is interference limited, and cell breathing prevents the maximum cell range at high loads. By Zapp’s calculations, operating at 50% capacity causes a loss of 3dB in the link budget, which then results in a 20% loss in range; however, 20% loss from 50 Km still results in a range of 40 Km. This is an acceptable tradeoff in most real-world situations; however, it is important to remember that the maximum advertised range is not achievable in all situations.

**Large antennas and antenna spacing:** At lower frequencies, the required antenna sizes are much larger, both at the base stations and the handsets. The use of a low frequency carrier also affects implementation of antenna receive diversity for both the wireless handsets and base stations. Receiver diversity involves combining the signals from multiple receive antennas to enhance the quality of the received signal.

At the base stations, cellular systems use several diversity techniques in order to improve receiver performance in fading channel environments. Among these, *spatial* and *cross polarization* diversity are the preferred techniques. For spatial diversity, antenna elements need to be well separated in order for their respective channel fading processes to be uncorrelated. It has been determined through measurements that horizontally spaced antennas need to be separated by 10 to 30 times the wavelength in order for the correlation between antenna observations to be less than 0.7 [12]. At 850MHz this corresponds to an antenna spacing of 3.5 to 11 meters, which is challenging, but achievable; however at 450MHz this translates to distances of 6.5 to 20 meters, which is much more challenging to deploy, given that antennas must be mounted on the same tower. Thus, CDMA450 operators are usually constrained to employ cross-polarity diversity, which provides slightly less of a gain than spatial diversity.

Similar concerns also affect handsets. Due to the larger handset antenna sizes, it is difficult for CDMA450 handset producers to design small handsets featuring antenna diversity. To compete with small 850MHz handsets, 450 mobile handset producers

might have to drop handset antenna diversity altogether, or might have to opt for suboptimal antenna sizes and spacing, making the phones less sensitive overall.

While in theory these considerations can be regarded as important limitations, in practice they are not significant if we consider the main driver of the deployment to be morphology: in the *urban* environment the main driver is always *capacity*, therefore the antenna gain is not important, since the urban cell ranges are always very small as a result of the capacity driven cell density. On the other hand, in the rural environments the main driver is always *coverage*, and CDMA can translate the low rural capacity demand into extended coverage regardless of the antenna gain/size. Moreover, the user in the rural environment is likely to be less sensitive to antenna size and therefore ready to accept high gain/diversity antenna solutions to boost the range and performance even further.

**Low volumes for CDMA450 terminals:** CDMA450 relies on established technology from the CDMA2000 family, which means that most of the network equipment enjoys the benefits of high-volume production. However, when it comes to CDMA450 terminals, the production volume is still considerably lower than production volume for competing bands (850/1900). Out of the 318 million CDMA phone users worldwide, only 7 million are CDMA450, and there are fewer manufacturers involved in the CDMA450 terminal market.

Fortunately, the inherent issue of low economies of scale has been substantially reduced in the last two years, with the number of CDMA450 worldwide subscribers rapid growth, and is expected to be further reduced in the near future. Moreover, in the context of rural deployments, the use of fixed wireless phones (WLL) is one of the most appropriate solutions, as we shall argue in section V. In this respect, CDMA is the worldwide market leader, with more than 65% of the WLL market, and low-cost CDMA450 WLL terminals are already available on many markets.

**Large required customer base:** As with any other cellular technology, in order for the deployment to be cost-efficient, the customer base (and thus the scale of the deployment) must exceed a certain threshold, at which the investment in the core network is justified financially. In other words, any CDMA450 must exceed at least a few tens of thousands of users; a small, incremental rural-only deployment targeting only a few hundreds or thousands of users cannot be envisioned. This is especially true for deployments supporting voice, where the core network includes circuit switching components, which come in coarser granularity of incremental capacity, and are much more expensive than IP-based data switching equipment. An EVDO-only deployment, however, can be of smaller scale since it requires cheaper IP-based data switching equipment only at the core.

This means that very small-scale, experimental deployments are not possible. On the other hand, most commercial, real-life deployments can easily reach the required scale.

## V. CDMA450 AND RURAL CONNECTIVITY: WLL AS A POSSIBLE SOLUTION

As we have seen in section III, one of the key factors in reducing overall network deployment costs in rural areas is reducing the coverage cost, which can be done by improving the range covered by each base station. While the use of the 450MHz spectrum enables large cell sizes, we have seen that sometimes cell breathing and the requirement for large antennas can reduce the maximum cell size.

We argue that, in rural scenarios, additional extension of range is possible by adopting a fixed wireless deployment model, often called *wireless local loop* (WLL). In addition to the potential cost advantages of WLL, we argue that a fixed wireless model can sometimes be better suited for data transfer in rural areas where devices will be shared at fixed locations such as Internet cafes or kiosks.

In this section, we first list several technical improvements now achievable with fixed wireless terminals that are otherwise impossible using mobile wireless terminals. We then show from measurements from the ZAPP CDMA 1xEVDO network that substantial gains can be realized by using these techniques in practice.

### A. Techniques for enhancing cell size

**Increased effective transmit power at terminals:** In cellular systems the transmission power of handsets is orders of magnitude smaller than the one of base stations (0.2W vs. 23W) and thus the reverse data link (from terminal to base station) is often the range bottleneck.

- *Directional Antennas:* The fixed location of a WLL terminal enables the use of directional antennas pointed at the omnidirectional base station. In the 450MHz frequency band, inexpensive Yagi directional antennas with gains of 9–12 dB are easy to deploy.
- *Higher transmit power in terminals:* A significant advantage of fixed terminals is the CDMA450 standard that allows them to transmit at a much higher transmission power compared to the limited power output of mobile handsets. Increasing the terminal transmit power from 200mW (typical for a mobile handset) to values of 500mW or even 2W

(as supported by some WLL cellular terminals) can significantly increase range and signal quality. These improvements can add 4–10 dB to the reverse link budget.

By using these two techniques, terminals would be able to maintain the same SINR (Signal to Interference Noise Ratio) at the base station from farther distances thus negating the cell breathing effect.

#### **Better receive signal at receivers:**

- *Directional Antennas:* The use of these antennas symmetrically increases the quality of the received signal as well.
- *Receive Diversity:* Multiple receiver antennas connected to a single terminal can be used to boost receiver signal strength. For example, a Yagi and an omni antenna can be attached to a single terminal, which uses processing to combine the signals from the two antennas. As shown in the following section, significant forward link improvements can be seen by using receive antenna diversity.

#### *B. Measurements using directional antennas and dual receive diversity*

In order to measure the improvements caused by using directional antennas and dual receive antennas at the fixed terminal side, we perform several range tests for various cell sites in the ZAPP CDMA1xEVDO cellular network.

We present our findings for a site placed atop a large hill at a ground elevation of 727 m. The antenna height is 30 m relative to the base of the tower on the hill. We use this base station location because it is located in a rural area and overlooks a wide plain with few obstacles or changes in altitude. This provides us with a more uniform testing environment, where the signal strength varies relatively uniformly with distance. In these measurements we do not exceed distances of 50 km, a software limitation imposed at the base station, which in general is avoidable with some reconfiguration.

For the fixed terminal, we use the Zapp-branded Z020 wireless EVDO modem with receive diversity enabled. At all measurement sites the terminal antennae are mounted at a height of 2 m above ground level. Given that the surrounding area is a wide plain the ground elevation of all the measurement sites is roughly the same.

We configured our terminal and target base station to communicate on a channel reserved for testing, and not used by any nearby base stations or terminals, thus avoiding interference with any other source. The terminal was connected to a laptop running Qualcomm's QCait software to collect information such as the Signal-to-Noise-plus-Interference Ratio (SINR) and the terminal transmit power (Tx Power) at the terminal.

We start by investigating potential increases in EVDO cell radius. We compare four scenarios: the first uses a single 1.5 dB gain omnidirectional antenna; the second uses a single 9 dB directional Yagi antenna, aligned towards the base station; the third utilizes a combination of two antennas, in which the omni is used as the primary antenna, both for transmit and receive, while we use an additional Yagi only for receive diversity; finally, the fourth scenario has the Yagi as the primary antenna, while the additional omni is used for diversity.

In each of these setups we measure the average transmit power used by the wireless terminal when sending data packets to the base station. This is relevant because it reflects how close the terminal is from the cell edge. In order to properly receive the terminal's packets, the base station requires the terminal to send packets at a specific power level, which is higher as the terminal is closer to the cell edge. When the required transmit power exceeds the maximum possible power output, the terminal is effectively out of range. The results of our first experiment are presented in Figure 2, and show that the determining factor for the transmit power, and thus cell size, is solely the antenna used as the primary. The antenna used for diversity makes no difference in this case. In both of the scenarios that use a Yagi as the primary, the power output required is much lower than for the cases when an omni is used for transmission. At large distances (50 km), the transmit power required is close to its maximum when the omni is used at the primary, while there is a significant reserve (in power and thus range) when the directional antenna is used. We conclude that all configurations can function at ranges of up to 50 km, and this range can be further increased with Yagi antennas.

Even though it is not a bottleneck in terms of range, we also examine the effect of different antennas on the forward link, by measuring the SINR (Signal to Interference plus Noise Ratio) at the terminal for each of the scenarios already presented. The results of these measurements are shown in Figure 3.

We observe that in terms of SINR, and thus in terms of the forward link quality, the scenarios using receive diversity outperform the ones using a single antenna, with SINR improvements ranging between 2–9 dB.

We continue by examining how these effects of different antenna configurations on Tx power and SINR reflect on data transfer performance. Since TCP is the data transport protocol most used in existing network applications, we use TCP throughput as an indication of link quality.

The TCP upload measurements, presented in Figure 4, can be correlated very well with the transmit power measurements, confirming that the quality of the reverse link is only determined by the gain of the primary antenna, which is good for directional Yagis, and bad for omnidirectional antennas.

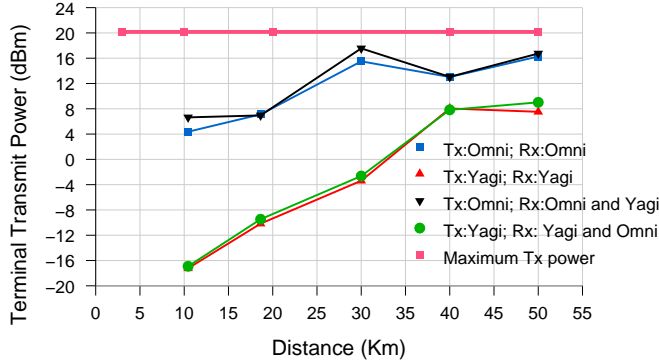


Fig. 2. Phone TxPower vs. Distance for Various Antennae

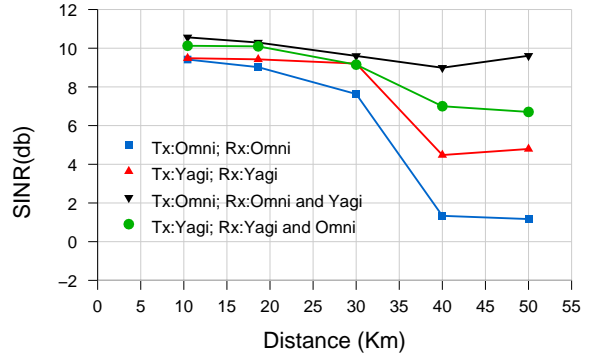
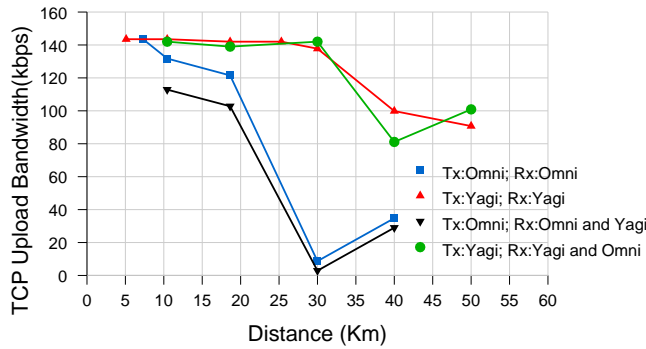
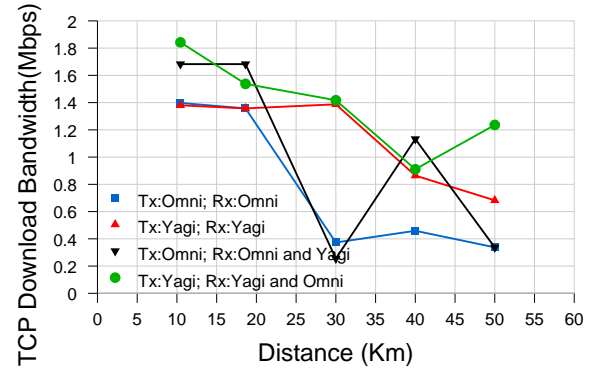


Fig. 3. SINR vs. Distance for Various Antennae



(a) Upload



(b) Download

Fig. 4. Upload and download throughput vs. distance for various types of antennas

Finally, we investigate the effect of various antennas on the TCP download speeds, and we present the results in Figure 4(b). A slightly unexpected result is that, same as for uploads, the configurations using the Yagi as the main antenna perform better. This is surprising because one might think that SINR is the determining factor for the forward link performance. This effect can be explained by the fact that the download throughput is influenced by the upload throughput if TCP is used, since TCP acknowledgments travel in the reverse direction. The receive diversity is also useful, the best performance being obtained using a Yagi on the primary with an additional omni for receive diversity.

In conclusion, we show that: a) directional antennas can be used to increase cell range; b) both receive diversity and directional antennas improve link performance, especially close to the cell edge, and c) in single-user conditions, CDMA450 EVDO can exceed ranges of 50 km and maintain good download and upload performance.

## VI. DISCUSSION: VOICE VS. DATA SERVICES

An important connectivity question is related to the types of services to support (voice, low and high speed data), and the choice of technology to support them.

In terms of technology choices, CDMA450 operators can choose to either deploy 1xRTT, 1xEVDO, or both. There are several advantages to each of these, and we will discuss them in the following:

- **1xRTT only deployments.** 1xRTT has the advantage of supporting both voice and data services using the same technology. It also has the advantage that terminal chipsets are much cheaper for 1xRTT (\$25) compared to EVDO (\$75).
- **EVDO deployed together with 1xRTT.** EV-DO has the advantage of supporting broadband datarates. Moreover, upgrading a network from 1xRTT to EV-DO is relatively simple and inexpensive, without requiring any forklift upgrades. A cell site can be upgraded to EVDO by simply adding a new channel card and another RF carrier. If E1 wireless

links are used in the transport network, additional such links might also be required to increase the transport capacity accordingly.

- **EVDO only deployments.** If the network supports only EV-DO data services, the circuit switching part of the core network is not required. Since data switching is IP-based, data switches (high volume IP switches and routers) are an order of magnitude cheaper than circuit switches. Consequently, since CSNs are not required, the cost of the core network is drastically reduced.

Depending on the morphology, user density and other factors, any of the above-mentioned types of networks could be the best choice. Some operators, such as Eurotel in the Czech Republic, chose to go after urban markets, a quicker deployment (only four months for Eurotel) and smaller deployment costs by choosing to offer EV-DO data services only. Other operators, like Romania's ZAPP, adopted the strategy of offering both data and voice by covering the entire country using 1xRTT, and upgrading select urban cell sites to EV-DO, when indicated by increased data traffic demand.

Considering the case of connectivity for rural areas, where no other operators offer voice services, it is currently essential to deploy 1xRTT, because voice remains the "killer application". Telephony using VoIP in an EV-DO Release 0 only deployment suffers due to the asymmetry between the forward and reverse links (2.44Mbps vs. 153Kbps), severely limiting the number of possible simultaneous VoIP calls.

However, the situation changes with the introduction of EV-DO Revision A. This new version of the standard offers more symmetric data rates (3.1Mbps for downlink and 1.8Mbps for uplink), and is expected to support 40-60 simultaneous VoIP calls per 1.25MHz channel [13], an 48-120% increase in voice capacity over 1xRTT. This enables EV-DO Rev A deployments to efficiently support both data and voice services.

## VII. CONCLUSION

CDMA technology provides a trade-off between capacity and coverage by leveraging its embedded power control mechanism to either serve large extended ranges when peak capacity is not required or to serve high capacity where extended coverage range is not needed. With CDMA 450 in particular, owing to the superior propagation characteristics of the 450 MHz frequency, this flexible trade-off can be realized at much larger ranges, making it a potentially suitable candidate for deployment in low density rural areas.

To investigate this possibility, we presented the main strengths of CDMA 450: large, flexible cell sizes with competitive performance in both rural and urban morphologies. We also argued that despite some potential limitations resulting from cell breathing, potentially large antennas, low terminal volumes, and the requirement for a large number of users, the achievable capacity-coverage trade-offs are acceptable to enable real commercial deployments. This lead us to believe that a business model in which the carrier uses urban operations to subsidize rural operations can be viable.

We also presented techniques to enhance cell sizes in WLL scenarios. Specifically, we showed that by using directional antennas and receive diversity at the fixed terminals, one can increase the range of the cell and dramatically increase SINR, TCP download and upload bandwidths achieved at the higher ranges.

In conclusion, we believe that WLL using EVDO over CDMA 450 is a feasible and promising technology to provide data services in rural areas.

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