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# Using 1xEV-DO to Launch Residential Broadband Services

Network Design and Business Considerations

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<b>Executive Summary</b> .....	<b>3</b>
<b>Introduction</b> .....	<b>4</b>
<b>Understanding 1xEV-DO</b> .....	<b>4</b>
1xEV-DO Network Architecture .....	4
1xEV-DO Forward Link (Downlink) .....	5
1xEV-DO Reverse Link (Uplink) .....	6
<b>Designing a 1xEV-DO Network</b> .....	<b>6</b>
Spectrum Requirements .....	6
Determining Cell Size .....	7
Estimating Capacity .....	8
Backhaul and Internet Connection .....	10
<b>Developing the Business Case</b> .....	<b>11</b>
Target Market .....	11
Marketing Strategy .....	12
Market Penetration .....	13
Revenues .....	14
Capital Expenditure .....	15
Operating Expenses .....	16
Financial Summary .....	20
<b>Improving the Business Case</b> .....	<b>22</b>
<b>Summary</b> .....	<b>24</b>
<b>Appendix A. Link Budget Analysis</b> .....	<b>25</b>
<b>Appendix B. Forward Link Capacity Calculation</b> .....	<b>27</b>
<b>Appendix C: Understanding SINR variation</b> .....	<b>28</b>

## Executive Summary

CDMA2000 1xEV-DO (1x Evolution – Data Optimized) is the first third-generation (3G) mobile air interface standard that offers the data rates required to launch a competitive residential broadband service. With proper network design and planning, operators can use 1xEV-DO to launch a service that has operating profits in the second year of its operation and a payback period of less than five years—attractive financial returns by any measure.

1xEV-DO can deliver these attractive financial returns because it offers wide area coverage and very high data rates. As explained later in this paper, at PCS frequencies, a typical suburban 1xEV-DO cell site can cover more than 17 square miles of area and serve more than 1000 typical residential subscribers. Once the network is serving over 1000 subscribers per cell site, it can be operated at a monthly cost as low as \$5 per subscriber. In addition, there are no costs to install a modem at the subscriber's location since 1xEV-DO subscriber modems do not require external antennas or line-of-sight to the cell site.

The adoption of 1xEV-DO by several large operators will further improve its economics. Unlike several proprietary technologies that offer wide area coverage and comparable data rates, 1xEV-DO is part of the global CDMA2000 3G standard and is supported by several large infrastructure and subscriber device vendors. Two of largest wireless operators in the world, SK Telecom<sup>1</sup> and KT Freetel<sup>2</sup> of Korea, have already launched commercial 1xEV-DO service while Verizon Wireless is currently conducting 1xEV-DO trials<sup>3</sup>. Several other large operators have announced their support for 1xEV-DO.

Even though 1xEV-DO is part of the CDMA2000 standard, it does not rely on any element in the CDMA voice network to provide service, mobility or roaming. The operator does not require a Mobile Switching Center (MSC) or network elements such as the home and visitor location registers (HLR/VLR). As a result, 1xEV-DO can be deployed by any voice operator irrespective of the voice technology it is currently using, or by a green-field operator. All that is required for launching 1xEV-DO service is 1.25 MHz of paired spectrum and a relatively small infrastructure investment of less than \$150 per subscriber.

The market opportunity for providing affordable, home broadband access is now. Analysts estimate broadband penetration in North America to grow by over 60% in 2002 and at double-digit rates for the next five years. The potential for high-speed wireless service is even higher in markets with limited wireline infrastructure. 1xEV-DO allows an operator to seize this opportunity and build a 3G mobile wireless network that can rapidly build a large customer base and reach profitability.

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<sup>1</sup>“SK Telecom Launches The World's First Commercial IMT-2000 (1xEV-DO) Service”, SK Telecom Press Release, January 28, 2002

<sup>2</sup>“Korea Telecom Launch 3G Wireless”, News story on [www.3g.co.uk](http://www.3g.co.uk)

<sup>3</sup>“Verizon Wireless And Lucent Technologies To Launch CDMA2000 1xEV-DO Network Trial In Washington, D.C. Area”, Verizon Wireless Press Release, March 19, 2002.

“Verizon Wireless, Nortel Networks Plan 1xEV-DO Field Trial, CTIA Demonstration”, Verizon Wireless Press Release, March 19, 2002.

## Introduction

This paper analyzes the business case for using 1xEV-DO to offer a wireless residential broadband service. It begins with a primer on 1xEV-DO network architecture and air interface. Subsequent sections discuss the design of a 1xEV-DO network and the economics of offering a service.

The section on network design examines four key questions that determine the economics of the service:

- How much spectrum is required?
- How much area can each cell site cover (coverage)?
- How many subscribers can each cell site support for a given amount of spectrum (capacity)?
- What are the backhaul and Internet interconnection requirements?

The section on service economics analyzes the revenues, expenses and profitability for a specific scenario. It uses realistic and conservative assumptions, supported by technical simulations, analyst reports and industry averages, to demonstrate that a 1xEV-DO network offers attractive financial returns.

## Understanding 1xEV-DO

### 1xEV-DO Network Architecture

A 1xEV-DO network has three key elements:

- Radio Nodes (RNs)
- Radio Network Controller (RNC)
- Packet Data Serving Node (PDSN)

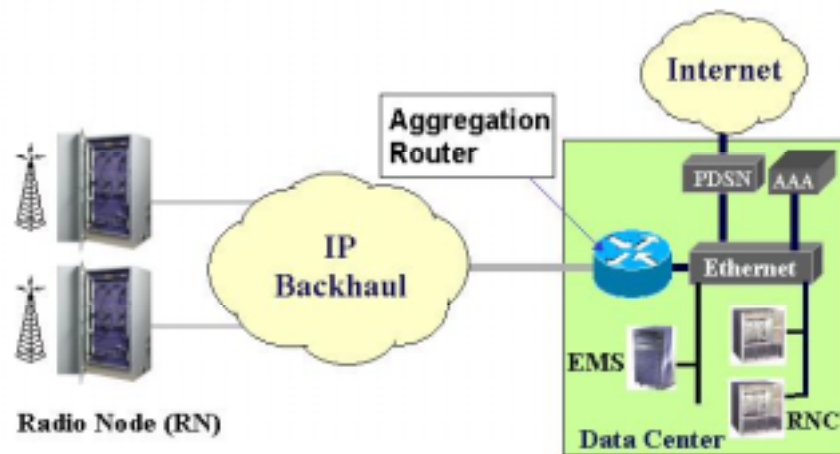


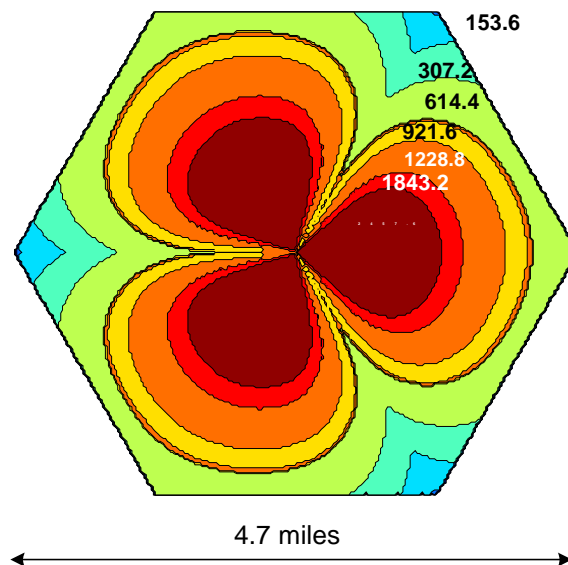
Figure 1: 1xEV-DO Network Architecture

Each radio node typically supports three sectors and serves one cell. A dedicated transceiver in each sector terminates the 1xEV-DO airlink between the subscriber modem and the radio node. Higher layers of the 1xEV-DO protocol are processed at the RNC. The RNC also manages handoffs and passes user data between the RNs and the PDSN. The PDSN is a wireless edge router that connects the radio network to the Internet. Unlike some other 3G wireless technologies, this architecture does not depend upon a Mobile Switching Center (MSC).

In addition to the RNC and the PDSN, a 1xEV-DO data center has an aggregation router, an element management system (EMS) and several ISP servers. The aggregation router terminates IP traffic from the RNs and passes it to the RNC. The EMS manages the radio access network. Commonly used ISP servers include, among others, standard IP servers for the Domain Name System (DNS), Dynamic Host Configuration Protocol (DHCP) and Authentication, Authorization, and Accounting (AAA).

### 1xEV-DO Forward Link (Downlink)

The basic unit of transmission on the 1xEV-DO forward link is the airlink frame. Airlink frames destined for different users in the same sector are time-division multiplexed. The radio nodes transmit each airlink frame at the *link rate*, which can vary between 38.4 Kbps and 2.4 Mbps. The link rate depends on the signal-to-interference-plus-noise-ratio (SINR)<sup>4</sup> at the subscriber's location. SINR can vary significantly within a cell. This variation is an inherent characteristic of all wireless systems and occurs primarily because of variations in RF propagation loss, building penetration loss, fading effects, and co-channel interference. (See "Appendix C: Understanding SINR variation" for more information on reasons for SINR variation.) As a result, the link rate experienced by a subscriber depends on the position of his or her home (within the cell)—just as it does in DSL.



**Figure 2: Link Rate Distribution in a 1xEV-DO Cell**

<sup>4</sup>  $SINR = S/(N + I)$ , where  $S$  is the received signal power,  $I$  is the interference received from other sectors and  $N$  is the receiver's thermal noise.

Figure 2 illustrates how the link rate varies within a three-sector suburban cell. This figure includes the effect of interference from all adjacent sectors and cells. (For other assumptions used in this figure, refer to “Appendix A. Link Budget Analysis”.) Notice that the link rate is generally highest near the cell site and away from sector and cell boundaries. The average link rate in a sector, sometimes referred to as forward link sector throughput, is approximately 1.2 Mbps and is indicative of the total available link capacity in each sector.

As in cable modems, since the link between the network and the subscribers is shared, depending on *system load*, the actual data rate experienced by a subscriber can be less than the link rate. Roughly speaking, the number of subscribers who are receiving data at the same time in the same sector determines the system load. For instance, when two subscribers are downloading simultaneously at a fixed link rate of 1.2 Mbps, the actual data rate they experience will be around 600 kbps.

1xEV-DO radio nodes use a flexible scheduler to allocate channel capacity among multiple subscribers. In this paper, we assumed a special case of this flexible scheduler, often referred to as the Proportional Fairness Scheduler. The Proportional Fairness Scheduler transmits airlink frames to individual subscribers during times when that subscriber’s channel conditions are *relatively* good.

## 1xEV-DO Reverse Link (Uplink)

1xEV-DO subscribers can transmit on the reverse link at data rates ranging from 9.6 kbps to 153.6 kbps. Unlike the forward link, in which a scheduler time-division multiplexes airlink frames over the channel, the reverse link uses CDMA, which allows multiple users to transmit at the same time. As a result there is no difference between a user’s link rate and data rate on the reverse link.

The reverse link sector throughput represents the total link capacity of the reverse link. Computed as the sum of the reverse link data rates of all simultaneously transmitting subscriber modems, it is about 250 kbps per sector or one-fifth the forward link sector throughput. 1xEV-DO radio nodes equitably share this throughput among all active subscribers by using a rate control mechanism.

## Designing a 1xEV-DO Network

This section describes how an operator can design a 1xEV-DO radio access network to offer residential broadband services. It provides guidance on determining the cell size and cell capacity for different morphologies and describes the backhaul options.

### Spectrum Requirements

Operators require just 1.25 MHz of paired spectrum to start deploying a 1xEV-DO network. This spectrum can be in any frequency band between 450-3500 MHz. Bands currently used for wireless voice systems, such as the PCS (1900 MHz) and Cellular (850 MHz) bands, are especially well suited because they allow an operator to lease or reuse existing CDMA cell sites.

Additional spectrum can be added in 1.25 MHz slices. A 1.25 MHz slice of paired spectrum is often referred to as a carrier or a CDMA channel. The capacity of the network increases linearly

with the number of carriers deployed.

## Determining Cell Size

The radius of a cell is the maximum distance from the radio node at which the radio node can provide acceptable forward and reverse link service. The cell radius determines the number of radio nodes required to cover an area, which has a direct impact on capital expenditure.

Cell radius can be estimated using link budget analysis. This analysis estimates the maximum RF propagation loss or path loss that is allowable between the subscriber modem and the radio node for acceptable service. Path loss can be translated into cell radius using well-established RF propagation models.

Path loss generally increases as the subscriber moves away from the cell site. The modem overcomes the increased loss on the reverse link by increasing its transmit power. At the cell radius, the modem transmits near its maximum power (typically 200 mw) to support the minimum acceptable reverse link rate. Increasing path loss degrades forward link data rates as well. However, our link budget analysis demonstrates that the maximum allowable path loss on the forward link is higher than that on the reverse link. Therefore, the reverse link determines the cell radius.

To perform link budget analysis on the reverse link, an operator must define the following service parameters:

- Target minimum reverse data rate
- Reverse link outage probability: % of subscribers in the cell whose reverse link data rate may fall below the target minimum reverse data rate

Table 1 shows the cell size (coverage area) for a PCS (1900 MHz) cell as a function of the target minimum reverse data rate and morphology. A reverse link outage probability of 10% is assumed. Other assumptions are listed in “Appendix A: Link Budget Analysis”. This table shows that in a suburban area, one 1xEV-DO cell can cover over 17.5 sq. miles with over 90% of the subscribers getting a reverse data rate of at least 19.2 kbps. A cell can cover a larger area in a rural area, or at a lower target minimum reverse data rate. Further, if the radio node were operating at 800 MHz, for the same service parameters and morphology, cell size would be approximately four times larger because of lower path loss.

Target Minimum Reverse Link Data Rate	PCS Cell Coverage Area (sq. mi)			
	Urban	Dense Suburban	Suburban	Rural
9.6 kbps	7.3	14.5	21.6	42.1
19.2 kbps	6.0	11.7	17.5	33.9
38.4 kbps	3.6	7.0	10.5	20.3

**Table 1: PCS Cell Coverage Area for Different Morphologies**

The number of households covered by each cell depends upon the density of households covered. Table 2 shows that, for a target minimum reverse data rate of 19.2 kbps, a single cell can cover almost 12,000 households in a typical dense suburban area with 1000 households per square mile while it can cover only half as many subscribers in a typical rural area with 167 households per

square mile. As a result, to obtain the same revenue per cell site, an operator would have to capture twice as many households in a typical rural area as it does in a typical dense suburban area.

	Urban	Dense Suburban	Suburban	Rural
Households per sq. mi.	3000	1000	500	167
Coverage Area (sq. mi)	6.0	11.7	17.5	33.9
Households Covered per Cell	18,000	11,700	8,750	5,660

**Table 2: Total Number of Households per Cell at a Minimum Reverse Link Rate of 19.2 kbps**

## Estimating Capacity

Cell capacity is the maximum number of subscribers that can be served by a radio node during busy hour<sup>5</sup> using one carrier. Each carrier represents 1.25 MHz of paired spectrum. Once a cell is being utilized at its capacity, an operator must either deploy more radio nodes or add more carriers.

Statistics indicate that residential Internet users download five times more data than they upload. As discussed in “1xEV-DO Reverse Link”, the average forward link sector throughput is higher than the reverse link throughput by the same ratio. Therefore, cell capacity can be estimated by just analyzing forward link capacity. Forward link capacity depends upon:

- Link rate distribution (see Figure 2)
- Activity factor: Percentage of subscribers that are active during busy hour
- Average usage: Average amount of data downloaded by an active subscriber during busy hour
- Target minimum forward data rate
- Forward link outage probability: percentage of subscribers who may not receive the target minimum data rate during busy hour.

In this section, we assume an activity factor of 20% and average usage of 2 MB per hour. This usage is equivalent to over 40 web pages or over 100 emails. Cell capacity is inversely proportional to both these parameters, i.e. doubling either one of them will reduce the capacity numbers presented below by half. On the other hand, reducing any of them by a factor of two will double them. Other assumptions used in the capacity calculation are described in “Appendix B. Capacity Calculation”.

Figure 3 shows the numbers of subscribers that can be supported by a three-sector PCS cell as a function of the target minimum forward data rate. Different bars in this plot correspond to different outage probabilities. According to this plot, if the operator expects a minimum forward data rate of 153.6 kbps (middle set of bars) for all but 5% of its subscribers, each cell in the

<sup>5</sup> The busy hour for residential Internet access is typically 9-10 PM in North America

network can support almost 1100 subscribers. However, if the operator would like to provide a minimum forward data rate to all but 10% of its subscribers, each cell in the network can support almost 1400 subscribers.

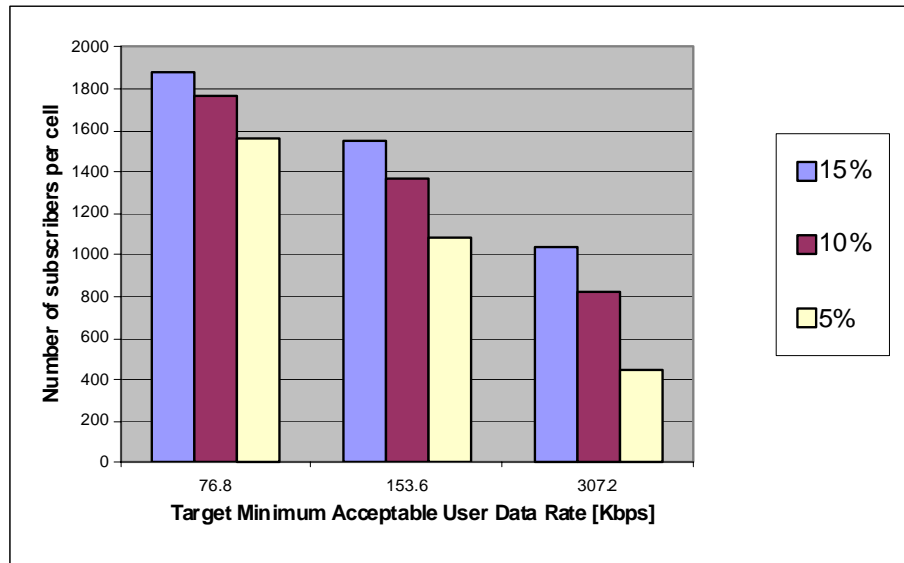


Figure 3: Number of Subscribers vs. Minimum Forward Data Rate for 5%, 10% and 15% Outage Probabilities

According to our simulations, capacity numbers are not significantly affected by morphology, i.e. a cell in an urban area will support approximately the same number of subscribers as a cell in a rural area. Since the household density in an urban area is many times higher than it is in a rural area, a cell in an urban area will run out of capacity at a much lower household penetration than a cell in a rural area. Table 3 shows the market penetration that can be supported in different morphologies. Once a cell is operating at full capacity, an operator has to either add more carriers or deploy more cell sites.

	Urban	Dense Suburban	Suburban	Rural
<b>Households Covered per Cell</b>	18,000	11,700	8,750	5,660
<b>Subscribers per Cell (153.6 kbps, 10% outage probability)</b>	1390	1370	1370	1350
<b>% Households Served (Market Penetration)</b>	7.7%	11.7%	15.6%	23.8%

Table 3: % of Covered Households Served by one 3-Sector 1-carrier PCS Radio Node.

Even when a radio node is fully utilized, i.e. supporting as many subscribers as its capacity, the data rate for most users will be significantly higher than the target minimum data rate. For a suburban PCS cell with a target minimum data rate of 153.6 kbps, 1370 subscribers and 10% outage probability, 25% of subscribers will have a data rate that exceeds 1.2 Mbps, 52% will have

a data rate that exceeds 600 kbps, and 75% a data rate that exceeds 300 kbps. (See “Appendix B. Capacity Calculation” for a plot of the forward rate distribution.)

## **Backhaul and Internet Connection**

Airvana has chosen to use Internet Protocol (IP) to connect RNs and the RNC. Along with making the network more reliable and scalable, IP gives operators the flexibility to choose between several available backhaul options. These include dedicated T1/E1 leased lines, a routed network, wireless backhaul, Metro Ethernet, and Frame Relay.

In the scenario where T1/E1 leased lines are used, each cell site connects to the nearest central office over a T1/E1 local access line. To reduce local access line charges, multiple incoming T1/E1 circuits may be combined at a (possibly different) central office and delivered to the data center where the RNC is located over one or more T3 access lines.

The cost of backhaul from the cell sites to the data center depends on the number of T1/E1 lines needed per cell site. The capacity numbers shown in Table 3 assume that at least 3 T1's are available for backhaul. However, our simulations have shown that using 2 T1's reduces capacity by less than 10% and should be adequate when the network is not fully utilized.

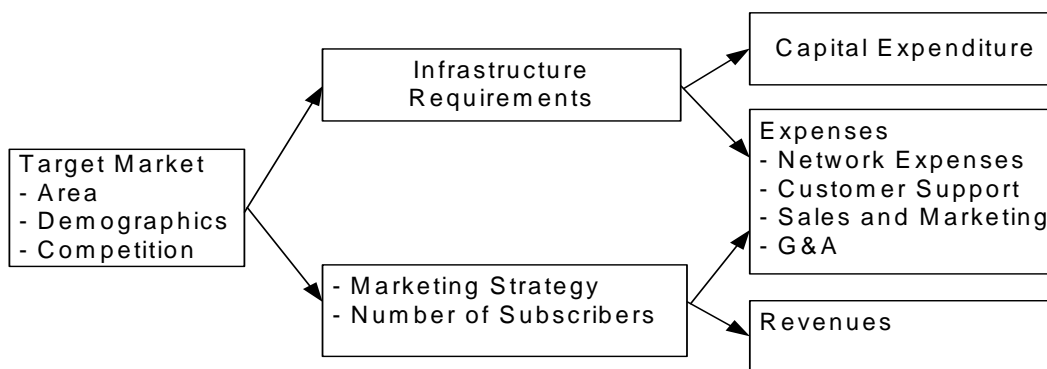
The wireless operator needs to purchase Internet access from a nationwide Tier 1 or a regional Tier 2 ISP in order to connect its customers to the Internet. The cost of this Internet connection often depends on the 95<sup>th</sup> percentile aggregate forward link data rate as measured at the PDSN. For a large network, with 1370 subscribers per cell (see Table 3) this translates to approximately 1.5 Mbps per cell and decreases linearly as the number of subscribers in the cell is reduced.

If the ISP has a Point-Of-Presence (POP) in the same data center where the RNC and PDSN are located, the wireless operator can connect the PDSN to the Internet directly. Otherwise, a dedicated local access line (T3 or OC-3) is needed between the data center and the ISP POP.

## Developing the Business Case

This section presents a business case for a green-field North American operator that uses 1xEV-DO to offer a flat-rate residential broadband service. Based on conservative assumptions for revenues and industry-averages for expenses, this analysis shows that a 1xEV-DO network can provide a positive operating profit in the second year of operation and a payback period of five years.

The figure below provides a high-level view of the business modeling approach and an outline for the remaining part of this section.



**Figure 4: Business Case Modeling Methodology**

### Target Market

For the purpose of this example, we have chosen a 500 square mile area, with 225,000 households. This area has a mix of suburban, dense suburban, and rural morphologies as shown in the table below. In addition, we assume that all major dial-up Internet service providers serve this market, and some regions have cable, DSL and satellite-based broadband services.

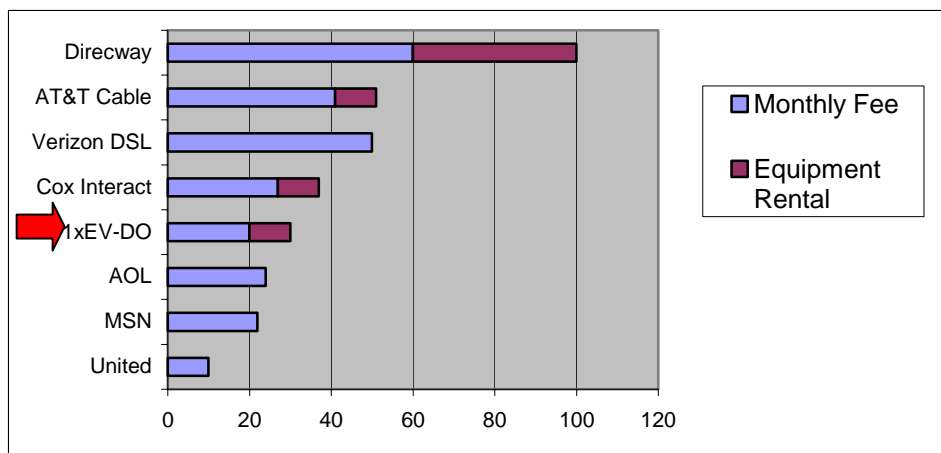
	Household Density (per sq. mi)	Area (sq. mi)	Number of Households
Dense Suburban	1000	50 (10%)	50,000 (22%)
Suburban	500	300 (60%)	150,000 (67%)
Rural	167	150 (30%)	25,000 (11%)
<b>Entire Region</b>	<b>450</b>	<b>500 (100%)</b>	<b>225,000 (100%)</b>

**Table 4: Demographics of Target Market**

## Marketing Strategy

Dial-up Internet access remains the biggest competitor for residential broadband services because of its low monthly fee and ubiquitous availability. According to several market research groups, at the end of 2001, 90% of US households accessed the Internet from their homes using a dial-up connection. For a residential broadband service to gain widespread adoption, it should be able to present customers of dial-up services with a competitive price and compelling value proposition.

A 1xEV-DO service can provide the attractive financial returns mentioned at the beginning of this section even if it is priced as low as \$24.95/month, with a \$10/month modem rental fee. Even with the modem rental fee, the customer pays just \$10 more than leading dial-up services like AOL and MSN. Further, as shown in Figure 5 below, this price is approximately \$15 below the price of competing cable and DSL services.



**Figure 5: Proposed Pricing Compared to Other Residential Internet Access Alternatives<sup>6</sup>**

At this price, the 1xEV-DO service would offer a compelling value proposition to the customer, which would include:

- Always-on access, without tying up a phone line
- Average data rates that are at least three times faster than dial-up access
- Mobility throughout the coverage area
- Peak data rates that are comparable to DSL and cable services (that are 40% more expensive)
- Easy installation and instant, over-the-air, service provisioning

Based on pricing trends in the ISP business, we believe that the operator will not have to reduce prices in the near future. Over the last year, broadband as well as dial-up ISPs in North America have actually increased their prices. Cable modem and DSL prices have increased by as much as

<sup>6</sup> 1. Pricing for United, MSN and AOL is the price advertised on the web site of each company on April 25, 2002.

2. Pricing for AT&T Broadband is for cable service offered in Cambridge, MA in May 2002

3. Pricing for Direcway 2 way Satellite service from DirectTV web site on 5/3/2002. Equipment Rental applies to first year of service only.

4. Cox Interact is a lower tier cable service with a peak rate of 256 kbps. Pricing from Cox site, 5/8/2002.

\$5/month in many areas. AOL has increased its price by \$1/month, while United Online has successfully converted over a million free subscribers into subscribers that pay \$9.95/month.

	Year 1	Year 2	Year 3	Year 4	Year 5
Base Monthly Subscription Fee (\$)	24.95	24.95	24.95	24.95	24.95
Modem Lease Fee (\$)	10.00	10.00	10.00	10.00	10.00
Total Monthly Service Fee (\$)	34.95	34.95	34.95	34.95	34.95

**Table 5: Proposed Pricing for 1xEV-DO Residential Internet Service**

We do recommend that the operator purchase modems as part of its capital expenditure and lease them to subscribers instead of expecting subscriber to purchase them. 1xEV-DO modems may cost up to \$350 in the early 2003 time frame and expecting subscribers to purchase them will slow down adoption. Unlike the option of subsidizing the modem purchase, leasing ensures that the operator recovers its expense on the modem if a subscriber switches to another service. Cost of subscriber devices is expected to fall to the \$150 range by 2005, at which stage subscribers have an option to buy it rather than lease it.

One counter-argument to flat rate pricing is that excessive usage by few subscribers can degrade the experience of other subscribers. As reported in *Business Week*<sup>7</sup>, 1% of users in AT&T's cable network download 16% of the data. Airvana's priority-based 1xEV-DO QoS architecture can prevent this situation. By monitoring usage on a subscriber basis, our system can detect when a subscriber exceeds certain service-dependent usage levels. At that point, Airvana's radio node can lower the relative priority of that user in the scheduler and prevent further degradation of other users' experience.

## Market Penetration

We assume that the adoption of the 1xEV-DO service will depend upon the overall rate of broadband adoption. At the end of 2001, around 10% of the approximately 100 million households in United States had broadband access. Several market research groups including Jupiter Media Metrics, Yankee, and eMarketer expect broadband penetration to increase to 16% by the end of 2002 and grow linearly to 42% by the end of 2007.

Based on these analyst estimates, we assume that when the service is launched, 16% of households in our target market will have broadband connections. Over the next five years, 6% of households will sign up for broadband service each year, increasing total broadband penetration linearly to 46% of all households by the end of year 5. Though we expect that the availability of a lower-cost broadband service will boost overall penetration, to be conservative, we have not factored this effect in our analysis.

We estimate that a 1xEV-DO service should be able to garner at least 35% of all new broadband subscribers in suburban areas where it is competing with two other broadband services and at least 50% of new subscribers in less competitive rural areas. The three factors that will provide the 1xEV-DO service with a competitive advantage compared to wire-line broadband alternatives are lower price, no per-user installation cost and over-the-air service provisioning.

<sup>7</sup> "Will Cable Unplug the File Swappers," *Business Week Online*, June 12 2002

	Year 1	Year 2	Year 3	Year 4	Year 5
Households	225,000	225,000	225,000	225,000	225,000
% of Households with Broadband (year-end)	22%	28%	34%	40%	46%
Number of Broadband Subscribers (year-end)	49,500	63,000	76,500	90,000	103,500
<b>Number of New Broadband Subscribers (Net Adds)</b>	<b>13,500</b>	<b>13,500</b>	<b>13,500</b>	<b>13,500</b>	<b>13,500</b>
% of New Broadband Subscribers Selecting 1xEV-DO Service					
In dense suburban areas	35%	35%	35%	35%	35%
In suburban areas	35%	35%	35%	35%	35%
In rural areas	50%	50%	50%	50%	50%
<b>Year-end 1xEV-DO Subscribers<sup>8</sup></b>	<b>4,950</b>	<b>9,900</b>	<b>14,850</b>	<b>19,800</b>	<b>24,750</b>
<b>Year-end 1xEV-DO Market Penetration</b>	<b>2.2%</b>	<b>4.4%</b>	<b>6.6%</b>	<b>8.8%</b>	<b>11.0%</b>

**Table 6: Market Penetration of 1xEV-DO Service**

## Revenues

The operator's expected revenue and revenue run rate can be calculated based on the pricing strategy and market penetration assumptions explained in the previous section. The calculation of annual revenue is based on the average number of subscribers during the year while the calculation of the revenue run rate depends upon the number of subscribers at the end of the year.

	Year 1	Year 2	Year 3	Year 4	Year 5
Year-end number of subscribers	4,950	9,900	14,850	19,800	24,750
Average number of subscribers	2,475	7,425	12,375	17,325	22,275
Revenue (\$ '000s)	1,038	3,114	5,190	7,266	9,342
Revenue Run-Rate (\$ '000s)	2,076	4,152	6,228	8,304	10,380

**Table 7: Annual Revenue and Revenue Run-Rate**

<sup>8</sup> Since 22% of households are dense suburban, 67% are suburban, and 11% are rural (Table 4)

Year-end 1xEV-DO subscribers = Subscribers at the end of previous year +  
Net Broadband Additions \* (22 % \* 35% + 67% \* 35% + 11% \* 50%)

## Capital Expenditure

### Network Infrastructure

Service can be provided to the entire 500 sq. mi. area by deploying 28 three-sector radio nodes. Of these radio nodes, 18 will provide service to the 300 sq. mi. suburban area while the other 10 would be evenly divided over dense suburban and rural areas. In addition to deploying radio nodes, the operator must build a data center with a Radio Network Controller (RNC), a Packet Data Serving Node (PDSN) and other networking equipment, as explained in “1xEV-DO Network Architecture”. Table 8 shows the network infrastructure costs for first generation 1xEV-DO equipment.

Network Infrastructure	Expense ('000s \$)
1 Cell Site (Includes radio node, antennas and cables)	113
28 Cell Sites (Includes radio node, antennas and cables)	3,150
Data Center (Includes RNC, PDSN, EMS, AAA, Routers, other ISP Servers)	1,035
Network Installation (Includes site acquisition, RF planning, drive testing, RF optimization, backhaul installation)	1,301
<b>Total</b>	<b>5,486</b>

**Table 8: Break-up of Capital Expenditure on Deploying Network Infrastructure**

Based on Table 1 and Table 3 the radio nodes deployed in the first year are sufficient to cover the entire area and serve up to 38,260 subscribers. Considering that an investment of \$5.4 M is required to build this network, the capital expenditure per subscriber (for network infrastructure) is \$143. Notice that this amount includes not only the equipment costs but also the cost of installing and optimizing the network.

No additional capital expenditure is required to support the subscriber numbers projected over the first five years. Table 9 below shows that even in the fifth year, average network capacity utilization is below 70%.<sup>9</sup>

	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Radio Nodes	28	28	28	28	28
Network Capacity	38,260	38,260	38,260	38,260	38,260
Number of Subscribers (Year-end)	4,950	9,900	14,850	19,800	24,750
Capacity Utilization (%)	13%	26%	39%	52%	65%

**Table 9: Network Capacity Utilization**

<sup>9</sup> Network capacity will first be depleted in the dense suburban cells. However, even in those cells network utilization will be less than 77% by the end of Year 5.

### *Modems (Access Terminals)*

As discussed in “Marketing Strategy”, the operator must purchase modems that can be leased to subscribers. Based on our discussions with several modem vendors, we expect modems to cost \$350 in early 2003, and drop in price to \$150 over the next five years.

	Year 1	Year 2	Year 3	Year 4	Year 5
Unit Cost of 1xEV-DO Modem (\$)	350	250	200	175	150
Number of Subscribers (Year-end)	4,952	9,903	14,855	19,806	24,758
Capital Expenditure on Modem Purchase ('000s \$)	1,733	1,238	990	866	743

**Table 10: Capital Expenditure on Subscriber Modems**

## **Operating Expenses**

### *Network Operating Expenses*

Recurring network operating costs include the cost of backhaul, network interconnection, real estate leases, utilities and maintenance.

Backhaul and network interconnection charges comprise almost 40% of the recurring expense. For the purpose of this analysis, we assume that the operator will use T1 lines for backhaul. Though two T1 lines are sufficient in the first two years of operation, to be conservative, we have assumed that the operator will provision three T1 lines from the start. Table 11 summarizes our estimates for backhaul requirements and expense.

	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Radio Nodes	28	28	28	28	28
Number of T1 lines per Radio Node	3	3	3	3	3
T1 Pricing (\$, per month)	450	428	406	386	367
<b>Annual T1 Expense (000's \$)</b>	<b>454</b>	<b>431</b>	<b>409</b>	<b>389</b>	<b>369</b>

**Table 11: Backhaul Requirements and Expenses**

The network interconnection charge depends on system utilization. As described in section “Backhaul and Network Interconnection”, in a large network, a cell with 100% capacity utilization requires approximately 1.5 Mbps of bandwidth. The bandwidth required scales down linearly with lower utilization. Table 12 shows our estimates for network interconnection requirements and the expense required to meet them.

	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Radio Nodes	28	28	28	28	28
% Network Utilization	13%	26%	39%	52%	65%
Bandwidth Required (Mbps)	5.3	10.6	16.0	21.3	26.6
Bandwidth Pricing (\$, per month)	300	285	271	257	244
<b>Annual Network Interconnection Expense (000's \$)</b>	<b>19</b>	<b>36</b>	<b>52</b>	<b>66</b>	<b>78</b>

**Table 12: Network Interconnection Bandwidth Requirement and Expenses**

Real estate and utilities comprise the other large expense that an operator incurs. We have assumed that these costs remain unchanged over the period of this analysis. Real estate cost includes the cost of leasing tower space from commercial tower management companies and leasing data center space at an Internet co-location facility. In addition, network expenses include hardware and software maintenance fees and dedicated headcount to monitor and operate the network. No hardware and software maintenance fees are assumed in the first year of operation since the infrastructure will be covered by warranties.

Network Operating Expenses ('000s \$)	Year 1	Year 2	Year 3	Year 4	Year 5
Backhaul Expense	454	431	409	389	369
Network Interconnection Charge	19	36	52	66	78
Site and Data Center Lease, Utilities	493	493	493	493	493
Hardware and Software Maintenance	0	177	177	177	177
Network Operations	150	150	150	150	150
<b>Total</b>	<b>1116</b>	<b>1287</b>	<b>1281</b>	<b>1274</b>	<b>1267</b>

**Table 13: Break-up of Annual Network Operating Expenses**

It is useful to look at network operating expenses on a per subscriber basis and compare them to other technologies. In year 5, as network utilization approaches 65%, the monthly network operating expense drops to as low as \$4.75 per subscriber. At a price point of \$24.95 (excluding modem lease), this provides the operator with a margin of over \$20 (80%). This margin can be used to retain existing customers through superior service and support, acquire new customers, and build out the network.

	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Subscribers (average)	2,475	7,425	12,375	17,325	22,275
Annual Network Operating Expense per Subscriber (\$)	451	173	104	74	57
Monthly Network Operating Expense per Subscriber (\$)	37.6	14.5	8.6	6.1	4.7

**Table 14: Network Operating Expense per Subscriber**

### *Customer Support and Billing*

The cost of customer support and billing starts at \$25 per subscriber in the first year and declines 10% each year thereafter as costs are spread over a larger number of subscribers. Though this amount is lower than the expense incurred by wireless voice operators, it is comparable to the expense incurred by companies that provide a flat rate service.

	Year 1	Year 2	Year 3	Year 4	Year 5
Annual Per-customer Support Expense (\$)	25	22	20	18	16
Number of Subscribers (average)	2,475	7,425	12,375	17,325	22,275
Annual Cust. Support Expense ('000s \$)	62	167	251	316	365

**Table 15: Annual Customer Support and Billing Expenses**

### *Sales Expense*

We assume that the cost of customer acquisition starts at \$200 in the first year, and decreases to \$150 by year three. This cost includes the cost of marketing, advertising and sales commissions. It, however, does not include the cost of subsidizing subscriber modems since the operator is leasing modems to the subscriber.

Churn is assumed at 1% a month. Though this is much lower than the churn faced by wireless voice operators, it is in-line with the churn faced by Internet and broadband service providers. As a consequence of churn, gross subscriber additions are higher than the increase in penetration.

	Year 1	Year 2	Year 3	Year 4	Year 5
Cost of Customer Acquisition (\$)	200	175	150	150	150
Number of Subscribers (year-end)	4,950	9,900	14,850	19,800	24,750
Gross Subscriber Additions	4,950	5,841	6,435	7,029	7,623
Total Customer Acquisition Expense (000's \$)	990	1,022	965	1,054	1,143

**Table 16: Customer Acquisition Expense**

### *General and Administrative*

General and Administrative (G&A) expense is factored at 8% of the revenue, assuming the operator has sufficient scale to share G&A expenses across multiple businesses. In addition to the expense of administrative personnel and real estate, this charge includes bad debt expense. We expect bad debt expense to be as low as 2% of revenue since the service offered has a flat rate that can be billed one month in advance. For the first year of operation, we have assumed an additional charge of \$165,000 for one-time startup expenses.

	<b>Year 1</b>	<b>Year 2</b>	<b>Year 3</b>	<b>Year 4</b>	<b>Year 5</b>
G&A (as % of Revenue)	8%	8%	8%	8%	8%
G&A ('000s \$)	131	142	146	157	168
Startup expenses ('000s \$)	165	0	0	0	0
<b>Total G&amp;A &amp; Start-up Expenses</b>	<b>317</b>	<b>204</b>	<b>250</b>	<b>303</b>	<b>355</b>

**Table 17: Break-up of Annual General and Administrative (G&A) expense**

## Financial Summary

### *Income Statement*

The following table shows the income statements for the network over a five-year period. Notice that the network has positive operating profit (EBITDA) in the second year of operation and positive net income in the third year of operation.

(000's \$)	Year 1	Year 2	Year 3	Year 4	Year 5
Revenues:					
<b>Service Revenue</b>	<b>1,038</b>	<b>3,114</b>	<b>5,190</b>	<b>7,266</b>	<b>9,342</b>
Operating expenses:					
Network operating expense	<b>1116</b>	<b>1287</b>	<b>1281</b>	<b>1274</b>	<b>1267</b>
Customer support expense	62	167	251	316	365
Sales and marketing	990	1,022	965	1,054	1,143
General and administrative	317	204	250	303	355
<b>Total operating expenses</b>	2484	2680	2746	2947	3130
<b>EBITDA (revenue – operating expense)</b>	<b>(\$1,282)</b>	\$434	\$2,444	\$4,320	\$6,212
Depreciation (5-year, straight line)	1,444	1,691	1,914	2,112	2,261
Tax (35%, accounting for tax loss carry forwards)	0	0	0	0	991
<b>Net Income (EBITDA – depreciation and taxes)</b>	<b>(\$2,725)</b>	<b>(\$1,257)</b>	\$555	\$2,257	\$3,011

**Table 18: Income Statement**

### *Free Cash Flow Analysis*

The following table shows the free cash flow from the network. It shows that the network requires an investment of \$8.5M in the first year of operation with a subsequent investment of \$1M in the second year. Most of this investment goes towards building network infrastructure and towards acquiring modems that can be leased to subscribers. From the second year onwards, capital expenditure includes the cost of purchasing modems only. From the third year onwards, this capital expenditure can be made using cash generated by operations, obviating the need for further external investment.

	Year 1	Year 2	Year 3	Year 4	Year 5
Net Income	(\$2,725)	(\$1,257)	\$555	\$2,257	\$3,011
Add (deduct):					
Depreciation Expense	\$1,444	\$1,691	\$1,914	\$2,112	\$2,261
Capital Expenditure	(\$7,219)	(\$1,238)	(\$1,114)	(\$990)	(\$743)
Free Cash Flow	(\$8,500)	(\$804)	\$1,454	\$3,453	\$4,479

**Table 19: Free Cash Flow Analysis**

Analyzing the free cash flow shows that this network will have a payback period of 5 years. Further, if the network stops growing at this point and continues operating with the same number of subscribers, it generates an IRR of 21% over 7 years and an IRR of 30% over a 10 year period.

## Improving the Business Case

The business case presented in the previous section is based on conservative estimates for capital expenditure, operating expenses and revenue opportunities. However, 1xEV-DO and Airvana's implementation provide the operator with several opportunities to improve the financial returns presented in the business case analysis above. This section briefly discusses few of these opportunities.

1. *Increasing revenue by offering mobile services:* With 1xEV-DO, an operator can offer mobile and nomadic services in addition to residential services. These services allows an operator to expand its subscriber base and earn significant additional revenue, while sharing capital and operating costs with residential services.
2. *Increasing revenue by serving vertical applications:* As a high-speed data service that does not require line of sight, 1xEV-DO can be used for vertical applications like utility meters and point-of-sale transactions. Several access terminal vendors have announced plans to build 1xEV-DO modules that can be incorporated in other computing devices for vertical applications.
3. *Earning additional revenue from roaming:* Several large CDMA operators around the world are currently deploying 1xEV-DO or have announced plans to do so in the 2002-2003 time frame. However, it is unlikely that these networks will have ubiquitous coverage. This provides smaller 1xEV-DO operators with opportunities for roaming revenue.
4. *Reducing marketing expense through bundling:* An existing wireless operator can reduce its marketing expense (currently estimated as \$150-\$200 per subscriber) by bundling the 1xEV-DO residential broadband service with its existing service offering.
5. *Reducing backhaul expenses by using IP-based backhaul services:* With Airvana's IP-based implementation, the operator is not limited to using dedicated T1/E1 lines for backhaul. Instead the operator can chose between the several low-cost IP transport services available such as Frame Relay, Fixed Wireless and Metropolitan Ethernet. Airvana's backhaul congestion control algorithm can lower backhaul costs by reducing the number of T1/E1 lines needed per cell site.
6. *Reducing operating expense by sharing data centers across markets:* If an operator has networks in several markets, it can use Airvana's IP-based solution to cost-effectively centralize its data center. In such a case, an operator would aggregate the traffic from radio nodes in each market at a local aggregation router and then transport it using a low cost IP transport service to the central data center. Centralizing the data center reduces the initial capital expenditure as well as recurring operating costs.
7. *Reducing initial capital expenditure by enhancing coverage:* Since 1xEV-DO is spectrally similar to cdmaOne (IS-95) and CDMA2000 1xRTT, it can take advantage of the various approaches developed for these technologies to extend cell site coverage. These include repeater systems and tower-top low-noise amplifiers (LNA's). Off-the-shelf wireless repeaters can be used in place of radio nodes to bring coverage to low-density (especially rural) areas. These can be purchased at 1/6<sup>th</sup> the cost, have no

recurring backhaul expense and incur reduced site lease costs. Similarly, tower-top LNA's can be used to extend coverage of a radio node by eliminating antenna cable loss at the cell site, thereby improving reverse link budget by about 3 dB.

8. *Higher Capacity:* In this paper, we have assumed that households are distributed uniformly within each cell. In reality, however, household distribution will often be highly non-uniform. By placing the cell site near where the household density is highest, significant improvements in link rate distribution, and hence capacity, can be achieved.

Subscribers *on their own* can increase their data rates by placing the 1xEV-DO modem in a location that offers the most favorable SINR (e.g., upper floors). Almost optimal placement is possible using off-the-shelf wireless LAN bridging products. The subscriber can place the 1xEV-DO modem in the best location in the house, directly connect it to a wireless LAN bridge via USB or Ethernet, and then wirelessly connect to a wireless LAN adapter card in the subscriber's PC.

## Summary

The business case for 3G wireless networks has often been constructed based on the rapid adoption of mobile applications that work on cell phones and personal digital assistants. In this paper we have demonstrated that operators can use 1xEV-DO to build a profitable business, with a payback period of less than five years, by serving a fast growing and well understood market – Residential broadband access.

Even amidst the economic slowdown of 2002, demand for high-speed residential Internet access remains strong. Over the next few years, analysts expect broadband adoption in North America to grow at double-digit rates. Today, a major deterrent to the growth of broadband services is the speed at which wireline operators can roll out networks and the price at which they offer broadband service. In contrast to wireline operators, a 1xEV-DO operator can launch service that covers an entire city in a very short period of time. In addition, as demonstrated in this paper, the operator can get attractive financial returns at a price point as low as \$34.95/month.

1xEV-DO allows operators to capitalize on the strong demand in the residential broadband market today and build a mobile network that will generate revenues for years to come. 1xEV-DO is not a proprietary technology with doubtful longevity but a globally accepted standard that is being deployed by some of the largest operators in the world. The widespread adoption of 1xEV-DO will not only provide operators with cost savings on network equipment and modems, but also new revenue streams as much-anticipated mobile applications become a reality.

With Airvana and its partners, an operator can deploy a 1xEV-DO network today. Architected from the ground up using an IP platform and adherence to open standards, Airvana's products include a IP-based radio node, Radio Network Controller, and Element Management System. With no dependence on legacy voice infrastructure, Airvana products reduce an operator's capital expenditure, operating expenses and time to market.

Airvana has developed a planning tool that can be used to demonstrate the economic advantages of implementing an all-IP 3G network in your market(s). For more information about the Airvana Operator Planning Tool or about deploying a residential broadband wireless data network, please contact Amit Jain or David Hassman at +1 (866) 344-7437 or +1 (978) 250-3000. Or, visit our web site at [www.airvananet.com](http://www.airvananet.com).

## Appendix A. Link Budget Analysis

In the budget analysis, we estimate the maximum cell size that can support a minimum reverse link data rate of 9.6, 19.2 or 38.4 kbps with an outage probability of 10%.

In the link budget analysis, we first calculate the maximum signal loss that can be tolerated between the 1xEV-DO modem and the cell site antenna. The system parameters used in this calculation include:

- Reverse Link Loading<sup>10</sup>: 50%
- Shadow Fading Standard Deviation: 8 dB
- Maximum Power of 1xEV-DO Modem: 200 mW
- Base Station Noise Figure: 5 dB
- Base Station Antenna Gain: 17 dB
- Base Station Cable Loss: 3 dB
- Base Station Correlation<sup>11</sup>: 50%
- Number of Receive Antennas at the Base Station: 2

From the maximum allowed path loss, we can calculate the maximum cell radius, using the so-called extended Hata model.<sup>12</sup> This calculation uses the parameters shown below, which depend on morphology.

	Urban	Dense Suburban	Suburban	Rural
Homes per Square Mile	1200-3600	600-1200	200-600	50-200
Antenna Height (m)	30	40	40	45
Penetration Loss (dB)	16	14	12	8
Path Loss at 1 km (dB) <sup>13</sup>	126.0	123.3	122.3	121.6
Path Loss Exponent	3.52	3.44	3.44	3.41

Once the cell radius is determined, we can compute the link rate distribution in the forward link shown in Figure 2. The primary assumptions for computing this distribution include:

- Total Number of Base Stations<sup>14</sup>: 19
- Number of Sectors per Base Station: 3
- Forward Link Loading in Interfering Sectors<sup>15</sup>: 50%

<sup>10</sup> Reverse Link Loading represents the fractional loading with respect to the pole capacity of the reverse link. 50% loading corresponds to 3 dB increase in transmission power of 1xEV-DO Modems due to interference from all other 1xEV-DO transmissions in the reverse link.

<sup>11</sup> Base Station Correlation determines the correlation of shadow fading between adjacent base stations. This affects the so-called soft handoff gain used in link budget calculations.

<sup>12</sup> The HATA model is explained in *Wireless Communications Principles and Practice* by T. S. Rappaport.

<sup>13</sup> Path Loss at 1 km is determined using widely available empirical data

<sup>14</sup> The main cell in the center is used for computing the airlink data rate distribution. Other 18 hexagonal cells are distributed as two rings around the main cell.

- Transmit Power of the Base Station: 20 W
- Base Station Antenna Gain: 17 dB
- Base Station Cable Loss: 3 dB
- Number of Receive Antennas at 1xEV-DO Modem: 2
- 1xEV-DO Modem Noise Figure: 9 dB

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<sup>15</sup> This refers to the sectors except the sector of interest. This includes 18 surrounding base stations and two other sectors in the center cell.

## Appendix B. Forward Link Capacity Calculation

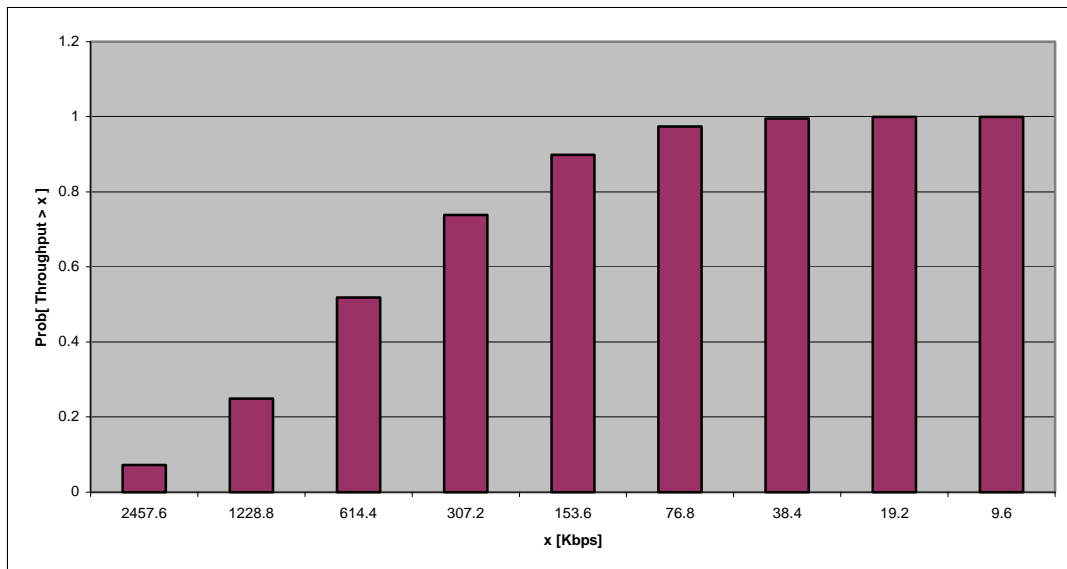
As the system is loaded with more subscribers, the data rates drop due to the sharing of a wireless channel. In this section, we explain the assumptions behind the system capacity calculation. The system capacity is the maximum number ( $N$ ) of subscribers each cell site can support given the outage probability, target minimum data rate, and a specific link rate distribution within the cell coverage area.

In this calculation, we assumed the following:

- Scheduling at the Base Station: Proportional Fairness Scheduler
- Probability of Arrivals of Download Requests: Poisson
- Percentage of Subscribers Active During the Busy Hour: 20%
- Number of Bytes Downloaded per Active Subscriber during the Busy Hour: 2 MB<sup>16</sup>

We used these assumptions to simulate the distribution of data rates. We then used the distribution to compute maximum number ( $N$ ) of subscribers each cell site can support, assuming that the data rate is not less than a given target minimum data rate 90% of the time.

The figure below shows the cumulative probability distribution of data rate for a suburban area using the assumptions summarized above. It shows that if the cell had 1368 subscribers (middle, red bar), 25% of them will have a data rate greater than 1.2 Mbps, over 50% will have a data rate greater than 614 kbps, over 75% will have a data rate higher than 307 kbps, and over 90% will have a data rate higher than 153.6 kbps.



<sup>16</sup> We assume the average number of bytes downloaded per active user is independent of the user's average channel condition. If the amount of data downloaded for each user is positively correlated with the average channel condition of the user, then the system capacity will be improved.

## Appendix C: Understanding SINR variation

This appendix describes some of the common factors that affect the signal to interference plus noise ratio (SINR).

**Path Loss:** This is the *average* signal loss experienced by radio signals as a function of distance from the cell site. Path loss also depends on cell site antenna height and the terrain. There are widely available empirical propagation data that can be used to estimate path loss.

**Shadow Fading:** Shadow fading accounts for the signal loss caused by various obstructions such as buildings, trees, etc. It is often modeled as a random quantity with a Gaussian distribution in the dB scale. The mean value of shadow fading is often captured as part of the path loss, while its standard deviation is about 8 dB.

**Penetration Loss:** This is an additional signal loss experienced in indoor use. Penetration loss depends strongly on the position of the modem inside the home.

**Rayleigh Fading:** This is caused by mobile objects near the 1xEV-DO modem, and results in rapid variations in the signal level.

**Other Cell/Sector Interference:** Interference originates in transmitting antennas of other sectors or cell sites. The same factors that contribute to loss in the desired signal also contribute to loss in the interfering signals.

**Noise:** This is the internal noise of the receiver. It is affected by the receiver design (noise figure), but is not affected by the location of the 1xEV-DO modem.



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