All-IP 1xEV-DO Wireless Data Networks

A Technical White Paper

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Introduction

CDMA2000 1xEV-DO (Evolution-Data Optimized) is the only commercially available 3G technology that delivers data rates exceeding 2 Mbps in 1.25 MHz of spectrum, offering bandwidth efficiency for data traffic that is three to four times greater than other voice-centric standards such as CDMA2000 1xRTT and W-CDMA.

Leading operators such as Verizon Wireless (USA), KDDI (Japan), SK Telecom (S. Korea) and KTF (S. Korea) already operate successful commercial 1xEV-DO networks and several other CDMA operators are rapidly deploying the technology. The cost advantages of 1xEV-DO are compelling. CDMA operators can deploy 1xEV-DO at a fraction of the cost GSM operators incur with W-CDMA deployments because 1xEV-DO operates in the same spectrum band as existing CDMA technologies, including IS-95 and 1xRTT, and can be introduced as a channel card upgrade to existing CDMA base stations.

The revenue generated by commercial 1xEV-DO networks bears testament to the compelling user experience that 1xEV-DO delivers. Annualized 1xEV-DO revenue already exceeds US$1 billion in South Korea. Further, the average revenue per user (ARPU) coming from 1xEV-DO data services in South Korea is two to four times higher than data ARPU generated by CDMA 1xRTT networks. Operators such as Eurotel (Czech Republic) and Vesper (Brazil) are using 1xEV-DO to deliver residential broadband at approximately US$35, while Verizon Wireless (United States) is using 1xEV-DO to offer mobile broadband to laptops at $79.99/month.

All CDMA 1xEV-DO handsets and PC cards are backward compatible to 1xRTT. Unlike W-CDMA/GSM, 1xEV-DO and 1xRTT allow a connection to be maintained when subscribers roam in and out of 1xEV-DO service areas. This allows operators with large 1xRTT networks to introduce 1xEV-DO into their markets in a cost-effective phased manner.

Airvana's unique All-IP network architecture helps operators further reduce their operating costs by using an IP-based backhaul network to connect 1xEV-DO radio nodes (or base stations) to Radio Networks Controllers. This reduces backhaul and network equipment costs for operators and creates a fault-tolerant and scalable network.

This paper provides an overview of how a 1xEV-DO network works. It explains the basic network architecture, provides an overview of the 1xEV-DO airlink and discusses the benefits of Airvana's All-IP architecture.

1xEV-DO Network Architecture

A 1xEV-DO network includes three key elements:

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

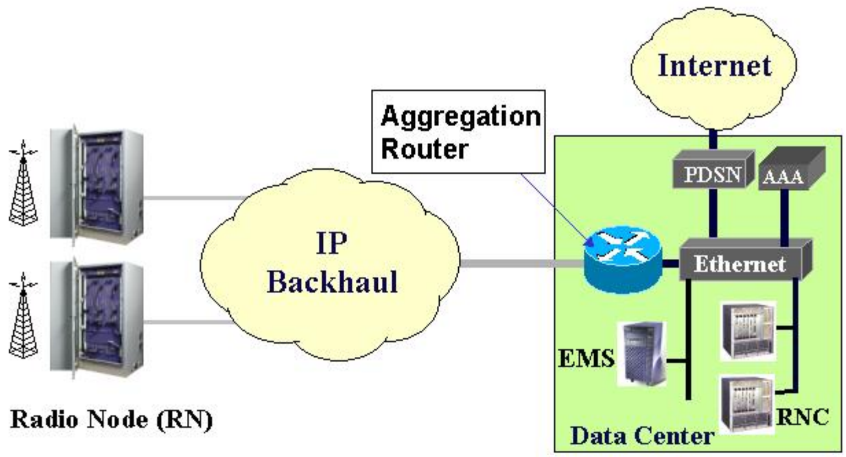

Figure 1: Airvana 1xEV-DO Network

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 RN. Higher layers of the 1xEV-DO protocol are processed at the RNC, which also manages handoffs and passes user data between the RNs and the PDSN. The PDSN is a wireless edge router that connects the radio access network (RAN) 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)

Since most Internet applications (web browsing, e-mail, video streaming) have asymmetric bandwidth requirements, with a typical ratio of download to upload traffic of about 4:1, optimizing the forward link is especially important.

In 1xEV-DO, the forward link is optimized for data applications by:

- Offering each subscriber the highest data rate that can be supported at any given instant;
- Effectively dividing the air interface resources among active subscribers.

Increasing the Burst Data Rate

1xEV-DO offers each subscriber the highest data rate that can be supported at any given instant by:

- Adapting its data rate to channel conditions that are rapidly changing because of subscriber mobility and fast signal fading;
- Applying advanced coding and multi-level modulation techniques; and
- Taking advantage of macro diversity to better combat fading.

By using these techniques, 1xEV-DO delivers average burst data rates of 600-1200 Kbps per subscriber, where the upper range is achieved using antenna diversity in the subscriber terminal. This is at least two times higher than what is achievable with existing voice-centric 3G standards, such as 1xRTT or W-CDMA (when normalized to the same amount of spectrum used).

Adaptive Rate Operation

For packet data, it is not important to guarantee a certain data rate as long as some minimum performance level can be maintained. Further, in sharp contrast to voice, a higher data rate improves the experience of a packet-data user. Therefore, an air interface designed for Wireless Internet should provide the highest data rate possible at any given instant. This requires a system that can adapt the data rate based on the channel quality seen by each subscriber.

Cellular voice systems are designed to provide a constant bit rate to each voice call, typically between 8 to 16 kbps. Voice-centric packet data systems such as 1xRTT and W-CDMA are optimized for delivering a fixed data rate, with no efficient mechanism for adapting the data rate to a subscriber’s channel quality. The result is significantly lower data capacity. For example, a user may end up being served at 32 Kbps, even when the channel conditions would have allowed a much higher data rate.

1xEV-DO uses a powerful adaptive-rate scheme that allows the base station to rapidly (once every few milliseconds) adapt its data rate for each active user. To make this possible, all active terminals constantly measure their channel condition based on pilot signals received from all surrounding base stations and report the maximum data rate at which they can receive data to the radio access network. The base station serves each user at the highest data rate that the user’s channel condition permits. Based on the maximum data rate reported, which ranges anywhere from 38.4 Kbps to 2.45 Mbps, the 1xEV-DO base station selects a suitable modulation format (QPSK, 8-PSK, 16-QAM). Adaptive-rate operation in 1xEV-DO further includes a sophisticated Hybrid ARQ scheme that provides additional robustness against any inaccuracies in the data rate estimation by the terminal, especially in situations that involve high mobility.

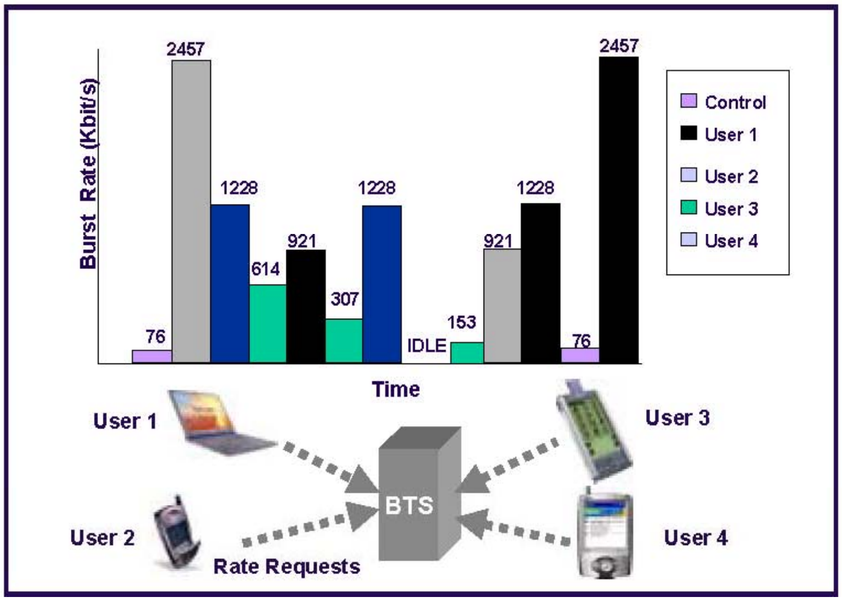

Figure 2: Adaptive Modulation Scheme in 1xEV-DO

Advanced Coding and Modulation

1xEV-DO uses Turbo coding to correct errors in the presence of noise and interference. Turbo coding is a powerful error correction scheme, which allows a communication system to operate near the Shannon limit, at least as far as its performance in the presence of receiver noise and interference is concerned. 1xEV-DO uses a powerful Turbo code with 100% to 400% redundancy. On the forward link, its maximum redundancy is 33% greater than 1xRTT's redundancy.

Furthermore, 1xEV-DO is the first commercially available mobile wireless system to use multi-level modulation (8PSK and 16-QAM). Other 3G standards are limited to QPSK. Use of higher-level modulation allows 1xEV-DO to operate at higher bandwidth efficiencies.

Macro Diversity via Radio Selection

Macro Diversity plays an important role in combating fading over a radio channel by enabling a mobile terminal to communicate with the RAN using more than one radio link.

In voice-centric CDMA systems such as 1xRTT and W-CDMA, macro-diversity enables soft handoff on the forward link. In soft handoff, multiple base stations transmit the same air link frame, allowing the mobile station to combine the received signals to improve reliability in the presence of fading. However, since multiple radios end up using airlink resources for sending the same frame, the real benefit of forward link soft handoff on system capacity is much less than the gain macro diversity can provide. In addition to using up excessive air resources, forward link soft handoff in packet data systems also pushes packet scheduling from the base station to the radio network controller. This introduces delays and significantly reduces the packet scheduling efficiency.

1xEV-DO overcomes the shortcomings of forward link soft handoff by using a macro-diversity scheme that is based on radio selection diversity. In radio selection diversity, each active terminal measures the quality of the pilot signal it receives from RNs in its vicinity and tells the network which RN has the strongest signal. The RN with the strongest signal is then selected to be access terminal's serving RN. The RNC ensures that packets destined for that access terminal are delivered to its serving RN. The serving RN schedules the packets for transmission at the data rate selected by the access terminal.

Efficient Multiplexing

In Wireless Internet, the base stations must divide the available forward link throughput among all active subscribers using some form of multiplexing. The efficiency of such multiplexing critically affects the system performance, particularly during busy periods.

In cellular CDMA voice systems, a single base station can support multiple voice calls by allocating the available transmit power and code space (code division multiplexing) among all calls. Existing 3G packet data systems use a similar approach to support multiple active data users. Such systems often allocate more air resources (power) to users when they are experiencing poor channel conditions in order to maintain a target data rate. This approach, while quite appropriate for voice, is actually counterproductive for packet data since a user who is experiencing very poor channel conditions can siphon significant bandwidth away from others.

To improve the multiplexing efficiency, 1xEV-DO uses a packet-based time-division multiplexing (TDM) scheme. The RN transmits short packets to users one at a time using all available air resources (power and code space) and at the maximum data rate allowed by the recipient's channel conditions. A scheduler in the base station determines the sequence in which packets are transmitted.

Instead of using a round-robin scheduler that allocates the same amount of time to all active subscribers, 1xEV-DO schedules packets based on a user's channel quality. By serving active subscribers when their channel condition is relatively good, the effective throughput seen by each active subscriber is significantly improved (Figure 3). This improvement in throughput is referred to as the multi-user diversity. Multi-user diversity depends on a number of factors, but can easily reach 50% to 100% with only a few active users.

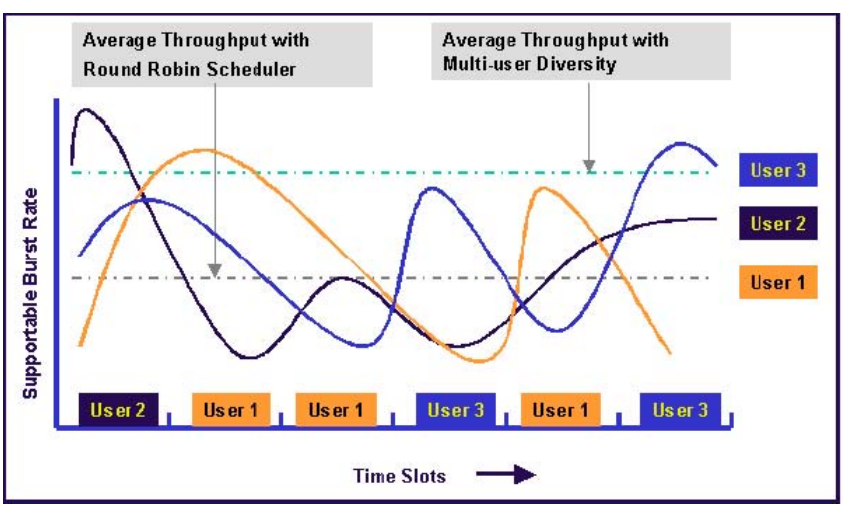

Figure 3: Increased Average System Throughput with Multi-Diversity

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.

A key advantage of 1xEV-DO over 1xRTT and W-CDMA on the reverse link is its adaptive rate control capability. With adaptive rate control, the base station can control the data rate of the terminals, both individually and globally, and thereby increase total reverse-link throughput while controlling interference. Such rate control allows the base station to achieve a reverse link throughput that can be as much as 50% higher than voice-centric 3G systems.

Always-On Operation

Always-on operation means that when a terminal is ready to send or receive data, it does so almost instantly without lengthy connection set-up procedures.

However, in all mobile wireless access systems, a subscriber terminal is in either an *active* or a *dormant* state and transmits or receives packets only when it is active. Such two-state operation is needed to:

- Allow an inactive terminal to go to sleep to conserve battery power;
- Reduce required addressing overhead for forward link frames; and
- Better manage the forward and reverse link performance.

When a 1xEV-DO terminal is in an active state, it is said to have “a connection” with the network. The concept of a connection is akin to a call in voice systems with some very important differences. In voice, a call typically lasts a couple of minutes. In packet data, a connection may be very short and may have to be set-up and torn down several times during a packet data session. For example, in a web-browsing session, it may be desirable to tear down a connection between page downloads in order to make room for other users.

A 1xEV-DO system gives users an always-on experience by supporting quick connection set-up and teardown. Terminals can initiate connections by sending a very short connection request message to the RN. Since this message is designed specially for packet data, it is shorter than similar messages used in voice-centric 3G systems. In addition, 1xEV-DO supports a Fast Re-Connect capability that allows the network to quickly re-establish a connection with a subscriber.

Interoperability

1xEV-DO is an international standard supported by several standards bodies, including 3GPP2, TIA, CDG and ITU. This ensures interoperability between terminals/handsets and the radio network.

1xEV-DO includes a network standard, called 1xEV-DO Interoperability Specification (IOS), which defines the interfaces between the various elements of a 1xEV-DO network. This includes the interface between the radio access network and other network equipment, including Packet Data Serving Nodes (PDSN), Authentication, Authorization and Accounting (AAA) servers, as well as interfaces between different vendor's 1xEV-DO radio access networks. These standards give wireless operators greater freedom in vendor selection, allowing them to use the best available equipment in every part of their network.

1xEV-DO also supports interoperability with 1xRTT and IS-95A/B CDMA voice networks, which means a user with a dual-mode (CDMA/1xEV-DO) handset can receive or initiate voice calls even when actively engaged in a 1xEV-DO data session.

IP in the Radio Access Network

Globally, IP networks have become the de-facto standard for transporting data traffic. Wireline service providers have leveraged IP's global economies of scale to reduce their equipment and operating costs. Operators have also benefited from IP's status as an open, evolving standard to rapidly create new services such as Internet access, streaming multimedia, Voice over Internet Protocol (VoIP) and Virtual Private Networking (VPN). The same benefits are now available to wireless service providers. There are several areas in which IP technology can be beneficially applied to RANs.

Flexible, Low-Cost, IP Transport

The use of IP as the common Layer 3 (L3) transport protocol over which RNs and RNCs communicate gives operators the flexibility to choose between multiple Layer 1 (L1) and Layer 2 (L2) backhaul technologies. For example, based on cost and availability, an operator can chose between Frame Relay, ATM, Metro Ethernet or dedicated T1/E1 links to connect RNs and RNCs. Operators can also mix-and-match backhaul technologies. They can use low-cost Metro Ethernet to backhaul RNs that are located in a dense urban area while use a dedicated T1 link to sites located along a rural highway. Since the RN and RNC communicate over IP, the underlying backhaul network will be transparent to them.

A study conducted by Airvana along with Verizon, MCI and a Metropolitan Ethernet Provider showed that backhaul costs can be reduced by as much as 70% by using packet-based L1/L2 backhaul services as compared to traditional dedicated T1/E1s. The study compared the monthly backhaul costs for a 1xEV-DO network of 75 RNs and one RNC deployed over a small (500 sq. mile), medium (2000 sq. mile) and large (5000 sq. mile) area. The study showed that as the deployment area becomes larger, dedicated T1/E1's become expensive because of their distance-based tariffs. In such situations, operators can gain significant cost reductions by using Frame Relay or Routed IP services. Metro Ethernet, where available, has the potential to reduce backhaul costs by a factor of three. Though the exact cost reduction depends upon the deployment size and the availability of alternate backhaul services, this study clearly showed that IP backhaul can significantly reduce a network's operating expenses.

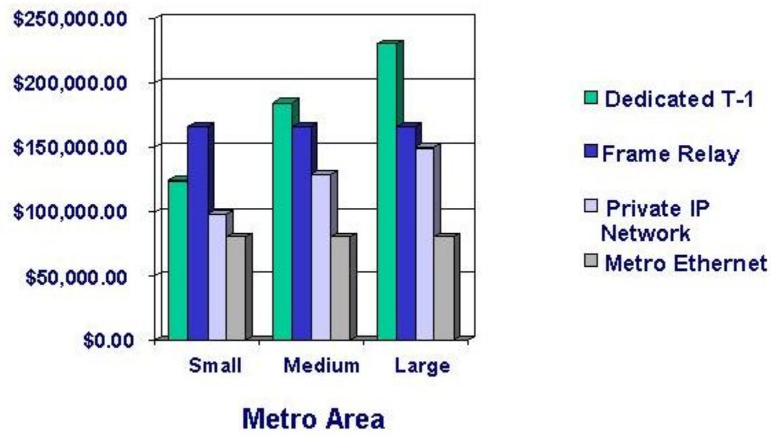

Figure 4: Comparison of monthly backhaul expense in three metro areas using different backhaul technologies

IP backhaul also reduces operating expenses by allowing an operator to combine central offices. In traditional cellular networks, operators use dedicated T1/E1 circuits for backhaul. Since T1/E1 circuits have distance-based tariffs, operators build multiple central offices to house base station controllers (similar to RNCs) to reduce backhaul cost. With IP, operators can use backhaul technologies that do not have distance-based tariffs and cost effectively connect geographically distributed RNs to RNCs. Consolidating central offices reduces the amount of equipment and human resources that an operator has to employ to operate the network.

Standards-based Network Elements

Using IP in the RAN gives operators the choice to use low-cost, off-the-shelf network components. For example, off-the-shelf multi-service aggregation switch/routers can be used to terminate the Layer 1 and 2 transport protocols and forward the traffic as IP packets to the RNC. Not only are such IP switch/routers cheaper and have a faster technology evolution compared to traditional voice telecom equipment, but they also bring additional benefits. For example, operators receive a wide choice of network interfaces such as T1, E1, T3, and OC3 for terminating backhaul traffic on the aggregation router. As new, lower-cost, backhaul technologies become available operators can adopt them without changing the RN or the RNC. For instance, an operator can move from dedicated E1 lines to Metro Ethernet by simply adding replacing interface cards in the aggregation router. The change in backhaul will be transparent to the RN and RNC.

Scalability

Data Networks evolve at a much faster pace than voice networks. It is therefore important for next-generation wireless networks to efficiently scale and support the independent evolution and upgrade of individual network elements. An All-IP architecture is a powerful way to achieve this goal. Unlike traditional cellular networks, in an IP-RAN, RNCs are connected to RNs using an aggregation router. As more RNs are added to the network, operators can simply add additional RNCs to an existing rack and connect them to the aggregation router using Ethernet.

Superior Fault Tolerance

Since IP networks can reroute packets to alternate links in case a link becomes congested or unavailable, IP networks are fundamentally fault-tolerant. A 1xEV-DO IP RAN can deliver carrier-class reliability and support multiple levels of fault tolerance by building upon this attribute. For instance, even in the event of a catastrophic failure like the failure of an entire RNC, service can be maintained by automatically rerouting subscribers to another RNC on the network.

Standards-based Quality of Service

In response to intense competition, wireless service providers are looking for ways to differentiate their services. IP-based 1xEV-DO RAN elements, in particular, the scheduler in the RN can be designed to deliver Quality of Service (QoS) differentiation using established IETF standards such as DiffServ and MPLS. The ability of All-IP 1xEV-DO RAN elements to deliver end-to-end QoS using open, interoperable standards can enhance an operator’s ability to create and bring new, differentiated services to market.

Ease of Network Management

In today’s wireless networks, configuration and management of network elements is an expensive, time-consuming manual operation. In All-IP RANs, elements can be remotely configured and managed using open protocols such as SNMP and web technologies such as XML and HTTP. The use of open protocols also simplifies the task of integrating a vendor’s management system with third-party OSS and management platforms. Remote management and configuration of network elements via open protocols and familiar client platforms such as browsers helps keep network management costs low.

Conclusion

1xEV-DO is the only 3G air interface that is optimized for packet data, not voice. The 1xEV-DO forward link offers each subscriber the highest supportable data rate at any instant by rapidly adapting modulation and coding schemes to changing radio conditions. Subscribers are efficiently multiplexed over the forward link by a scheduler that determines the sequence in which packets should be transmitted. Connections are set up and torn down rapidly to maximize sector throughput, subscribers an "always-on" experience.

1xEV-DO is a particularly attractive technology for CDMA operators. These operators can deploy 1xEV-DO as a channel card upgrade to their existing CDMA base stations. Further, all 1xEV-DO handsets and modem cards support CDMA 1xRTT and IS-95. As 1xEV-DO subscribers move into 1xRTT coverage, they seamlessly handoff to the lower rate data service. Unlike GSM/W-CDMA, there are no interoperability problems between 1xRTT and 1xEV-DO.

Airvana's All-IP 1xEV-DO RAN allows wireless operators to benefit from the global economies of scale that the Internet Protocol (IP) provides. Airvana's unique All-IP RAN enables an operator to reduce the cap-ex of its backhaul network by using standards-based components and reduces its op-ex by choosing the most cost-effective backhaul transport technologies. In addition, an IP-RAN is fault-tolerant, easy to scale and easy to manage.

About Airvana

Airvana Inc. (www.airvananet.com) makes infrastructure equipment that allows wireless operators to deploy broadband, mobile, Internet and multimedia services. The company's equipment is based on the 3G CDMA2000 1xEV-DO standard, and its differentiation is centered on its ALL-IP (Internet Protocol) network technology. Major operators around the world are using Airvana's technology to deliver Internet, video, and voice services to phone and personal computer users. Airvana's primarily sells equipment and software to leading wireless equipment companies such as Nortel and Ericsson. The company is based in Chelmsford, MA, USA.

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