cdma2000 1xEV-DO: A 3G Wireless Internet Access System

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Abstract – This paper provides an overview of CDMA2000 1xEV-DO, also referred to as HDR (High Data Rate) and officially recognized as IS-856, a 3G standard. 1xEV-DO is a wireless telecommunications standard optimized for high-speed cellular data communication. An overview of the specification, along with a description of key characteristics of the specification is provided. Special attention is given to describing the differences between data and voice that support the design of a specification to efficiently transfer data.

INTRODUCTION

Few could have imagined in the early 80s that wireless communication would enjoy the popularity that it does today. A cellular phone once thought of as a luxury is now considered by many to be a necessity. First generation (1G) systems used analog technology. Although primitive and unreliable by today's standards due to poor voice quality and frequent call drops, 1G showed that mobile communication was technically feasible and economically viable. The late 90s introduced second generation (2G) systems using digital technology. This new generation brought substantial improvements to voice quality, call reliability, miniaturization, battery life, and heralded the beginning of data services. At the dawn of the new millennium, third generation (3G) advanced digital systems are being deployed worldwide. This latest generation is characterized by improvements to system capacity, reliability, extended services, and most importantly, expanded support for high speed data communications. High speed means, for the first time, bandwidth hungry multimedia applications once limited to the desktop can be provided to the mobile user.

cdma2000 1X and Wideband Code Division Multiple Access (WCDMA) supports both voice and data while cdma2000 1xEV-DO is unique in that it is ideal for supporting data communication. The technical specification for 1xEV-DO is IS-856, released by the Third Generation Partnership Project 2 (3GPP2). It is intended to efficiently support data services. The specification is sometimes called by the branding name High Data Rate (HDR), but is most commonly referred to as 1xEV-DO. The 1x prefix stems from its use of 1X (1 times) the 1.2288 Mcp (Mega chips per second) spreading rate of a standard IS-95 CDMA channel. EV emphasizes that it is an EVolutionary technology building on and improving on 2G technology. The evolutionary nature of IS-856 represents a major difference with other 3G technologies such as WCDMA that uses a new air interface that requires new frequency spectrum and equipment, which carries both technical and economic risk. The DO (Data Optimized) suffix indicates that 1xEV-DO is designed to efficiently transfer data. Although it is primarily intended to data only, with the additional of Quality of Service (QoS) to limit latency, it is entirely possible to efficiently provide Voice over IP (VoIP) using 1xEV-DO.

By optimizing the system for data, it is unhindered by voice requirements and makes more efficient use of the available frequency spectrum. IS-856 is RF compatible with IS-95, a 2G standard. They both require the same 1.25 MHz bandwidth. This allows network architects greater flexibility in designing networks since there is no need for new frequency spectrum. In areas where 5 MHz 3G spectrum is available, network designers can assign three 1.25 MHz channels (3X) consisting of any combination of voice and data channels.

Devoting a channel exclusively to data can be hard to justify, but demand for data services is expected to increase substantially. As wireless access to the Internet increases, the demand on data services will continue to expand. The ubiquitous use of wireless PDAs, mobile PCs, and other products will place a heavy burden on bandwidth hungry data applications. Telematic products will rely heavily on data communication to provide vehicles with roadside assistance, real-time traffic conditions, weather reports, and automated emergency communication.

The remainder of this paper provides a technical overview of IS-856. It explains how the standard was designed to optimize throughput. Some design considerations are presented and details of the tradeoffs necessary to assure data optimization and spectral efficiency are discussed. To understand throughput optimization and how the 1xEV-DO peak data rate of 2.4 Mbps is achieved in a 1.25 MHz bandwidth, many factors must be considered. Foremost among them is an understanding of the differences between voice and data.

VOICE VS. DATA

An understanding of the difference between voice and data is crucial to an appreciation of IS-856. For example, voice communication has strict latency requirements. A delay of 100ms makes communication between two parties difficult. Longer delays make useful communication virtually impossible. For this reason, voice frames are short (i.e., 20ms). Like many engineering decisions, frame size selection is a compromise. Long voice frames introduce delays, while shorter frames increase overhead resulting in poorer efficiency.

Data communication is inherently bursty in nature and more forgiving of delays than voice. A user is likely not to care, or notice, if email is delayed by seconds or even minutes. However, that is not to say all data services are immune to high latency; some video and audio streaming applications have stringent delay requirements. To support these applications, Quality of Service can be incorporated into the protocol to provide a fixed or maximum latency.

Because most data applications can support a wide range of delays, data frame sizes can be longer than voice frames. Extending the frame length has significant benefits since it reduces overhead and results in increased system efficiency. There are more subtle advantages to increasing the frame size, most notably the efficient use of Turbo codes. Both voice and data in modern communications systems use coding techniques to reduce error rates to make the communications channel more robust. Efficient coding techniques allow corrupted data to be retrieved using Forward Error Correction (FEC). Convolutional coding is often used for this purpose and is well suited for short voice frames. However, Turbo coding is more powerful than convolutional coding when frames are long (e.g., several hundred bits or more). Therefore, by removing the voice requirement for short frames and allowing larger frame sizes, Turbo coding becomes practical for encoding the data stream. Turbo coding with large frames size significantly improves performance by allowing the use of lower RF power while still achieving the same error rate. In fact, Turbo coding allows the communication channel to perform close to the Shannon limit which we shall discuss later in this paper.

For these reasons, it makes sense to separate voice and data services to allow each to be optimized. To force data to be limited by voice requirements results in a less than optimal solution. Other considerations when designing a data optimized system include: data asymmetry, spectral efficiency, throughput optimization, and system overload.

DATA ASYMMETRY

For the most part, when two parties speak, the communication channel is shared equally. Person A speaks while person B listens; followed by A listening to B. Data users operate in a significantly different environment. IS-856 takes advantage of the way data users communicate. A data user will typically connect to download email, followed by an extended disconnect period while the user reads and composes a response. When ready, a brief connection is required to send a response. Surfing the web has similar periods of activity and silence. For example, a user retrieves a web page, browses it and moves on to another link. Only streaming audio and video require virtually continuous uninterrupted connection. However, even here the asymmetry of the communication allows us to exploit the way the system is used. In each of these examples, data traffic is predominately from the network to the mobile user. Data traffic from the user back to the network is statistically low.

To optimize throughput and make best use of available bandwidth, IS-856 sends and receives at different data rates, similar to most cable modems where upload and download speeds are unequal. Download rates from the base station to the mobile user vary from 38.4 to 2,457.6 Kbps. In practice, application throughput is lower (e.g., 10-15%) due to overhead. Later in this paper we will discuss how the data rate are dynamically allocated according to changing RF channel conditions. Upload speeds from the mobile to the base station vary from 9.6 to 156.3 Kbps.

IS-856 shares another characteristic with cable modems; all users share the available bandwidth. If there is only one active cable modem user, all bandwidth is available to that user. However, as more users enter the system, data rates are reduced. IS-856 works in much the same way. This may appear a significant disadvantage, but due to the bursty nature of data, unless a system is highly loaded, on average the data user will experience few, if any, delays.

SPECTRAL EFFICIENCY

The near miracle of providing continuous communication in a myriad of hostile RF environments is accomplished in a voice optimized cellular system, such as IS-95, by the use of power control. Users with weak signals increase their transmitting RF power to overcome path loss and/or fading while users close to the base station reduce power. IS-856 solves the problem in a different manner; the data rate, rather than the power, is altered when signal levels change.

The capacity of a channel, C, has been shown by Shannon to be a function of bandwidth B, and the signal to noise ratio (SNR) of the channel. Error free communication is possible over a noisy channel at any data rate lower than the channel capacity. Data rates in excess of the channel capacity are possible at the expense of increased error rates.

To assure the mobile data user receives the highest possible SNR, RF from the base station to the mobile user is sent at full power. If path loss increases, a concomitant reduction in the SNR will occur resulting in higher error rates. The errors are reduced not by increasing RF power, but my reducing the data rate, which keeps channel capacity fixed. It is important to note that in practice error free communication is not possible. A reasonable error rate (e.g., 1%) is selected that allows the system to operate efficiently.

Table 1 shows the IS-856 data rates transmitted from the base station to the mobile (a.k.a. Forward Link). There are twelve data rates ranging from 38.4 to 2,457.6 Kbps with some rates (i.e., 614.4 Kbps) appearing twice. Although these data rates appear to be redundant, the number of time slots used to send the same rate is different. A slot is defined by IS-856 as 1.67 ms. and represents the minimum transmission period to a user.

The data rate and number of slots used to transmit is determined by channel conditions. When conditions are unfavorable, a lower data rate with more slots is used. It is important to note that additional time slots provide redundant information. If the mobile can successfully decode a packet before all slots are sent, it sends an acknowledgement informing the base station there is no need to send the remaining slots. This results in early termination and a substantial increase in effective throughput by preventing the base station from sending information that the mobile has already decoded.

The code rate shown in Table 1 refers to the Turbo encoder coding rate. When poor channel conditions exist, the coding rate provides increased redundancy to help assure packets are decoded when received by the mobile.

The modulation technique used to transmit information also varies with the data rate. This is done to provide a more reliable communications channel. Various modulation methods are more robust than others. Higher order modulation schemes give higher data rates at the cost of higher power requirements for the same error rate.

When channel conditions are poor, QPSK (Quadrature Phase Shift Keying) is used. As channel conditions improve, the coding rate and modulation technique can be modified. If conditions are good, 16-QAM (Quadrature Amplitude Modulation) is used. To achieve the peak 2,457.6 Kbps data rate, a single slot is used with 1/3 Turbo coding and 16-QAM modulation resulting in maximum throughput and spectral efficiency.

It is important to emphasize that the data rate continuously changes as RF channel conditions change. The data rate to send to the mobile is determined by the RF signal strength received by the mobile. The mobile is constantly updating the base station with data rate requests based on the SNR and expected future channel conditions. To maximize throughput the mobile tries to predict future conditions based on past and present SNR. For example, as a mobile user travels into a highway underpass, the SNR will decrease. Sensing the decrease, the mobile can predict and therefore request a lower data for the next transmission from the base station since the SNR is likely to continue to worsen as the mobile continues. When the mobile leaves the underpass, the SNR will rise causing the mobile to predict and request a higher data rate for the next transmission rather than a lower rate. Methods such as this provide the user with maximum throughput in a dynamic RF environment.

Table 1 - Forward Link Variable Rate Parameters

Rate (kbps)	Slots	Bits	Code Rate	Modulation
38.4	16	1,014	1/5	QPSK
76.8	8	1,014	1/5	QPSK
153.6	4	1,014	1/5	QPSK
307.2	2	1,014	1/5	QPSK
614.4	1	1,014	1/3	QPSK
307.2	4	2,048	1/3	QPSK
614.4	2	2,048	1/3	QPSK
1,228.8	1	2,048	1/3	QPSK
921.6	2	3,072	1/3	8-PSK
1,843.2	1	3,072	1/3	8-PSK
1,228.8	2	4,096	1/3	16-QAM
2,457.6	1	4,096	1/3	16-QAM

Table 2 shows data rates from the mobile to the base station (a.k.a. Reverse Link) supported by IS-856. Similar to the forward link, the reverse link varies the coding rate to accommodate different channel conditions. However, unlike the forward link, transmissions from the mobile back to the base station suffer from very limited RF power and antenna gain. For this reason, care has been taken to select a coding rate and modulation technique that is less affected by harsh RF channel conditions.

Table 2 - Reverse Link Variable Rate Parameters

Data Rate (kbps)	Bits/Physical Layer Packet	Code Rate	Modulation
9.6	256	1/4	BPSK
19.2	512	1/4	BPSK
38.4	1,024	1/4	BPSK
76.8	2,048	1/4	BPSK
153.6	4,096	1/2	BPSK

THROUGHPUT OPTIMIZATION

Cellular systems, such as the IS-95 voice system shown in Figure 1, are designed to give all users equal access and performance. Users have come to expect reliable communication in varying RF environments. The solution for voice optimized systems is power control. Specifically, the base station decreases the transmitted RF power to advantaged users capable of receiving a high SNR and increases the RF power transmitted to disadvantaged users.

In contrast to IS-95, IS-856 systems provide full power to each mobile for a 1.67 ms time slot. As shown in Figure 2, the transmission burst to a single mobile consists of traffic and overhead information that includes synchronization and control messages. During the time slot each mobile receives the highest data rate it can receive according its SNR.

Allocating time slots among users is the responsibility of the scheduler. It has the complex task of servicing each mobile fairly, while trying to optimize sector throughput. Various scheduling algorithms provide substantially different throughputs. To gain some understanding of the scheduler and how it can optimize sector throughput, let's look at two scenarios.

Take the simple case where there is a single user. Here the scheduler gives all time slots to the user at the rate requested by the mobile according to the mobile's SNR. If the SNR seen by the mobile is low, the date rate to that user will be low and hence sector throughput will be low.

Now take the more realistic scenario in which there are many users. By taking advantage of the widely varying RF environments when multiple users are normally distributed, the scheduler can intelligently allocate time slots to optimize throughput. With multiple users, there will be widely varying SNRs from moving users. Even when a mobile is stationary, the environment around the mobile is changing which causes a varying SNR. The scheduler can take advantage of the mobile's SNR peaks and valleys by transmitting during expected peak SNR periods.

The result is that more users can actually improve sector throughput. A. Jalali et. al. provides a more rigorous discussion using simulations to model sector throughput with a varying number of users and cell site antenna configurations.

SYSTEM OVERLOAD

When a voice call is initiated, resources are assigned to support the call. When additional resources are no longer available, the user receives a busy tone and the call is rejected. A data call has similar restrictions, but rather than being denied access, a data optimized system can be gracefully degraded by momentarily interrupting existing connections to give new users access. In fact, depending on the severity of the overload, the user may not notice a momentary pause in service. To assure the connection can be quickly re-established, only non-critical resources are de-allocated. The session state, IP address, and other information are maintained until the call is complete.

Deciding which user to remove during overload can be difficult. In its simplest form, a user can be selected at random. While easy to implement, it would be unfair and provide for a less than ideal solution. If we decide based on system usage, a high traffic user is momentarily removed to allow another user access. Alternatively, if activity is the determining factor, service to a user that has been continuously using the system can be paused to allow an infrequent user access.

There are many algorithms that can be used to determine which user to momentarily shed from the system. Like most engineering decisions, the solution is a matter of tradeoffs. The salient point is not the algorithm, but that data services are less prone to system overload and therefore can be more reliable when emergency communication is required.

Disconnecting users from a cell site for a brief period is not part of the IS-856 specification, it is discussed here to show how a data communications system can support a very large number of users and continue to provide communication even when heavily loaded. This technique allows a data optimized system the ability to support far more users than one would normally expect based strictly on available resources.

CONCLUSION

cdma2000 1xEV-DO is a specification optimized to support a wide variety of data services. It does this by drawing a clear distinction between voice and data and designing the system to meet data requirements. The data rates supported by IS-856 represent a quantum leap forward in speed from 2G systems. Yet despite this increase, it would be naïve to think the mobile user will be satisfied. If the past can be used to help us predict the future, few would argue that one can ever have enough speed. Speeds may be sufficient for a particular application, but new applications continue to evolve placing additional requirements on data rates and limited spectrum. However, technology is often just one of many factors that play into the development of a standard. Economics, business strategies, and politics all play an important role that in some cases lead to a less than optimum solution. Ultimately the consumer determines which technology wins. For the near term at least, it does not appear Internet usage or the need for speed will decrease anytime soon. While we are waiting for the next new technology, IS-856 is here providing the mobile user wireless bandwidth that few would have thought possible a decade ago.

READ MORE ABOUT IT

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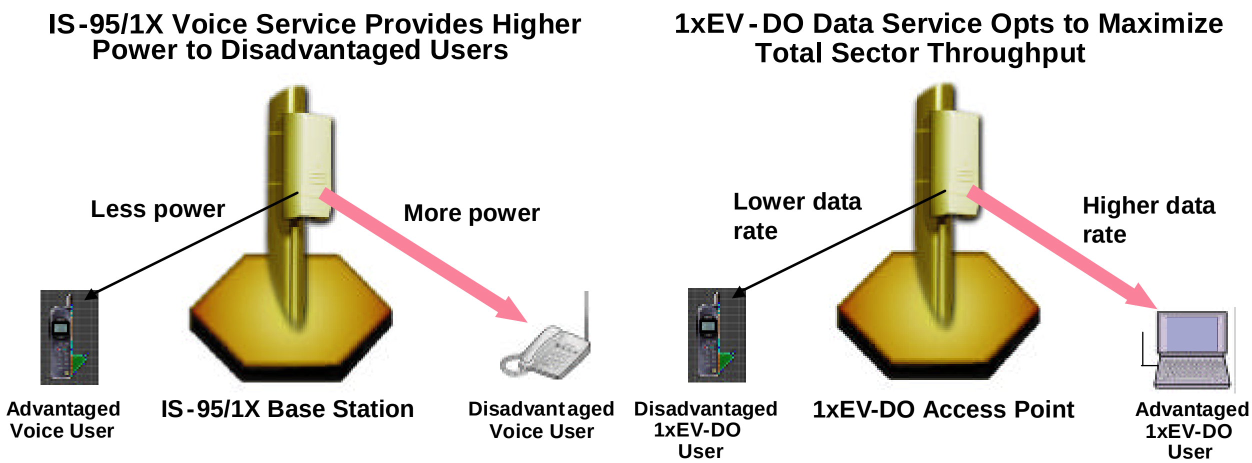

Figure 1. CDMA voice cellular systems use power control to assure that disadvantaged users in harsh RF environments receive the same voice quality as advantaged users. This is very different than 1xEV-DO which gives preference to RF advantaged users by using higher data rates.

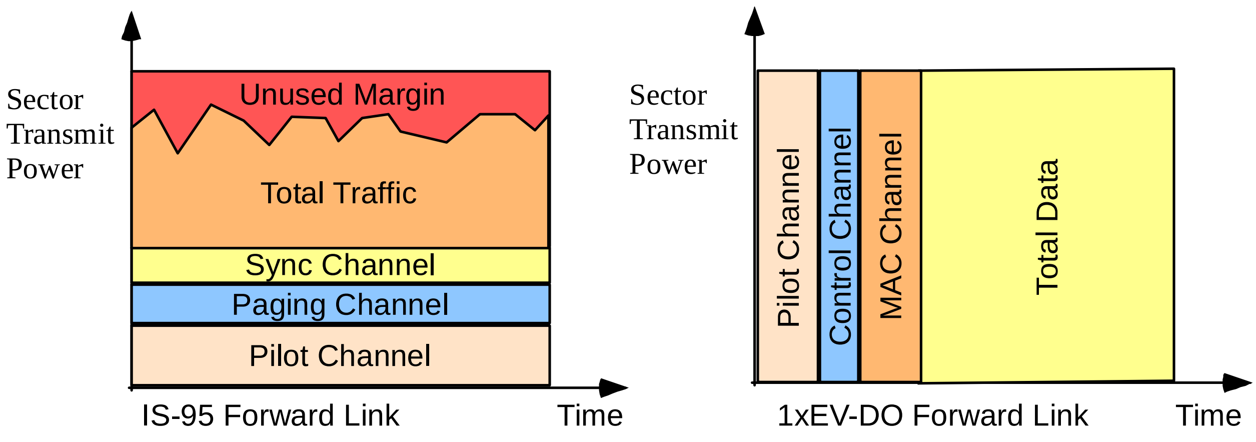

Figure 2. The IS-95 CDMA voice standard services all users simultaneous and RF power to each user varies according to path loss. This is very different than IS-856, which services a single user at any given instant (time slot). During that period, the user receives full power from the base station.