Evolution Towards Simultaneous High-Speed Packet Data and Voice Services: An Overview of cdma2000 1xEV-DV

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***ABSTRACT* - Recently, the Third Generation Partnership Project 2 (3GPP2) and Telecommunications Industry Association (TIA) have approved and published cdma2000 1xEV-DV (data and voice) specifications as an evolution of cdma2000 family of standards. Meanwhile, the cdma2000 1xEV-DV specifications also have been submitted to ITU for formal approval as an IMT-2000 3G global standard. This technology will provide integrated voice with simultaneous high-speed packet data services including non-real-time as well as near-real-time applications at peak data rate higher than 3 Mbps. It also provides backward-compatibility with cdma2000 1xRTT system. This paper provides a technical overview and discusses key technology elements adopted to increase system capabilities. In addition, the protocol and control scheme of cdam2000 1xEV-DV packet data channel will be described.**

1. INTRODUCTION

For packet data services, 3GPP2 adopts evolutional approaches of radio technology [1]. Prior to cdma2000 1xRTT, IS-95-B was intended to be an enhancement for High Speed Data (HSD), which is provided using code aggregation with up to eight Walsh codes assigned to a HSD mobile station during a data burst period. The fundamental channel and one or more supplemental code channels can be assigned for an active user that requests HSD service. Ideally, the peak data rates offered by IS-95-B are 76.8 kbps and 115.2 kbps for Rate Set (RS) 1 and 2, respectively. To meet ITU IMT-2000 technology requirements, the next evolution step for high speed packet data service is cdma2000 1xRTT which utilizes several advanced technology components. The peak data rate of each 1.25 MHz RF carrier is aimed for 307 Kbps. In contrast to IS-95-B, cdma2000 supports supplemental channels with a wide range of data rates. Additional enhancements to the cdma2000 physical layer for HSD include various frame size options, QPSK modulation, fast forward power control, optional forward link transmit diversity, turbo coding, reverse pilot channel for coherent detection, auxiliary pilot channel, etc. In addition, to enable high variety of services with high data rates, cdma2000 incorporates sophisticated enhancements to link layers such as Radio Link Protocol (i.e. RLP Type 3), Link Access Control (LAC), Multiplexing & QoS sublayers, etc. The layering structure of cdma2000 1xRTT protocols is intended to allow any combination of voice and data concurrently.

To further satisfy the rapidly increasing demands on high speed services such as ftp downloading, web browsing, video streaming, etc. in cellular communications environment, cdma2000 1xEV-DV technology strive to increase data rate in forward link and reverse link, while preserving the existing voice capacity. Key requirements for this evolutional step include maintaining backward compatibility with cdma2000 1xRTT system and using the same RF carrier for both voice and data services. The Revision C of cdma2000 specifications, mainly focusing on 1xEV-DV forward link, has been approved in mid-2002, while the Revision D will be focused on reverse link improvement and is expected to be finalized after 2002.

The rest of the paper is organized as follows: In Section 2, key enhancements and technology features in cdma2000 1xEV-DV are discussed. The operation, control, and its performance of 1xEV-DV packet data channel are described in Section 3. Finally, Section 4 concludes this paper with future work directions.

2. KEY ENHANCEMENTS AND FEATURES

The key elements of techniques that have been adopted in cdma2000 1xEV-DV include:

- Adaptive Modulation and Coding (AMC)
- Adaptive TDM/CDM code allocation and multiplexing
- Physical layer hybrid ARQ (Automatic Repeat reQuest)
- Cell switching technique
- Packet data control hold operation

A. *Adaptive Modulation and Coding (AMC)*

Radio link adaptation technique is used to accommodate the radio channel conditions that vary over time in any mobile systems. AMC is a common practice in many modern cellular systems. The principle of AMC is to change the modulation and coding scheme in accordance with

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variations in the channel conditions. In 1xEV-DV, the channel condition or quality is estimated at the base station, based on reverse link feedback from the mobile station. Users with better channel quality are typically assigned higher order modulation (e.g. 16QAM), while users with worse channel quality are assigned lower order modulation with lower code rates (e.g. QPSK with R=1/2 Turbo Codes). The usage of AMC can adaptively provide appropriate data rates for users, and hence increases the average cell throughput. Also, AMC instead of power control is used to reduce interference variation caused by variations in transmit power.

B. *Adaptive TDM/CDM code allocation and multiplexing*

An optimal radio resource allocation can increase system throughput. Depending on traffic model, different allocation schemes can be used as appropriate. 1xEV-DV system aims to provide mixture of applications such as FTP, WAP, HTTP, and near-real-time streaming applications. This mixture of applications requires the packet data traffic channel to carry both large and small data packets per timeslot. As shown in Figure 1, likely only less than three Walsh code channels are required for various combinations of traffic types; meaning that the rest of Walsh codes can be assigned for other users during a timeslot.

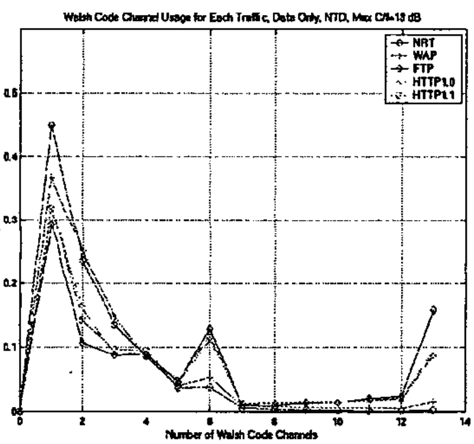


Figure 1: Walsh code channel usage distribution for various traffic types (i.e. near-real-time video, WAP, FTP, and HTTP) [2].

For efficient utilization of radio resource, 1xEV-DV adopts time & code division multiplexing (TDM/CDM) scheme, by which the BS can allocate various number of Walsh codes to more than one user within one or more timeslots. The optimal utilization of radio resources, however, may incur signaling overhead over the air. If the numbers of users sharing the "fat-pipe" traffic channel increase, TDM/CDM scheme may also increase mobile terminal complexity. Hence, the 1xEV-DV system allows up to two users simultaneously sharing the channel. In 1xEV-DV, a shared "fat-pipe" packet data channel is composed of N (1 to 28) parallel physical channels, i.e. Walsh codes. Up to two (active) users can simultaneously receive packet data from the shared channel. The base station, based on factors such as QoS requirement, traffic loading, and channel quality, can allocate M channels ($M \leq N$) to a user for 1, 2, or 4 timeslots, while the second user can be allocated with N-M channels at the same time.

C. *N-Channel Physical Layer Hybrid ARQ*

Among many techniques, Forward Error Correction (FEC) codes such as turbo or convolutional codes at the physical layer and Automatic Repeat reQuest (ARQ) protocol at the upper layers have been used in cdma2000 1xRTT to satisfy high data rate and low error rate requirements. As the technology advances, 1xEV-DV concatenates FECs and ARQ protocols at the physical layer to further offer better QoS than 1xRTT. The concatenation of FECs and ARQ is known as Hybrid ARQ (HARQ), which can increase throughput and reduce transmission delay, as compared with long delay caused by higher-layer retransmission in case of errors. The physical layer HARQ is incorporated with adaptive modulation coding (AMC) to provide radio link adaptation. Furthermore, various combining technique such as soft combining and incremental redundancy can also improve radio link performance in case of transmission error.

1xEV-DV implements HARQ with an N-channel Stop-and-Wait (SAW) ARQ operation, where N is up to 4. As an example shown in Figure 2, there are two active mobile stations (MS) sharing the forward packet data channel (F-PDCH). Each individual HARQ channel of each MS receives a data packet from downlink and sends an ACK/NACK message in uplink. As there are four HARQ channels operating simultaneously for each MS, the base station can schedule the shared F-PDCH as efficiently as possible. The MS also can buffer any sub-packet that was negatively acknowledged for combining with other related sub-packet(s).

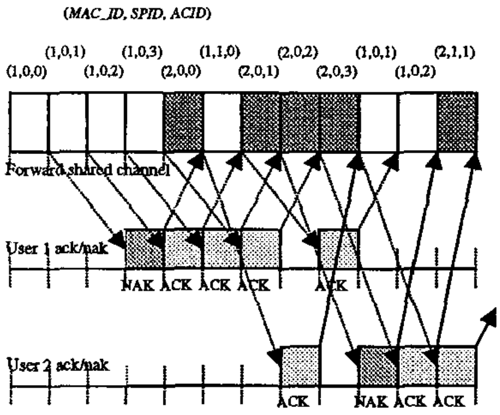


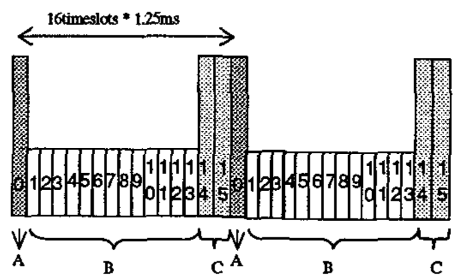
Figure 2: Principles of *N*-channel stop-and-wait HARQ used in 1xEV-DV high-speed packet data shared channel, for *N*=4 and two active users. Note that *SPID* is sub-packet ID and *ACID* is ARQ channel ID.

D. *Cell Switching Technique*

In general, a shared channel like 1xEV-DV F-PDCH cannot be in soft handoff, by which the MS may expect to simultaneously receive identical packet data from multiple F-PDCHs sent by multiple base stations. The difficulties of F-PDCH soft handoff include the implementation complexity of the MS and the scheduling constraints at the BS. Instead of soft handoff, 1xEV-DV utilizes cell switch technique to leverage macro diversity and potentially reduce the forward link interference. The 1xEV-DV MS only receives packet data from a cell selected by the mobile terminal based on appropriate forward link channel quality indication (CQI). In other words, only the base station that has the best radio link to the user terminal will actually send the data.

The CQI is used to estimate the forward link pilot strength to total noise and interference density ratio (i.e. E_{pilot}/N_t) for F-PDCH serving sector/cell. 1xEV-DV specifies two types of CQI report format: full CQI report and differential CQI report [4]. The former uses an encoder 4-bit value to represent an absolute measurement, while the latter uses 1-bit (UP or DOWN) value to represent the quality variation compared with previous estimated quality. The advantage of differential CQI report is to reduce the reverse link overhead that may be caused by CQI reporting.

The MS indicates cell switching, if needed, to the BS during a reverse CQI reporting cycle. The transmission pattern of reverse CQI reporting varies, depending on several factors: full or differential CQI, CQI gating rate, and CQI repetition rate. As an example shown in Figure 3, a CQI reporting cycle consists of 16 timeslots * 1.25ms/timeslot and carries a series of full CQI reports and differential CQI reports. According to the pilot strength measurements, if no cell/sector switch is needed, the MS report CQI with the current serving cell/sector "Walsh_Cover"; otherwise, when the new cell/sector switching procedure occurs, the mobile station reports CQI with a new cell/sector "Walsh_Cover" as a cell switching indication at the end of CQI reporting cycle, i.e. timeslots 14 and 15. During a cell switching transition period, this reporting cycle can be repeated more than once, depending on system configuration. The switching transition period also can be terminated earlier than pre-configured cycles, if the BS wishes to do so. Upon the completion of the cell/sector switching transition, the MS receives packet data from the new cell/sector. This switching procedure is considered to be fast, compared with traditional handoff procedures.



A = Full CQI report; "Walsh_Cover" = Current_sector.

B = Differential CQI report; "Walsh_Cover" = Current_sector.

C = Cell Switch Indication; Walsh_cover = Target_sector

Figure 3: Example of CQI report and cell switching *indication used in 1xEV-DV. A CQI report cycle consists* of 16 timeslots. "Walsh_Cover" is to identify which sector/cell the mobile station is listening to and reporting to. When the MS decides to switch to a new cell, the "Walsh_Cover" is set to be the new target sector/cell.

E. *Packet Data Control Hold Operation*

The Control Hold (CH) mode [3] is an intermediate mode of MS awareness between active mode and idle state. Since 1xEV-DV is required to support a large number of packet data users and the packet data traffic for 1xEV-DV is likely to be bursty, the CH mode is a way to save the mobile station battery life without completely entering into the idle state; furthermore, the CH mode can facilitate the MS quickly re-entering into the active mode when there is a packet data to be received from the base station. The design scope of CH mode includes (1) CH steady-state behaviors at MS and BS and (2) state transition protocols. The 1xEV-DV control hold mode is appropriately designed so that the control overheads of state transition on forward link and reverse link is minimized; MS battery life can be optimally preserved during the CH mode; fast and reliable state transition initiated by either MS or BS is possible too.

When the MS is in 1xEV-DV CH mode, the reverse link pilot is operated at a reduced rate of ½ or ¼. The MS may also report channel quality indication (CQI) at a reduced rate of ½, ¼, or gated-off. The rate of reverse link power control command from the BS is also reduced and aligned with the gating rate of reverse pilot channel. Through channel gating or rate reduction in the CH mode, the MS battery life can be preserved.

The state transition between active mode and CH mode needs to be fast and reliable. Both the MS and BS can initiate the transition from CH mode to active. The MS uses the physical layer signaling mechanism, i.e. increasing reverse pilot and CQI to be full rate, to inform the BS that it is entering into the active mode. The physical layer signaling incurs shorter delay than upper layers signaling. The BS, on the other hand, also can initiate the state transition from CH mode to active mode by sending full-rate (i.e. 800Hz) reverse link power control commands or sending a resource allocation message to the MS. When there is no more packet data for the MS and the BS decides to bring the MS from active mode to CH mode, the BS can send relevant cdma2000 Layer 3 signaling message, e.g. resource release message, to the MS.

3. PACKET DATA CHANNEL OPERATION

The 1xEV-DV packet data channel operation uses all the enabling techniques described in the previous section. In addition to all these component technologies, the communication protocol and associated control channels between MS and BS are designed. Figure 4 is a simplified illustration of 1xEV-DV packet data channel operations.

For an active mobile station assigned with a medium access control ID (MAC ID), the BS decides packet size, the number of time slots, and the number of Walsh codes for the proceeding transmission. Note that the packet size, the numbers of time slots and Walsh codes are decisive factors of the modulation and coding selection. The base station may multiplex packet data from multiple packet data applications into an 1xEV-DV F-PDCH physical layer data frame, according to the "allocated" packet size. To achieve incremental redundancy, each packet (i.e. encoder packet (EP)) is turbo-encoded and divided into four sub-packets (SP), which are distinguished by *SPID*. The first SP (*SPID=0*) carries the most important information about a packet, so it is usually sent first. Subsequently, any other subpackets can be sent if a retransmission is needed. An explicit indication on the control channel is used to indicate whether the current transmission is a new transmission or a retransmission. It is apparent that sub-packet retransmissions decrease the radio spectral efficiency.

For CDM purpose, two forward packet control channels (F-PDCCH0 and F-PDCCH1) are designed. F-PDCCHs are time aligned with F-PDCH. Controlling information such as MAC ID, ARQ channel ID, SPID, EP size, new packet identifier, and Walsh code index are transmitted on F-PDCCHs.

An active mobile station must continuously monitor and decode the F-PDCCH0. If its MAC ID matches, the MS demodulates and decodes a subpacket being transmitted using the Walsh code space indicated in F-PDCCH0; otherwise, if its MAC ID doesn't match with the MAC ID carried in F-PDCH0, the MS must attempt to decode the second packet control channel, F-PDCCH1, to determine if there is packet data on F-PDCH for it. In this case, the Walsh code space can be implicitly derived from both F-PDCCH0 and PDCCH1. Combining all previously received subpackets related to an encoder packet (EP) in an ARQ channel, the MS attempts to decode that packet. Whether the decoding is successful or failed, after an acknowledgement delay period (e.g. 1 or 2 timeslots), the MS should send an ACK or NAK to the base station on the reverse acknowledgement channel (R-ACKCH). The acknowledgement delay is a necessary timing buffer for the MS to decode the control channel and data channel prior to sending acknowledgement, which concludes a subpacket transmission period as shown in Figure 4.

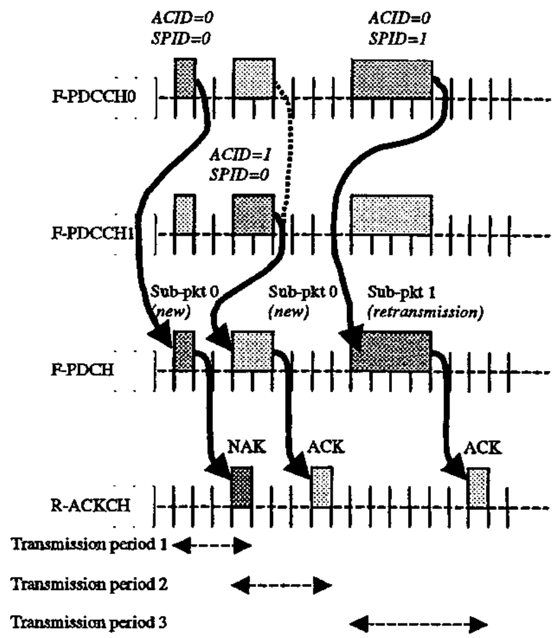


Figure 4: Example of 1xEV-DV F-PDCH operations. The MS monitors F-PDCCH0 and possibly F-PDCCH1 to derive relevant control information to receive downlink packet data on F-PDCH.

System simulations [5] based on a well-defined evaluation methodology [6] have been shown that the 1xEV-DV systems, with the pre-determined outage criteria, can reach high throughput and capacity in various scenarios for data-only services as well as simultaneous data and voice services. For example, for data-only services with mixed traffic types of 56.43% WAP application, 24.43% HTTP application, 9.29% FTP application, and 9.85% near-real-time video application, the total throughput is about 450kbps and 480kbps for 45users and 50users, respectively, per 1.25MHz RF carrier in a sector. On the other hand, for simultaneous voice and data services, when 50% of total voice capacity is set aside for voice users, the cell throughput can reach about 300kbps and 350kbps for 30 and 35 users, respectively. Furthermore, if the data traffic is "full buffer" type (e.g. for ftp downloading), the data throughput is even higher than that of mixed traffic types.

4. CONCLUSIONS

cdma2000 1xEV-DV technology increases peak and average user data rate in forward link to satisfy the rapidly increasing demands on high speed packet data services such as ftp downloading, web browsing, video streaming, etc. in cellular communications environment. The system also aims for backward compatibility with cdma2000 1xRTT and provide simultaneous data and voice services using the same RF carrier. Many enabling technology elements have been adopted in cdma2000 1xEV-DV, especially for forward link high-speed packet data channel. These elements include adaptive modulation and coding, adaptive TDM/CDM code allocation and multiplexing, physical layer hybrid ARQ, packet data control hold operation, and cell switching technique.

3GPP2 is continuing to strive for technology evolution. Several technical areas of improvement and enhancement are desirable. Enhancements for high-speed 1xEV-DV reverse link are expected soon. Broadcast and multicast services over F-PDCH are also possible. Real-time applications such as video conferencing are feasible too. Furthermore, increasing voice capacity using voice over IP technique underlying 1xEV-DV technologies is another promising alternative. Multi-antenna and diversity techniques are also areas to be explored in 3GPP2 in the future.

5. REFERENCES

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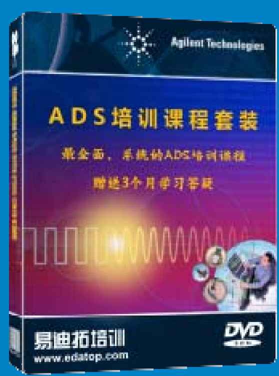

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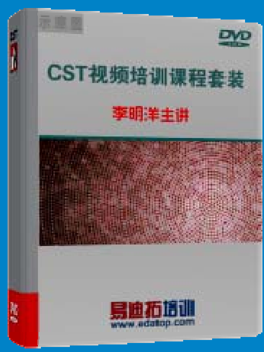

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