MPEG4 VIDEO OVER PACKET SWITCHED CONNECTION OF THE WCDMA AIR INTERFACE

Jamil Y. Khan¹, Pratik Das²

School of Electrical Engineering and Computer Science, University of Newcastle, Callaghan, NSW 2308, Australia

¹ jkhan@ee.newcastle.edu.au, ² pratik@ee.newcastle.edu.au

Abstract - This paper presents strategies for transmitting MPEG4 video by using rate matching techniques over the WCDMA air interface. We use an OPNET simulation model to analyze the channel utilization and transmission delay performance when transmitting MPEG4 traffic over dedicated channels in the WCDMA UP link.

Keywords – MPEG-4, WCDMA, Rate-matching, Packet transmission

I. INTRODUCTION

With the increasing demand for wireless multimedia services and introduction of IP (Internet Protocol) based services, packet switched information will be the dominant traffic component on the UMTS (Universal Mobile Telecommunication System) air interface [1]. UMTS and other 3G systems will be based on the WCDMA air interface support for both circuit and packet switched data [2]. The first WCDMA standard has been released in 1999 but the standard will continue to evolve for sometime. To transmit multimedia traffic on the WCDMA air interface it is necessary to handle packets from different sources according to their quality of service of requirements. The WCDMA air interface offers several options of transmitting packets using either dedicated, shared or common packet channels. Each of the channels has its advantages and disadvantages. These channels can be mapped according to the quality of service (QoS) requirements of different traffic sources. Another advantage of the WCDMA air interface is the option of variable transmission data rates through different spreading factors.

One of the key requirements of the 3G air interface is the support for multiplexing different services with different QoS on a single connection. These services may include loss-sensitive traffic as well as delay-sensitive traffic to best-effort traffic sources. The WCDMA standard supports three types of packet data transport channels, which include common, shared and dedicated channels. In this paper we propose an architecture to support MPEG4 video on packet transmission channels of the WCDMA air interface using the dedicated and shared channels.

In the UMTS architecture, the physical layer offers several transmission channels to higher layers such as the MAC

layer. The MAC layer maps transport channels onto the physical channels. Appropriate channels are selected by the MAC layer of the air interface using a scheduling algorithm to match the QoS requirements of a requested service. RACH (Random Access Channel), FACH (Forward Access Channel) and CPCH (Common Packet Channel) are the common channels used for carrying packet data. These channels carry signalling traffic as well as data traffic. DCH (Dedicated Channel) is the dedicated packet channel and can support packet data transmission rates of up to 960 kbps with a single code and 2.3 Mbs using six parallel codes [3]. DSCH (Downlink Shared Channel) and USCH (Uplink Shared Channel) are the shared channels that support bursty data packets. Shared channels can be used in parallel with a lower bit rate dedicated channel. USCH is only available in the TDD (Time Division Duplex) mode. The packet scheduler in RNC (Radio Network Controller) selects the above channels for different services according to the following service requirements.

- Service type parameters such as delay, packet loss, etc.
- Data volume.
- Current load of common and shared channels.
- Interference level of air interface.
- Performance of different transport protocols under current load.

This paper is organised as follows. Section II introduces the WCDMA air interface and packet transmission channels. Section III presents a brief introduction of video traces used in this simulation. In section IV we look at different rate matching processes for efficient channel utilisation which have been simulated. Section V presents some simulation results. Brief conclusions are made in section VI.

II. WCDMA PACKET ACCESS

Packet transmission systems can handle a wide range of traffic sources that include voice, data, video, images, etc. For successful transmission of such information, it is necessary to select suitable channels to match the QoS requirements. As mentioned earlier, three types of packet

access channels are supported by the WCDMA air interface. Among them the dedicated channel (DCH) is suitable for non-bursty traffic such as MPEG4 video transmission or for large file transfer applications. Common (FACH, RACH, CPCH) and shared (DSCH) channels are suitable for bursty traffic. However the shared channel can be conditioned to carry non-bursty traffic to offer some elastic bandwidth during the peak traffic. CPCH and DSCH may also carry medium size data bursts compared to RACH and FACH. Some of the packet channels are logical channels, which are mapped on to physical transport channels. The main functions of the MAC layer include logical and transport channel mapping, selection of transport format, priority handling and dynamic scheduling [4]. Priority handling and the dynamic scheduling features of the MAC protocol are important for transmitting multimedia traffic. The priority-handling attribute can be used to select high or low data rates. Dynamic scheduling can be applied for common and shared downlink transport channels. Figure 1 shows the MAC layer architecture at the UE (User Equipment) side.

Fig. 1. User Equipment (UE) side MAC architecture [4].

The main features of the dedicated, shared and common packet channels are listed in table 1. The table shows that dedicated channels can offer a certain class of guaranteed quality of service because of soft handover and fast power control. However the drawback of the dedicated connection is the long connection set up time. So the dedicated connection will be suitable for connection-oriented traffic. Shared channel access can be used for a range of services including non-real-time services, e.g. SMTP, HTTP, FTP, etc. [2]. The shared channel can be used for bursty data and services that require quick access.

DCH is a dedicated channel supported on both the UP and DOWN links. It carries all the information including higher layer user data and control information. The physical layer supports the dedicated physical data channel (DPDCH) and dedicated physical control channel (DPDCCCH) using I/Q multiplexing on each radio frame [3]. The UP link dedicated channel structure is shown in the figure 2. The DPDCH

carries data only and the DPDCCCH carries necessary control bits associated with the data channel. The TFCI is an optional transport format combination indicator. The TFCI informs the receiver about the transport format combination of the transport channels to be mapped simultaneously onto an uplink DPDCH frame. The DPDCH data rate is variable and is controlled by the spreading factor. Table 2 lists the DCH channel bit rates and number of bits/slot for different spreading factors.

Table 1
WCDMA data transmission channels

	Common Channels	Shared Channels	Dedicated Channels
Connection Time	Short	Medium	Long
Fast power control	No	Yes	Yes
Soft handover	No	No	Yes
Data suitability	Short bursts (10ms). Low bit rate	Long bursts (<640ms). Medium bit rates	Long bursts. High bit rates

For transmitting video frames on the DCH channel, a UE transmits a request specifying the bit rate it requires for transmitting its queued information. Depending on whether the BS is able to grant the UE the bandwidth it desires, it either sends a failure or confirmation message to the UE. The MAC can repeat the channel access request if it fails to receive an access confirmation or failure message within a period of time specified by the RRC (Radio Resource Control). The maximum number of times it can do so is also determined by the RRC. Upon receiving confirmation of channel access, the MAC generates a packet by appending headers with video data from its buffer and forwards this MAC PDU to the physical layer at every slot interval. The BS can ask a particular UE to update its rate of transmission over a dedicated channel and can do so as often as every TTI (Transmission Time Interval). The BS can also ask a UE to stop transmitting on a dedicated channel and force it to re-apply for channel access if there is more data to transmit.

Fig. 2. Frame structure of the dedicated channel on the UP link

The downlink shared channel (DSCH) can be used to offer extra bandwidth on the downlink to handle peak traffic. The DSCH can be shared by many users on the downlink. It supports fast power control as well as variable bit rate on a frame-by-frame basis. The DSCH is always associated with a downlink DCH. This feature is an advantage because DCH and DSCH can be allocated in parallel to carry the peak traffic for a short duration. Since the DSCH is shared by many users, it saves a number of orthogonal codes on the downlink.

Table 2
DCH transmission capacity

DPDCH Spreading Factor	DPDCH Channel Rate (kbps)	No. of bits/slot	User data transmission rate (kbps)
256	15	10	12
128	30	20	24
64	60	40	45
32	120	80	105
16	240	160	215
8	480	320	456
4	960	640	936

III. MPEG-4 VIDEO TRACES

MPEG-4 video streams consist of video frames compressed into I, B or P frames, depending on the state of the video encoder when each raw video frame arrives. I frames are coded independently from any past or future frames and are the largest, on average. P frames are coded as modifications to the previous frame and are usually smaller on average when compared to I frames. I frames and P frames can be displayed as soon as they arrive at the receiver. B frames are coded as modifications to the previous frame and the next frame. B frames are typically the smallest in size but cannot be displayed till the next frame has already been received and decoded. The average data rate of VBR MPEG-4 video varies according to the nature of the images captured and the amount of visual activity, the frame rate, the frame size, and, the encoding process - with influencing factors such as the frequency of I frames and the use of B frames. For real-time video communication between two WCDMA terminals at say, 25 frames per second, the interval between the arrivals of two consecutive video frames is 40 ms. Since end-to-end delays must be kept under 250 ms for effective communication, the use of B frames takes away, in this case 40 ms or 16%, from the delay budget because the receiving terminal needs to wait for the next video frame to arrive before the B frame can be displayed. For this reason, video streams for the simulations discussed later on have been coded without using B frames at the cost of an increase in the overall data rate of the video stream.

IV. RATE MATCHING PROCESSES

While the WCDMA standard supports a number of transmission rates over the uplink through dedicated channels, in most cases channel capacity is not efficiently utilized if data is transmitted at a constant rate. This is because typical data sources have output rates that vary in time. Bandwidth is wasted during periods when the data rate is lesser than the transmission rate, and spare bandwidth is left unused when the data rate exceeds the transmission rate. In the latter case, the output buffer builds up rapidly and the transmission delay experienced by packets in the buffer increase proportionally too. A more efficient transmission process would involve varying the transmission rate according to the data rate, and in doing so maintaining the transmission delay of the packets within acceptable limits. Processes that control the transmission rate over the channel can be broadly classified into BS-assisted or UE-assisted methods. We will now discuss some processes that belong to each of these classes.

A. BS-assisted Rate-matching

By monitoring the transmission delays of packets received at the BS, it is possible to determine if the transmission rate of a UE is appropriate. By using the transmission rate, the current data arrival rate at the BS, and the packet transmission delay as inputs to a function, it is also possible to estimate a more appropriate transmission rate. This process could be repeated at regular intervals, referred to hence forth as the adaptation interval, to ensure that packet transmission delays are maintained within limits. When the amount of data received during one adaptation interval approaches the maximum limit for the current transmission rate, and if transmission delays are high, the transmission rate can be incremented by a step or two, depending on the nature of the data being transmitted and its delay requirements. When the amount of data received during one adaptation interval is considerably less than the maximum limit, the transmission rate can be rounded off to the WCDMA standard rate nearest to the rate of data arrival. The new transmission rate is then relayed to the UE through common channels. The algorithm used at the BS to obtain the simulation results presented in a later section is as follows:

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if (Video and RateRX > 0.9 x RateTX)
    if (TDELAY > 0.120)
        Increase RateTX by 2 steps (if available)
    else
        Increase RateTX by 1 step (if available)
else if (Data and RateRX > 0.8 x RateTX)
    if (TDELAY > 0.240)
        Increase RateTX by 2 steps (if available)
    else
        Increase RateTX by 1 step (if available)
else if (RateRX < 0.3 x RateTX)
    Set RateTX to the nearest rate greater than RateRX

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$Rate_{RX}$ - Received data rate over the last adaptation interval
 $Rate_{TX}$ - Transmission rate of the UE
 T_{DELAY} - Transmission delay of last received packet

B. UE-assisted Rate-matching

Another way of controlling the transmission rate is to have the UE use the size of its data buffer to determine the transmission rate necessary to clear the buffer within a certain period of time. And as with BS-assisted methods, this would also have to be repeated at regular intervals. The critical difference between UE-assisted and BS-assisted processes is that while the former involves uplink signaling to request a rate that may or may not be allocated to it, depending on the available channel capacity, the latter involves downlink signaling to confirm a new transmission rate. However, UE-assisted processes are able to maintain transmission delays within stricter bounds because of a more accurate estimation of the required transmission rate. A UE calculates its required transmission rate $Rate_{TX}$ by dividing the transmission buffer length L with a rate parameter R_a whose value depends on the traffic type, traffic intensity and the priority for data over other traffic types as shown in equation 1.

$$Rate_{TX} = \frac{L(bits)}{R_a(sec)} \quad (1)$$

Since it is very unlikely for $Rate_{TX}$ to match a WCDMA standard rate, the transmission rate requested of the BS is the standard rate nearest to $Rate_{TX}$. For the simulation results presented later, R_a was set to 0.1s for data terminals and 0.04s for video terminals. This means that video terminals will request the BS for a greater transmission rate than data terminals would clear the same buffer size, and would therefore transmit video frames with a lower mean delay.

V. SIMULATION RESULTS

To observe the performance of video and data transmission over uplink DCH channels and to explore the use of rate adaptation schemes, an OPNET simulation model was created. The user equipment (UE) has MAC and L1 layers to queue user data, apply for channel access, split the data packets into slots for transmission and, if required during transmission, request the base station for a higher or lower transmission rate for the next frame depending on the size of the input buffer and the delay requirements that need to be met. The transmission time interval is set to 10ms.

When UE-assisted rate matching is enabled, all rate update requests from different UE's are priority-queued and processed every TTI. Requests from video terminals are processed before requests from data terminals. This ensures that data terminals don't capture a large portion of the spare transmission capacity thereby leaving little or no extra capacity for video terminals.

15 UE's transmitted one of 5 different MPEG-4 traces and 6 UE's transmitted exponentially distributed packets sizes at exponentially distributed inter-arrival times to model typical data terminals. The total channel capacity was set to 1.98 Mbps. The mean total data rate of the 21 terminals was approximately 1.35 Mbps. To model overheads in the transmitted packets, user data was not transmitted at the channel transmission rate but at a rate lower than it, as shown in the table 2.

Figure 3 shows the variable bit rate output of an MPEG-4 video clip recorded from a television news program with a mean data rate of around 31 kbps but with segments of very high bit rate.

Fig. 3. Output data rate of a QCIF MPEG-4 news clip at 25 fps.

Fig. 4. Transmission Delays with a) no adaptation, b) BS-assisted rate adaptation, c) UE-assisted rate adaptation

Figure 4a shows the high delays experienced by the video frames when constant transmission rate of 60 kbps is allocated. Figure 4b and 4c show video frame transmission delay using BS assisted and UE assisted rate adaptation algorithms respectively. Results show that UE assisted rate adaptation algorithm allocates bandwidth more efficiently resulting low end-to-end delay. The peak in figure 4c at around 165ms is because of saturation in channel utilization at the time and the lack of any spare capacity that could be allocated to the UE. Figure 5 below shows the variation in the transmission rate of the UE with BS-assisted rate matching and its effect on the transmission buffer size.

Fig. 5. BS-assisted rate adaptation during a portion of the news clip

The table 3 and 4 summarise mean allocated transmission rate and delay for different MPEG-4 video streams with BS and UE assisted rate adaptation.

Table 3
Channel utilizations with rate matching enabled

<i>BS-assisted</i>		Mean channel rate (kbps)	
	Data rate (kbps)	$T_{\text{adap}} = 50\text{ms}$	$T_{\text{adap}} = 100\text{ms}$
UE 2	17.6	26.9	25.5
UE 3	12.6	20.1	18.7
UE 4	30.5	41.6	40.5
UE 5	11.6	18.2	17.2
UE 19	144.4	169.3	167.1

<i>UE-assisted</i>		Mean channel rate (kbps)	
	Data rate (kbps)	$T_{\text{adap}} = 50\text{ms}$	$T_{\text{adap}} = 100\text{ms}$
UE 2	16.4	24.0	23.8
UE 3	12.4	19.3	19.0
UE 4	31.3	40.9	41.2
UE 5	11.4	16.6	16.9
UE 19	143.7	174.1	178.6

T_{adap} : Adaptation interval

Table 4
Transmission delays with rate matching enabled

<i>BS-assisted</i>	Mean T_{delay} (secs)		Max. T_{delay} (secs)	
	$T_{\text{adap}} = 50\text{ms}$	$T_{\text{adap}} = 100\text{ms}$	$T_{\text{adap}} = 50\text{ms}$	$T_{\text{adap}} = 100\text{ms}$
UE 2	0.100	0.102	1.037	0.733
UE 3	0.072	0.074	0.563	0.496
UE 4	0.094	0.090	0.733	0.453
UE 5	0.062	0.065	0.601	0.805
UE 19	0.432	0.370	4.992	2.004

<i>UE-assisted</i>	Mean T_{delay} (secs)		Max. T_{delay} (secs)	
	$T_{\text{adap}} = 50\text{ms}$	$T_{\text{adap}} = 100\text{ms}$	$T_{\text{adap}} = 50\text{ms}$	$T_{\text{adap}} = 100\text{ms}$
UE 2	0.113	0.147	2.637	1.664
UE 3	0.087	0.114	2.141	1.655
UE 4	0.086	0.107	1.799	1.389
UE 5	0.071	0.083	1.795	0.661
UE 19	0.119	0.141	1.690	1.218

T_{adap} : Adaptation interval

T_{delay} : Video frame transmission delay

VI. CONCLUSIONS

The ability of WCDMA DCH channels to support variable bit rates, soft handover and fast power control make them most suitable for transmission of VBR MPEG-4 traffic. The channel utilization and transmission delay performance of MPEG-4 video streams over such channels improve significantly when BS-assisted or UE-assisted rate-matching schemes are used.

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