QOS SUPPORT IN UMTS NETWORKS USING RATE MATCHING ATTRIBUTES

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ABSTRACT

UMTS with WCDMA radio interface increases spectral efficiency with its ability to transport multiple parallel services to the same mobile with different quality requirements on one physical connection. To support the above key feature, every transport channel has an associated semi static attribute called the Rate matching Attribute(RMA).

In this work, we investigate the problem of how downlink RMA values can be set such that appropriate amounts of puncturing or repetition occur on the multiple transport channels leading to satisfactory performance seen by each. Specifically, we consider two traffic sources - one a CBR source and another generating bursty traffic. A procedure for setting the RMA values is proposed and evaluated using simulation as well as analysis. The analytical evaluation uses the framework of Rate Compatible Punctured Codes (RCPC), as well as the Distance Spectra typically associated with performance evaluation of convolutional codes.

We demonstrate that, for a given target signal to noise ratio $\frac{E_b}{N_0}$, proper choice of RMA is indeed critical to satisfy the QoS requirements as well as to increase spectral efficiency. The results of the simulation, performed over an AWGN channel, closely match the tight upper bounds calculated using analytical expressions.

I. INTRODUCTION AND RELATED WORK

One of the key advantages of Wide-band CDMA (WCDMA) is that it supports simultaneous access to multiple users. For network operators, third generation systems improve spectrum efficiency and increase the flexibility to deploy new services. Additionally, the WCDMA radio interface supports multiple parallel services with different quality requirements on one single physical connection [1]. This is possible because a single orthogonal code may be used to transport multiple services destined to a single mobile [2]. However, successful deployment of the above scenario is practical only if the BER specified in the QoS profile of individual flows is satisfied. The WCDMA access in UMTS offers great flexibility and variety of logical channels mapped to physical channels. For instance, several user rates and protections are possible by choosing suitable parameters such as Spreading Factors (SFs), Coding rates ($\frac{1}{2}, \frac{1}{3}$) including higher rates by use of punctured codes, and Automatic Repeat request (ARQ) schemes [3]. Spectral efficiency depends on a number of parameters including radio environment, user mobility, location, services and quality of service, and propagation environment [4].

The UMTS specification provides modification of radio bearers [5] where, multiple calls destined to the same User Equipment (UE) may be supported by use of multiplexed transport channels. These transport channels may be supported within a single physical channel and thus using a single spread code. The individual transport channels within the Code Composite Transport Channel (CCTrCH) may be provided with differentiated QoS support by the use of RMA.

RMA is a semi-static parameter provided by higher layers to control the relative rate matching (puncturing or repetition) between different transport channels. On the downlink, the RMA values associated with different channels determine the number of bits from that channel in one fixed size radio frame. By adjusting the RMA, different Bit Error Ratios (BER), can be achieved.

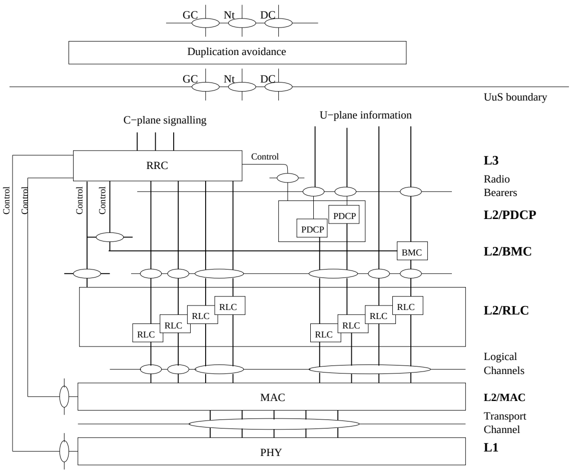

Fig. 1. *Radio interface protocol architecture.*

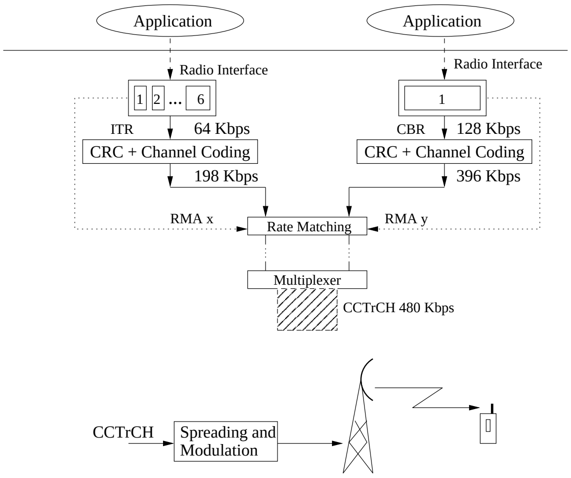

Fig. 2. *Rate matching scenario in UMTS.*

In this paper we propose a simple mechanism to choose RMA values for the flows from a “joint RMA space”, which meets the QoS of each flow, yet obtain high spectral efficiency.

I-A. UMTS Radio Interface

Figure 1 shows the radio stack available both at the wired-side Radio Network Controller (RNC) and wireless UE [6]. One may divide this radio stack into three horizontal layers - Radio Resource Control (RRC) in layer 3, Radio Link Control (RLC) and Media Access Control (MAC) in layer 2 and WCDMA physical layer in layer 1. In the vertical plane, we can divide the three layers into two sections: control and user plane.

As shown in Figure 1, initially, the packets generated by application sources are mapped to logical channels. The choice of logical channel to Transport channel to Physical channel map depends on the QoS requirement of the flow, which is decided during the signaling phase. The QoS requirement includes fast power control, soft handover and data rate variation on frame-by-frame basis. An example of channel mapping is: if Dedicated Traffic Channel (DTCH) is the logical channel, then DTCH gets mapped to a transport channel called Dedicated Channel (DCH). The physical channel corresponding to DCH is the Dedicated Physical Data Channel (DPDCH). The DPDCH after passing through an exhaustive channel coding and multiplexing chain, is subjected to spreading followed by scrambling and finally QPSK modulated before transmitting on the air interface. The scrambling operation is needed to separate terminals or base stations from each other.

WCDMA access in UMTS uses a 10ms frame structure. Each 10ms frame, also called a radio frame, is divided into 15 slots. In the downlink, the control and data channel information is time multiplexed. The position of data and control information bits in a radio frame depends on the Slot Format Index (SFI) corresponding to each spreading factor. Transport blocks can arrive at the physical layer every 10, 20, 40 or 80ms and the associated semi static attribute Transmission Time Interval (TTI) is regarded as having 10, 20, 40 and 80 TTI. The rate matching block operates with TTI as the basic unit of time.

II. PROBLEM STATEMENT

The problem is best captured in Figure 2 which shows two traffic flows. The constant Bit Rate (CBR) traffic source generates data at a rate of 128 Kbps. After CRC attachment, $\frac{1}{3}$ convolution coding, and addition of trellis bits, the coded bit rate corresponding to CBR traffic is 396 Kbps. The Bursty traffic source (ITR) generates bursty data with a maximum bit rate of 64 Kbps. After CRC attachment and rate $\frac{1}{3}$ turbo coding, and addition of trellis bits, the bit rate is 198 Kbps. The bursty source is characterized by having multiple transport formats. Both sources, which are essentially applications, enter the above discussed radio interface. They undergo the downlink transmission chain, and are destined for the same User Equipment (UE). The transport channels are within a CCTrCH and share a single physical channel supporting 480 Kbps.

It is clear that both the flows have to undergo puncturing in order to meet the physical channel bit rate of 480 Kbps. We ask the question: for a given target $\frac{E_b}{N_0}$, how does one achieve the target QoS (BER) for each of the flows when they still need to undergo puncturing to meet the target bit rate?

III. TRAFFIC MODEL

CBR Traffic: A file of mean size = 350 KB is downloaded by the UE. Each packet arriving from the FTP source is broken down into a single Transport Format block of 1280 bits. A single block of 1280 bits is transmitted every 10ms and thus the bit rate of CBR is maintained at 128 Kbps. On the average, a file transfer lasts 21.84 seconds.

ITR Traffic:We apply the traffic model specified by the 3GPP document [7].In order to facilitate transmission of bursty packets (or variable size packets), packets are converted into transport blocks and mapped into previously agreed upon transport format blocks and transmitted in one TTI. Depending on the input packet size, we map our incoming packets to any of the following transport formats: 64*1, 128*1, 256*1, 320*1, 256*2, 640*1, where a transport format of m*n means that the format specifies n blocks of m bits each. For packets smaller than 8 bytes, padding operation [8] is performed.

IV. THE PROPOSED QOS MECHANISM - PUNCTURING RATIO (PR), CHANNEL RATIO (CR) AND RMA EVALUATION

To explain our mechanism, we first define and then use the following simple expressions. From Figure 2, the physical channel, carrying the CBR and ITR supports 480 Kbps and uses a Spreading Factor of 16. The corresponding SFI of 14, as specified by the UMTS standard, is applied at the rate-matching block. The given SFI, only supports a *data* rate of 432 Kbps, since control information requires 48 Kbps. We define N_{data} as the maximum number of outgoing channel coded data bits. In our case, this is 4320 bits per 10ms [9].

When multiplexing several transport channels onto a CCTrCH, puncturing or repetition may be required. Let $N_{Bits\ of\ i}$ denote the number of channel coded bits per TTI of transport channel i that will appear in the CCTrCH. Also, let $N_{Max\ of\ i}$ denote the maximum number of bits per TTI that can be generated by the transport channel i. Then, the Puncturing Ratio (PR) for any coded transport channel i is defined as:

$$PR_i = \left[\frac{N_{Bits\ of\ i}}{N_{Max\ of\ i}} - 1\right] \tag{1}$$

For instance, for the above ITR source, $N_{Max\ of\ i}$ is 1980 bits in a TTI, while $N_{Bits\ of\ i}$ is 825 (say). Then PR_i is -0.5833 or -58.33%. Note that the evaluated PR may be associated with a minus $(-)$ sign, indicating puncturing, or plus $(+)$, indicating repetition. From the SFI of 14, we may apportion N_{data} into 825 bits for ITR and the remaining 3495 bits for CBR.

Channel Ratio (CR) for a CCTrCH is calculated using the maximum coded transport format of each channel. The channel ratio for ITR, CR_i (say), is defined as:

$$CR_i = \frac{RMA_i * N_{Max\ of\ i} * \frac{1}{F_i}}{[\sum_{k=ITR,CBR} RMA_k * N_{Max\ of\ k} * \frac{1}{F_k}]} \tag{2}$$

In Equation(2), k and i are the two transport channel variables, which are carried within the CCTrCH. '$\frac{1}{F_i}$' is the length of a radio frame in units of TTI of channel i. For instance, $\frac{1}{F_i}$ may take $1, \frac{1}{2}, \frac{1}{4}$, or $\frac{1}{8}$ as values. From [10], we know that RMA for each channel can range from 1 to 256. We take the ratio $\frac{RMA_i}{RMA_k}$ for all possible combinations. Thus, a ratio table is prepared. For example, if a CBR source has an RMA of x (say 1) and an ITR source has an RMA of y (say 2), then $\frac{RMA_{CBR}}{RMA_{ITR}} = \frac{x}{y} = 0.5$. An exhaustive table of $\frac{x}{y}$ values starting from $\frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \ldots$ until $\frac{255}{256}$ is prepared.

By substituting the desired channel ratio for a flow i in the Left Hand Side (LHS) of Equation(2), we may calculate $\frac{x}{y}$, the fraction corresponding to the two required two RMA values.

Relation between PR and CR: We may relate PR and CR using the following expression:

$$CR_i = \frac{(PR_i + 1) * N_{Max\ of\ i} * (\frac{1}{F_i})}{N_{data}} \tag{3}$$

In Equation(3), CR_i is the required channel ratio for transport channel i with its puncturing ratio being PR_i. $N_{Max\ of\ i}$ is the maximum possible channel coded bits of transport channel i.

To obtain the RMA values from the joint RMA space, we propose the following mechanism.

1. Pick any one of the flows and choose its PR.
2. Apply the PR in Equation(3) and obtain the corresponding CR
3. Substituting the value of in the LHS of Equation(2), we obtain the ratio of RMA values $\frac{x}{y}$.
4. Consult the readily available RMA table and obtain the RMA values.

An operator has to follow the above steps and obtain a plot for several puncturing ratios. Subsequently, a polynomial expression may be used to choose a PR for the user specified target Block Error Ratio(BLER). The polynomial expression itself can be obtained by curve fitting.

V. SIMULATION ENVIRONMENT

Our experimental environment uses Radiolab 3G [11] running over Matlab. We set the RMA values using the above ratio table and carry out the simulation study. From [12], one may set the target $\frac{E_b}{N_0}$ based on the following expression

$$\frac{E_b}{N_0} = SNR * SF \tag{4}$$

The performance indicator $\frac{E_b}{N_0}$ (energy of a bit to noise spectral density) is always related to some quality target such as BLER. Therefore, all closed loop power control schemes attempt to keep the $\frac{E_b}{N_0}$ constant. Thus, for a chosen service, channel conditions, and a chosen required BLER, the received power on the traffic channel divided by the interfering power is approximately constant [13]. The simulation was conducted with only a single source over an AWGN channel. We therefore assume the notion of closed loop power control.

VI. SIMULATION RESULTS

The proposed mechanism is simulated for an AWGN channel. We fix the target $\frac{E_b}{N_0}$ at 0.9dB, the spreading factor chosen is 16. The results for the BLER of ITR and that of CBR traffic is shown in Figure 3. In Figure 3, the ITR BLER is high when puncturing is high. However, this gradually decreases as the puncturing is reduced. On the other hand, the BLER of CBR rises. Therefore, one needs to choose an RMA pair, which meets the target BLER performance of both sources. As an example, if QoS target for both flows is a BLER of 10%, then this is achievable only when the RMA pair is so chosen that ITR is punctured to about -0.333.

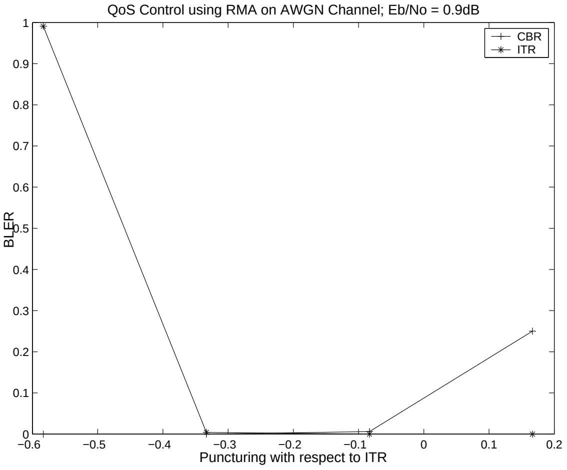

Fig. 3. *BLER of ITR and CBR over AWGN channel.*

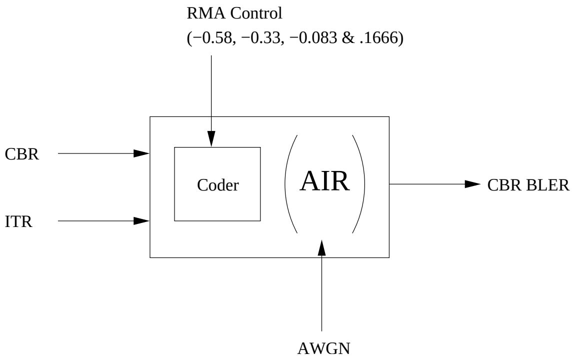

Fig. 4. *CBR BLER model for mathematical analysis.*

VII. CBR BLER MODELING AND ANALYSIS

We now mathematically analyze the BLER associated with the CBR source, which is 1/3 convolution coded. The model may be best understood by considering Figure 4. In general, the bit error performance criterion of a convolutional coder with a Viterbi decoder is characterized by: (a) a large free distance d_{free}; (b) a small number of paths a_d; (c) a small information error weight c_d on all paths with $d \geq d_{free}$ [14]. In our case, we use the UMTS convolution coder as mentioned in [15]. From [16], we know that BLER may be obtained from the BER by the following expression:

$$BLER = 1 - (1 - BER)^L \tag{5}$$

In Equation(5), BER corresponds to the bit error probability. L is the length of the transport block size. In our case, L=1280 bits. From [17], the Bit Error Probability (BER) is given by

$$P_b \leq \frac{1}{P} \sum_{d=d_{free}}^{\infty} c_d P_d \qquad (6)$$

In Equation(6), P_d is the probability that the wrong path at distance d is selected. $\{c_d\}$ is called the distance spectra. From [18], c_d is defined as the number of input 1's in all finite length code words of hamming weight d. In Equation(6) P is the puncturing period. Since c_d is obtained by summing over all starting points, averaging by the puncturing period P is necessary to have the correct bound. However, in our case, we have experimentally verified that UMTS rate matching on the downlink, there is only one starting point. Thus, $P = 1$ in our case. P_d, which is also called the pairwise error probability depends on the channel. For coherent detection of a QPSK signal over an AWGN channel, P_d is evaluated by the following expression:

$$P_d = Q\left[\sqrt{\frac{2dE_c}{No}}\right] \qquad (7)$$

In Equation(7), $\frac{E_c}{N_0}$ is the target energy of coded bit to noise spectral density. The 'd' is the hamming distance, starting with the minimum hamming distance d_{free}. One may therefore represent all d values in the form $d \geq d_{free}$. The $Q(x)$ function is given by the following expression:

$$Q(x) = \frac{1}{2} erfc[\frac{x}{\sqrt{2}}] \qquad (8)$$

As a final step towards evaluation of P_b, c_d values were experimentally obtained by performing a computer search for several values of CBR puncturing ratio. We have tabulated these results in Table 1. The d_{free} in each is also mentioned. The distance spectra with CBR puncturing ratio of -0.4924 is only partial at the time of writing this paper. Finally, we show the comparison of our simulation and analytically computed values both for BER and BLER. Figure 5 shows the comparison of simulation and analytically computed values of BER. Observe that the tight upper bound mentioned in [14], gradually loosens with increasing coding rate of CBR flows. In other words, as the puncturing of CBR increases, d_{free} drops to 6 and has large impact on calculated BER values. Figure 6 shows the comparison of simulation and analytically computed BLER values. Although the calculated BLER remains an upper bound, the calculated values are tight upper bound on the simulation values only as long as d_{free} remains 10. At d_{free} of 6, the difference between simulated and calculated BER is $0.5 * 10^{-3}$, while at the previous d_{free} of 10, the difference was $5 * 10^{-6}$. This indicates that the basic assumption underlying the formula as indicated by Equation(5), viz., independent bit errors, ceases to hold when the puncturing of CBR traffic is high. Hence the analytical formula overestimates the BLER significantly.

TABLE I

c_d VALUES OBTAINED FOR 1/3 RCPC CONVOLUTION CODER

CBR Puncturing	d_{free}	c_d - Values
-0.1174	14	3, 6, 20, 54, 98, 207, 343, 580, 1189, 2590
-0.2424	11	3, 0, 13, 28, 69, 244, 397, 855, 2202, 4755
-0.3674	10	21, 6, 174, 539, 1428, 3467, 9060, 25241, 65527, 172570*
-0.4924	6	12, 0, 114, 164, 1912, 4419, 22528*, 64261*, 205871*

Note: * indicates that the c_d values correspond to partial distance spectra.

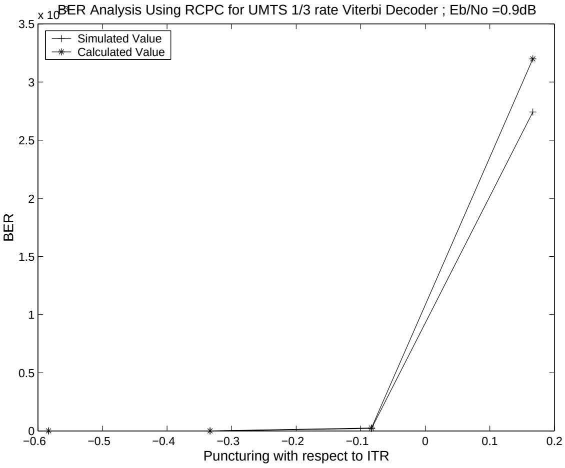

Fig. 5. *Comparison of simulation and analytical computation of BER values.*

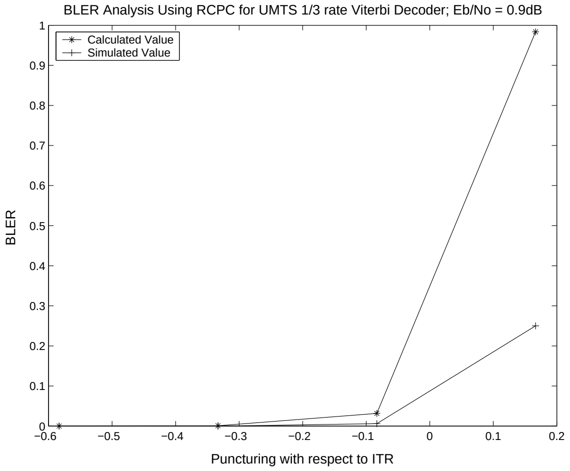

Fig. 6. *Comparison of simulation with analytically computated BLER values.*

VIII. CONCLUSIONS

We have proposed a simple mechanism for UMTS operators to choose RMA values from the joint RMA space, based on simple expressions related to puncturing and channel ratios for flows. The choice of RMA pair is critical to meet the target BLER requirement. The operator may also verify the BER of CBR flows with Equation(6) using precompiled optimum distance spectra values till about d_{free} of 10.

REFERENCES

[1] Erik Dahlman et al, “WCDMA - The Radio Interface for futhre Mobile Multimedia Communications”, *IEEE Transactions on Vehicular Technology*, Vol 47, Issue 4, November 1998, pp. 1105-1118.

[2] Ojanpera. T, Prasad. R, “An Overview of Air Interface Multiple Access for IMT-2000/UMTS”, *IEEE Communications Magazine*, Vol. 36, Issue 9, September 1998, pp. 82-86.

[3] Berruto. E, “Research Activities on UMTS Radio Interface, Network Architectures and Planning”, *IEEE Communication Magazine*, Vol. 36, Issue 2, February 1998, pp. 82-95.

[4] Harri Holma and Antti Toskala, “WCDMA for UMTS”, John Wiley and Sons.

[5] 3GPP TS 23.107 v3.0.0 (1999-10), “QoS Concept and Architecture”.

[6] 3GPP TS 25.301, v.3.10.0 (2002-06), “Radio Interface Protocol Architecture”.

[7] UMTS TR 101.112 v3.2.0 (1998-04), “Selection Procedures for the choice of Radio Transmission technologies of the UMTS” (UMTS 30.03 v3.2.0).

[8] 3GPP TS 25.322 v3.11.0 (2002-06), “RLC protocol specification”.

[9] 3GPP TS 25.211, v.3.6.0 (2001-03), “Physical Channel and Mapping of Transport Channel onto Physical Channel (FDD)”.

[10] 3GPP TS 25.433, v3.12.0 (2002-12), “UTRAN Iub interface NBAP signalling”.

[11] “User guide for Radiolab3G” - http://www.radioscape.com

[12] Klein S.Gilhousen, Irwin M.Jacobs, Roberto Padovani, Andrew J.Viterbi, Lindsay A.Weaver, Jr., and Charles E.Wheatley III, “On the Capacity of a Cellular CDMA System”, *IEEE Transactions on Vehicular Technology*, Vol. 40, Issue 2, May 1991, pp. 303-312.

[13] Jaana Laiho, Achim Wacker and Tomas Novosad, “Radio Network Planning and Optimisation for UMTS”, John Wiley & Sons.

[14] Andrew J. Viterbi and Jim K Omura, “Principles of Digital Communication and Coding”, McGraw Hill.

[15] 3GPP TS 25.212, v.3.6.0 (2002-12), “Multiplexing and Channel coding (FDD)”.

[16] Flaminio Bargonovo, “Packet service in UMTS: delay - throughput Performance of Downlink shared channel”, *Elsevier - Computer Networks*, Vol. 38, 2002, pp. 43-59.

[17] J. Hagenauer, “Rate Compatible Punctured Convolutional Codes (RCPC Codes) and their Applications”, IEEE Transaction on Communications, Vol. 36, Issue 4, April 1988, pp. 389-398.

[18] Jean Conan, “The Weight Spectra of Some Short Low-Rate Convolutional Codes”, *IEEE Transactions on Communications*, Vol. COM-32, Issue 9, September 1984, pp.1050 - 1053.