Color-aware Link Adaptation for DiffServ over CDMA Systems

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ABSTRACT
In this paper, a link adaptation scheme is proposed that integrates QoS information from the IP layer of the Differentiated Service Architecture (DiffServ) with lower layer criteria in order to improve Assured Forwarding (AF) traffic performance in a wireless CDMA system. The schemes for scheduling and rate adaptation are designed as integrated parts of the link adaptation, working jointly to adjust the AF users’ transmission adaptively to increase the throughput of the conforming traffic by suppressing transmission of nonconforming traffic in a congestion state.

I. INTRODUCTION
With the trend of convergence of fixed networks and mobile networks, all IP-networking has become one of the most common visions in the research community for future mobile communications [1]-[4]. In 3GPP specifications, DiffServ edge functions have been supported in UMTS systems with a logical element called IP BS manager [5], which is responsible for the connection between the gateway and mobile networks, since Release 5. In the current developing Release 6 specifications, the IP BS managers have been distributed into the radio network controller level. Under this structure, the radio link is actually integrated as the last hop of the IP end-to-end QoS architecture. To support IP traffic efficiently, the interactions between radio link layer over the air-interface and IP network layer are inevitable.

In this paper, a link adaptation scheme is proposed that integrates QoS information from the IP layer of the Differentiated Services Architecture (DiffServ) with lower layer criteria in order to support packet transmission over a WCDMA-based wireless interface in the differentiated way in consistent with DiffServ core. Many optimization solutions to link-adaptation schemes for CDMA wireless networks have been studied intensively in recent years [5][6][7][8]. However, in these approaches, the system performances are only optimized subject to link-level performance measures such as throughput, delay and bit-error-rate or packet error rate. Network-layer QoS requirements are not explicitly included in these solutions. In the proposed link adaptation scheme, we integrated a color aware scheduler, which is based on the output of a Time Sliding Window three colour marker (TSWtcm) of the ingress DiffServ node of radio access network, and a rate adaptation algorithm into this link adaptation scheme. Under the joint control of the scheduler and rate adaptation, the resource in the CDMA systems is dynamically allocated to differentiate the in and out profile of DiffServ packets, where the conforming traffic performance is enhanced whilst the performance of non-conforming traffic is penalized in the congestion state.

The paper is organized as follows: Section 2 gives a brief description of DiffServ and TSWtcm; in Section 3, the link adaptation is described in detail and in Section 4, we discussed the results presented. And finally, conclusions are drawn in Section 5.

II. TSWtcm Marking in DiffServ
Traffic aggregates are individualized by the DiffServ Code Point (DSCP) and the AF PHB RFC proposes four classes and three-drop preferences per class. AF can be seen as an extension of the RIO scheme [9], which uses single FIFO queue and two-drop preferences. Most of the current studies of differentiated drop mechanisms are based on the RIO approach. The discussion in this paper is based on the most general case and thus assume that a three level drop preference. The three level drop mechanism utilize the RED (Random Early Detect) queue for performing differentiated dropping of packets during congestion at the node. The three level drop mechanism scheme utilizes a single queue. All user packets are directed to and served from the same queue.

Metering and marking functionalities of packets inside AF classes are on per flow basis (even though these policies can also be applied for aggregated flows). Marking incoming traffic at the ingress DiffServ router is one of its most important functionalities. This building block is responsible for marking sender's traffic according to a specific profile. Traffic that conforms the service profile will be handled with low drop precedence, while non-conforming traffic will be handled with high drop precedence. Depending on the mechanism used to measure the conformity of the traffic, traffic marking can be in general classified in two general categories: Token Bucket and Average Rate Estimation. In the sequel, the marking algorithm that we use for our study is from the second family, called the Time Sliding Window three color marking TSWtcm [10]. In this marking scheme, the arrival rate is calculated according to the weighted average of the arrival rate over a certain time window. Thus, whenever a packet arrives, the marker calculates the estimated arrival rate. If the estimated arrival rate is less than the Committed Information Rate (CIR), the arriving packet is marked as green; otherwise, they are marked as green, yellow or red according to a calculated probability which also depends
on Peak Information Rate (PIR). If we denote the measured average rate of the flow as \( r \), the pseudo code of the TSWtcm can be described as follows,

\[
\text{TSWtcm Algorithm}
\begin{align*}
\text{if } r \leq \text{CIR} & \quad \text{mark packet as green} \\
\text{else if } (\text{CIR} < r \leq \text{PIR}) & \quad \text{mark packet as yellow with probability of } p_0 \\
\text{else } & \quad \text{mark packet as red with probability of } p_1
\end{align*}
\]

Figure 1 shows the probability of packet marking with the arrival rate normalized to CIR (PIR=1.5CIR). The system architecture that we consider in this paper is shown in Figure 2, which is based on the end-to-end QoS architecture for UMTS presented in [5] and currently under study within EVEREST. In this architecture, DiffServ edge function is provided by the gateway. In the gateway, IP BS manager is responsible to communication with other DiffServ domains as a Bandwidth Broker. If policy based QoS end-to-end management is applied, Policy decision function can be regarded as a Policy Decision Point. In this case, mobile network can be seen as an autonomous stub network. Thus, through the translation function located in the gateway, we assume that each DiffServ flow’s marking information can be made transparent to radio network controller for a better resource management.

### III. Link Adaptation Scheme

#### A. Radio Resource Management in CDMA

In this study, we consider an UMTS-based CDMA system. In which, multiple transmission rates are supported with a constant chip rate \( C \) by deployment of Variable Spreading Factor modulation (VSF). The chip rate \( C \) is set as 3.84 MHz and four transmission rates \{60kb/s, 120kb/s, 240kb/s, 480kb/s\} are supported for AF services.

In a CDMA system, the resources of interest are power and data-rate. In the downlink, the total BS transmission power is shared among the users in the cell. Each of users transmits its information with the fraction of the total power \( (\phi) \) that is allocated to them by the radio resource controller. The relation between the power and rate is given as follows, adopting the Gaussian approximation for the Multiple Access Interference (MAI),

\[
\phi_i = \frac{\text{SINR}_i \cdot \sqrt{R_i \cdot S_i^2 + I_{\text{other}}}}{\beta \cdot \varphi},
\]

where the MAI has been decomposed in its intra-cell \( (I_{\text{intra}}) \) and other interference \( (I_{\text{other}}) \) include background noise and other cell interference components. \( S \) is the total output signal power from the BS, \( R \) is the transmission rate, and \( \beta \) is the attenuation due to the radio propagation. SINR is the target signal-to-interference-plus-noise-ratio for this user.

With multiple simultaneous users, the power constraint is applied as

\[
\sum_{i=1}^{N} \phi_i \leq 1 (2)
\]

#### B. Link Adaptation Scheme

The proposed link adaptation concentrates on the differentiation of the radio resource based on the colour marking scheme and improving the data transmission subject to the BS power constraint. To achieve this, two types of queues are constructed in the BS as shown in Figure 3. One is used as a buffer for each user to store the incoming traffic packets, the other is an ID queue, which contains the active users’ IDs. In the link adaptation, the ID queue and rate adaptation scheme work jointly to decide the transmission window size \( D \). Here the transmission window is the set of users permitting to transmit in the current frame, denoted by numbered shaded blocks in the request queue in Figure 3. Its size \( D \) is adjusted by the proposed link adaptation scheme from frame to frame.

In the ID queue, queuing policies are applied to keep an order list for users’ transmission. Two queuing policies are considered in this paper for comparison. They are Modified Round Robin (MRR) and Interference Factor (IF):

- **MRR:** At the end of each frame, if the user on the top of the queue has just transmitted, then in the next frame, the user is moved to the end of the queue and the users after it in the queue shift up. If because of
lack of capacity, the user on the top is not permitted to transmit any information during this frame, it will remain at the top until transmission occurs.

- IF: At each frame, the users are ordered according to their propagation conditions. The user with the best propagation condition will be placed on the top the queue. The propagation condition is judged by the Interference Factor:

\[ F_i = \frac{l_{\text{other}}}{\beta_i} \]

where \( l_{\text{other}} \) is the estimated interference for user \( i \), and \( \beta_i \) is the estimated the attenuation due to the radio propagation.

To cooperate with the DiffServ marking scheme presented section 2, we further divide the queue into three sections corresponding to Green Section, Yellow Section and Red Section. In this separation, the green section is always on top of the other two sections and the yellow is on the top of the red section. In each section, the above mentioned queuing policies such as MRR and IF are applied. With this queuing structure, the high transmission priority is guaranteed for the conforming traffic over non-conforming traffic. The resource over air interface is allocated in the consistent way with the DiffServ core.

Based on the priority in ID queue, rate adaptation is designed here to minimize the packet delay subject the power constraint. In this paper, one of the most important performance measures is the data delay. An intuitive way to minimize the average transmission delay would be to maximize the instantaneous aggregate data throughput all the time. Maximization of data throughput in an interference-limited CDMA system through power and rate adaptation has been studied in [11][12][13]. As proved in [13], there actually exists an optimal SIR for ARQ type of data transmission, with which an asymptotic maximum data throughput can be achieved. With the optimal SIR value, a rate adaptation scheme is designed in [13] to maximize the data throughput with a constant power allocated to each data user. Further study in [11] [12] takes account of more constraints including each user’s maximum power and remaining message size. Basically, in this solution, a target SIR is set up for the data traffic and maximizing the instantaneous throughput becomes a problem of maximizing the instantaneous aggregate transmission rate subject to these two constraints. This optimisation problem can be solved using some optimisation method transmission rate and corresponding power level for each user. In our case, based on the previous studies [11]-[12], we propose the adaptation algorithm shown in Figure 5. This is to cooperate with the priority given by the scheduling scheme and discrete transmission rate subject to the constraint of BS power.

So in the proposed link adaptation scheme, AF users’ transmission order is given by the ID queuing algorithm, and the priorities are updated every frame. Then the rate adaptation algorithm is performed starting from the user on the top of the queue to choose a highest transmission rate among the four predefined transmission rates in section 3A with the constraints presented in (2). So, the queuing policy and rate adaptation work jointly to decide which users to transmit and the transmission rate for each of them. Through this rate adaptation, each transmitting user can transmit at the highest available transmission rate, and thus at the same time the transmission window size (\( D \), Figure 4) is kept to a minimum in terms of the number of simultaneous transmission data users, and this reduces the mutual interference between data users and thus increases aggregate throughput.

### IV Results and Discussions

The simulations are carried out with an AF class traffic. The performance measures in our evaluations are listed as following:

- Packet Delay, the time for transmitting an IP packet
- Transmission Rate, the number of bytes transmitted per user for each types of packets
- Aggregate Throughput, the number bytes successfully transmitted in one radio frame.

The major parameters are shown in table 1. In the simulations, the users are uniformly distributed over a cell with a radius of 1km. The packet flow interval is generated with exponential distributions with a mean of 1s and each
packet with a size of 576kbytes[14], thus the average rate \(Rm\), for a packet flow 576kbytes/s. Four CIRs are considered in our case: 0.5\(R_m\), 1\(R_m\), 1.5\(R_m\), and 2\(R_m\). The path loss model follows [15]:

\[
\beta_i = 144 + 38.4 \log_10 \left( \frac{d}{1000} \right) + S_L
\]

where \(d\) is the distance between mobile and the BS and \(S_L\) is the slow fading with 0 mean and std of 6dB.

In the proposed link adaptation algorithm, the DiffServ packet marking information is integrated into the scheduler, so that the resource allocated to each type of packet is differentiated in a consistent way with the DiffServ core: conforming traffic has a priority over non-conforming traffic. Results in Figure 5 clearly show the differentiation in resource allocation in terms of transmission rate with the proposed scheme. In this Figure as expected, the transmission rate decrease for all type of users, because as the traffic load increase, the limited resource is shared by more and more users. And the transmission rates for all types of packet are almost the same without color aware, which is shown by the solid line. However in the case with color aware queue, the transmission rate for each color is different to each other. Green users always have a better rate than other users because they are given high priority than other users. Also as traffic load increases, the difference becomes larger. The red users’ transmission rate decreases more rapidly (from more than 145byts drops to just over 100bytes) and in the contrast, the green users rate are only drop about 10bytes. The impacts of this differentiation on the performance on throughput and delay are given in Figure 6 and 7.

Figure 5 Throughput performance (solid lines—no color aware queue, dash lines—color aware)

In figure 6, we can find that actually the system throughput performances with or without color aware are almost the same. In general throughput increases as traffic load and then tend to be flat because the limited resource, in contrast to consistent declining trend in transmission rate. The diverse in the transmission rate and throughput is caused by our rate adaptation intend to minimize the average delay which is corresponding to the aggregate throughput not individual transmission rate as [13].

Figure 6 Delay Performance of IF and MRR with color aware.

Figure 6 shows the delay performance of MRR and IF queue both with color aware. IF offers a better performance in the average delay. The diversity of delay performance for different colored packets shows the consistence with the differentiation in transmission rate allocation presented in Figure 5. Again to enhance the delay performance of the in profile packets such as green packets, the out profile packets such as red packets are penalized in high traffic load situation.

V Conclusions

In this paper, a link adaptation scheme is designed to support DiffServ over CDMA air interface. With this link adaptation scheme, a scheduler is developed in cooperate with DiffServ marking scheme so that the resource is used in a differentiated way, which is in consistent with the DiffServ core, i.e. conforming traffic is given high priority in the resource allocation to enhance its performance whilst penalizing the non-conforming traffic in the congestion state. Further link adaptation is proposed to work with scheduler to improve the overall system performance in terms of total throughput and average delay. Further studies will carried out on the multiple
DiffServ classes, in which the radio resource will be further differentiated between different DiffServ classes.

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REFERENCES


Table 1. System Parameters

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<td>Spreading Factor</td>
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<td>Radio Data Block</td>
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<td>Channel Coding</td>
<td>1/3 Convolutional coding</td>
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