Flexible Layer One for the GSM/EDGE Radio Access Network (GERAN)

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ABSTRACT

In Release 6 of the 3GPP standards, a major enhancement of the physical layer is being designed for the GSM/EDGE Radio Access Network (GERAN): the Flexible Layer One (FLO). The main advantage of FLO is that configuration of the physical layer is specified at call setup. Consequently support of new services such as IP Multimedia Subsystem services can be handled smoothly without having to specify new coding schemes for each release. Through several enhancements, the radio bearers offered by FLO fulfils the IMS requirements in terms of flexibility and performance, and also improves the link level performance of real-time IMS services compared to GERAN Release 5. This paper describes the proposed architecture for FLO, highlights the commonalities with UTRAN and presents the gains it provides for the support of real time services compared to Release 5.

Keywords: GERAN, FLO, IMS, IP, UTRAN, channel coding, rate matching, error detection, interleaving.

I. INTRODUCTION

During the last few years, a major topic within the 3GPP standardization has been the introduction of the IP Multimedia Subsystem (IMS). The aim of the IMS is to provide IP based multimedia services to the user through the UMTS network. A key issue for the user of IMS Services is the Quality of Service (QoS) for the given application. Since each element of the network contributes to the total QoS, the Radio Access Network be it UTRAN or GERAN, has great importance when considering the total QoS. The radio bearers of UTRAN are designed in a way that is flexible enough to cope with the introduction of future IMS services such as real time multimedia. However, the radio bearers of GERAN have until now solely been either dedicated bearers specialized for given services, such as AMR speech services or they have been generic data bearers having fixed payload sizes, such as the (E)GPRS coding schemes. The fact that the nature of future IMS services to a large extent is unknown, have given rise to new work in designing and specifying a new layer one for GERAN, which can smoothly cope with the introduction of new services and greatly improve the spectral efficiency of these services.

This paper describes the new layer one for GERAN and highlights some of the design issues that have been taken into account. Furthermore the performance of FLO generated radio bearers are compared to the GERAN radio bearers of Release 5 of the 3GPP specifications.

The paper is organized as follows. Section II and III describe the motivation for and principles behind the flexible layer one. Section IV describes the architecture in details along with some performance issues related to the design. Section V contains an example of a Real Time multimedia service and provides a comparison of the new layer one and the layer one of Release 5. A main conclusion is given in section VI.

II. MOTIVATION

As mentioned in the introduction, the need for a flexible layer one in the Release 6 of GERAN is driven by the introduction of IMS services. For an efficient support of IMS services, the following requirements are set on the radio bearer service of the RAN [1] [2] [3] [4]:

- the radio bearers should be flexible enough to efficiently deploy any IP multimedia application;
- the radio bearers should allow the transport of several flows in parallel (e.g. text and video);
- the radio bearers should satisfy the user in a spectral efficient manner;
- the radio bearer should support the UMTS QoS concept and architecture.

In order to fulfil these requirements in an efficient manner, a flexible layer one similar to the UTRAN one is needed. The introduction of such a flexible layer one will enable optimised support of real time IMS services in GERAN.

III. OVERVIEW

III.1 General

In GERAN Release 5, the MAC sublayer is responsible for the mapping between the logical channels (traffic or control channels) and the basic physical channels [5]. The logical channels are the channels the physical layer offers

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to the MAC sublayer. Until now these logical channels and the mapping to the basic physical channel have been fully specified in [5].

In UTRAN a different approach has been taken, where instead of providing logical channels the physical layer offers Transport Channels (TrCH), which can be used by the MAC sublayer [6]. A transport channel is used to transmit one data flow with a given QoS over the radio interface. A number of transport channels can be active at the same time and multiplexed at the physical layer. The transport channels are configured at call setup by the network. With FLO, the concept of transport channels is introduced in GERAN.

III.2 Principles

When introducing FLO, the physical layer of GERAN offers one or several transport channels to the MAC sublayer. Each of these transport channels can carry one data flow providing a certain Quality of Service (QoS). A number of transport channels can be multiplexed and sent on the same basic physical channel at the same time.

The configuration of a transport channel i.e. the number of input bits, code type, interleaving, etc. is denoted the Transport Format (TF). As in UTRAN, a number of different transport formats can be associated to one transport channel.

The Transport Formats of each Transport Channel is defined by a number of attributes, which can be either dynamic or semi-static. The semi-static attributes are common for all Transport Formats associated to a given Transport Channel. The dynamic attributes can however be different for each Transport Format. Both types of attributes are defined at call setup and can be only be reconfigured using layer 3 signalling. Figure 1 illustrates the principles of transport channels and transport formats of FLO.

The configuration of the transport formats is completely controlled by the RAN and signalled to the MS at call setup or when the channel is reconfigured. In both the MS and the BTS, the transport formats are used to configure the encoder and decoder units. When configuring a transport format, the RAN can choose between a number of predefined CRC lengths, transport block sizes, and code types.

On transport channels, transport blocks (TB) are exchanged between the MAC sublayer and the physical layer on a transport time interval (TTI) basis (e.g. 20ms). For each transport block a transport format is chosen and indicated through the transport format indicator (TFIN). In other words, the TFIN tells which channel coding to use for that particular transport block on that particular TrCH during that particular TTI.

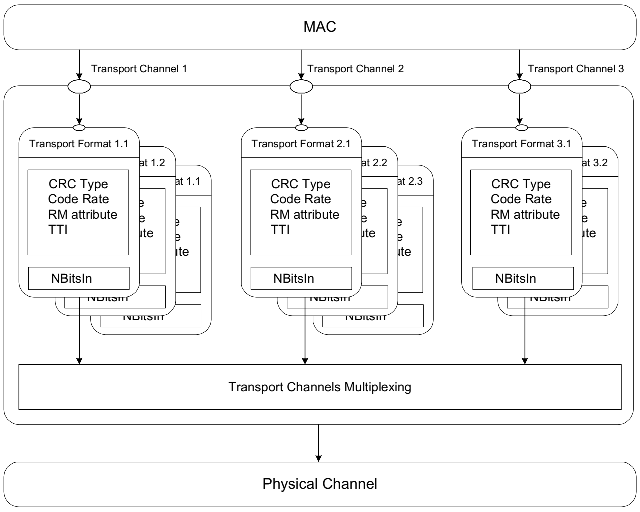

Figure 1: Transport Channels and Transport Formats

Only a limited number of combinations of the transport formats on the different TrCHs are allowed. A valid combination is called a Transport Format Combination (TFC). The set of valid TFCs on a basic physical channel is called the Transport Format Combination Set (TFCS).

In order to decode the received sequence the receiver needs to know the active TFC for a radio block. This information is transmitted in the Transport Format Combination Indicator (TFCI) field. This field is basically a layer 1 header and has the same function as the stealing bits in conventional GSM. Each of the TFC within a TFCS are assigned a unique TFCI value and when a radio block is received this is the first to be decoded. From the decoded TFCI value the transport formats for the different transport channels are known and the decoding can start.

IV. ARCHITECTURE

The proposed architecture for FLO in GERAN is depicted on Figure 2 below. In the following sections purpose and configuration of each building block of the architecture are given.

IV.1 CRC Attachment

Error Detection is provided on each transport block through a CRC. The size of the CRC to be used is fixed on each TrCH and configured by layer 3 (semi-static attribute of the transport format). The entire transport block is used to calculate the parity bits. Code blocks are output from the CRC attachment. In order to fulfil the residual BER QoS requirements given in [4], CRC sizes of 0 (no error detection), 6 (as in AMR), 12 (as in EGPRS) and 24 bits (as in UTRAN) were selected:

$$g_{CRC24}(D) = D^{24} + D^{23} + D^{6} + D^{5} + D + 1$$

$$g_{CRC12}(D) = D^{12} + D^{11} + D^{10} + D^{8} + D^{5} + D^{4} + 1$$

$$g_{CRC6}(D) = D^{6} + D^{5} + D^{3} + D^{2} + D^{1} + 1$$

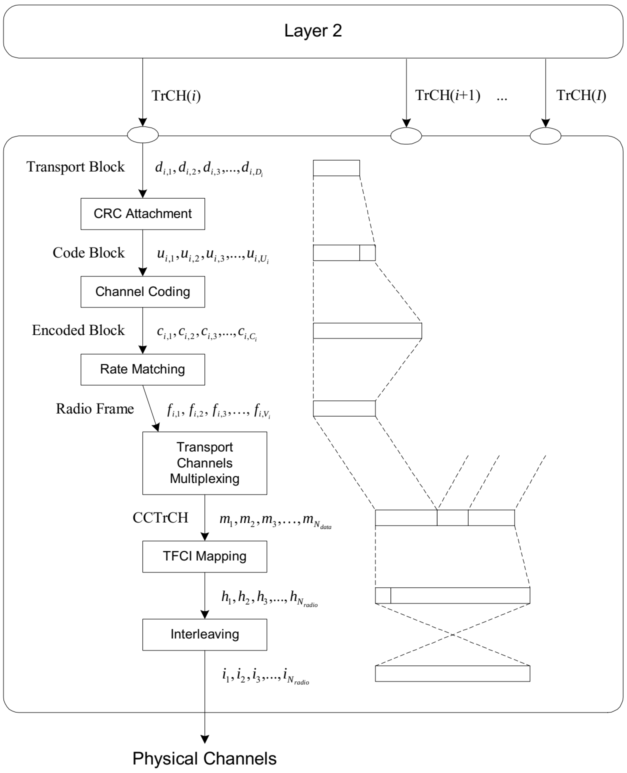

Figure 1: FLO Architecture

Upper limits for of the resulting RBER at 100% of BLER are listed in Table 1 below.

Table 1. Residual Bit Error Rate

CRC size	RBER
24 bits	6.10^{-8}
12 bits	2.10^{-4}
6 bits	2.10^{-2}

IV.2 Channel Coding

After CRC attachment, the code blocks are processed through channel coding, producing encoded blocks. In order to select the code that present the best performance when "randomly" punctured through rate matching, three different non recursive non systematic convolutional codes of constraint length 7 were compared:

rate 1/2 : G4 G7	as in ECSD
rate 1/3 : G4 G7 G5	as in EGPRS
rate 1/4 : G4 G5 G6 G7	new one

where $G4 = 1 + D^2 + D^3 + D^5 + D^6$

$G5 = 1 + D + D^4 + D^6$

$G6 = 1 + D + D^2 + D^3 + D^4 + D^6$

$G7 = 1 + D + D^2 + D^3 + D^6$

Simulations were run in TU3iFH at 900Mhz over 20000 frames always. Typical MS impairments were included. Interleaving was 8 bursts diagonal. Input block sizes ranged from 50 to 400 bits by 25 bits steps. Error detection was provided by a 12 bits CRC. In total, 90 different simulations were run, giving a realistic picture of the performance differences. Figure 2 summarizes the link level performance. It clearly appears that rate 1/3 in most cases is superior to rate 1/2 and 1/4 of which the behaviour

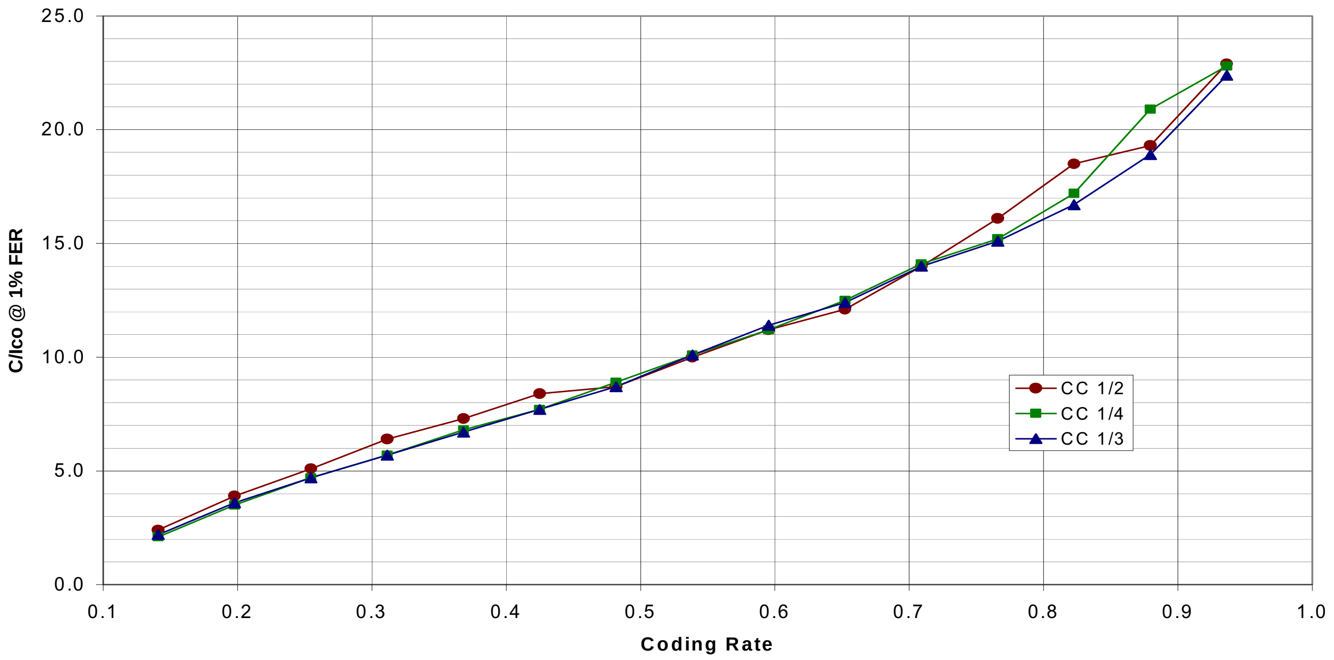

Figure 3. Mother Code Performance (TU3iFH - 900Mhz - 8 bursts diagonal interleaving)

is irregular for different coding rates, especially above coding rate of 0.6. Note that the very same conclusion can be drawn from simulations that were run in HT100nFH and RA250nFH, for which even larger differences were seen.

Furthermore using only one code rate simplifies the architecture, and eases the work of upper layers since no code selection is to be performed.
This is a clear simplification compared to UTRAN, where support of different code rates is available.

IV.3 Rate Matching

The rate matching is the core of FLO. In rate matching, bits of an encoded block on a transport channel are repeated or punctured. Since the block size is a dynamic attribute, the number of bits on a transport channel can vary between different transmission times. When it happens, bits are repeated or punctured to ensure that the total bit rate after TrCH multiplexing is identical to the total channel bit rate of the allocated basic physical channel (e.g. 464 bits every 20ms for full-rate GMSK and 1392 bits for full-rate 8PSK).

When only one transport channel is active at a time, the coding rate only depends on the transport block size and on the available channel bandwidth. But when more than one transport channel is active, the coding rate also depends on the rate matching attributes associated to each transport channel. The rate-matching attribute is used when the number of bits to be repeated or punctured for each transport channel is calculated.

Outputs from the rate matching are called radio frames. For every radio block the rate matching produces one radio frame per encoded block, i.e. per TrCH.

IV.3.1 Rate Matching Algorithm

The rate matching algorithm for GERAN is based on the algorithm defined for UTRAN [8]. A few simplifications are made since there is no spreading factor, nor compressed mode, nor special cases such as turbo codes and therefore many parameters of the UTRAN algorithm can be fixed either to 0 or 1 in GERAN. Notation used:

$\lfloor x \rfloor$: integer such that $x - 1 < \lfloor x \rfloor \le x$.

$|x|$: absolute value of *x*.

I: number of TrCHs in the coded composite transport channel (CCTrCH).

N_{data}: total number of bits that are available in a radio block for the CCTrCH.

$N_{i,j}$: number of bits in an encoded block before rate matching on TrCH *i* with transport format combination *j*.

$\Delta N_{i,j}$: if positive, denotes the number of bits that have to be repeated in an encoded block on TrCH *i* with transport format combination *j* in order to produce a radio frame. If negative, it denotes the number of bits that have to be punctured in an encoded block on TrCH *i* with transport format combination *j* in order to produce a radio frame. If null, no bits have to be punctured nor repeated, i.e. the rate matching is transparent and the content of the radio frame is identical to the content of the encoded block on TrCH *i* with transport format combination *j*.

RM_i: semi-static rate matching attribute for transport channel *i*.

e_{ini}: initial value of variable e in the rate matching pattern determination algorithm.

e_{plus}: increment of variable e in the rate matching pattern determination algorithm.

e_{minus}: decrement value of variable e in the rate matching pattern determination algorithm.

For each radio block using transport format combination *j*, the number of bits to be repeated or punctured $\Delta N_{i,j}$ within one encoded block for each TrCH *i* is calculated with the following equations:

for all $i = 1 \ldots I$:

$$Z_{0,j} = 0$$

$$Z_{i,j} = \left\lfloor \frac{\left(\sum_{m=1}^{i} RM_m \times N_{m,j} \right) \times N_{data}}{\sum_{m=1}^{I} RM_m \times N_{m,j}} \right\rfloor$$

$$\Delta N_{i,j} = Z_{i,j} - Z_{i-1,j} - N_{i,j}$$

For the calculation of the rate matching pattern of each TrCH *i* the following relations are defined:

$$e_{ini} = 1$$

$$e_{plus} = 2 \times N_{i,j}$$

$$e_{minus} = 2 \times \left| \Delta N_{i,j} \right|$$

The rate matching rule is as follows:

```
if $\Delta N_{i,j} < 0$
    $e = e_{ini}$
    $m = 1$
    do while $m \le N_{i,j}$
        $e = e - e_{\mathrm{minus}}$
        if $e \le 0$ then
            puncture bit $b_{im}$
            $e = e + e_{plus}$
        end if
        $m = m + 1$
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    end do
else if $\Delta N_{i,j} > 0$
    $e = e_{ini}$
    $m = 1$
    do while $m \le N_{i,j}$
        $e = e - e_{minus}$
        do while $e \le 0$
            repeat bit $b_{i,m}$
            $e = e + e_{plus}$
        end do
        $m = m + 1$
    end do
else do nothing
end if.
```

IV.3.2 Rate Matching Attribute

Higher layers assign the rate matching attribute for each transport channel. This attribute is semi-static and can only be changed through layer 3 signalling. The rate matching attributes define priorities between the coded bits of different transport channels. The higher the rate matching attribute is, the more important the coded bits are. By setting different rate matching attributes to different transport channels, the coding rate of the transport channels can be adjusted.

In UTRAN the rate matching attribute ranges from 0 to 255. In the following it is studied whether the same should be used in GERAN. From Figure 2 a simple relation can be found between the coding rate (CR) and the C/Ico required to reach 1% of BLER in TU3iFH: C/Ico = 23 × CR + α. This means that a 0.004 difference in coding rate triggers a 0.1dB difference in performance. Such a difference is considered as acceptable and will be the basis for this study.

In the analysis, two transport channels were considered. On each transport channel, block sizes ranged from 32 to 416 bits. For each possible combination of transport block sizes, the rate matching attribute of the first transport channel was adjusted to generate all possible coding rates for this transport channel. A coding rate was declared as reached when the difference between this coding rate and the one obtained with the rate matching attributes was not larger than 0.004 (for a 0.1dB loss in link level performance). For each coding rate that could not be reached, the triggered loss was computed as follows:

$$loss(dB) = \frac{closestCR - wantedCR}{0.004} \times 0.1 + 0.05$$

Four scenarios were studied where the rate matching attribute of the transport channels was limited to 8, 16, 32 and 64. The additional losses compared to an “ideal” case where the RM attributes ranges from 1 to 256 (as in UTRAN) were computed and are summarized in the table 2 below.

It appears that the range should not be limited to either 8 or 16 because of the triggered losses. A limit of 32 only has limited losses, while a limit of 64 provides the same performance as the existing UTRAN limit of 256. However, since the rate matching attribute is only signalled at call set-up, and since it would only save 2 bits per transport channel if the range was limited to 64 instead of 256, it is proposed to keep the existing range of 256 values.

Table 2: Effect of limiting the Rate Matching Attribute

RM limit	**Additional unreached CR**	**Average Loss (dB)**	**Probability Loss above**		
			0.5 dB	**1.0 dB**	**1.5 dB**
8	57.5 %	0.3	16.6%	3.1%	0.8%
16	23.9 %	0.1	1.5%	0.0%	0.0%
32	4.6 %	0.0	0.1%	0.0%	0.0%
64	0.3 %	0.0	0.0%	0.0%	0.0%

CR: Coding Rate

IV.4 Transport Channel Multiplexing

For every radio block to be transmitted, one radio frame from each active TrCH is delivered to the TrCH multiplexing. These radio frames are serially multiplexed into a Coded Composite Transport Channel (CCTrCH).

IV.5 TFCI Mapping

In order to decode the received sequence the receiver needs to know the active TFC for a radio block. This information is transmitted in the TFCI. From the decoded TFCI value the transport formats of the different transport channels are known and the actual decoding can start.

In UTRAN, the size of the TFCI is 10 bits allowing 1024 different transport format combinations on the same channel. The working assumption in GERAN is to assign the FLO configurations independently on each time slot. It is therefore proposed to limit the TFCI size to 5 bits, allowing a maximum of 32 different transport format combinations on the same basic physical channel. In other words, for a single time slot it is proposed to have a maximum of 32 different channel coding and/or multiplexing possibilities at the same time. During a connection a reconfiguration is of course possible. Because the TFCI is the very first thing to decode, its decoding should not limit the performance of the TrCH. Practically its coding should be strong, and at least as strong as the strongest coding that is used for a TrCH. In order to assess how many bits should be used on every radio block for the coded TFCI, we assumed that the strongest coding of a TrCH is obtained with a data rate of 5kbit/s for a full-rate GMSK connection.

Through simulations, two kinds of BLER were compared. One for which only the transmitted data was checked through the CRC, and another one where the TFCI errors were included in the BLER. The performance of the TFCI is acceptable when its decoding does not increase the BLER of the data. In other words, the performance of the TFCI is satisfactory if it does not trigger the loss of a packet that could have been decoded otherwise. The applied codes were simple block codes having the code lengths described below, see [8], [9] and [10] for the actual code tables.

Simulations were made for a GMSK full-rate channel using a TU3 profile with ideal frequency hopping, at 900Mhz (20000 frames). Error detection was provided by a 6 bits CRC, attached to every 100 bits data block (5kbit/s). A mother code of 1/3 was used (see IV.2). The TFCI was interleaved with the data using an 8 burst diagonal interleaving scheme as described in IV.6. The triggered loss for the selected code lengths is shown in Table 3.

Table 3: TFCI coding performance.

TFCI Coding uncoded - coded	**Triggered Loss C/Ico at 1%FER**
5 - 36	0.0
5 - 32	0.1
4 - 28	0.0
4 - 24	0.1
3 - 24	0.0
3 - 20	0.1
3 - 16	0.2
2 - 16	0.0
2 - 12	0.0
1 - 8	0.0
1 - 4	0.8

From these results it can be observed that in order not to limit the performance of the TrCHs, the TFCI should be coded as follows on GMSK full rate channels:

5 bits TFCI ⇒ 36 coded bits
4 bits TFCI ⇒ 28 coded bits
3 bits TFCI ⇒ 24 coded bits
2 bits TFCI ⇒ 16 coded bits
1 bit TFCI ⇒ 8 coded bits

Studies have shown that for 8PSK channels, a very good performance is obtained when using the same codes repeated once. That is, for a 4 bits TFCI the 28 bits codeword is repeated once for an 8PSK channel resulting in 56 bits [8].

IV.6 Interleaving

The coded TFCI and the CCTrCH are interleaved together on radio blocks. The interleaving can be either diagonal or block rectangular and is configured at call set-up. The interleaving is based on the following equations:

for $k = 0,1,2, \ldots K\text{-}1$

$$b = k \bmod D$$

$$\text{if } \quad \frac{K}{2} \bmod D = 0 \quad \text{then} \quad s = \operatorname{int}\left[\frac{k}{K/2}\right]$$

else $s = 0$

$$j = \frac{D}{M} \times \left[\left(49 \times (k+s)\right) \bmod \frac{J}{D/M} \right] + \operatorname{int}\left[\frac{k \bmod D}{M}\right]$$

where: j is the position of the bit k within the burst b; D is the interleaving depth in bursts; J is the burst size in bits; K is the size of the radio block in bits ($K = N_{radio}$); M is the size of the radio block in bursts ($M = K / J$).

V. EXAMPLE OF RT IMS SERVICE

One key aspect in the support of IMS services is that the RAN should be flexible enough to accommodate any service (see section II). For this example, no assumption is therefore made on the content of the RTP packets. It could be MPEG4 audio, MPEG4 video or anything else. Only the three following QoS requirements are set in order to set up the radio bearers:

Source rate:

- 8kbit/s: 160 bits IP packet / 20ms
- 12kbits/s: 240 bits IP packet / 20ms
- 16kbit/s: 320 bits IP packet / 20ms

RBER that requires a 12 bits CRC to be used.

Delay that allows a 40ms interleaving depth to be used but does not allow the RLC to be acknowledged, i.e. link level improvement by retransmission is not possible.

V.1 Radio Bearers

In this section the radio bearers that can be used for the support of the RT multimedia service example are given.

V.1.1 Release 5

In Release 5 radio bearers that can be used for RT multimedia services are based on the (E)GPRS coding schemes. However, these coding schemes are not optimised for the support of unacknowledged RT multimedia services as they were designed for acknowledged traffic on shared channels. Firstly, although a 40ms interleaving depth is allowed, according to the delay requirements, it is not possible to apply it when using the (E)GPRS coding schemes. Then, fortunately the RBER requirement matches the capability of the EGPRS coding schemes where 12 bits CRC are used. And finally since the payload to be carried does not exactly fit into one RLC packet some padding has to be used. The resulting release 5 radio bearers are therefore:

- for the 8kbit/s source rate, MCS-1 is used with 16 bits of padding;
- for the 12kbit/s source rate, MCS-3 is used with 56 bits of padding;
- for the 16 kbit/s source rate, MCS-4 is used with 32 bits of padding.

V.1.2 Release 6

With FLO, it is possible to optimise the physical layer according to the QoS requirements at radio bearer setup. For the RT multimedia service example, it means that:

- the coding scheme can be adjusted at a bit level and no padding bits are used;
- the RLC/MAC header can be optimised for unacknowledged mode;
- 12 bits CRC is used as requested by the RBER requirement;
- 40ms interleaving depth is used as allowed by the delay requirement.

V.2 Link Level Performance

The link level performance of the radio bearers of release 5 and the ones that can be obtained with FLO in release 6 are here compared for the support of the RT multimedia service example. The RLC was unacknowledged, the MAC mode dedicated, 20 000 frames were simulated in TU3iFH, and typical MS impairments were included. For FLO, a 24 bits coded TFCI was assumed. Simulation results are presented on Figure 3 and summarized in Table 4. For an 8kbit/s RT multimedia service, the simulations show that FLO can bring a 3.6dB gain. At this rate, only a few padding bits are used in the Release 5 radio bearer. Consequently, the gain of FLO mainly comes from the reduced overhead and the longer interleaving depth. For a 12kbit/s RT multimedia service, FLO is shown to bring 8.7dB gain and for a 16kbit/s RT multimedia service, the gain is 9.7dB. The increased gains compared to 8kbit/s come from the padding bits.

In brief by the introduction of FLO the performance of RT multimedia services is improved. Note that it is important to remember that it does not mean that the performance of EGPRS is poor, but simply that EGPRS was not optimised for the support of unacknowledged dedicated RT services on dedicated channels as it was designed for acknowledged traffic on shared channels.

Table 4: Link Level improvement with FLO

RT service Source Rate	**Release 5**	**Release 6 with FLO**	**Gain from FLO**
8 kbit/s	11.0 dB	7.4 dB	3.6 dB
12 kbit/s	19.5 dB	11.3 dB	8.2 dB
16 kbit/s	25.1 dB	15.4 dB	9.7 dB

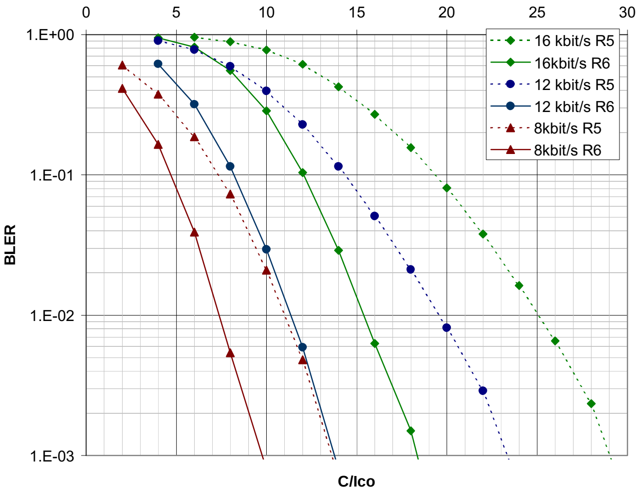

Figure 3: Link Level Performance (TU3iFH - 900MHz)

VI. CONCLUSION

This paper has described FLO, the enhancement of the physical layer that is being designed for an optimised support of IMS Services in the Release 6 of GERAN. The main advantage of FLO is that configuration of the physical layer is specified at call setup allowing smooth introduction of new services. Performance simulations have shown that FLO can provide gains compared to the Release 5 radio bearers for RT multimedia services. The gains obtained, originate from enhanced granularity (the payload of FLO can be tailored to the given application), reduced overhead and flexible interleaving. Besides having described the performance gains of FLO, the paper has dealt with some of the considerations when designing FLO. Different solutions when choosing mother codes and block codes for the TFCI coding have been compared and optimized through simulations. Last but not least, the architecture of FLO brings GERAN even closer to UTRAN and together with Iu alignment, it enables seamless provision of services over the two radio access technologies.

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