Circuit-Switched Voice over Scalable UMTS

Soumya Das, Yuheng Huang, Edwin Park, and Samir Salib Soliman
QUALCOMM Technologies, Inc.
San Diego, CA 92121
{soumyad, yuhengh, epark, ssoliman}@qti.qualcomm.com

***Abstract*— Scalable Universal Mobile Telecommunications System (S-UMTS) carriers occupy bandwidth different than regular UMTS carriers and may fit in available spectrum that cannot be used by UMTS carriers today. Due to the bandwidth scaling, the data rates in S-UMTS are scaled by the bandwidth scaling factor compared to regular UMTS for the same physical layer configuration. However, some services like Circuit-Switched (CS) voice needs the same data rate in S-UMTS as in regular UMTS. The modified configuration needed in S-UMTS to maintain the data rate of such services is proposed. Additionally, both uplink and downlink voice capacity in S-UMTS are shown to scale with the bandwidth scaling factor.**

Keywords- S-UMTS; AMR; TTI; spreading factor; slot format.

I. Introduction

UMTS has a chip rate of 3.84 Megachips per second (Mcps) and a nominal 5 MHz channel bandwidth. Many operators own spectrum that is non 5 MHz multiples, creating unusable narrow-bandwidth fragments where a 5 MHz carrier cannot be accommodated. Fig. 1 shows an example where a regular UMTS carrier may not fit the available spectrum between two UMTS carriers while a S-UMTS carrier occupying less than 5 MHz may fit.

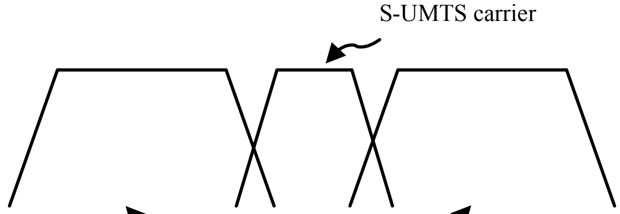

Figure 1. Scalable bandwidth UMTS carrier

This paper focuses on generating a S-UMTS carrier by scaling down the chip rate with respect to a regular UMTS carrier. Hence, such a S-UMTS carrier occupies smaller bandwidth than a regular UMTS carrier. Accordingly, the chip duration is increased or "dilated" by the same factor. For example, to generate a 2.5 MHz S-UMTS carrier, the chip rate is reduced by a factor of 2 from 3.84 Mcps to 1.92 Mcps. In S-UMTS due to the time dilation, chip duration, slot duration, frame duration, sub frame duration, and Transmission Time Interval (TTI) get scaled up, i.e., dilated by a factor of D_{cr} which is the chip rate divisor (D_{cr} =2 for 2.5 MHz S-UMTS). Hence, the data rate in S-UMTS gets scaled down by the same factor D_{cr} compared to regular UMTS. The same Power Spectral Density (PSD) is assumed for S-UMTS and UMTS. S-UMTS has the same link budget as UMTS and thus maintains the same coverage. S-UMTS parameters with respect to regular UMTS are shown in TABLE I.

TABLE I. Scalable UMTS Parameters

	Regular UMTS (Dcr=1)	S-UMTS
Nominal Bandwidth (MHz)	5	5/Dcr
Chip Rate (Mcps)	3.84	3.84/Dcr
Radio Frame Duration (ms)	10	10xDcr
Data Rate	D	D/Dcr
Power	P	P/Dcr
Range	R	R
Capacity	C	C

The scaling down of data rate in S-UMTS poses a challenge to support services like CS voice using the same vocoder where the service needs to maintain the same data rate as in regular UMTS. The support for 12.2 kbps Adaptive Multi-Rate (AMR) over 2.5 MHz (D_{cr}=2) S-UMTS is discussed in this paper. The rest of the paper is organized as follows. Section II discusses the configurations for supporting AMR 12.2 kbps over regular UMTS; Section III discusses the changes in configurations needed for supporting AMR 12.2 kbps over D_{cr}=2 S-UMTS; Section IV shows that the voice capacity of S-UMTS scales with the bandwidth while Section V concludes the paper.

II. Full Rate AMR 12.2kbps voice over UMTS

Full rate AMR corresponds to bit rate 12.2 kbps, namely "Conversational / speech / UL:12.2 DL:12.2 kbps / CS RAB + UL:3.4 DL:3.4 kbps SRBs for DCCH", as defined in [1], Section 6.10.2.2. Every 20 ms, the AMR vocoder produces a set of voice frames designated Class-A, Class-B, and Class-C. The Class-A bit sequence is the most important, is CRC protected and convolutionally encoded at rate 1/3. The Class-B does not have a CRC, but is encoded at the same rate of 1/3 as Class-A. The Class-C is the least important, which does not have a CRC and only encoded at rate 1/2. Each class is mapped to a separate Radio Access Bearer (RAB) subflow, which is then mapped to a separate Dedicated Traffic Channel (DTCH logical channel). The 3 DTCHs operate in Radio Link Control (RLC) Transparent Mode (TM) with a maximum Service Data Unit (SDU) size of 81, 103, and 60 bits respectively. The configuration for the DTCH carrying Class A bits also allows a SDU size of 39 bits for the Silence Indicator Descriptor (SID) and 0 bits for a Null frame. Medium Access Control (MAC) maps each DTCH directly

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onto the associated Dedicated Channel (DCH transport channel) without adding a header. Using a TTI of 20 ms, half of the MAC Protocol Data Unit (MPDU) is transmitted during one radio frame (10 ms), and the other half is transmitted during the next radio frame.

There are four DCCHs allocated to carry control plane signaling, two for Radio Resource Control (RRC) and two for Non Access Stratum (NAS). MAC multiplexes the four DCCHs onto a single DCH, adding a header containing the C/T (Control/Traffic) field to identify the logical channel from which the data was sent. The DCH is CRC protected and convolutionally encoded at rate 1/3. Using a 40 ms TTI, the MAC PDU is distributed over four radio frames, concatenated with the blocks from the voice DCHs. Therefore, there are four Signaling Radio Bearers (SRBs) for RRC and NAS signaling and one RAB for voice. The mapping is as follows:

- 4 SRBs → 4 DCCHs → 1 DCH using 40 ms TTI
- 1 RAB → 3 DTCHs → 3 DCHs using 20 ms TTI

Fig. 2 shows the transport channel procedure for "AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB" in UMTS.

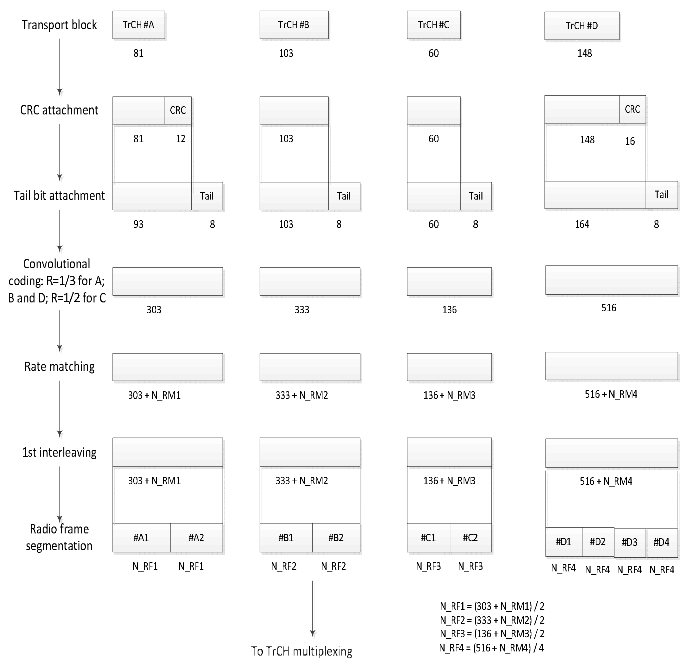

Figure 2. TrCH procedure for "AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB" in UMTS

The individual TrCHs are broken from their TTI into 10 ms frames. These frames are then serially multiplexed into a Coded Composite Transport Channel (CCTrCH). Thus each CCTrCH contains a portion of the AMR Class-A, Class-B, and Class-C bit sequences, plus a portion of the signaling information. A downlink Dedicated Physical Channel (DPCH) with 60 kbps is allocated to carry one CCTrCH. A second round of interleaving is done on the CCTrCh. The 510 coded bits per radio frame include CRC and tail bits, rate 1/2 or 1/3 bits-to-coded bits coding, and rate matching (RM). Then the coded bits go through serial-to-parallel conversion and are placed onto a 30 ksps Dedicated Physical Data Channel (DPDCH). Fig. 3 shows the transport channel multiplexing and mapping to physical channels for "AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB" in UMTS. It is to be noted that the Fig. 2 and 3 are for one of the six transport format combinations (TFCs) as specified in [1], Section 6.10.2.4.1.4: *(RAB subflow#1, RAB subflow#2, RAB subflow#3, DCCH) = (TF2, TF1, TF1, TF1)*

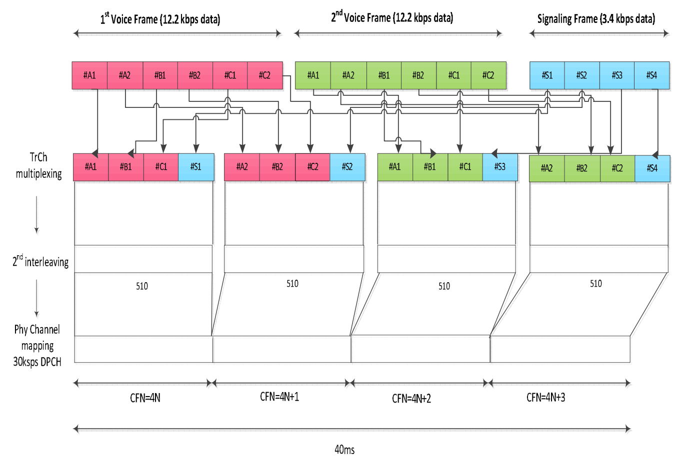

Figure 3. TrCH multiplexing and mapping to PhCH for "AMR DL: 12.2kbps RAB + DL: 3.4 kbps SRB" in UMTS

TABLE II. TRANSPORT CHANEL PARAMETER FOR CONVERSATIONAL/SPEECH/UL/DL 12.2 KBPS /CS RAB

RAB/Signalling RB		RAB subflow #1	RAB subflow #2	RAB subflow #3
TB sizes, bit		39, 81 (alt. 0, 39, 81)	103	60
TFS	TF0, bits	0x81	0x103	0x60
	TF1, bits	1x39	1x103	1x60
	TF2, bits	1x81	N/A	N/A
TTI, ms		20	20	20
Coding type		CC 1/3	CC 1/3	CC 1/2
CRC, bit		12	N/A	N/A
Max number of bits/TTI after channel coding		303	333	136
Uplink: Max number of bits/radio frame before rate matching		152	167	68
RM attribute		180 to 220	170 to 210	215 to 256

TABLE II and TABLE III show the UL/DL transport channel parameters for CS RABs and SRBs respectively [1]. In regular UMTS, slot format 8 is typically used in DL, slot format 2 for UL DPDCH, and slot format 0 for UL Dedicated Physical Control Channel (DPCCH) for AMR 12.2 kbps. During compressed mode, slot format 8B is used in DL, slot format 3 for UL DPDCH, and slot format 0A or 0B for UL DPCCH. The DL DPDCH and DPCCH fields for different slot formats, UL DPCCH fields for different slot formats and UL DPDCH fields for different slot formats are defined in [2].

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TABLE III. TRANSPORT CHANEL PARAMETER FOR DL/UL 3.4 KBPS SRBS FOR DCCH

RAB/Signalling RB		SRB#1	SRB#2	SRB#3	SRB#4
User of radio bearer		RRC	RRC	NAS_DT High prio	NAS_DT Low prio
TB sizes, bit		148 (alt 0, 148)			
TFS	TF0, bits	0x148 (alt 1x0)			
	TF1, bits	1x148			
TTI, ms		40			
Coding type		CC 1/3			
CRC, bit		16			
Max number of bits/TTI after channel coding		516			
UL: Max number of bits/radio frame before RM		129			
UL RM attribute		155 to 185			
DL RM attribute		155 to 230			

TABLE IV. DL SLOT FORMAT – DPDCH AND DPCCH FIELDS FOR UMTS

Slot Format	Channel Bitrate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Slot	DPCCH Bits/Slot NTPC, NTFCI, NPilot	DPDCH Bits/Slot NData1, NData2	Transmitt-ed slots per radio frame
8	60	30	128	40	2,0,4	6, 28	15
8B	120	60	64	80	4,0, 8	12, 56	8-14

TABLE V. UL SLOT FORMAT – DPDCH FIELDS FOR UMTS

Slot Format	Channel Bitrate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/Frame	Bits/Slot	Ndata
2	60	60	64	600	40	40
3	120	120	32	1200	80	80
4	240	240	16	2400	160	160

TABLE VI. UL SLOT FORMAT – DPCCH FIELDS FOR UMTS

Slot Format	Channel Bitrate (kbps)	SF	Bits/Frame, Bits/Slot	NPilot, NTPC, NTFCI, NFBI	Transmitted slot per radio frame
0	15	256	150, 10	6, 2, 2, 0	15
0A	15	256	150,10	5, 2, 3, 0	10-14
0B	15	256	150, 10	4, 2, 4, 0	8-9

For the RM example in TABLE VII, the DL slot format is 8 with (6+28) x 15=510 (NData1 and NData2 in TABLE IV) data bits in a 10 ms radio frame. The RM attributes and the channel coded blocks for the four transport channels are shown in TABLE VII. After the radio frame segmentation, using the TTI of each of the four transport channels, the above bits match 510, i.e., 312/2 + 328/2 + 166/2 + 428/4 = 510.

TABLE VII. RATE MATCHING EXAMPLE

	TrCh# A	TrCh# B	TrCh# C	TrCh# D
RM Attribute	200	190	235	160
Channel Coded Blocks	303	333	136	516
Rate Matched	312	328	166	428

III. FULL RATE AMR 12.2KBPS VOICE OVER S-UMTS (D_{CR}=2)

The physical layer configuration for AMR voice service in regular UMTS (e.g., up to Rel-11) no longer meets the required data rate for AMR 12.2 kbps in S-UMTS. On the other hand, supporting full rate AMR (12.2kbps) is a requirement for many infra vendors and operators. The proposed solution to facilitate the support of CS voice over S-UMTS uses

a) SF reduction

b) TTI inverse scaling

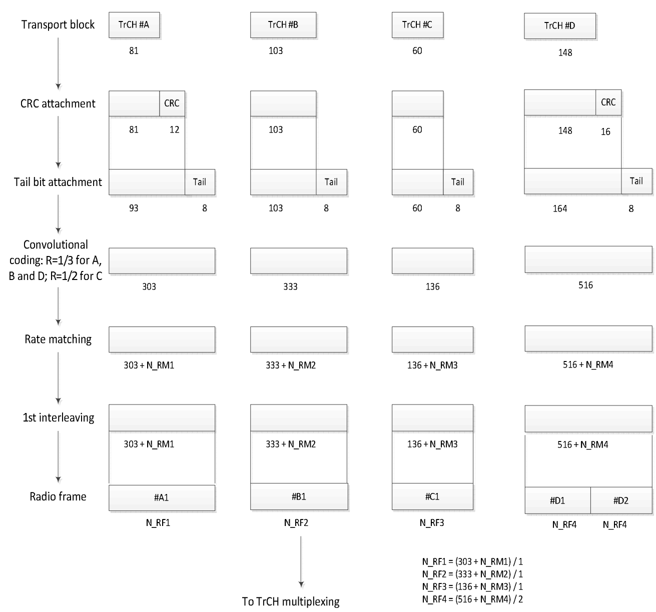

Figure 4. TrCH procedure for “AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB” in Dcr=2 S-UMTS

Fig. 4 shows the transport channel procedure for “AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB” in D_{cr}=2 S-UMTS. For 12.2 kbps AMR, one voice frame is still mapped to a 20 ms time window upon transmission, irrespective of D_{cr} in S-UMTS. To meet the requirements, SF reduction by D_{cr} in both DL and UL is proposed along with the following mapping

•4 SRBs → 4 DCCHs → 1 DCH using 20 x D_{cr}, i.e., 20 x 2 ms = 40 ms TTI

•1 RAB → 3 DTCHs → 3 DCHs using 10 x D_{cr}, i.e., 10 x 2 ms = 20 ms TTI

It is to be noted, that 10 x D_{cr} ms and 20 x D_{cr} ms TTI in S-UMTS correspond to 10 ms and 20 ms TTI respectively in regular UMTS except the time dilation in S-UMTS by D_{cr}.

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TABLE VIII. TRANSPORT CHANEL PARAMETER FOR CONVERSATIONAL/SPEECH/UL/DL 12.2 KBPS /CS RAB

RAB/Signalling RB		RAB subflow #1	RAB subflow #2	RAB subflow #3
TB sizes, bit		39, 81 (alt. 0, 39, 81)	103	60
TFS	TF0, bits	0x81	0x103	0x60
	TF1, bits	1x39	1x103	1x60
	TF2, bits	1x81	N/A	N/A
TTI, ms		10xDcr=10x2	10xDcr=10x2	10xDcr=10x2
Coding type		CC 1/3	CC 1/3	CC 1/2
CRC, bit		12	N/A	N/A
Max number of bits/TTI after channel coding		303	333	136
Uplink: Max number of bits/radio frame before rate matching		303	333	136
RM attribute		180 to 220	170 to 210	215 to 256

TABLE IX. TRANSPORT CHANEL PARAMETER FOR DL/UL 3.4 KBPS SRBS FOR DCCH

RAB/Signalling RB		SRB#1	SRB#2	SRB#3	SRB#4
User of radio bearer		RRC	RRC	NAS_DT High prio	NAS_DT Low prio
TB sizes, bit		148 (alt 0, 148)			
TFS	TF0, bits	0x148 (alt 1x0)			
	TF1, bits	1x148			
TTI, ms		20xDcr=20x2			
Coding type		CC 1/3			
CRC, bit		16			
Max number of bits/TTI after channel coding		516			
Uplink: Max number of bits/radio frame before rate matching		258			
UL RM attribute		155 to 185			
DL RM attribute		155 to 230			

Let SF_{UMTS} be the SF for AMR 12.2 kbps in regular UMTS. According to [1], Section 6.10.2.4.1.4, $SF_{UMTS,UL\ DPDCH}$ = 64 and $SF_{UMTS,DL\ DPCH}$ =128. For D_{cr} =2 S-UMTS, SF is calculated as in (1) for both UL and DL so that the number of channel bits per 20 ms stay unchanged.

$$SF_{S-UTMS} = \frac{SF_{UMTS}}{D_{cr}} \quad (1)$$

However, $SF_{UMTS,UL\ DPDCH}$=256 for both UMTS and S-UMTS. During the radio frame segmentation, 10 X D_{cr}, i.e., 10 x 2 = 20 ms AMR TTIs fit into 10 x D_{cr}, i.e., 10 x 2 ms = 20 ms radio frames while the 20 x D_{cr}, i.e., 20 x 2 ms = 40 ms DCCH TTI are broken into two 20 ms radio frames. TABLE VIII and TABLE IX show the transport channel parameters in UL and DL for CS RABs and SRBs respectively. In DL, DPCCH and DPDCH are time multiplexed as DPCH, and use the same SF.

The modified version of slot format 8 for D_{cr}=2 S-UMTS in TABLE X corresponds to slot format 8B for UMTS in TABLE IV for DL DPCH in terms of spreading factor and bits per slot. For D_{cr} =2 S-UMTS, as there is less bandwidth while the timing and bit requirements of AMR 12.2 kbps are the same, the SF is reduced to increase the bits/slot and bits/frame accordingly. However, the channel bitrate or channel symbol rate stays unchanged as time is dilated for D_{cr}=2 S-UMTS. The RM tuning method also stays unchanged in D_{cr}=2 S-UMTS as compared to regular UMTS. The slot format 8B in TABLE X does not correspond to any slot format in regular UMTS.

TABLE X. DL SLOT FORMAT – DPDCH AND DPCCH FIELDS FOR S-UMTS (DCR=2)

Slot Format	Channel Bitrate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Slot	DPCCH Bits/Slot NTPC, NTFCI, NPilot	DPDCH Bits/Slot NData1, NData2	Transmitted slots per radio frame
8	120/Dcr =60	60/Dcr= 30	64	80	4,0,8	12, 56	15
8B	240/Dcr =120	120/Dcr =60	32	160	8,0, 16	24, 128	8-14

TABLE XI. UL SLOT FORMAT – DPDCH FIELDS FOR S-UMTS (DCR=2)

Slot For-mat	Channel Bitrate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	Ndata
2	120/Dcr=60	120/Dcr=60	32	1200	80	80
3	240/Dcr=120	240/Dcr=120	16	2400	160	160

TABLE XII. UL SLOT FORMAT – DPCCH FIELDS FOR UMTS

Slot Format	Channel Bitrate (kbps)	SF	Bits/Frame, Bits/Slot	NPilot, NTPC, NTFCI, NFBI	Transmitted slot per radio frame
0	15/Dcr =7.5	256	150, 10	6, 2, 2, 0	15
0A	15/Dcr =7.5	256	150, 10	5, 2, 3, 0	10-14
0B	15/Dcr =7.5	256	150, 10	4, 2, 4, 0	8-9

The slot formats 2 and 3 for D_{cr}=2 S-UMTS in TABLE XI correspond to slot formats 3 and 4 respectively for UMTS in TABLE V for UL DPDCH. For D_{cr}=2 S-UMTS, as there is less bandwidth while the timing and bit requirements of AMR 12.2 kbps are the same, the SF is reduced to increase the bits/slot and bits/frame accordingly. However, the channel bitrate or channel symbol rate stays unchanged as time is dilated for D_{cr}=2 S-UMTS. The RM tuning method also stays unchanged. The slot formats 0, 0A and 0B for D_{cr}=2 S-UMTS in TABLE XII correspond to slot formats 0, 0A and 0B respectively for UMTS in TABLE VI for UL DPDCH. For UL DPCCH, all slot formats have SF 256. Hence, the bits/slot and bits/frame stays the same and channel bitrate and channel symbol rates are scaled down by D_{cr}. As a result, the Transmit Power Control (TPC) rate is reduced from 1500Hz in UMTS to 1500/ D_{cr}, i.e., 750 Hz in D_{cr}=2 S-UMTS.

Fig. 5 shows the TrCH multiplexing and mapping to physical channels for "AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB" in D_{cr}=2 S-UMTS. The TrCHs for AMR fit into radio frames entirely while the TrCH for signaling is broken from its TTI into 10 x D_{cr} ms, i.e., 20 ms frames. These frames are then serially multiplexed into a Coded Composite Transport Channel (CCTrCH). Thus, each CCTrCH contains an AMR Class-A, B, and C bit sequences, plus a portion of the signaling information. A downlink DPCH with 120/D_{cr}, i.e., 120/2=60 kbps is allocated to carry one CCTrCH. A second round of interleaving is done on the CCTrCh. The 510 x D_{cr}, i.e., 1020 coded bits per radio frame include CRC and tail bits, rate 1/2 or 1/3 bits-to-coded bits coding, and RM. Then the coded bits go through serial-to-parallel conversion and are placed onto a 60/ D_{cr}, i.e., 60/2=30 ksps DPDCH.

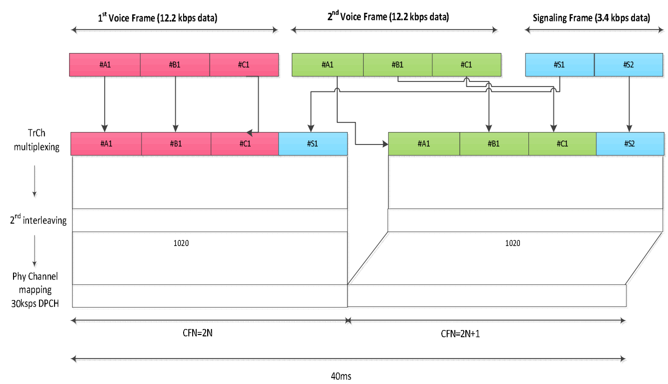

Figure 5. TrCH multiplexing and mapping to PhCH for "AMR DL: 12.2kbps RAB + DL: 3.4 kbps SRB" in Dcr=2 S-UMTS.

It is to be noted that Figs. 4 and 5 are for one of the six TFCs as specified in [1], Section 6.10.2.4.1.4:
(RAB subflow#1, RAB subflow#2, RAB subflow#3, DCCH) = (TF2, TF1, TF1, TF1)

RM is done before radio frame segmentation in the DL for UMTS. For D_{cr}=2, radio frame segmentation is not needed for TrCh# A, TrCh# B and TrCh# C. At this point, the number of bits are exactly equal for UMTS and D_{cr}=2 S-UMTS as there is no difference in processing till radio frame segmentation. As a result, RM attributes stay the same for D_{cr}=2 S-UMTS as in UMTS. For the RM example earlier shown in TABLE VII, the DL slot format is 8 (modified) with SF 64 (TABLE X). There are (12+56) x 15=1020 data bits in a 10 x D_{cr}, i.e., 20 ms radio frame. The RM attributes, the channel coded bits and bits after RM for the four transport channels stay the same as in TABLE VII. Using the TTI of each of the four transport channels, the above bits match 1020, i.e., 312 + 328 + 166 + 428/2 = 1020.

A. Transport Format Combination Indicator (TFCI)

a) Blind Transport Format Detection for D_{cr}=2 S-UMTS DL

In UMTS, Blind Transport Format Detection (BTFD) is used for "AMR DL: 12.2 kbps RAB + DL: 3.4 kbps SRB" as DL slot format 8 with SF 128 as shown in TABLE IV has no TFCI. BTFD is used in UMTS DL for AMR voice because if the TFCI field is sent, the SF would have to be lower and lower SFs for voice provide a greater potential to run out of Orthogonal Variable Spreading Factor (OVSF) codes. For D_{cr}=2, the modified slot format 8 as shown in TABLE X also has no TFCI. Section 4.3.1 of [3] puts a number of restrictions that need to be fulfilled for BTFD. In order to allow BTFD for AMR 12.2 kbps for D_{cr}=2 S-UMTS, the following restriction needs to be changed.

- the number of CCTrCH bits received per radio frame is 600 x D_{cr} or less instead of 600.

b) UL TFCI

There are 32 TFCI encoded bits that needs to be transmitted at least once every 20ms, i.e., every voice frame. TFCI is encoded using a (32, 10) sub-code of the second order Reed-Muller code [3]. If the TFCI consists of less than 10 bits, it is padded with zeroes to 10 bits, by setting the most significant bits to zero. The bits of the 32 bit TFCI code word are directly mapped to the slots of the radio frame. Within a slot the bit with lower index is transmitted before the bit with higher index. The coded bits b_k are mapped to the transmitted TFCI bits d_k according to the following formula:

$$d_k = b_k mod 32 \qquad (2)$$

For uplink physical channels regardless of the SF, bits b_{30} and b_{31} of the TFCI code word are not transmitted. Using slot format 0 in TABLE XII, there are 2x15 =30 TFCI encoded bits every frame duration of 10 x D_{cr}, i.e., 20ms. Therefore, bits b30 and b31 of the TFCI code word are not transmitted. For uplink compressed mode, the slot format is changed so that no TFCI coded bits are lost [3]. The different slot formats in compressed mode do not match the exact number of TFCI coded bits for all possible Transmission Gap Lengths (TGL). Repetition of the TFCI bits is therefore used.

B. TPC and Pilot

For the TPC and pilot bits in DL, the patterns defined in [2], are used. Similarly, for the TPC and pilot bits in UL, the patterns defined in [2], are used.

C. Transmission Power

Generally, a reduction in SF has impacts on the link budget. In order to maintain the same voice service coverage, the UE and NodeB need to increase the transmission power according to the chosen SF. The baseline assumption is that the Power Spectral Density (PSD) remains the same in both uplink and downlink for UMTS and S-UMTS. Since the S-UMTS bandwidth is 1/D_{cr} of that of regular UMTS, the total transmit power of S-UMTS is also 1/D_{cr} of the transmit power of regular UMTS. However, for supporting AMR voice, this has been relaxed. In the DL, the total transmit power of S-UMTS is still assumed to $1/D_{cr}$ of the transmit power of regular UMTS and hence, same PSD remains for S-UMTS. However, the transmit power for each voice channel is same in S-UMTS and in regular UMTS. In the UL, the UE transmit power in S-UMTS is assumed to be the same as that in regular UMTS. In other words, the transmit power in S-UMTS for AMR in both UL and DL is increased by $10log10(Dcr)$ dB w.r.t. same PSD to compensate for SF reduction.

D. Latency

Once the first voice frame (equivalently 20 ms long) is available at the MAC, it will be delivered to the PHY. After some PHY layer processing (assuming processing time does not scale with D_{cr}), the over-the-air transmission is allowed to start only at the next radio frame boundary due to the current specification restriction. However, for D_{cr}=2 S-UMTS, as the TTI is 10 x D_{cr} =20 ms and the radio frame is also 10 x D_{cr} =20 ms, there is no additional latency compared to regular UMTS. For $D_{cr} > 2$, there would be additional latency due to TTI (10 x D_{cr}) being greater than 20 ms.

IV. VOICE CAPACITY

The voice capacity in the uplink and downlink are compared between UMTS and S-UMTS in *A* and *B* respectively.

A. Uplink Capacity

The upper bound of the uplink capacity, referred to as the pole capacity (N_{pole}) of a UMTS carrier, can be estimated using the standard uplink capacity equation [8]

$$N_{pole} = \frac{W/_{R_b}}{E_b/_{N_t} * v * (1+\propto)} \quad (3)$$

where

W = Spreading bandwidth of the system
R_b = RAB rate for selected application, e.g., AMR 12.2 kbps
$E_b/_{N_t}$ = Required energy per bit to total noise spectrum density ratio
v = Voice Activity Factor (VAF)
$\propto$ = Interference factor (ratio between the other cell interference power and the total received signal power of users in the cell)
Note: VAF depends on the vocoder, channel coding etc. and is typically considered as 60%

The pole capacity is obtained by assuming that the user equipment (UE) has infinite transmission power and the interference at the Node-B receiver goes to infinity. For a practical system, both the UE transmission power and the node-B receiver allowed interference level are limited and the operating point is set well below the pole capacity. This operating point is referred to as the uplink loading and is defined as the percentage of the pole capacity. From the pole capacity, a practical cell capacity (Nuser,η) for a system can be calculated after the uplink loading (η) has been determined, as shown in (3).

$$N_{user} = N_{pole} * \eta \quad (4)$$

The link efficiency for UMTS is given by the following equation

$$\frac{E_b}{N_t} = \frac{E_c}{N_t} + 10log10\left(\frac{R_c}{R_b}\right) \quad (5)$$

where

- R_b is the UMTS traffic rate
- R_c is the UMTS chip rate

For AMR over S-UMTS,

- Chip rate is R_c/D_{cr}
- R_b is same as in UMTS

$$\left(\frac{E_b}{N_t}\right)_{S-UMTS} = \left(\frac{E_c}{N_t} * \frac{R_c}{R_b}\right)_{S-UMTS} = \left(\frac{Dcr * E_c}{N_t} * \frac{R_c/_{Dcr}}{R_b}\right)_{UMTS} = \left(\frac{E_b}{N_t}\right)_{UMTS} \quad (6)$$

The link efficiency for S-UMTS is same as the link efficiency for UMTS as seen from (6). Hence, S-UMTS maintains the coverage of UMTS. Therefore, in (3) for pole capacity in uplink, everything remain same for S-UMTS as in UMTS except W that changes from 3.84 MHz in regular UMTS to 1.92 MHz for D_{cr}=2 S-UMTS. The uplink loading (η) is also assumed to be same for S-UMTS. As a result, for the same loading factor, the uplink cell capacity for voice services is inversely proportional to the value of D_{cr} according to (3) and (4).

B. Downlink Capacity

In the downlink as well, the pole capacity can be interpreted as the maximum capacity with infinite base station power. The following equation is used or the downlink pole capacity

$$N_{pole} = \frac{(1-n_{OH}) * W/_{R_b}}{E_b/_{N_t} * v * (\delta+\beta)} \quad (7)$$

where
n_{OH} = percentage of overhead channel power
W = Spreading bandwidth of the system
R_b = RAB rate for CS voice

E_b/N_t =Required energy per bit to total noise spectrum density ratio
v = VAF
β = Interference factor (ratio between the other cell interference power and the total downlink cell transmission power at UE receiver)
δ = Orthogonally factor (percentage of the serving cell signal that becomes the interference at the UE receiver due to the multipath effect and the limitations of the rake receiver)

Note: Cell geometry is the inverse of β

The overhead channel power is the power for the overhead channels in UMTS and S-UMTS, e.g., Primary and Secondary Synchronization Channels, Primary Common Pilot Channel, Primary Common Control Physical Channel, Secondary Common Control Physical Channel, Paging Indicator Channel etc. In S-UMTS, the overhead scales with the bandwidth and hence, S-UMTS has the same signaling overhead percentage as UMTS.

TABLE XIII. SCALABLE UMTS PARAMETERS FOR AMR

	Regular UMTS (Dcr=1)	**Half BW UMTS (Dcr=2)**
Nominal Bandwidth (MHz)	5	5/Dcr=2.5
Chip Rate (Mcps)	3.84	3.84/Dcr=1.92
Radio frame duration (ms)	10	10xDcr=20
Data Rate	D	D
Power	P	P
Range	R	R
Capacity	C	C/Dcr=C/2

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In (7), everything except W remains same for S-UMTS as in UMTS. Hence, the downlink cell capacity for voice services is inversely proportional to the value of D_{cr}. Thus, a trade-off can be achieved in S-UMTS between data rate, power and capacity. For services that need to maintain the same data rate over S-UMTS as in UMTS, the capacity is scaled down by D_{cr} in S-UMTS while for other services, the capacity is unchanged but data rate is scaled down by D_{cr} in S-UMTS as shown TABLE I and TABLE XIII.

V. CONCLUSION

S-UMTS carriers occupy different bandwidth than regular UMTS carriers and may fit in spectrum where regular UMTS carrier cannot fit. Solutions for supporting full rate AMR (12.2 Kbps) over D_{cr}=2 S-UMTS have been proposed with no additional delay. As S-UMTS uses the same vocoder, it offers the same voice quality as regular UMTS. The proposed solution can be extended for other AMR rates and also for other S-UMTS D_{cr} values. It is also shown that the voice capacity for S-UMTS scales with the bandwidth. As the system bandwidth in S-UMTS is scaled by the bandwidth scaling factor D_{cr}, S-UMTS UL and DL voice capacity are also scaled by the same factor D_{cr} compared to regular UMTS.

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