Montage-based Graph Coding for Redundant Channels

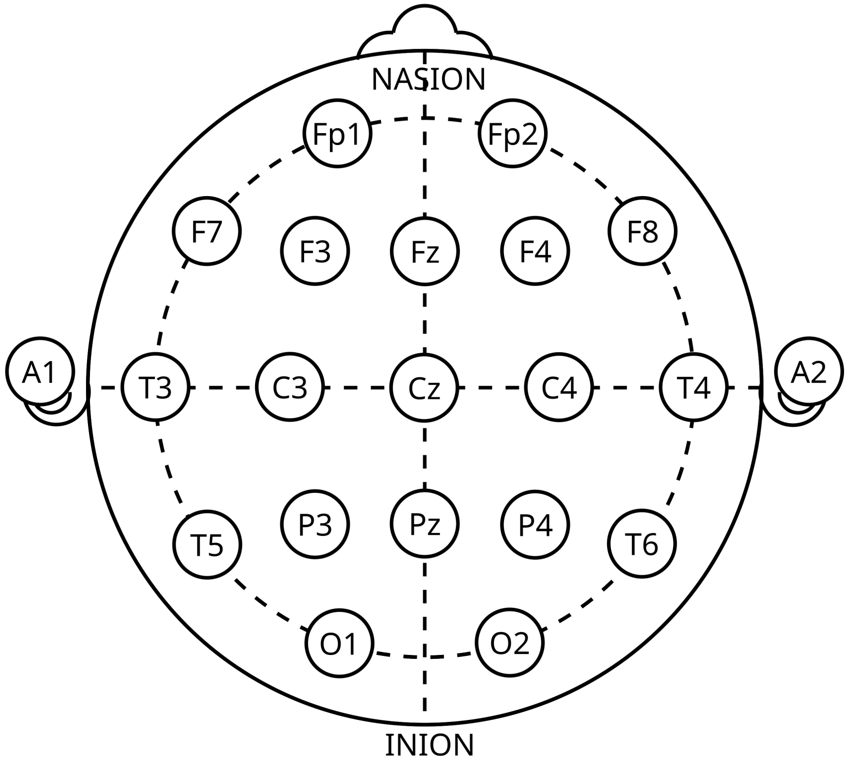
VCEG-BZ22 CE Proposal

Sooyoung Park, Byeongho Jo, Jongmo Sung

Electronics and Telecommunications Research Institute

What is Montage?

- **A montage specifies how multiple EEG electrodes are combined to visualize brain activity.**
  - Individual electrodes record local signals
  - A montage combines these signals into interpretable waveforms
  - Same electrodes, different connections → different views of brain activity



Polarity Rules in EDF Standard

- Specifications and Polarity Rules for EXG labels

2.4. Specifications and polarity rules for EXG labels

The 'Specification' of an EEG, EP or EMG signal consists of the locations of the two recording electrodes, separated by a '-' (minus) character. The voltage (i.e. signal) in the file by definition equals [(physical miniumum) + (digital value in the data record - digital minimum) x (physical maximum - physical minimum) / (digital maximum - digital minimum)]. This voltage must equal the potential at the first electrode (before the '-' character) minus the potential at the second electrode. For example, if the 'Specification' is Fpz-Cz (i.e. the standard label reads 'EEG Fpz-Cz '), then the voltage in the file must be the potential at Fpz minus the potential at Cz. In case of a concentric needle electrode recording, a positivity at the centrally insulated wire relative to the cannula of the needle is stored as a positive value in the file.

If electrodes are on any of the below-mentioned standard locations then the corresponding names must be used, for instance in 'EEG Fpz-Cz '. Else any other name is appropriate, like in 'EEG A-B '. If the electrode locations cannot be accurately specified in short form, like in some EMG recordings, the 'Specification' may be replaced by a less accurate indication such as the name of the muscle.

In many standard procedures in Clinical Neurophysiology, a relative negativity at the first electrode must be displayed as an upward deflection on the screen. The displaying software must implement any such 'negativity upward' rule by simply upwardly displaying a negative voltage in the file.

In standard EEG investigations, EEG electrode signals in the file are usually referenced to one, common, electrode, for example A1. The file then contains, in this example, the signals C1-A1, C2-A1, C3-A1, C4-A1, F1-A1, F2-A1, F3-A1, and so on. This enables re-referencing (remontaging) of derivations afterwards and reduces file size. In some cases, the reference electrode is an average over more than one electrode. In that case, define this average between round brackets. For instance, the EEG between C3 and linked earlobes has label 'EEG C3-(A1+A2)/2'. If the reference is unknown, irrelevant (for instance because it is only used temporarily), or makes the signal label exceed its 16 characters, then use the text Ref, for instance in 'EEG C3-Ref '. If more of such references exist, then use the text Ref1, Ref2, and so on.

The two EMG derivations for leg movement scoring, as described in "The AASM manual for the scoring of sleep and associated events", have specifications "RAT" and "LAT" for the right and left anterior tibialis muscle, respectively. So, the standard labels are "EMG RAT" and "EMG LAT".

If a standard ECG derivation I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6, or -aVR, or V2R, V3R, V4R, V7, V8, V9, or X, Y, Z is recorded, then the 'Specification' of the ECG signal must equal the name of that derivation, for instance resulting in label 'ECG V2R '.

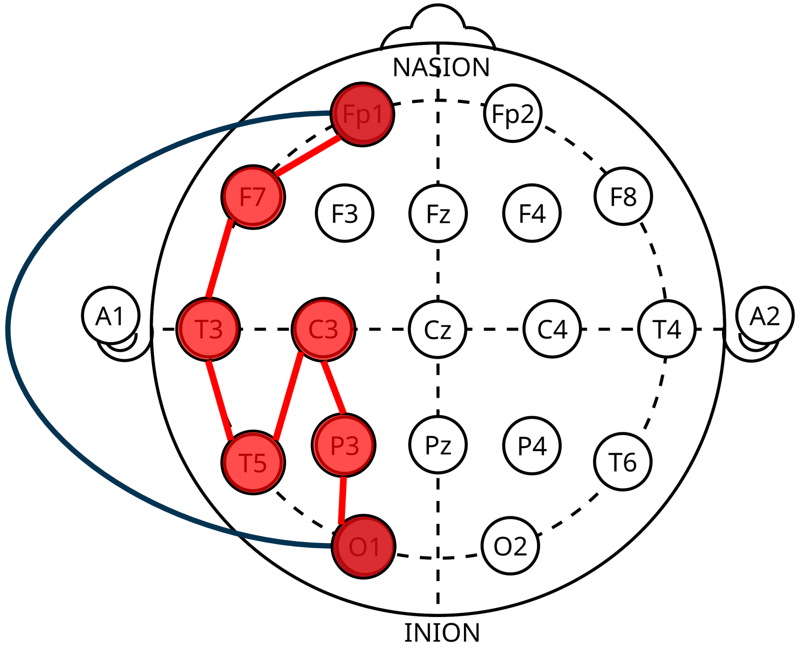
https://www.edfplus.info/specs/edftexts.html

- **Must** use standard 10/20 & 10/10% names if applicable.
- Bipolar derivations are marked with a **minus character (-)**.
  - Data represents **[Electrode 1] - [Electrode 2]**.

Motivation

- Hidden Redundancy in Bipolar Medical Waveform

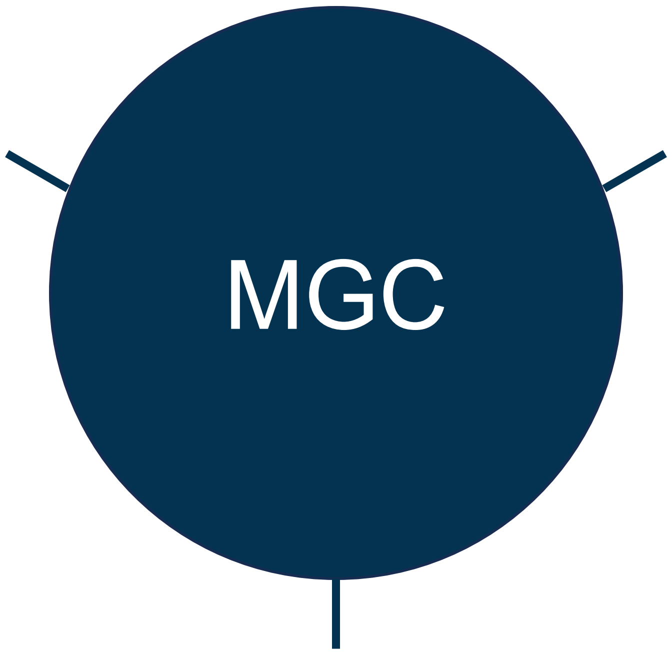
(Fp1-O1) = (Fp1-F7)+(F7-T3)+(T3-T5)-(C3-T5)-(P3-C3)-(O1-P3)



Key Idea

Metadata-driven

Construct electrode graph using header



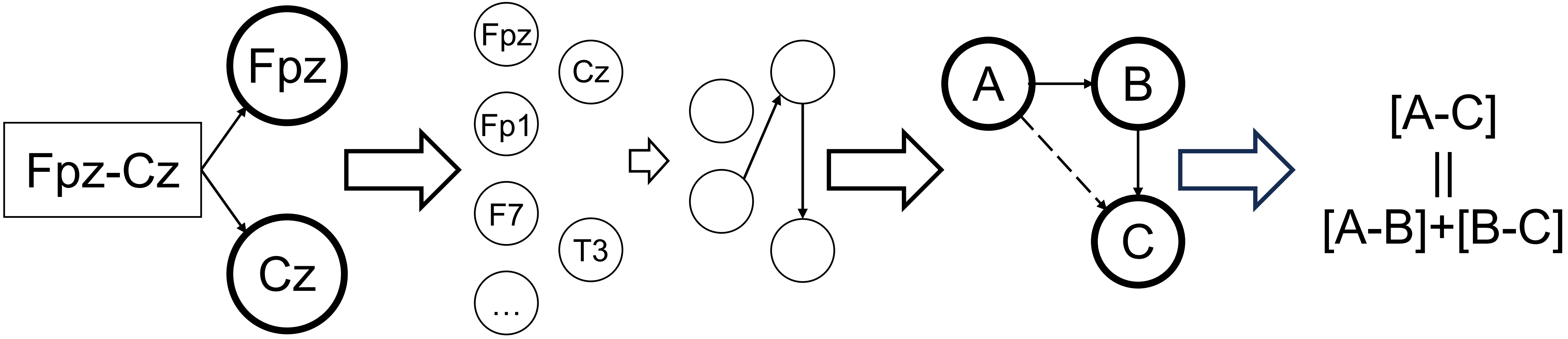
No Sample-level Analysis

Label-level, fast processing

Precise Prediction

Using oracle combination

Mechanism of MGC



1. Parse Label

2. Build Graph

3. Detect Redundancy

4. Form Oracle Combination

Signaling Graph Information

- Add Graph Information into WPS
  - Redundant Channel Flags (N bits)
    - Number of channels: N
  - Reference Indices (K*N bits)
    - Number of redundant channels: K
    - Combination vector per redundant channel
  - Reference Signs (K*N bits)

- If no redundant channels, + N bits
- Else, + (2K+1)*N bits

waveform_parameter_set( ) {	Descriptor
wps_waveform_parameter_set_id	u(4)
…	
wps_num_annotation_channels	ue(v)
for(j = 0; j < wps_num_annotation_channels; j++)	
AnnotationChannelNumSamples[j] = 0	ue(v)
/* MGC Graph Information Added */	
for(cgId = 0; cgId < NumChannelGroups; cgId++) {	
for(ch = 0; ch < NumChannels[cgId]; ch++) {	
wps_redundant_channel_flag[cgId][ch]	u(1)
}	
}	
for(cgId = 0; cgId < NumChannelGroups; cgId++) {	
numRedundant = count_flags(wps_redundant_channel_flag[cgId])	
for(idx = 0; idx < numRedundant * NumChannels[cgId]; idx++) {	
wps_redundant_channel_ref_index[cgId][idx]	u(1)
}	
}	
for(cgId = 0; cgId < NumChannelGroups; cgId++) {	
numIndices = size_of(wps_redundant_channel_ref_index[cgId])	
for(idx = 0; idx < numIndices; idx++) {	
wps_redundant_channel_ref_sign[cgId][idx]	u(1)
}	
}	
trailing_bits( )	

Coding Modes Using Graph

- Direct Reconstruction
  - Bypass residual coding using Oracle Combination
    - Bypass RDO loop in Encoder, CABAC in Encoder/Decoder
- Predictive Coding with RDO
  - Add additional block prediction methods using oracle combination

```
If (is_redundant[ch]){.                      // Check redundant
   direct_recon_flag;
   if (!direct_recon_flag) {                  // if not direct recon (MGC)
      predictive coding_flag;                 // Check predictive coding flag (MGC)
      if (!predictive_coding_flag).           // if not, original block prediction
         prediction_trafo_data[ch]
   } else
   prediction_trafo_data[ch]                  // if not redundant, original block prediction
}
```

Results

- Tested with H.BWC 4.0 (CTC, Joint)
  - Only CHBMIT dataset has redundant channels

Lossy Joint Channel Coding (vs H.BWC 4.0)

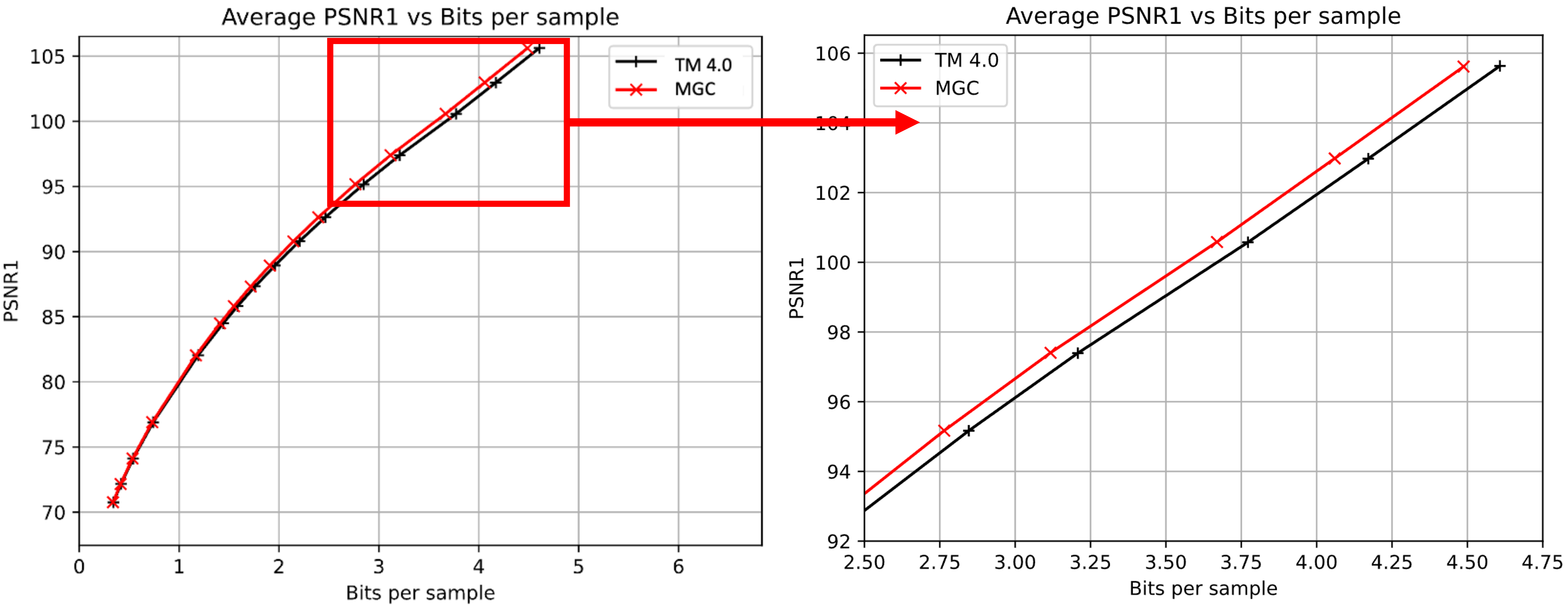
Dataset	BD rate #1 (%)	BD rate #2 (%)	EncT (%)	DecT (%)
CHBMIT_EEG	-2.054	-2.054	89.7	89.8

Lossless Joint Channel Coding (vs H.BWC 4.0)

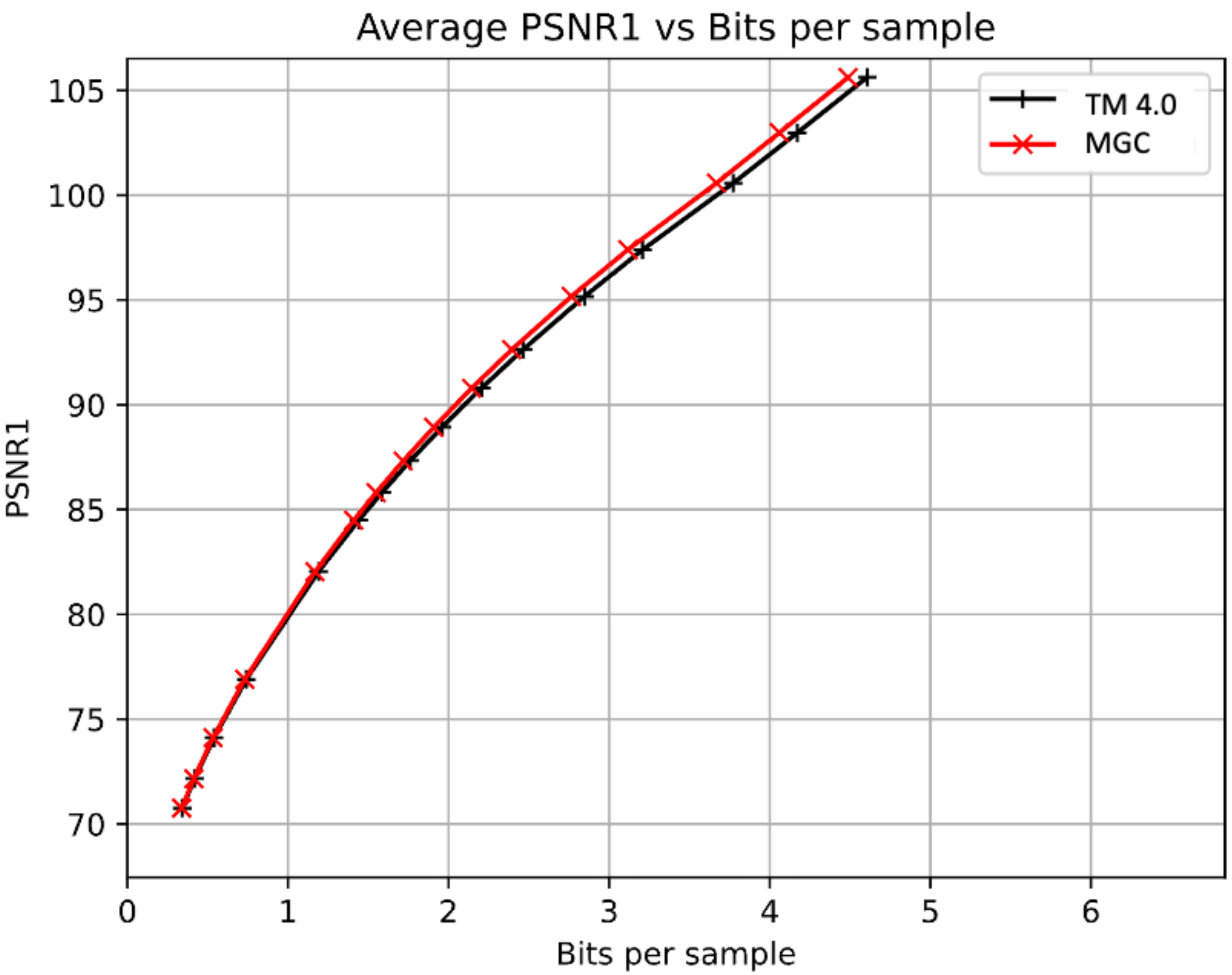
Dataset	BR-R (%)	EncT (%)	DecT (%)
CHBMIT_EEG	-3.185	98.1	91.5

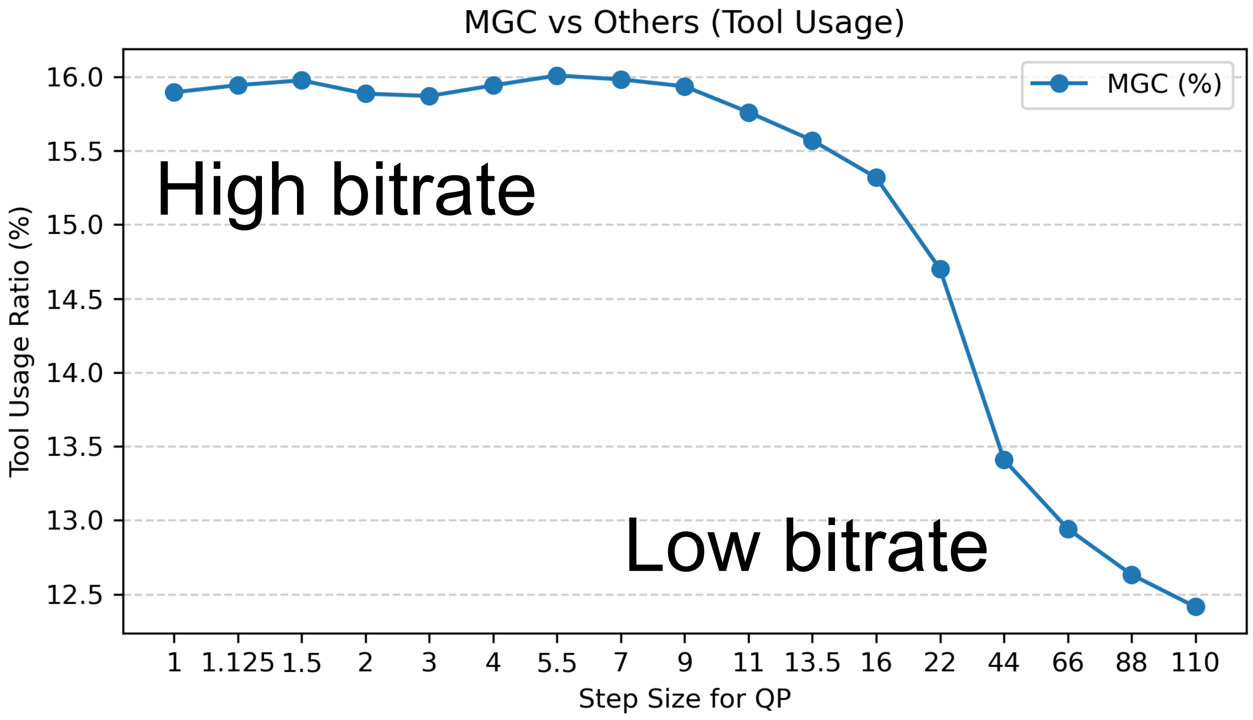
*Other datasets are identical to H.BWC 4.0 (+ N bit is too small, BD-rate 0.000, EncT 100%, DecT 100%)

Results


Average PSNR1 vs Bits per sample
TM 4.0
MGC
PSNR1
Bits per sample
Average PSNR1 vs Bits per sample
TM 4.0
MGC
PSNR1
Bits per sample

Analysis of MCG





Due to quality of reconstruction buffer

Conclusion

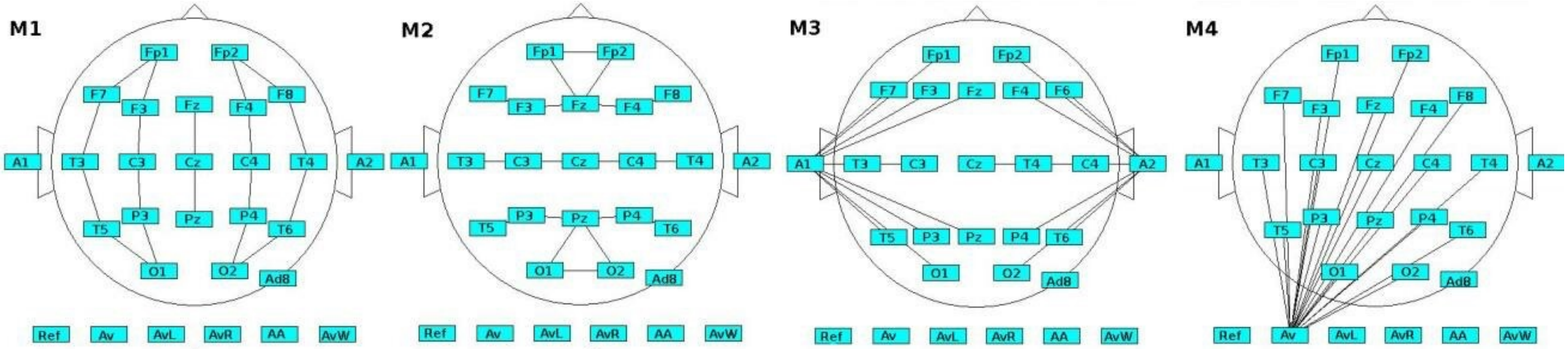
- **MGC** efficiently identifies channel redundancy using header information
- Delivers **substantial compression gains** for redundant montages, with no degradation on common datasets
- **Fast** enough for **always-on** operation

- *** Zero bit for graph** when header information is available in decoder

Thanks for your attention

Appendix

- EEG interpretation requires **multiple montages** (*clinical guidelines)
- Channels in different montages often **share electrodes**
- Shared electrodes lead to **overlapping signal content**



- **ACNS Guideline 1:** Multiple montages required for EEG interpretation
- **IFCN Standards:** Bipolar and referential montages are recommended