2.6 Multipulse Linear Prediction and Code-Excited Linear Prediction (CELP) for Speech Signals

Multipulse LPC

poor modeling of u(n) is the main source of quality degradation in LPC vocoder

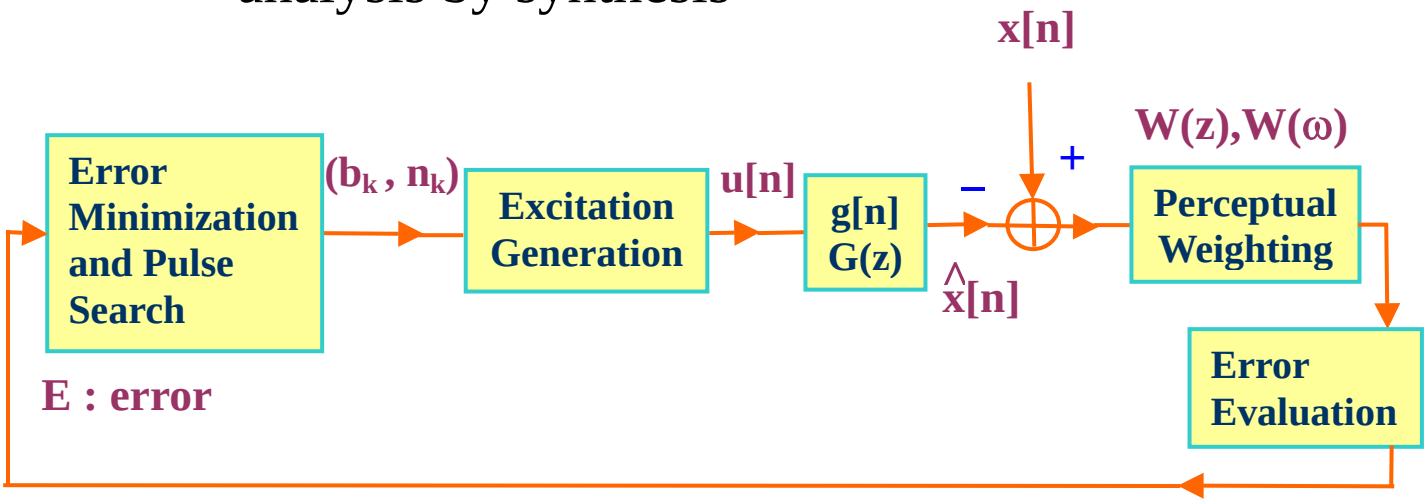
- **u[n] replaced by a sequence of pulses**

$$u[n] = \sum_k b_k \delta[n - n_k]$$

- roughly 8 pulses per pitch period
- u[n] close to periodic for voiced

  u[n] close to random for unvoiced

- **Estimating (b_k , n_k) is a difficult problem**
- analysis by synthesis



- large amount of computation is the price paid for better speech quality

Multipulse LPC

- **Perceptual Weighting**

$$W(z) = (1 - \sum_{k=1}^{P} a_k z^{-k}) / (1 - \sum_{k=1}^{P} a_k c^k z^{-k})$$

$0 < c < 1$ for perceptual sensitivity

$W(z) = 1$, if $c = 1$

$W(z) = 1 - \sum a_k z^{-k}$, if $c = 0$

practically $c \approx 0.8$

- W(z) proportional to $G(z)^{-1}$ to some degree
  errors in formant regions de-emphasized
  errors in low-signal-level regions emphasized

- **Error Evaluation**

$$E = \int_0^{2\pi} |X(\omega) - \hat{X}(\omega)|^2 W(\omega) d\omega$$

- **Error Minimization and Pulse search**

$$u[n] = \sum_k b_k \delta[n - n_k]$$

$$\hat{x}[n] = \sum_k b_k g[n - n_k]$$

$$E = E(b_1, n_1, b_2, n_2 \ldots\ldots)$$

- sub-optional solution

finding 1 pulse at a time

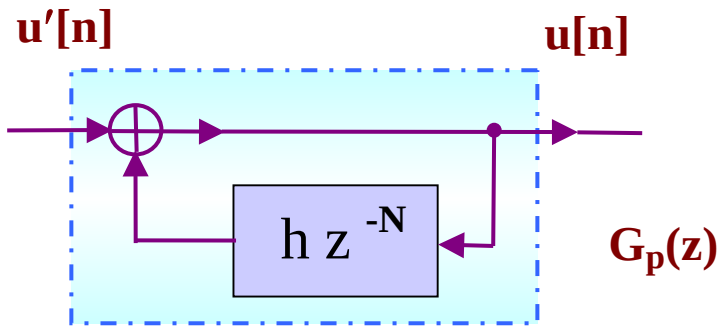
Multipulse LPC

- **Pitch Prediction**

  - excitation sequences are often highly correlated from one pitch period to the next

  - only the difference between the excitation and it was in a previous pitch period needs to be found

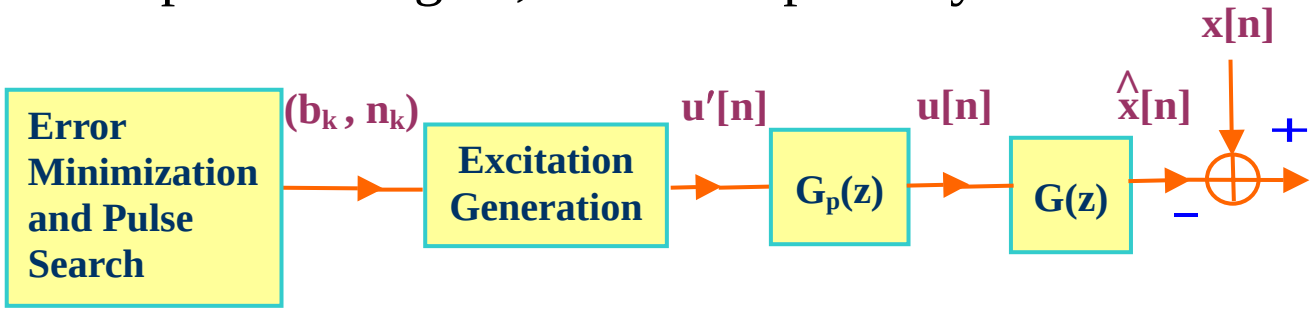
$$G_p(z) = \frac{1}{1 - hz^{-N}}$$



$u[n] = u'[n] + h\,u[n-N]$

N : pitch period, or an integer multiple of it

h : prediction gain, can be empirically chosen

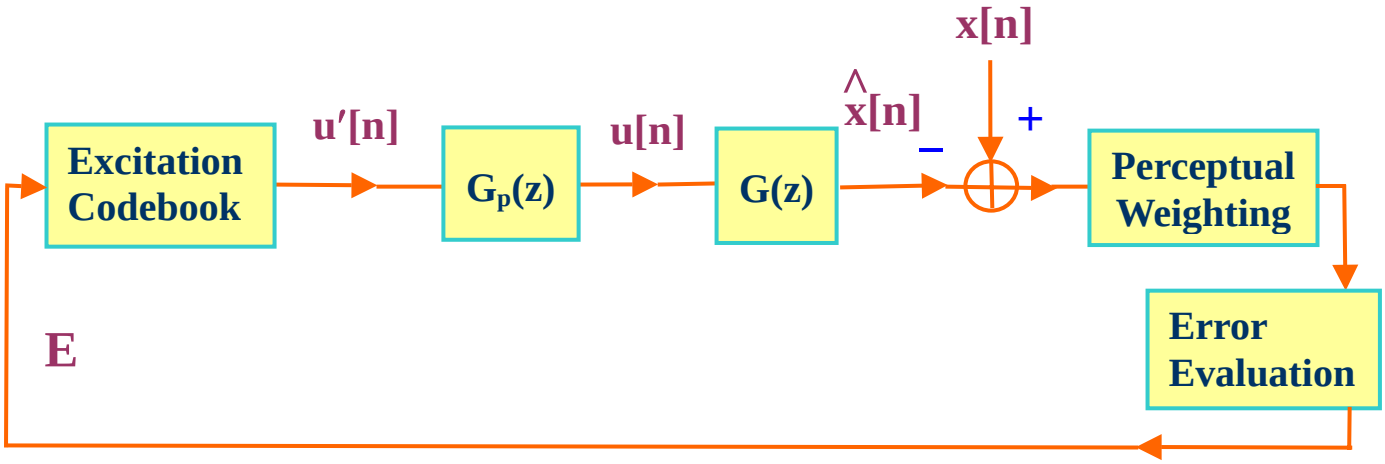


  - results : SNR improvement of 5 dB at 1000 pulses/sec, or saving 500 ~ 600 pulses/sec

Code-Excited Linear Prediction (CELP)

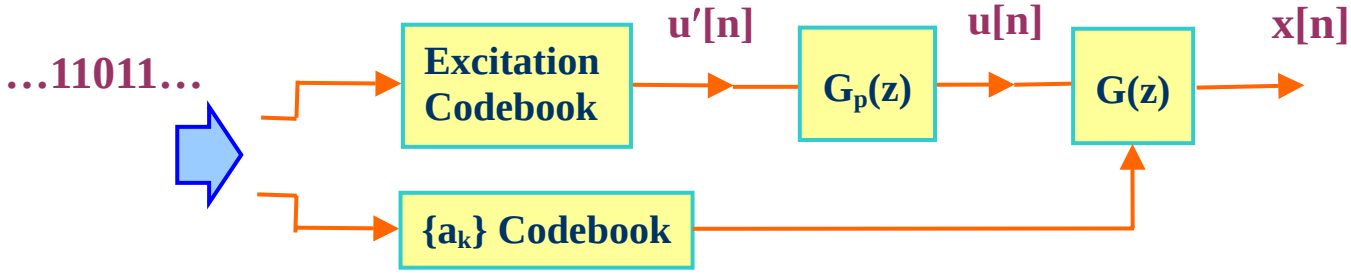
- **Use of VQ to Construct a Codebook of Excitation Sequences**
  - a sequence consists of roughly 40 samples
  - a codebook of 512 ~ 1024 patterns is constructed with VQ
  - roughly 512 ~ 1024 excitation patterns are perceptually adequate

- **Excitation Search – analysis by synthesis**



  - 9 ~ 10 bits are needed for the excitation of 40 samples , while $\{a_k\}$ parameters in G(z) also vector quantized

- **Receiver**

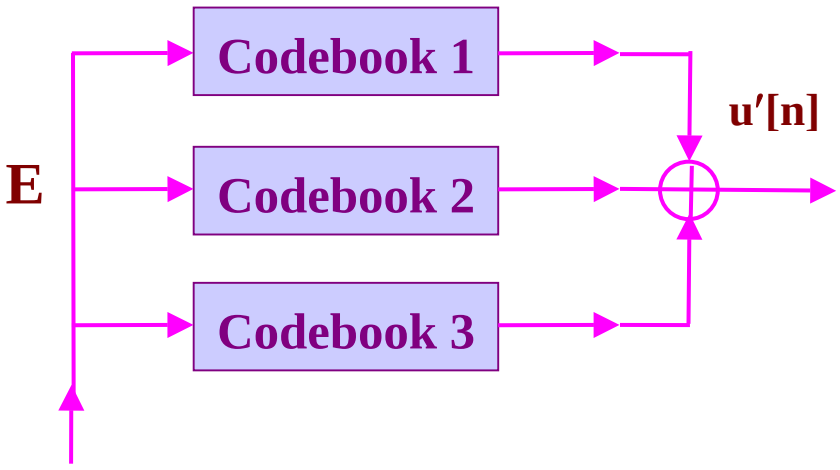


$\{a_k\}$ codewords can be transmitted less frequently than excitation codeword

Code-Excited Linear Prediction (CELP)

- **Modifications and Improvements**
  - Better excitation codebook
  - Improved filtering
  - Better computation algorithms
  - Efficient codebook search
  - Example : Vector-Sum-Excited Linear Prediction (VSELP)

    Excitation codebook is replaced by roughly 3 smaller codebooks of size of 128 or so, each codebook searched individually

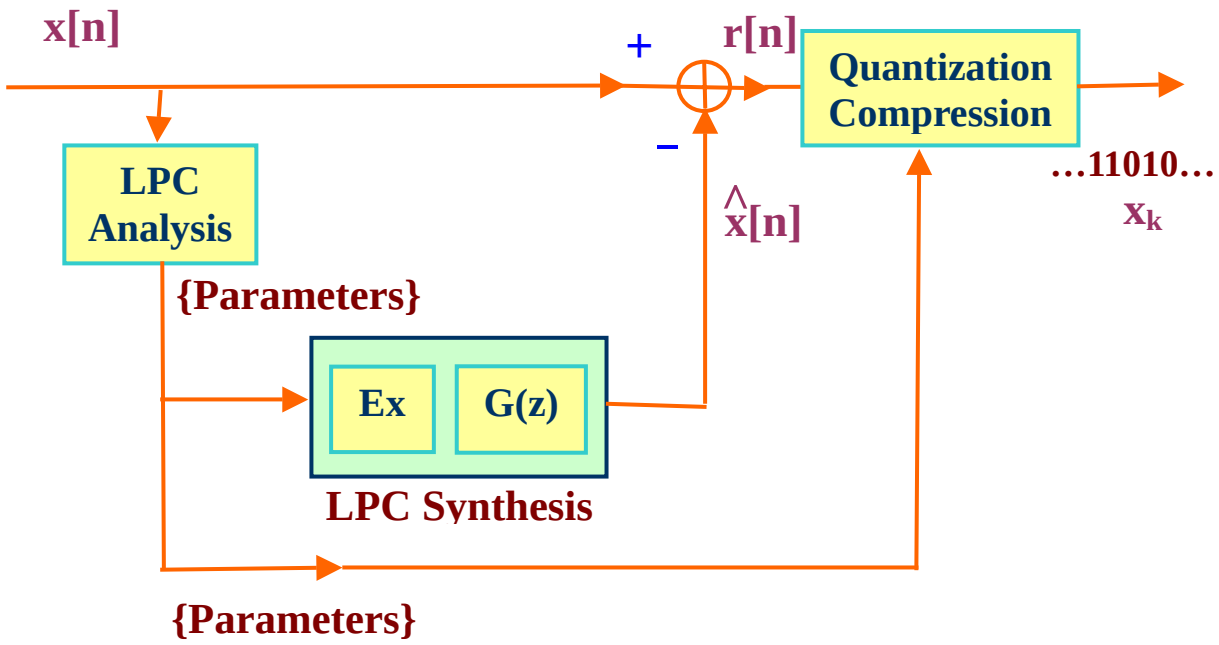


Ref : 33.8, 33.9, 33.10 of Gold

Example Speech Coding Standards

See Table 1 , p. 41, Fig. 1, p. 42, IEEE Communications Magazine Sept. 1997, Special Issue on Speech Coding Standards

Residual Excited Linear Prediction (RELP)

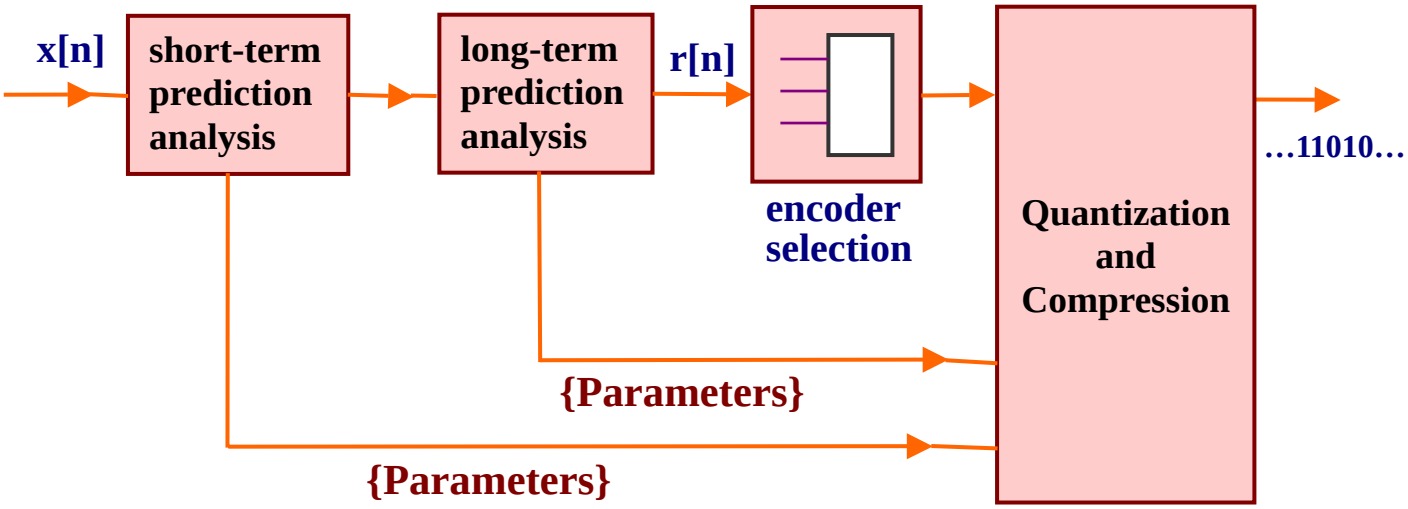


r[n] : residual signal

Speech Coder in GSM

Regular pulse excited long-term prediction (RPE-LTP)

- combination of RELP with long-term prediction



encoder selection: one out of three encoders is selected for the residual signal r[n]

- bit rate : 13 kbps