ELEC3026 MODEM: Brief Notes

Coherent and Non-coherent Receivers

Professor Sheng Chen
School of Electronics and Computer Science
University of Southampton
Southampton SO17 1BJ, UK
E-mail: sqc@ecs.soton.ac.uk

http://www.ecs.soton.ac.uk/~qc/EL334/
Coherent Receiver

(a) **Carrier recovery** for demodulation

- Receiver signal \( \hat{S}(t) = A \cos (\omega_c t + \varphi) + N(t) \)
- Local carrier \( \cos (\omega_c t + \bar{\varphi}) \)
- Carrier recovery (e.g. phase lock loop) circuit
  \[ \Delta \varphi = \varphi - \bar{\varphi} \to 0 \quad \text{i.e.} \quad \bar{\varphi} \to \varphi \]
- Demodulation leads to recovered baseband signal
  \[ Y(t) = X(t + \tau) + N(t) \]
  where \( X(t) \) is transmitted baseband signal

(b) **Timing recovery** for sampling

- Align receiver clock with transmitter clock, so that sampling \( \Rightarrow \) no ISI
  \[ Y_k = X_k + N_k \]
  where \( X_k \) are transmitted symbols, and \( N_k \) noise samples
Non-coherent Receiver

(a) No carrier recovery for demodulation

- Receiver signal $\hat{S}(t) = A \cos(\omega_c t + \varphi) + N(t)$
- Local carrier $\cos(\omega_c t + \bar{\varphi})$
- No carrier recovery,

$$\phi = \Delta \varphi = \varphi - \bar{\varphi} \neq 0 \quad \text{i.e.} \quad \bar{\varphi} \neq \varphi$$

- Demodulation leads to recovered baseband signal

$$Y(t) = X(t + \tau) e^{j\phi} + N(t)$$

(b) Timing recovery for sampling

- Align receiver clock with transmitter clock, sampling results in

$$Y_k = X_k e^{j\phi} + N_k$$

Could not recover transmitted symbols properly from $Y_k$!
Differential Detection

(a) **Differential encoding** for transmission

- Symbols \( \{C_k\} \Rightarrow \{X_k\} \) for transmission

\[
X_k = C_k \cdot X_{k-1}
\]

- As \( X_k \cdot X_{k-1}^* = C_k \cdot (X_{k-1} \cdot X_{k-1}^*) \),

\[
C_k = \frac{X_k \cdot X_{k-1}^*}{|X_{k-1}|^2}
\]  \hspace{1cm} (1)

(b) **Non-coherent** detection

- Receiver samples

\[
Y_k = X_k \cdot |H| \cdot e^{j\phi} + N_k
\]

\(|H|\): magnitude of combined channel tap, \( \phi \neq 0 \): unknown phase

- Differential decoding

\[
\hat{C}_k = \frac{Y_k \cdot Y_{k-1}^*}{|Y_{k-1}|^2}
\]  \hspace{1cm} (2)
Differential Detection (derivation)

\[ Y_k \cdot Y_{k-1}^* = \left( X_k \cdot |H| \cdot e^{j\phi} + N_k \right) \cdot \left( X_{k-1}^* \cdot |H| \cdot e^{-j\phi} + N_{k-1}^* \right) \]

\[ = X_k \cdot X_{k-1}^* \cdot |H|^2 \cdot e^{j(\phi-\phi)} + N_k \cdot N_{k-1}^* + X_k \cdot |H| \cdot e^{j\phi} \cdot N_{k-1}^* + N_k \cdot X_{k-1}^* \cdot |H| \cdot e^{-j\phi} \]

\[ |Y_{k-1}|^2 = X_{k-1} \cdot X_{k-1}^* \cdot |H|^2 + N_{k-1} \cdot N_{k-1}^* + X_{k-1} \cdot |H| \cdot e^{j\phi} \cdot N_{k-1}^* + N_{k-1} \cdot X_{k-1}^* \cdot |H| \cdot e^{-j\phi} \]

When noise \( N_k \) is very small

\[ Y_k \cdot Y_{k-1}^* \approx X_k \cdot X_{k-1}^* \cdot |H|^2 \quad \text{and} \quad |Y_{k-1}|^2 \approx |X_{k-1}|^2 \cdot |H|^2 \]

- Thus,

\[ \hat{C}_k = \frac{Y_k \cdot Y_{k-1}^*}{|Y_{k-1}|^2} \approx C_k + \tilde{N}_k \]

where power of enhanced noise \( \tilde{N}_k \) is larger than that of \( N_k \)

- Note that influence of channel phase \( \phi \) has been removed
Comparison

• Coherent detection
  – Require expensive and complex carrier recovery circuit
  – Better bit error rate of detection

\[ \hat{X}_k = X_k + N_k \]

• Non-coherent detection
  – Do not require expensive and complex carrier recovery circuit
  – Poorer bit error rate of detection

\[ \hat{C}_k = C_k + \tilde{N}_k \]

• Differential systems have important advantages and are widely used in practice