Introduction

- Full-duplex relay a.k.a. on-channel repeater a.k.a. gap filler
  - Patching coverage holes cost-efficiently
  - Boosting cell edge coverage by reducing path losses

- The main technical challenge is the loop interference, i.e., crosstalk between transmission and reception of the relay
  - In practice, spatially-separated transmit and receive antennas are required
  - Classification of countermeasures:
    1) Physical isolation between the relay antennas
    2) Directivity properties of the antennas
    3) Signal processing for loop interference cancellation
    4) Relay gain optimization (NEW in this presentation)

System model

- Standard OFDM transmission
  - Length of the fast Fourier transform $T_{FFT}$
  - Length of the cyclic prefix $T_{CP}$
  - Time of reference $T_{ref}$ marks the start of symbol demodulation

- The frequency-selective multipath channels are specified in terms of power-delay profiles (PDPs)
  - The classic (single-)exponential PDP
    
    \[ f_t(t) = f_t(t, g, r, \sigma, \tau) = \frac{1}{\sigma \sqrt{2 \pi}} e^{-\frac{(t - \tau)^2}{2 \sigma^2}} \]

  - Gain $g = \int_{-\infty}^{\infty} f_t(t) dt$, mean delay $\mu = \frac{1}{\int_{-\infty}^{\infty} t f_t(t) dt + \sigma + \tau}$

  - Mean square delay spread $\sigma^2 = \frac{1}{\int_{-\infty}^{\infty} t^2 f_t(t) dt}$

  - The new double-exponential PDP by convolution
    
    \[ f_d(t) = f_d(t, g, r, \sigma, \tau) = \int_{-\infty}^{\infty} f_i(t, g, r, \sigma, \tau) f_i(t - \tau, g, r, \sigma, \tau) dt \]

  - Combined delay $\tau = \tau_1 + \tau_2$, total end-to-end gain $g = \int_{-\infty}^{\infty} f_d(t) dt = g_1 g_2$

- The full-duplex relay with gain $G_R$
  - The PDP of the channel from transmitter $t$ to receiver $r$
    
    \[ f_{tr}(t) = \mathcal{F}\{g_{tr}(t)\} = \sum_{i=1}^{N_{RF}} f_i(t, g, r, \sigma, \tau) \]

  - $N_{RF}$ clusters: gain, delay and RMS delay spread of the $i$th cluster $g_{tr}(i)$, $g_{tr}(i)$ and $\sigma_{tr}(i)$

  - Total channel gain $G_{tr} = \int_{-\infty}^{\infty} f_{tr}(t) dt = \sum_{i=1}^{N_{RF}} g_{tr}(i)$

- The PDP of the loop interference channel $f_{li}(t) = G_R f_{tr}(t - \tau_1)$
  - Simple impulse with gain $G_R$ and delay $\tau_2$, because the main source of loop interference is the direct coupling between the direct transmit and receive antennas

- The end-to-end PDP becomes
  
  \[ f_{li}(t) = \int_{-\infty}^{\infty} f_{li}(t, g, r, \sigma, \tau) dt = \sum_{i=1}^{N_{RF}} g_{li}(i) \]

  - $g_{li}(i)$ includes the $i$th cluster $g_{li}(i)$, $g_{li}(i)$, $\sigma_{li}(i)$ and $\tau_{li}(i)$

  - The relay gain $G_R$ must be limited by $G_R < \sigma_{li}(i)$

  - Relay receive signal power $P_R G_R + P_L G_L + P_{th}$

  - Transmit power in the source $P_s$

  - Relay transmit signal power $P_R = (\mu_1^{i+1} + \mu_2^{i+1}) \mu_2^{i+1}$

  - Total signal power in the destination $P_s = P_R G_R + P_L G_L + P_{th}$

  - Total noise power in the destination $P_n = P_R G_R + P_L G_L + P_{th}$

  - Assuming relay receiver noise power $P_{th}$ and destination receiver noise power $P_{th}$

End-to-end SINR

- Signal-to-interference and noise ratio (SINR) is $\gamma = \frac{P_{sig}}{\sum_{i} P_{int} + P_{noise}}$
  - Useful signal power $P_{sig} = P_R f_{li}(t, g, r, \sigma, \tau) dt$

  - Interference power $P_{int} = P_L f_{li}(t, g, r, \sigma, \tau) dt$

  - Weighting function for OFDM:
    
    \[ c(t) = \max \left\{ 0, \min \left\{ 1, \frac{t - t_{CP}}{T_{ref}} \right\} \right\} \]

  - With large relay gain, the end-to-end PDP decays slowly due to the feedback loop, and more multipath components are transferred outside the cyclic prefix causing interference

  - Interference power may increase faster than the useful signal power

  - The optimal gain
    
    \[ G_{opt}^{RPT} = \arg \max_{G_{opt}} \gamma \]

    - Gain margin approach
      
      \[ G_{opt} = \frac{1}{\Delta_{opt} G_{lim}} \]

      - Margin $\Delta_{opt}$ usually 10-15dB

    - Power normalization approach
      
      \[ G_{opt}^{norm} = \frac{P_s}{P_R G_R + P_L G_L + P_{th}} \]

      - Pre-selected transmit power $P_s$

  \[ \Rightarrow \text{Optimization of the relay gain guarantees proper transmit power usage and minimizes the effect of the loop interference} \]