Open issues in Wireless Networks

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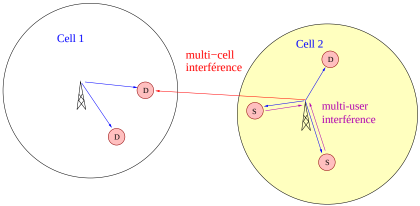
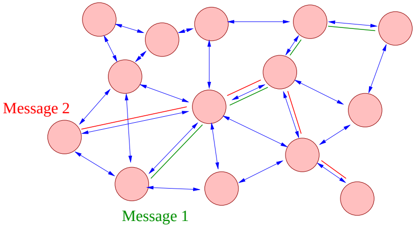
Wireless network

Wireless Cellular Network



Wireless Ad Hoc Network

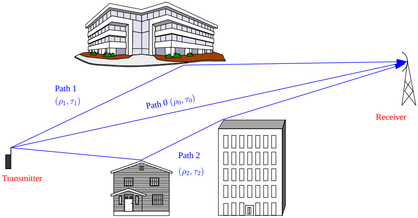


Interference management

- Orthogonal multiple access schemes: TDMA/FDMA (2G), CDMA (3G)
- Random access (Wifi)
- Usually, no frequency reuse

Interference avoidance ⇒ point-to-point communications

Wireless multipath channel

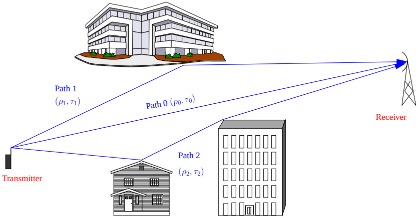


- $\longrightarrow$ Pathloss: SNR issue
- $\longrightarrow$ Multipath > bit period: frequency-selectivity
- $\longrightarrow$ Multipath < bit period: (time-varying) small-scale fading

Current solutions

- SNR issue: powerful error-correcting codes (Turbocodes at Telecom Bretagne)
- Frequency-selectivity: OFDM (Wifi, DVBT, 4G/LTE, ADSL)
- Fading: Diversity and MIMO (Golden codes at Telecom ParisTech)

Wireless multipath channel



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For point-to-point communications, only some **incremental** open issues

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Channel State Information (CSI) ?

CSI at the Receiver (CSIR) side

- Data-aided: trivial
- Non-data-aided: huge amount of works in 90's (especially at Telecom ParisTech)

CSI at the Transmitter (CSIT) side

- Time-varying wireless channel
- Huge amount of feedback (MIMO, multi-user)

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- Time-varying wireless channel
- Huge amount of feedback (MIMO, multi-user)

Only partial and/or statistical CSIT

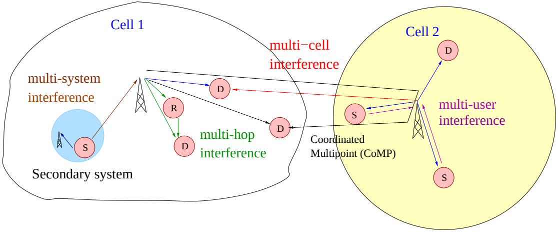
$\longrightarrow$ Diversity (MIMO, CoMP, etc)

$\longrightarrow$ Retransmission (Hybrid ARQ)

Performance improvement

Huge increase of data rate:

- Increase the QAM size $\Rightarrow$ high SINR
- Need to be close to the access point $\Rightarrow$ femto/small cells
- Spectrum re-use $\Rightarrow$ inter-cell and inter-node interference



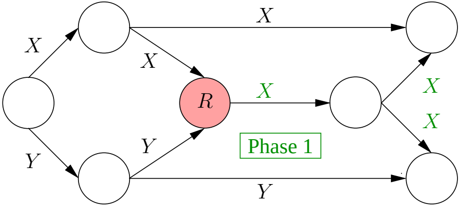
Interference-limited rather than power-limited

End-to-end communications

- **Interference management becomes crucial**
- **X-layer based resource allocation becomes crucial**

Challenge 1: wireless network coding

Famous "butterfly" **wired** network [2000]:



Routing replaced with (bit-level) packet sum ⇒ interference useful

In wireless context:

- Broadcast nature of the channel ⇒ sum in node R
  - done by the channel, but not by R
  - at the continuous-time signal-level (no algebraic structure)
- Usually, focus on more elementary scheme, typically relaying scheme

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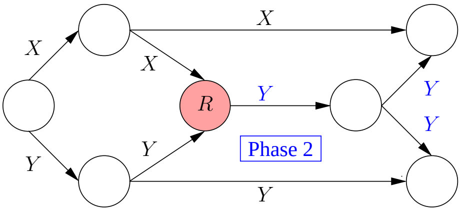

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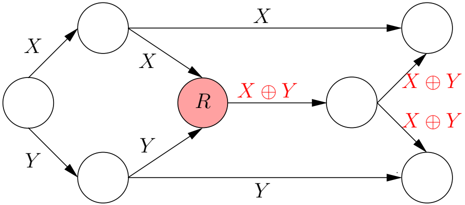

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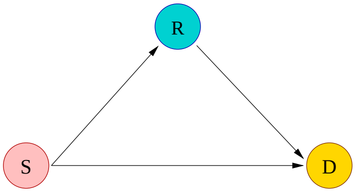
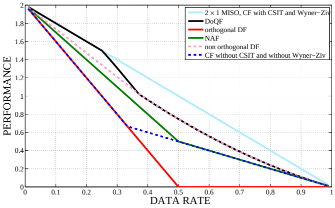
Focus on relaying scheme





- What does the relay?
  - Amplify and Forward
  - Decode and Forward
  - Quantized/Compress and Forward
- When does the relay speak? *our own contributions*
  - Slotted Amplify and Forward (SAF) [2009]
  - Flip and Forward (FF) [2010]
  - Decode or Quantize and Forward (DoQF) [2011]

Future works in wireless network coding

Extension of protocol and coding to any network:

- Problem 1: multi-flow interference (unlike relaying scheme)
- Problem 2: global system inversion

Solution: Amplify and Forward

$$\left\{ \begin{array}{lcl} Y & = & h_1 X_1 + h_2 X_2 + N \\ Z & = & aY \end{array} \right.$$

with

- X_1 and X_2 QAM inputs
- a real-valued

- Amplify: NO (noise enhancement)

Crucial open issue

- weights design (trade-off between approximation and system inversion)

Extension of protocol and coding to any network:

- Problem 1: multi-flow interference (unlike relaying scheme)
- Problem 2: global system inversion

Solution: Decode and Forward

$$\begin{cases} Y & = & h_1 X_1 + h_2 X_2 + N \\ Z & = & \tilde{X}_1 \end{cases}$$

with

- X_1 and X_2 QAM inputs
- $\tilde{X}_1 = X_1$ if X_1 well decoded

- Amplify: NO (noise enhancement)
- Decode: NO (no interference conservation)

Crucial open issue

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Future works in wireless network coding

Extension of protocol and coding to any network:

- Problem 1: multi-flow interference (unlike relaying scheme)
- Problem 2: global system inversion

Solution: Compute and Forward

$$\begin{cases} Y & = & h_1X_1 + h_2X_2 + N \\ Z & = & a_1X_1 + a_2X_2 \end{cases}$$

with

- X_1 and X_2 QAM inputs
- a_1 and a_2 integer weights

- Amplify: NO (noise enhancement)
- Decode: NO (no interference conservation)
- Compute [2008]: YES (interference as in -wired- network coding)

Crucial open issue

- weights design (trade-off between approximation and system inversion)

Challenge 2: X-layer optimization

Remark

Research addresses performance improvement at PHY layer, BUT **is it useful**?

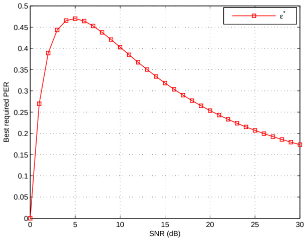
Indeed, let us assume coded ARQ (coded packet can be retransmitted if NACK)

$$\text{throughput: } \eta_\varepsilon = R_\varepsilon(1-\varepsilon)$$

with ε the PER and R_ε the packet rate.

$$\varepsilon^* = \arg\max_\varepsilon \eta_\varepsilon$$

is the best required PER [2009]



Relevant metrics:

- neither Shannon capacity ($\log(1+\mathrm{SNR})$) nor PER
- throughput, latency, jitter

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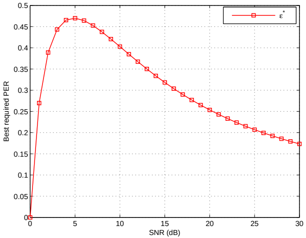


Relevant metrics:

- neither Shannon capacity ($\log(1+\text{SNR})$) nor PER
- throughput, latency, jitter

dropping standard metrics and revisiting resource allocation

Focus on X-layer resource allocation

Context: mobile ad hoc networks (MANET)

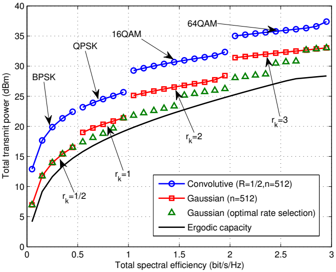
- K users
- statistical CSIT
- OFDMA: E_k subcarrier energy, γ_k bandwidth proportion for user k

Problem: power minimization under individual throughput constraints

$$\min_{\{\gamma_k, E_k\}} \sum_{k=1}^{K} \gamma_k E_k$$

s.t., $\forall k$,

$$\begin{aligned} \eta_k(\gamma_k, E_k) &\geq \eta_k^{\text{target}} \\ \gamma_k, E_k &\geq 0 \end{aligned}$$

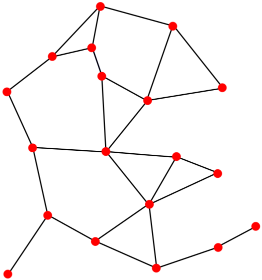


Convex or Biconvex problem [2012,2013]

Future works in X-layer optimization

- Extension to HARQ: non trivial, non-convex optimization
- Optimization within HARQ (between retransmission step): realistic code
- Distributed processing

Challenge 3: distributed optimization



$$\hat{\theta} = \arg\min_{\theta} \sum_{v} f_v(\theta)$$

BUT

- no fusion center
- each node v only knows $f_v(.)$
- data exchange only between neighbors

Applications in wireless communications

- Distributed resource allocation in mobile wireless ad hoc network
- Distributed detection

First step: distributed average computation

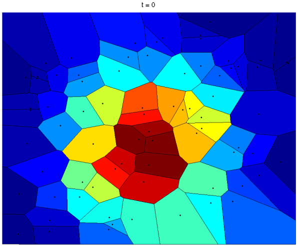
Focus on averaging algorithms

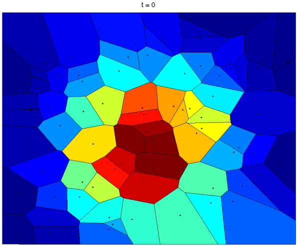
Let $x_v(0)$ and N be the initial value at node v and the nodes number.

Goal: computing the average in distributed and asynchronous way

$$x_{\text{ave}} = \frac{1}{N} \sum_{v=1}^{N} x_v(0)$$

At each time t, a node wakes up and exchanges linearly data with neighbor node(s)





(ave: ■)

Standard algorithm [2006]

Our algorithm [2012]

Future works in distributed optimization

To speed up distributed optimization, two approaches

- Improving the averaging computation step
  - Problem for coupling averaging and minimum search
  - Convergence proof in asynchronous case

- Improving the minimum search (no gradient-descent algorithm)
  - Synchronous case: algorithms available
  - Asynchronous case: very challenging topic $\longrightarrow$ no algorithm, no proof

Other applications

- Machine learning
- Cloud computing

Thus, strong collaboration with TSI/STA team

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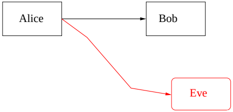
Concluding remarks

- Interference can be benefit: but we have to learn to use it
- Resource allocation in end-to-end communications: but hard optimization issue

Other hot topics in wireless networks:

- Fundamental limits (information theory) in wireless network
- Physical layer security



  - Secret capacity
  - New lattice based codes
- Distributed storage (connection with wired network coding)
- Cognitive radio
  - System/Modulation classification
  - Distributed cooperative spectrum sensing