Physical layer modelling for future wireless networks

4- Interference in wireless networks
Interference

1- Basis of interference
- Definition
- Various kinds
- Collisions
- Example

2- Interference modelling
- Switched interference
- Real interference
- Additive interference
  - Gaussian approximation

3- multi-channel systems
- Interference in CDMA
- Interference in FDMA

4- Interference reduction
- Avoidance
- Mitigation

5- Applications
- MAC problems
- Throughput
- Connectivity
- Routing

6- Conclusion
1- Basis

Basis of interference

1) Definition
2) Various kinds
3) Collisions
4) Example
1) Definitions

- **Interference**: Interference is produced by other terminals or systems and affects the quality of a given radio link.
2) Various kinds of interference

- **CCI:**
  - Co-channel interference is produced by interfering signals located in the same frequency band.

- **ACI:**
  - Adjacent channel interference is produced by interfering signals located in adjacent bands.

- **ISI:**
  - Inter-symbol interference is due to multi-path of the signal. ISS represents an auto-interference.

- **MSI:**
  - Multiple system interference represents interference between different systems exploiting the same frequency band (e.g. WiFi – Bluetooth).

Wireless Network design and performance evaluation involve CCI and ACI essentially.
3) Collision

- Collisions are experienced at MAC level
  - Two transmitted packets are simultaneously transmitted
  - Collision models involve basic interference models.

A collision refers to a packet loss due to concurrent transmissions.

When does it occur?
  illustrations of different cases and corresponding interference levels.
4) Example

- jammed areas
Example (cont.)

– **Setup**
  
  - *AWGN channel*
  - *mod BPSK*
  - *White noise*
  - *Nb bits (200)*

  ➔ \(\text{PER} \sim \text{Nb.BER}\)
Example (cont.)

- Unique interferer in AWGN

\[ \text{PER} = f\left( \frac{C}{N+I} \right) \]
Example (cont.)

– Unique interferer with RTS/CTS

Hyp : hidden node

PER

10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^2
10^3
10^4

d

Pe=Pcts . Pint

Pe=Pcts . Pint

N

A

B

C

I

D

Basis
Example (cont.)

- Unique interferer with RTS/CTS on Rayleigh channel
Example (cont.)

– multiple interference (AWGN)

\[ \text{PERtot} = f(\frac{C}{N + \Sigma I}) \]
2-Modelling

Interference modelling

1) Switched interference
2) Progressive interference
3) Additive Interference
   The gaussian model
1) Switched interference

- Switched interference is based on the idea of a jamming area:
  - It does not correspond to a realistic behavior
    - Details ...

\[
\frac{C}{N + I} \geq S_{th} \quad ???
\]

- Example on 2 BPSK signals received simultaneously
2) Progressive interference

- progressive interference refers to a unique interferer
  - A realistic behavior: which PER??
  - Caution: asynchronism is important to consider

- Example on 2 BPSK signals received simultaneously
3) Additive interference

- Interference are cumulative
  - The mean interfering received power is seen as a noise \( \Rightarrow \) AWGN in many practical applications
  - Fundamental equation:
    \[
    SINR(i, j) = \frac{A_{ij} \cdot P_j}{N_0 + \sum_{k \neq j} A_{ik} \cdot P_k}
    \]
  - Realistic model:
    \[
    BER(i, j) = f(SNR(i, j))
    \]
  - New disk range model:
    \[
    \overline{SINR(i, j)} > S_{th}
    \]
4) Shannon Capacity

• In an AWGN channel, the capacity is provided as:

\[
C(i, j) = W \cdot \log_2 \left(1 + \frac{dP_R}{\sigma^2}\right) \text{ bit/s}
\]

\[
C(i, j) = W \cdot \log_2 (1 + SINR(i, j))
\]
3-Multi-channel systems

Multi-channel systems

1) FDMA based systems
   Adjacent channels interference
   Example: 802.11b/g

2) CDMA based systems
   pseudo-orthogonal codes
   a general formulation under gaussian approximation
   Example: CDMA based ad hoc network
1) Multiplexing

– Orthogonal multiplexing
  = interference avoidance
  – Number of channels \times Unitary\ through\ throughput = total through\ throughput
  – Selection / assignment of channels
  – Near the maximal capacity if fine synchronisation
  – Ideal case: no interferences

– Pseudo-orthogonal multiplexing
  = interference cancellation or mitigation
  – Number of channels \times Unitary\ through\ throughput > total through\ throughput
  – Adaptative (random?) channel selection
  – Interference-limited systems
2) Time Division

– interference avoidance
  • Synchronized ➔ TDMA
    – Need synchronization

  • Carrier sense / random access
    ➔ CSMA/CA
    – Carrier sensing, collisions ➔ access rules
2) Frequency division

– Interference avoidance
  - OFDMA (interference avoidance)
    – Need synchronization, but near optimal use.
  - FDMA
    – Channel allocation, no synchronization
    – Adjacent carrier interference should be managed!!
3) Code division

   – Interference avoidance
     • orthogonal codes
       – Neads Synchronization
       – Codes allocation policy ?
     • pseudo-orthogonal codes
       – No synchronization
       – Large codes’ family ➔ random selection possible
       – Interference limited systems
       + possible interference mitigation
4) Overall throughput

- Link throughput with either time, frequency, coding (constant energy)

\[ Th(k) = C(k) \cdot T(k) = q(k) \cdot W \cdot T \cdot \log_2 \left( 1 + \frac{A_{kk} \cdot dP(k)}{q(k)} \right) \cdot \frac{1}{\sigma^2} \]

- Rem 1: \( \sum_k q(k) \leq 1 \)

- Rem 2: if regular division, \( q(k)=1/K \), and the maximal channel number is K.

- Rem 3: link capacity increases in \( \log(1+a.K) \) ... but energy as K !!!!
4) Overall throughput (cont.)

\[ Th(k) = q(k) \cdot W \cdot T \cdot \log_2 \left( 1 + \frac{A_{kk} \cdot dP(k)}{q(k) \cdot \sigma^2 + \sum_{i \neq k} \alpha_{ki} \cdot A_{ki} \cdot P_0} \right) \]

Inter-channel correlation

Example: CDMA: \( q(k) = 1/G \); \( \alpha = 1/G \)
5) Resource sharing

- Finding:
  - Max throughput
  - Fairness (min-max)
  - Delay
  - Min Energy

- Find $q(k)$ and $\alpha_{ki}$ such as maximizing the capacity.
  - NP complete problem
    (classical FAP + distributed algorithms)

\[
TH = \sum_{k} q(k) \cdot W \cdot T \cdot \log_{2} \left( 1 + \frac{A_{kk} \cdot dP(k)}{q(k) \cdot \sigma^{2} + \sum_{i \neq k} \alpha_{ki} \cdot A_{ki} \cdot P_{0}} \right)
\]
Interference reduction

1) Interference avoidance
   Contention based medium access
   Time division / Frequency division
   Throughput/interference trade-off

2) Interference mitigation
   Linear suppression of interference
   Multi-user detection: MLSE of interfering signals
   SIC/PIC algorithms
Applications in sensor nets

1) Throughput
   Why interference reduces throughput?

2) Connectivity
   How connectivity is affected by interference?

3) Routing / multi-hop
   Take care of interference for packet retransmission policies
6- conclusion

1- the throughput in Wireless LAN is limited by interference.

2- Interference is additive and progressive. It affects the packet error probability and leads to collisions.

3- Interference reduction can be done at the PHY layer (mitigation),
but can be managed at the MAC layer (avoidance).

4- Interference and collisions reflects the same fundamental problem in wireless networks:
   Resource sharing
More readings

**Books**

**Papers**
- M. Haenggi; “on routing in random Rayleigh fading networks”, IEEE transactions on Wireless Communications, July 2005
- H.R. Karimi et al; “the impact of interference cancellation on the uplink throughput of WLAN with CSMA/CA”. In IEEE GLOBECOM 2005