Managing Interference in Wireless Access Systems

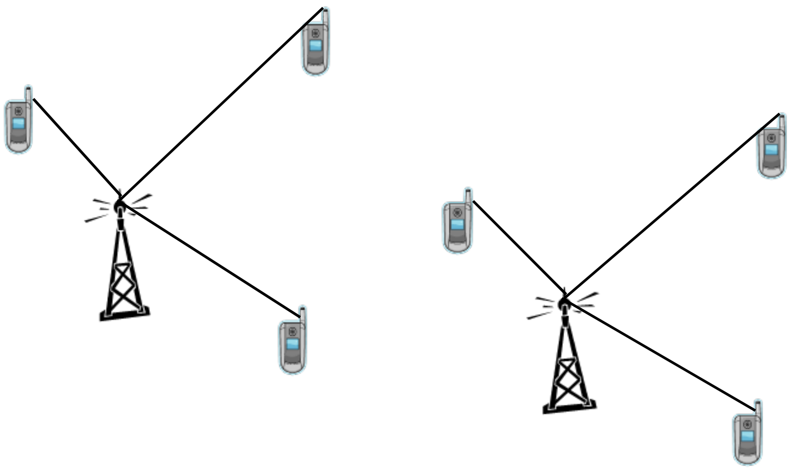
Sverrir Olafsson
Mobility Research Centre

Overview

- Discussion of the research challenges related to the increasing density of wireless devices
- Network and interference models
- Management of interference by
  - distributed channel allocation
  - distributed transmit power control
- Scalability and stability issues for WLANs

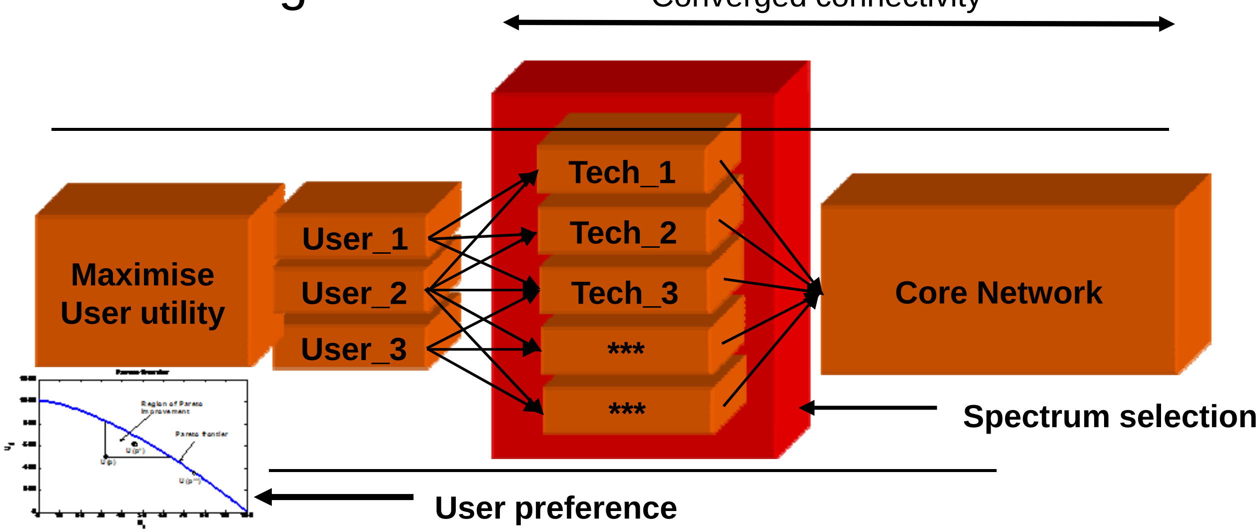
The challenge

- With growing density of wireless devices interference management becomes ever more important
- Main aim is to improve the utilisation of available spectrum
- Typical approaches
  - Access control
  - **Channel selection**
  - **Power control**
  - Rate control
  - Antenna technologies
  - **Spectrum trading**

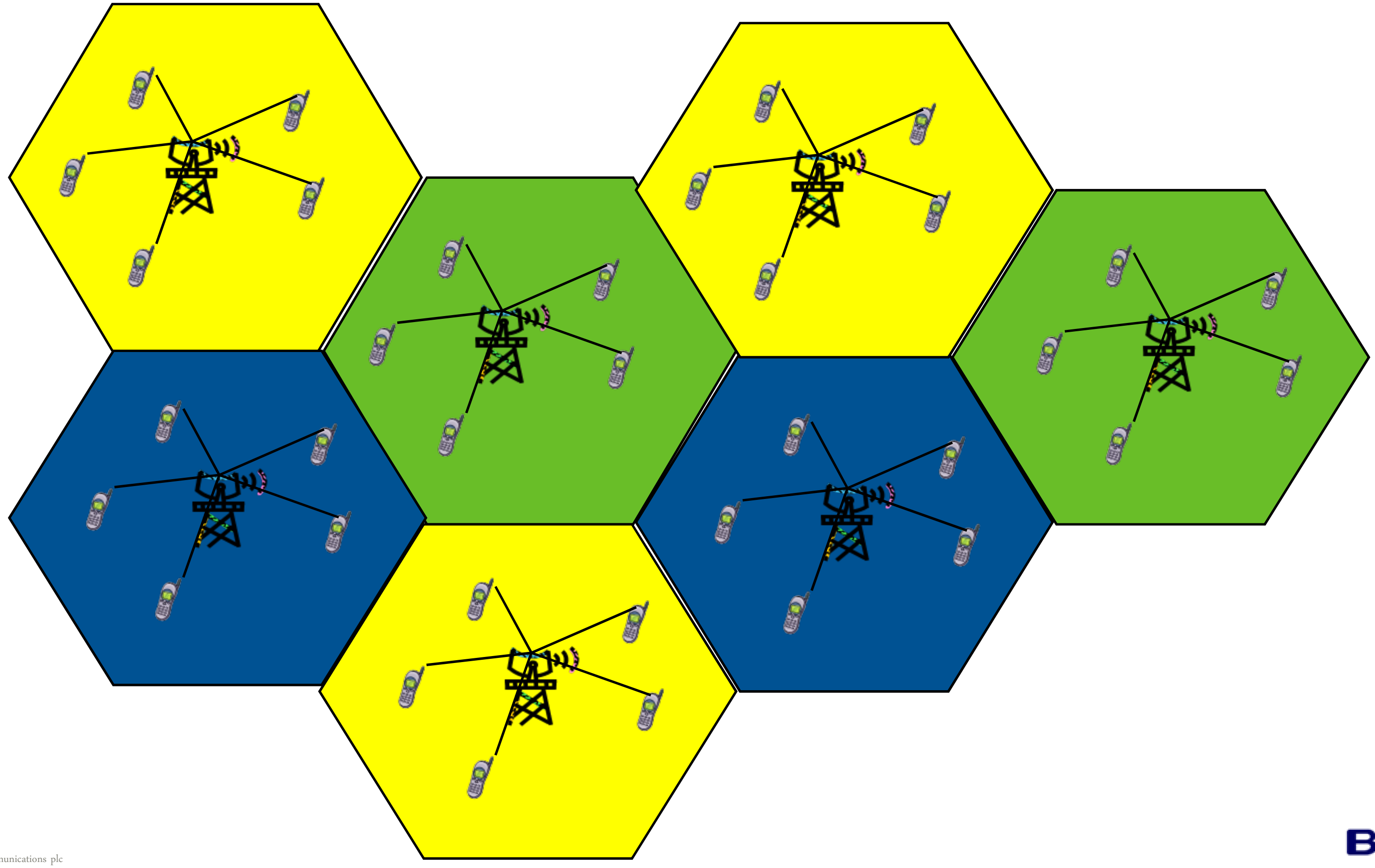


Heterogeneous access technologies

- Cellular networks
- Ad hoc networks
- WLANs (WiFi)
- Bluetooth
- - - - - -
- Future wireless networks may consist of a mixture of different access technologies

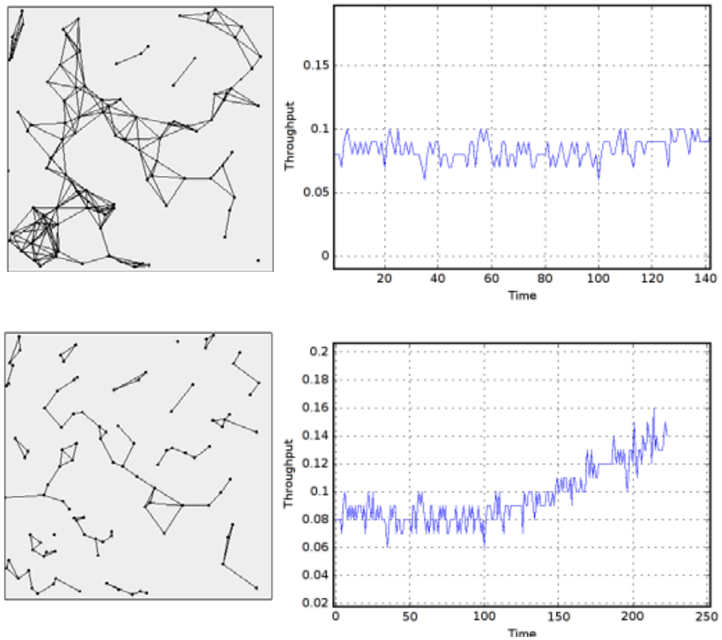


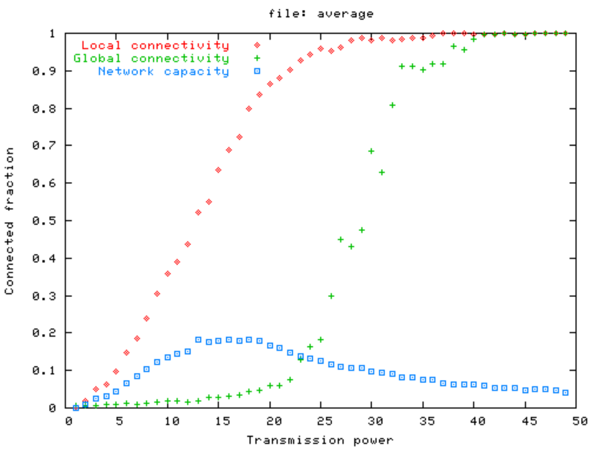
Spectral reuse in cellular systems



Power control in ad hoc networks

- The effect of power
  - Benefits
  - Disadvantages
- Optimal power control
  - Constraint optimisation
    - Connectivity
    - Capacity



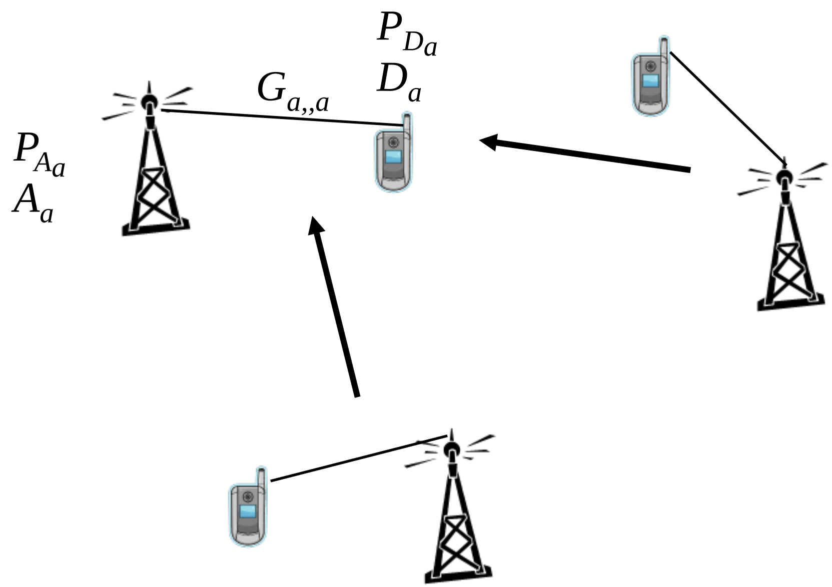


Motivation and objectives

- Implement channel optimisation in a distributed manner – i.e. by using only local information
- All access points (APs) search for a channel to minimise the interference they experience
- The algorithm needs to
  - Be robust
  - Scale well
  - Cope with growing wireless systems
- **Centralized algorithms are unlikely to be useful as**
  - They scale badly
  - Require global information across different domains

WLANs

- Neighbouring devices can cause interference making communication impossible
- The level of interference suffered depends on
  - Transmit power used by nodes
  - Channel allocation to APs



$$\rho(i,b) = \begin{cases} 1 & \text{if AP } b \text{ uses channel } i \\ 0 & \text{if AP does not use channel } i \end{cases}$$

$$I_a(i, \mathbf{P}_{-a}) = \sum_{b \in L(a)} \rho(i,b) G_{a,b} P_b + \eta_a$$

$$\mathbf{P}_{-a} = (P_1, \ldots, P_{a-1}, P_{a+1}, \ldots, P_N)$$

G_{ab} the link gain between APs a and b
P_b the transmit power used by AP b

Network model and problem formulation

- The channel distribution for N APs

$$\mathbf{c} = (c_1, c_2, \ldots, c_N)$$

- In this case the total interference in the system is

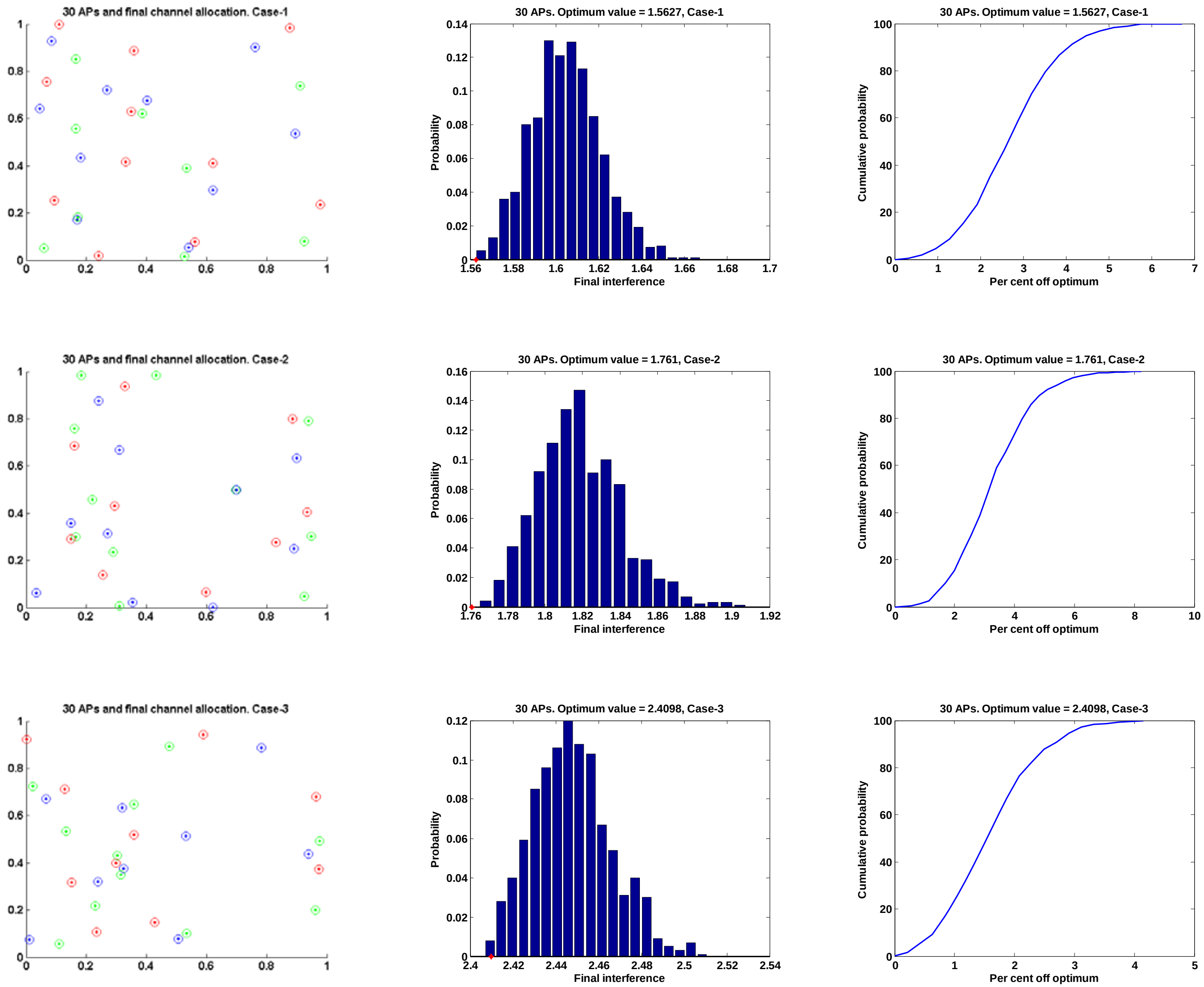
$$TI(\mathbf{c}) = \sum_{a \in AP} I_a(\mathbf{c})$$

- Find a channel distribution for $\mathbf{c} = (c_1, c_2, \ldots, c_N)$ that "minimizes" the total interference – by only using local information

Stochastic optimisation versus optimal solutions

- Stochastic optimisation $\rightarrow$ each run results in a different solution
- Important to understand
  - Mean interference
  - Variance in final interference values
  - Distance from the best solution (when it is known)

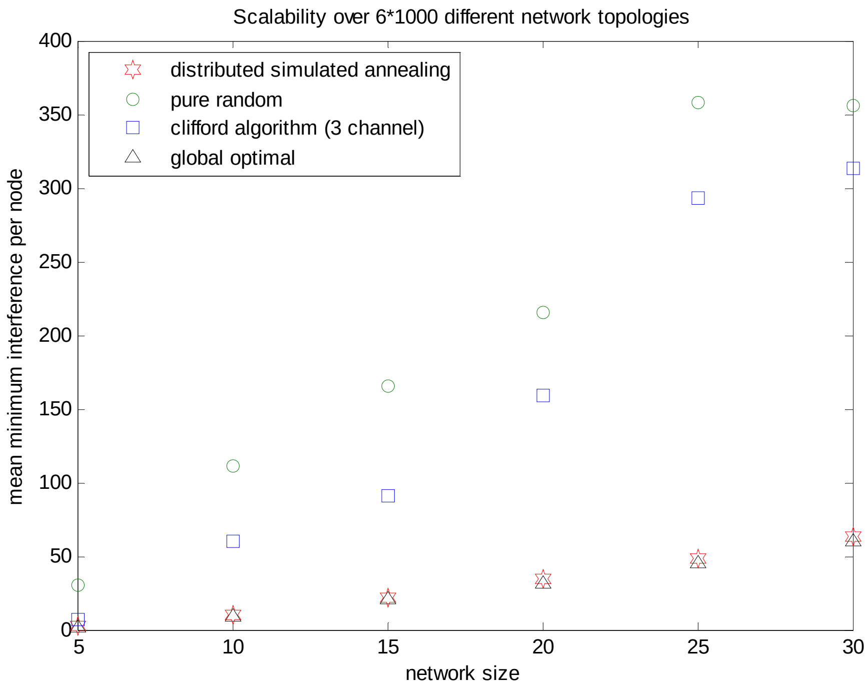
Comparison with optimal solutions



Scalability

- Scalability with increasing node numbers and densities is an important issue for each channel selection algorithms

- How does mean minimum interference per node increase with total number of access points?



Power control

- The signal to interference and noise ratio at user device a is

$$S_{D_a}(i, P_{A_a}) = \frac{G_{a,a} P_{A_a}}{I(i, \mathbf{P}_{-a})} \geq g_a$$

- Each communicating pair in the network seeks to achieve some required SINR value, which may depend on the application in question
- Following power dynamics can be arrived

$$\dot{P}_a(c_a) = b \sum_{b \in A\langle a \rangle} \left(-d_{a,b} + F_{a,b}^{(c_a)}\right) P_b + b \frac{g_a h_a}{G_{a,a}} \quad ; \quad F_{a,b}^{(c_a)} = g_a r(c_a, b) \frac{G_{a,b}}{G_{a,a}}$$

$$\dot{\mathbf{P}} = b\mathbf{W}\mathbf{P} + \mathbf{Q} \quad \Rightarrow \quad \mathbf{P} = \mathbf{Q}\mathbf{W}^{-1}\left(e^{b\mathbf{W}t} - 1\right) + \mathbf{P}(0)c^{b\mathbf{W}t} \quad ; \quad \mathbf{W} = -\mathbf{I} + \mathbf{F}$$

- If the power dynamics converges:

$$\lim_{t \to \infty} \mathbf{P} = \mathbf{P}^* = -\mathbf{Q}\mathbf{W}^{-1} = (\mathbf{I} - \mathbf{F})^{-1}\mathbf{Q}$$

Stability conditions

- Under what conditions does the power dynamic converge?
- Sufficient stability condition

$$G_{a,a} \geq \gamma_a \sum_{b \in A(a)} \rho(c_a, b) G_{a,b} \quad ; \quad \forall a$$

- The stability condition depends on three factors
  - The strength of the link gains
  - The required QoS
  - The allocation of channels

- **The implementation of the power dynamic is distributed**

$$\dot{\mathbf{P}} = \beta \mathbf{W}\mathbf{P} + \mathbf{Q} \quad \Rightarrow \quad P_a(t+1) = \frac{\gamma_a}{S_a} P_i(t)$$

Channel allocation and power control

- The channel allocation seeks to minimize the interference

$$I_a(i, \mathbf{P}_{-a}) = \sum_{b \in L(a)} \rho(i,b) G_{a,b} P_b + \eta_a$$

- This is done by modifying the entries in the channel allocation matrix

$$\rho(i,b) = \begin{cases} 1 \ \textit{if AP b uses channel i} \\ 0 \ \textit{if AP does not use channel i} \end{cases}$$

- Channel optimisation may succeed to “create” the stability condition

$$G_{a,a} \geq \gamma_a \sum_{b \in A(a)} \rho(c_a, b) G_{a,b} \ ; \ \forall a$$

- Making the power dynamic converge at sufficiently high SINR levels

Summary

- Dense presence of wireless devices requires techniques for optimal usage of spectrum
- Most important aspects are
  - Power control
  - Channel allocation
- We have presented algorithm that in a distributed manner simultaneously optimizes channel selection and transmit power
- Solutions are close to global optimum
- Solutions scale well