Challenges for non-3G ubiquitous wireless mobility

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*Disclaimer: the views expressed are those of the author and cannot be regarded as stating an official position of BT

Content

- BT Research
- Position and role of different wireless technologies
- Converged connectivity
- Position of ad hoc networks
- Power control – interference – game theory
- Spectrum management

BT research – Adastral Park

Adastral Park

- Martlesham Heath near Ipswich
  - 110 acres - 5000 people
- Mobility Research Centre
  - Ca. 50 people

BT

Present wireless technologies

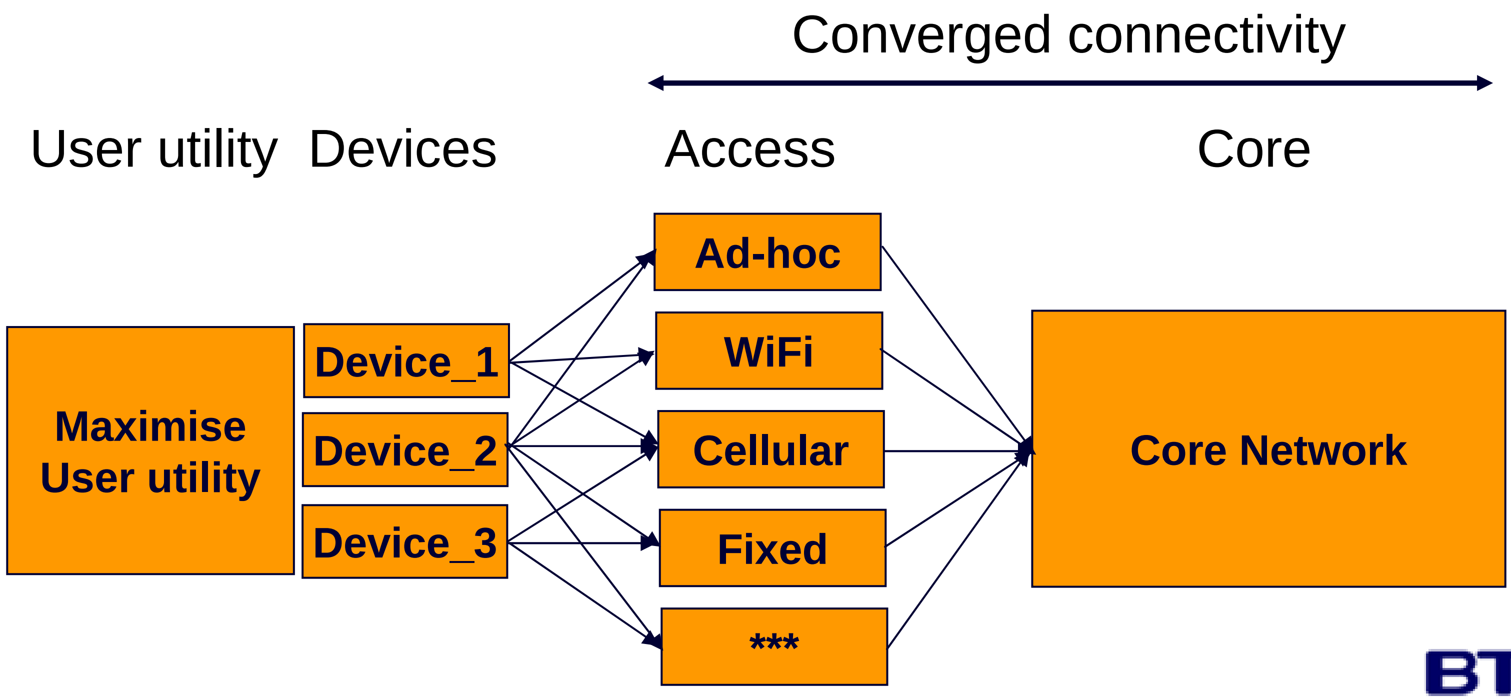
- What is the relative position and the future role of
  - 3G
  - WiFi
  - WiMax
  - Ad-hoc
  - …
- Are these technologies competitors or will they coexist in a converged world of Mobility and the Internet?
- Is 3G looking obsolete before it has really taken off?
- What is the best bet – one technology or a mix of technologies?

Present wireless technologies

- The outcome will depend on a mix of technical and regulatory developments – including
  - Regulation of spectrum
  - How spectrum can be accessed
    - Spectrum licenses
    - Spectrum trading
    - Open access
    - Opportunistic spectrum access – cognitive radios
    - ….
  - New modulation techniques
  - VoIP
  - Building of coalitions between major players
  - Standards

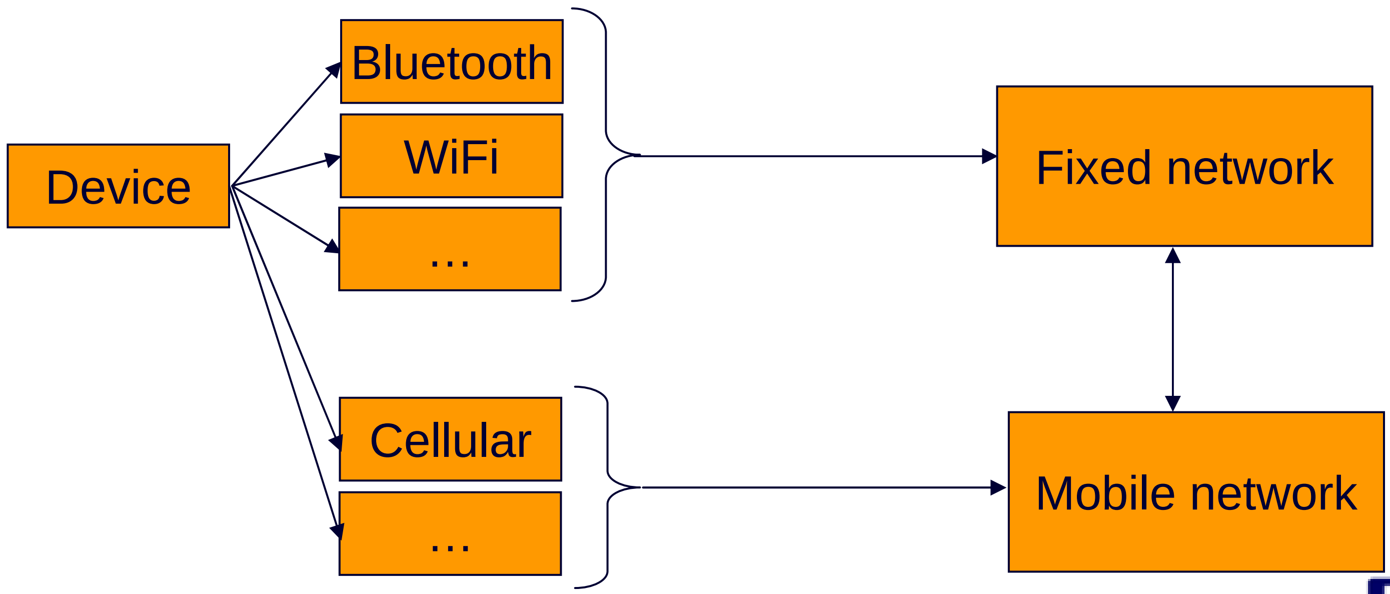
Always best connected

- *seamless communications – always available – best available connection* – utilizing both *fixed and mobile* networks –*device* of the customer's choice



Always best connected

- Example of converged fixed and mobile services (*bluephone*)
- Single handset for voice and data access anywhere
- Using different access technologies
  - Bluetooth, WiFi, WiMax, GSM, 3G,..



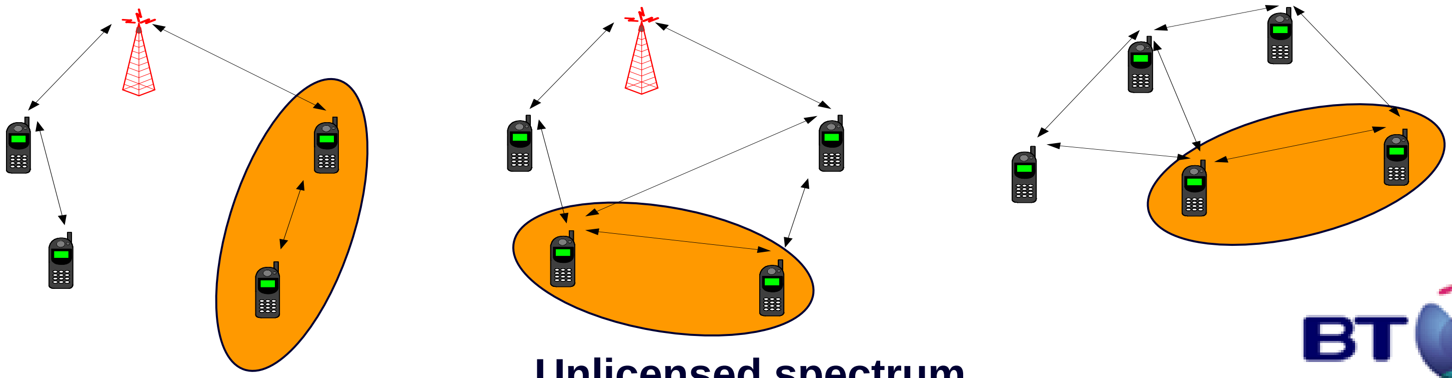
Ad hoc networks

- Ad-hoc networks
  - Group of nodes which communicate with each other over a wireless channel
  - There is no (limited) fixed infrastructure
  - The nodes operate in a decentralised manner
  - Each node can act as a router and forward packets on route to their destination
- What is their future role in wireless mobility evolution?
- Do they support 3G or WiFi systems – or replace them?
- Are they “attractive” for operators?

How do we use ad-hoc networks?

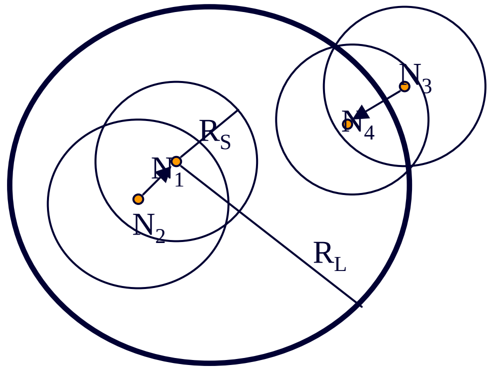
- Possible future drivers for the applications of ad hoc networks are mainly
  - Extensions to cell-size in cellular systems
  - Multi-hop extensions to to WiFi hot spots
  - Provision of self-contained infrastructure free networks for temporary coverage

- **Cellular with one hop**   **cellular and ad hoc**   **pure ad hoc**



Unlicensed spectrum

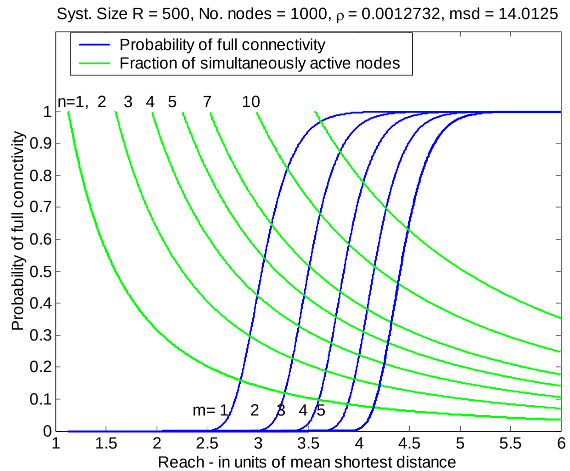
Some issues

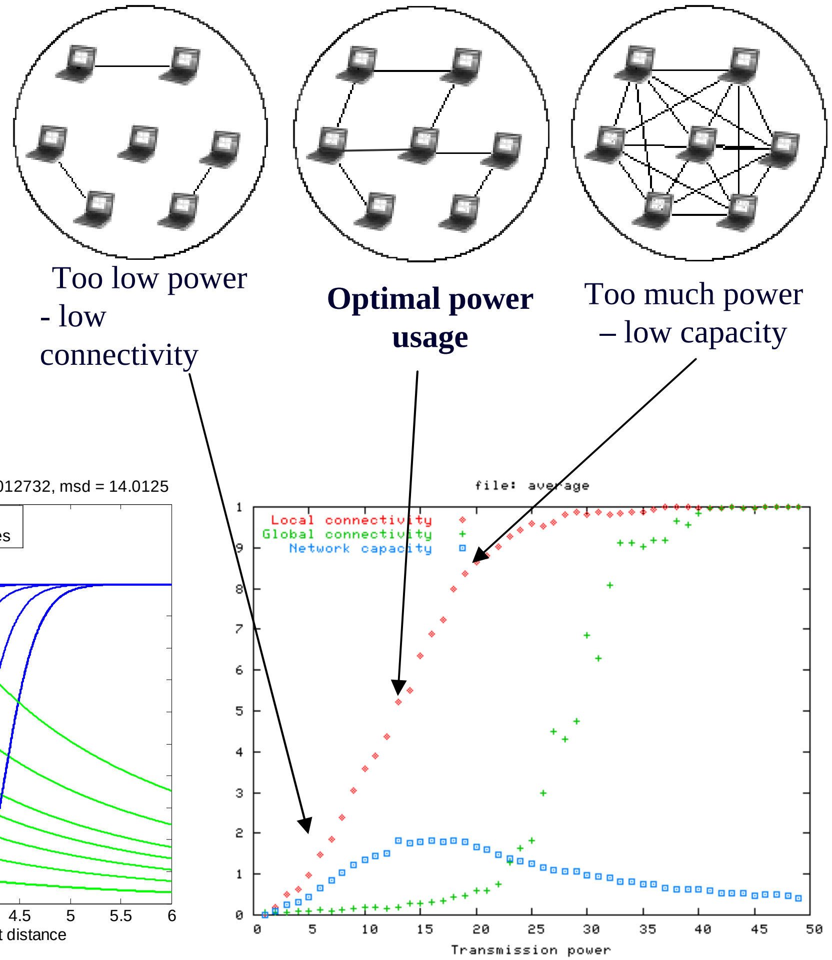


- Any model of ad-hoc networks should consider
  - Reach – stochastically distributed – not circles!
  - Interference
  - Power
  - Mobility
  - Node density distribution – arbitrary – including clusters – not just iid
  - …..
- Connectivity, capacity, stability and scalability need to be understood as functions of the above

Power control and connectivity

- Connectivity and capacity are complementary quantities
- Constraint optimisation
- Interference between nodes - reduces capacity
- Improving capacity by
  - Focused antennas
  - Effective power control
  - Improved access protocols
  - Smart antenna
  - MIMO systems
  - Hybrid network
  - etc





Power control in cellular systems

- Admissability condition

$$(I-F)P \geq \theta \;\; ; \;\; \theta_{B,i} = \frac{\gamma_{B,i}\eta_{B,i}}{G_{B,i}} \;\; ; \;\; F_{i,j} = \begin{cases} 0, & if \;\; i = j \\ \dfrac{\gamma_{B,i}G_{B,j}}{G_{B,i}}, & if \;\; i \neq j \end{cases}$$

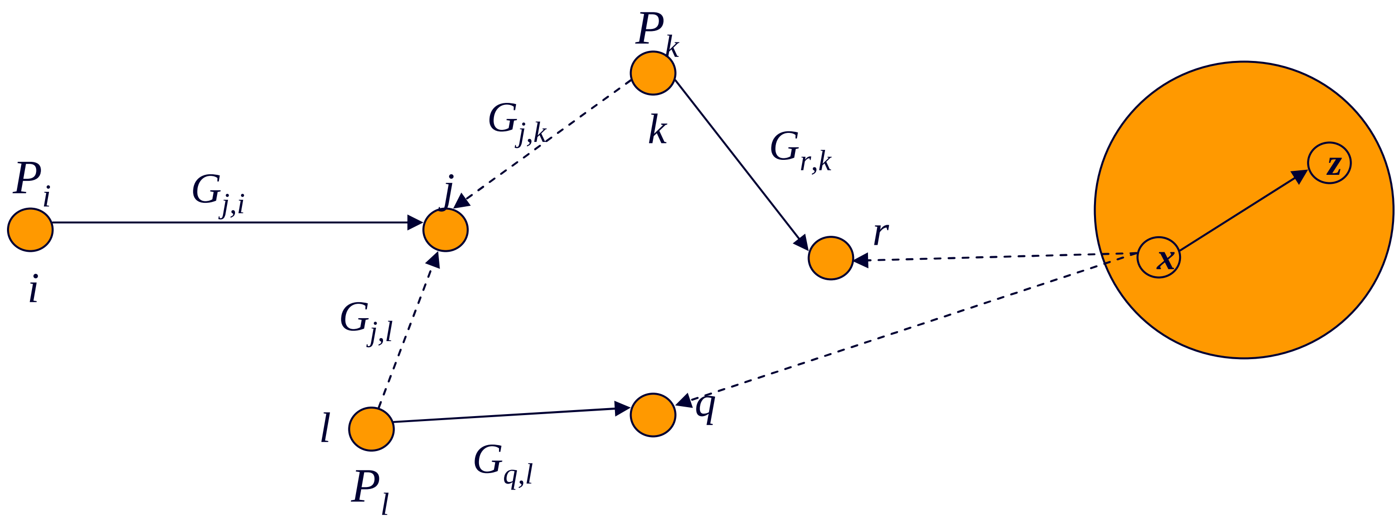
- Iterative power control

$$P(k+1) = FP(k) + \theta \;\Rightarrow\; \lim_{k\to\infty} P(k) = (I-F)^{-1}\theta \;\; if \;\; \max(\lambda(F)) < 1$$

- This solution is Pareto optimal [Mitra,1993]

- What is the “optimality” of power control in ad hoc networks?

Power control in ad hoc networks



$$S_{j,i} = \frac{G_{j,i}P_i}{\sum_{k \neq i} G_{j,k}P_k + \eta_j} \geq \gamma_{j,i} \quad \Rightarrow$$

$$G_{j,i}P_i - \gamma_{j,i}\left(G_{j,k}P_k + G_{j,r}P_r + G_{j,x}P_x\right) \geq \gamma_{j,i}\eta_j$$
$$G_{l,k}P_k - \gamma_{l,k}\left(G_{l,i}P_i + G_{l,r}P_r + G_{l,x}P_x\right) \geq \gamma_{l,k}\eta_l$$
$$G_{s,r}P_r - \gamma_{s,r}\left(G_{s,i}P_i + G_{s,k}P_k + G_{s,x}P_x\right) \geq \gamma_{s,r}\eta_s$$
$$G_{z,x}P_x - \gamma_{z,x}\left(G_{z,i}P_i + G_{z,k}P_k + G_{z,r}P_r\right) \geq \gamma_{z,x}\eta_z$$

- Active link protection [Bambos, Chen, Pottie 2000]
- Stochastic distributed optimisation [Heikkinen 2002]

Game theory for power control

- The game is distributed as players optimise individual utilities,
  - allocation P_i is worth $U_i(P_i)$ to user 'i' and may have different value to other users
  - The value may depend on the application
- Utility function forms the basis for decision making [Saraydar, Mandayam and Goodman, 2002]

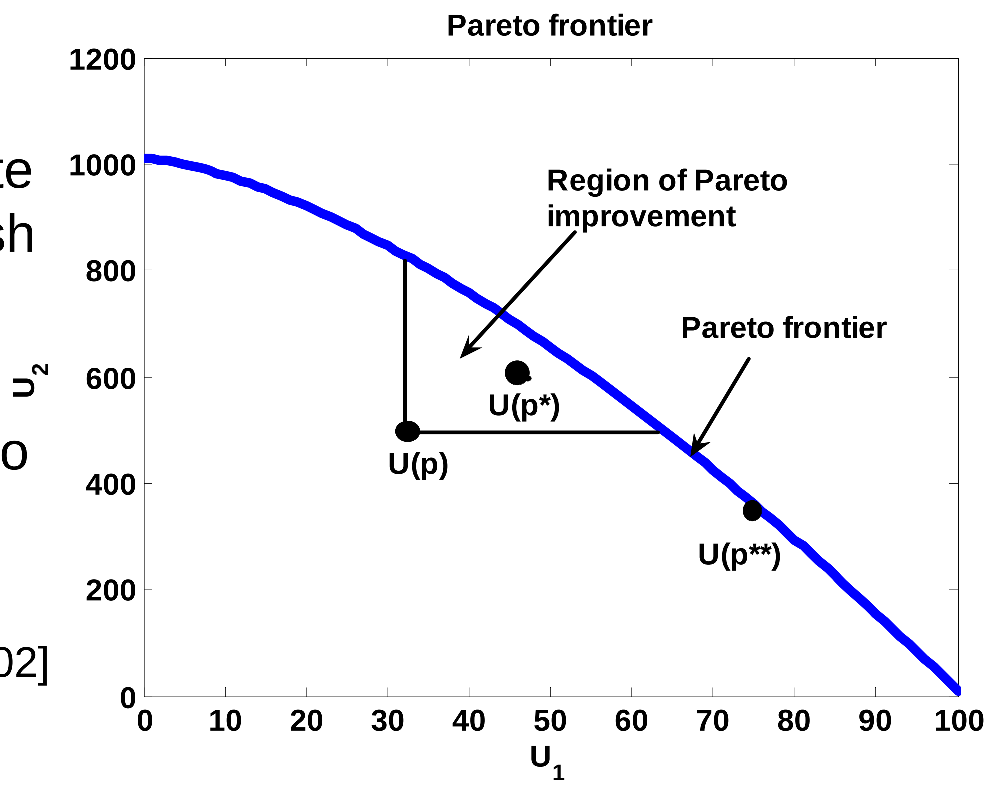
$$U_i = \frac{R}{P_i} f(\gamma_i) \ ; \ \frac{\partial U_i}{\partial P_i} = 0 \Rightarrow \textbf{Nash equilibrium}$$

- Distributed, non-cooperative strategy, leads to a Nash equilibrium
- However, the devices can increase their utilities by simultaneously reducing their powers by a small amount [As above]

Game theory for power control

- Pareto dominance and Pareto frontier
- By modifying the utility function new power equilibrium may dominate the non-cooperative Nash equilibrium
- However, there is no guarantee that the Pareto frontier is reached
- Modified utility [Saraydar, Mandayam and Goodman, 2002]

$$W_j = U_j - \sum_{k \neq j} \frac{\partial U_k}{\partial P_j} P_j$$

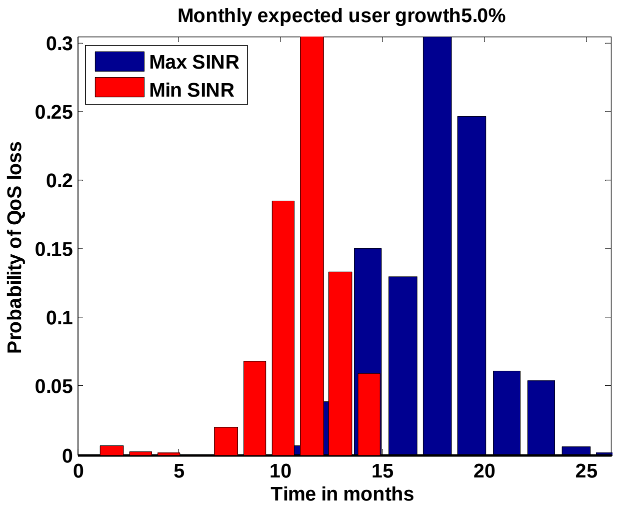


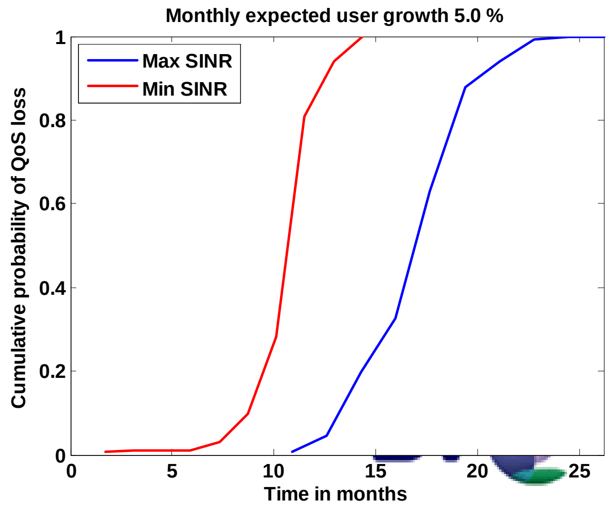
Interference in WiFi systems

- Interference in WiFi/ad-hoc systems potentially very serious
- Different ways to evaluate interference
  - Analytical models
    - From basic assumptions propagation properties, probabilities of packet collision,…
  - Simulations
    - Simulate different protocols, the effects of interference on throughput, packet loss, analyse what if scenarios, create probabilistic paths,…
  - Measurements
    - In situ measurements for different AP locations and different traffic profiles,…

Monte Carlo for interference analysis

- Risk assessment approach - VaR philosophy
- Assumptions:
  - Uptake and density of access points
  - Number of devices using each access point
  - Access technologies
  - Radio environment
- Evaluation:
  - SINR/QoS





UWB in ad hoc networks

- Benefits of UWB
  - Transmission spread over wide band $\Rightarrow$ very low spectral power density
  - Can share spectrum with other systems without causing interference
- Capacity enhancements by power constraint [Negi & Rajeswaran, 2004]

$$\Theta\left((n \log n)^{-1/2}\right) \Rightarrow \Theta\left(n^{(\alpha-1)/2}\right) \; ; \; \alpha \text{ distance loss exponent}$$

- Likely to become core technology for home/indoor entertainment networks/applications
  - Transferring video and audio between PCs, TVs, DVDs and stereos in the home environment

Spectrum utilisation

- The success of mesh networks depends on
  - Spectrum utilisation
  - Interference management
  - Efficient access
- Long term licensing of spectrum has resulted in an inefficient global utilisation - *artificial* shortage of spectrum
- Enhance spectrum utilisation by allowing dynamic and intelligent access to under-utilised spectrum
- Requires joint effort on different fronts
  - Technical
  - Regulatory
  - Economics

Spectrum utilisation

- Recent liberalisation trends are intended to encourage *market in license ownerships* and the *trading of spectrum*
- Some alternatives
  - ***Real time spectrum trading*** – allowing users to explore under – utilised spectrum – within and across applications
  - ***Open access*** – unlimited user access to unlicensed spectrum for all who comply with access etiquettes (example WLAN)
  - ***Opportunistic overlay*** – spectrum agile radios can search the spectrum and operate in licensed but temporarily unused spectrum – cognitive radios

Summary

- Ad hoc networks are likely to improve
  - Connectivity
  - Access
- Various important research issues
  - Power control
  - Game theory
  - UWB
  - Spectrum management