Lecture 12

December 1st, 2005

Cross-layer design – what should you take home from this course?

- General framework for cross–layer design
  - Maintain the layered approach but exchange information between layers and jointly optimize the performance
    - Abstraction of layers
      - General models for different layers
        - » capture important parameters which influence other layers
        - » Identify the cross-layer information that has to be exchanged between layers
    - Implement adaptation protocols at each layer, using the information exchange between the layers
    - Worry about convergence properties
- Several tools for analysis and optimization at different layers
  - Physical layer:
    - determine SIR as a key performance measure for the physical layer
    - Optimize powers, receivers, antennas
  - MAC and Network layers
    - QoS measures: Delay and blocking performance
    - Optimize scheduling, routes, number of users allowed in the network (admission control)

Examples of cross-layer integration for ad-hoc networks

- Physical layer + MAC
  - Adaptive beamforming and CSMA/CA [i] ✓
  - Adaptive modulation and MAC [ii]
  - Adaptive power control and MAC [iii] ✓

- Physical layer + network layer
  - Adaptive power control + routing [iv] ✓
  - Adaptive power control + receiver optimization + routing [v] ✓
  - Power control + routing + receiver optimization + admission control [vi]

- Physical layer + MAC + routing
  - Adaptive modulation + MAC + routing [ii]
  - Adaptive beamforming + MAC + routing [vii]

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- Physical layer + MAC + routing
  - Adaptive modulation + MAC + routing [ii]
  - Adaptive beamforming + MAC + routing [vii] ✓

Adaptive beamforming + MAC + routing

- The integrated MAC and beamforming design that we have discussed so far was not specifically consider routing

- In general, different MAC protocols differ based on
  - How RTS/CTS is transmitted (omni, directional)
  - Transmission range of directional antennas
  - Channel access schemes
  - Omni or directional NAVs

- The antenna gains are different for omnidirectional (Go) and directional transmission (Gd): Gd > Go
- An idle node listens omnidirectionally
  - Does not know who is going to transmit to it

Pros and Cons for directional antennas

Advantages

- Spatial reuse
  - Multiple transmissions in the same neighborhood
- Higher gains – better links
  - Two distant nodes may communicate with a single hop
  - Fewer hops in a route

Disadvantages

- Higher gains mean also high interference at distanced nodes

There are three types of links

- omnidirectional – omnidirectional : OO links – smallest range

- directional – omnidirectional: DO links

– usually used in the protocols discussed up to now because the node listens omnidirectionally

- directional –directional – largest range

- least number of hops

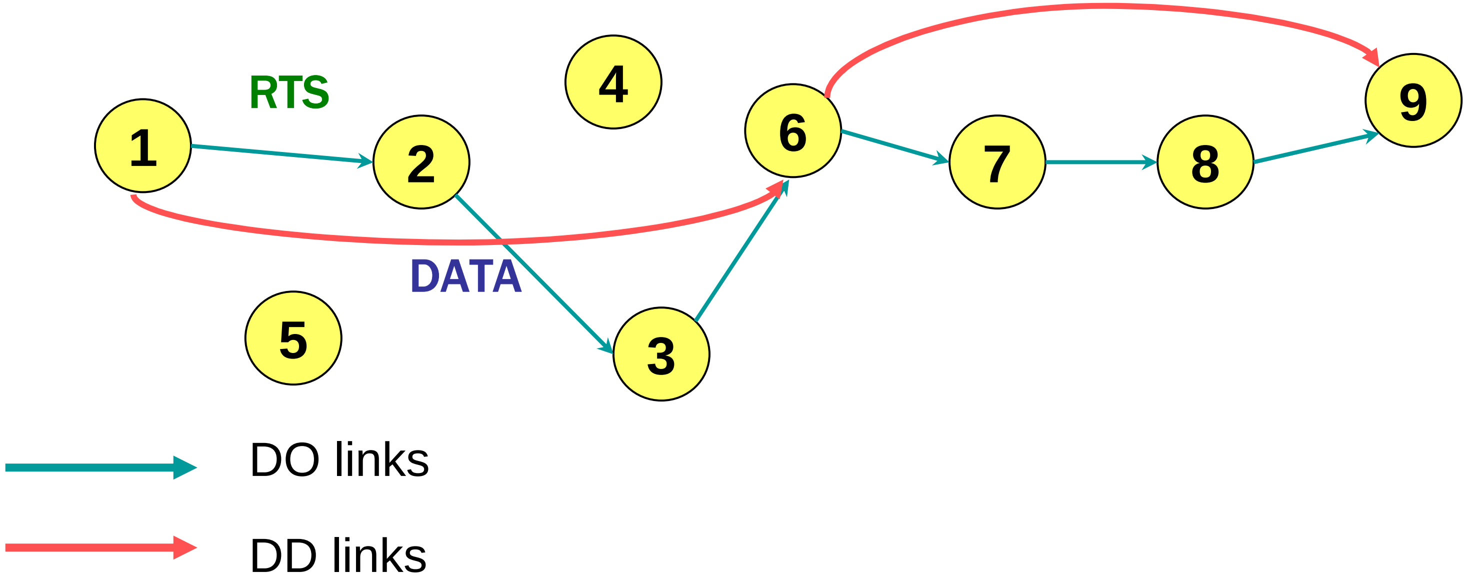
- problem: the nodes listen omnidirectionally

Joint MAC and routing solution [vii]

- Use the same MAC for directional antennas, but transmit RTS over multiple hops (MMAC protocol)

If source 1 wants to communicate with node 6
- transmits a forwarding RTS with the profile of node 6, using DO links
- when node 6 gets the RTS, it beamforms in the direction of 1, forming a DD link

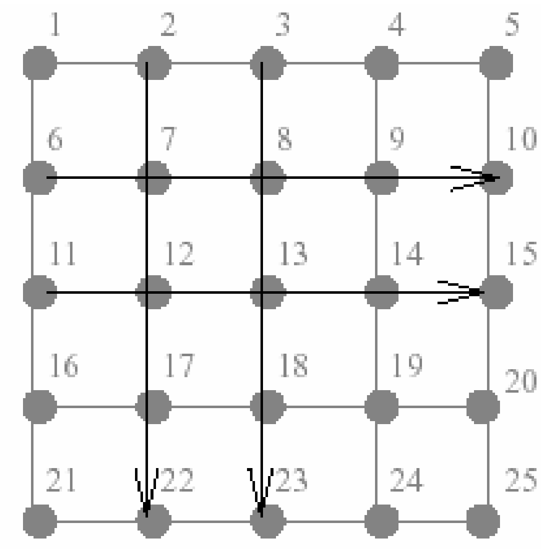
Transmission from 1 to 9 on DD links requires only 2 hops

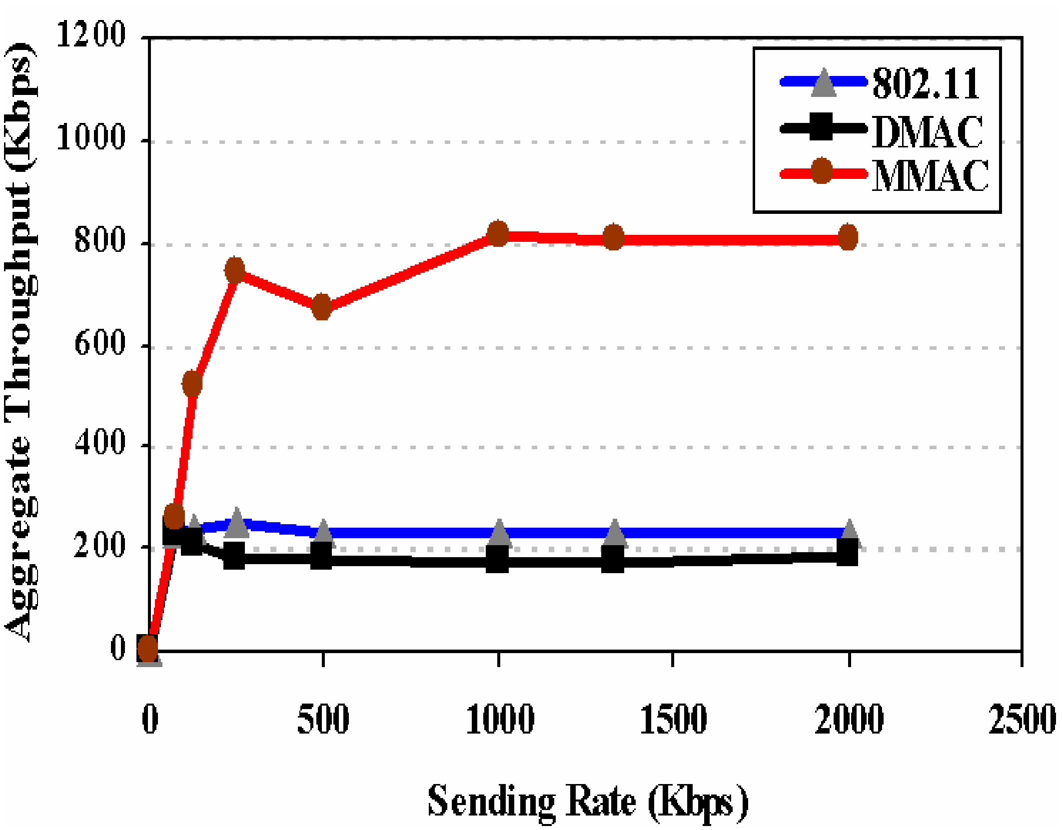


Some performance results and comparisons

- The performance of networks with directional antennas depends on the simulated network topology
- In [vii], several cases were studied:
  - (a) Manhattan networks with aligned routes
  - (b) Manhattan networks with random routes
  - (c) Random configuration
- For all three cases, the numerical parameters chosen:
  - Antenna beamwidth = 45
  - Omnidirectional transmission range = 250 m
  - Directional transmission range (DD link) = 900 m
- Performance measure
  - Average throughput

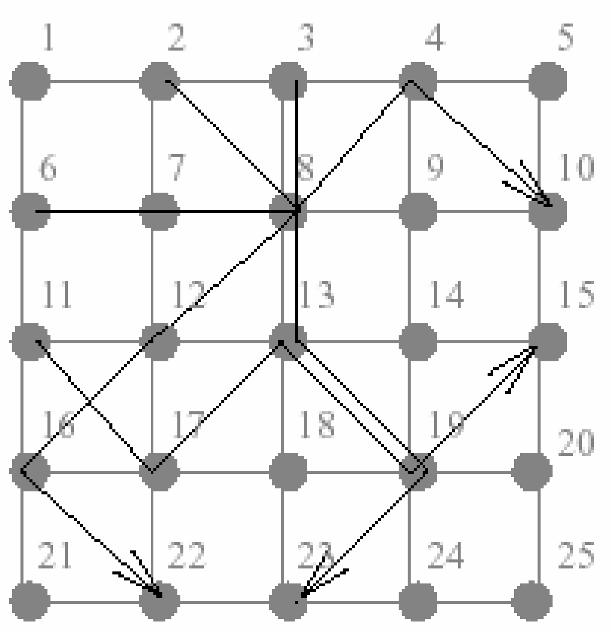
(a) Manhattan Networks with aligned routes [ii]

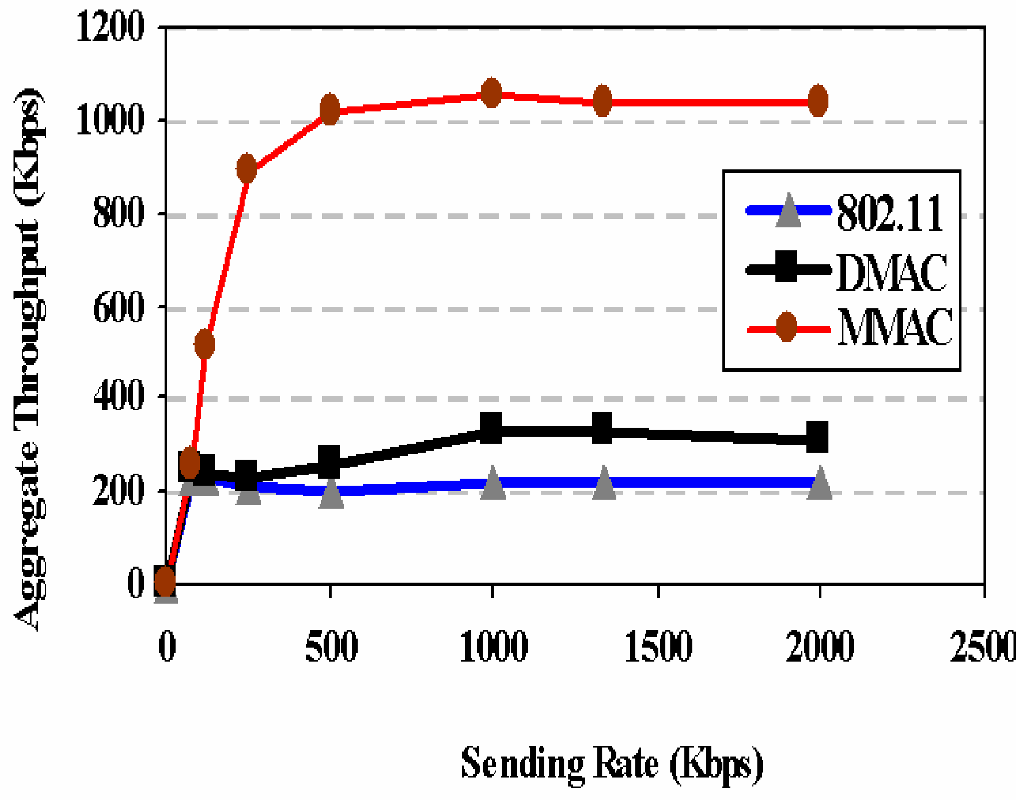




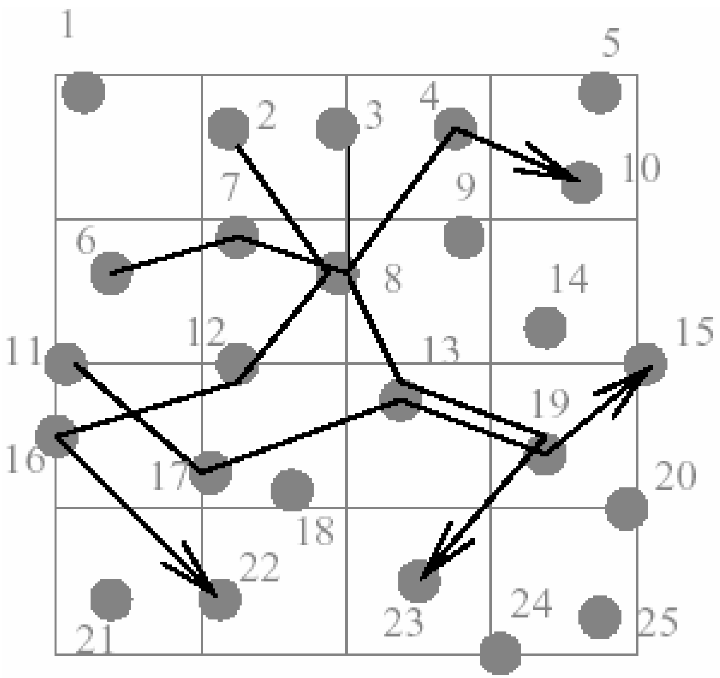
Note: 802.11 uses CSMA/CA with omnidirectional antennas
DMAC is the integrated MAC and beamforming protocol
MMAC is the multi-hop routing protocol

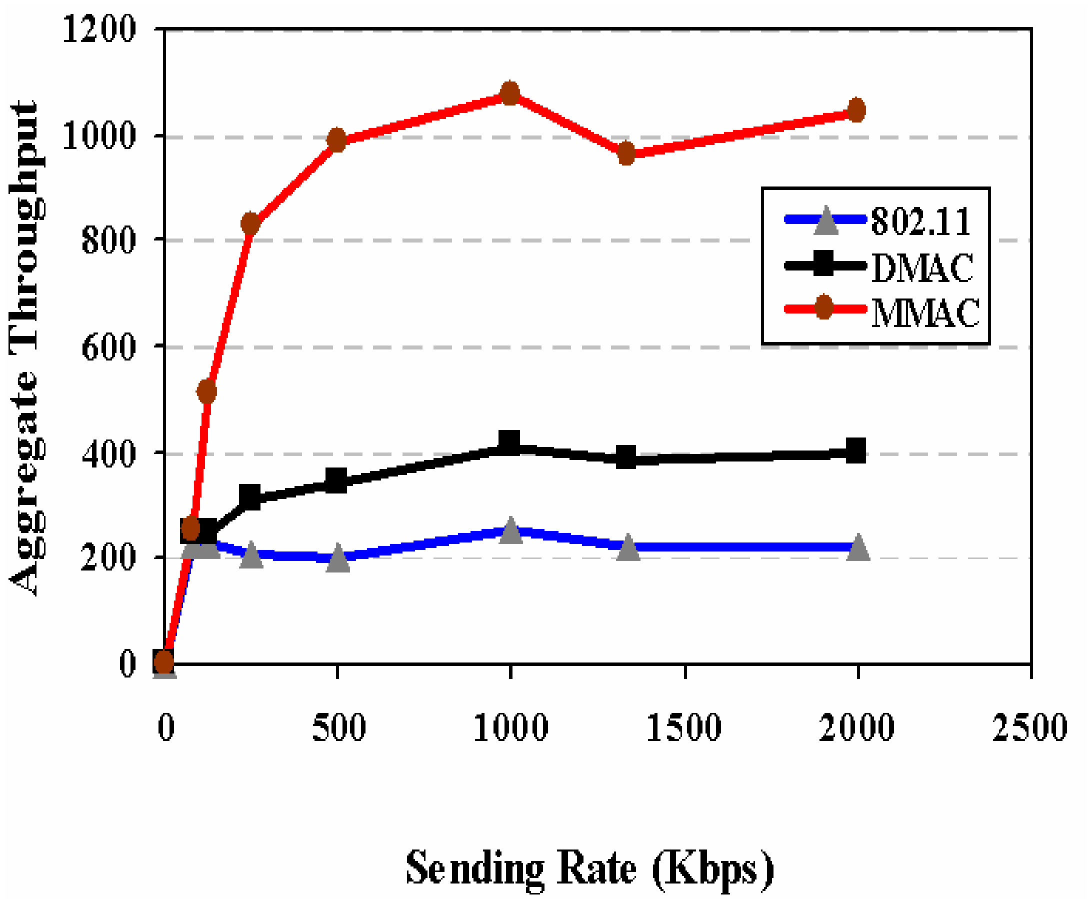
(b) Manhattan networks with random routes [ii]





(c) Random configuration [ii]





Some observations

- In general MMAC, better than DMAC, better than 802.11
- However, when the routes are aligned, as in (a), using MAC and directional antennas degrades the performance, compared to the case with omnidirectional antennas (802.11)
  - For (a) more directional interference occurs, due to the aligned paths
- You gain more if you can actually exploit the spatial reuse property of the directional antennas,
- If not, the performance will be worse because of the increased directional interference (higher gain for the directional antennas)

Power control + routing + receiver optimization + admission control [vi]

- In [vi], the problem of designing admission control for multicasting in ad hoc networks is addressed
  - Note that the network model for an ad hoc network is a graph, and not a queuing model as we have seen up to now in all the admission control problems that we have discussed
- The topology of the ad hoc network will depend on the selection of powers and receivers (link exists when SIR target is met), and also on the outcome of the admission control
- The analysis in [vi], considers circuit switched multicasting for synchronous CDMA networks and discusses three possible types of receivers
  - Matched filters
  - MMSE receivers
  - Decorrelators

Steps in setting up a new multicast session

- Admit the new session
- Set up the multicast tree
- Implement power control such that QoS requirements are met

- Admit the new session
  - Each node decides if it can take part in the new multicast session based on local information, i.e., its available residual capacity
    - Based on its residual capacity it establishes power bounds: $p_{\min}$ $p_{\max}$
    - $p_{\min}$ selected such that target SIRs are met at the receiving node
      - Fixed value – the choice of $p_{\min}$ influences the node's capacity
    - $p_{\max}$ determined such that the level of interference is kept low
    - $p_{\max}$ can be easily determined for the matched filter
  - A new session is admitted at a specific node *j* if its received power is within the specified bounds
  - It is assumed that the transmission power of that session is always set such that it will be received with at least the minimum required power level
    - If the system is lightly loaded, using this power level is not necessary
    - Alternate solution: increase the value of $p_{\min}$ gradually, as the load increases

Set up the multicast tree

- Nodes that decide to participate in the new session form a set of "potential downstream neighbors" for that session
  - *k* is a potential downstream neighbor of *j*, if node *j* can satisfy the power range requirements for node *k*
- The cost of a link (i,j) is the transmission power P_{ij} required for node *i* to be correctly received by node *j*
- The cost of a node is the maximum cost over all outgoing links
- The cost of the network: the sum of the costs for all nodes
- *Optimal multicast tree: minimize this cost* – NP-hard problem
- Suboptimal solution proposed in [vi]: PET – pruned extended tree algorithms

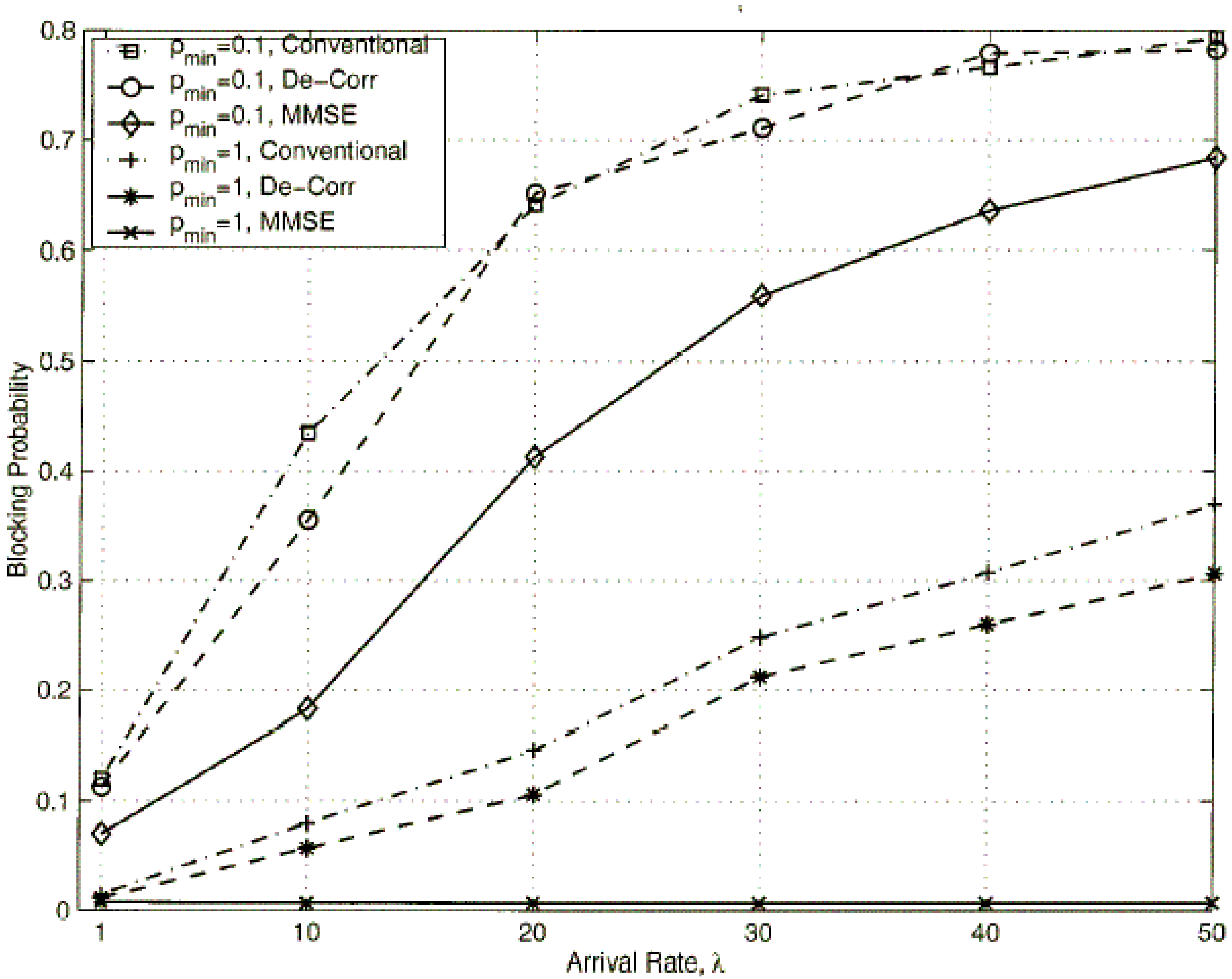
PET

- Starting with the source node, nodes are added to the tree until all multicast destination are added
- Rule for addition: minimal cost increase
- After adding a new link, backsweeping may be necessary
  - A node parent in the tree is changed, if this results in a overall reduction in the cost of the tree

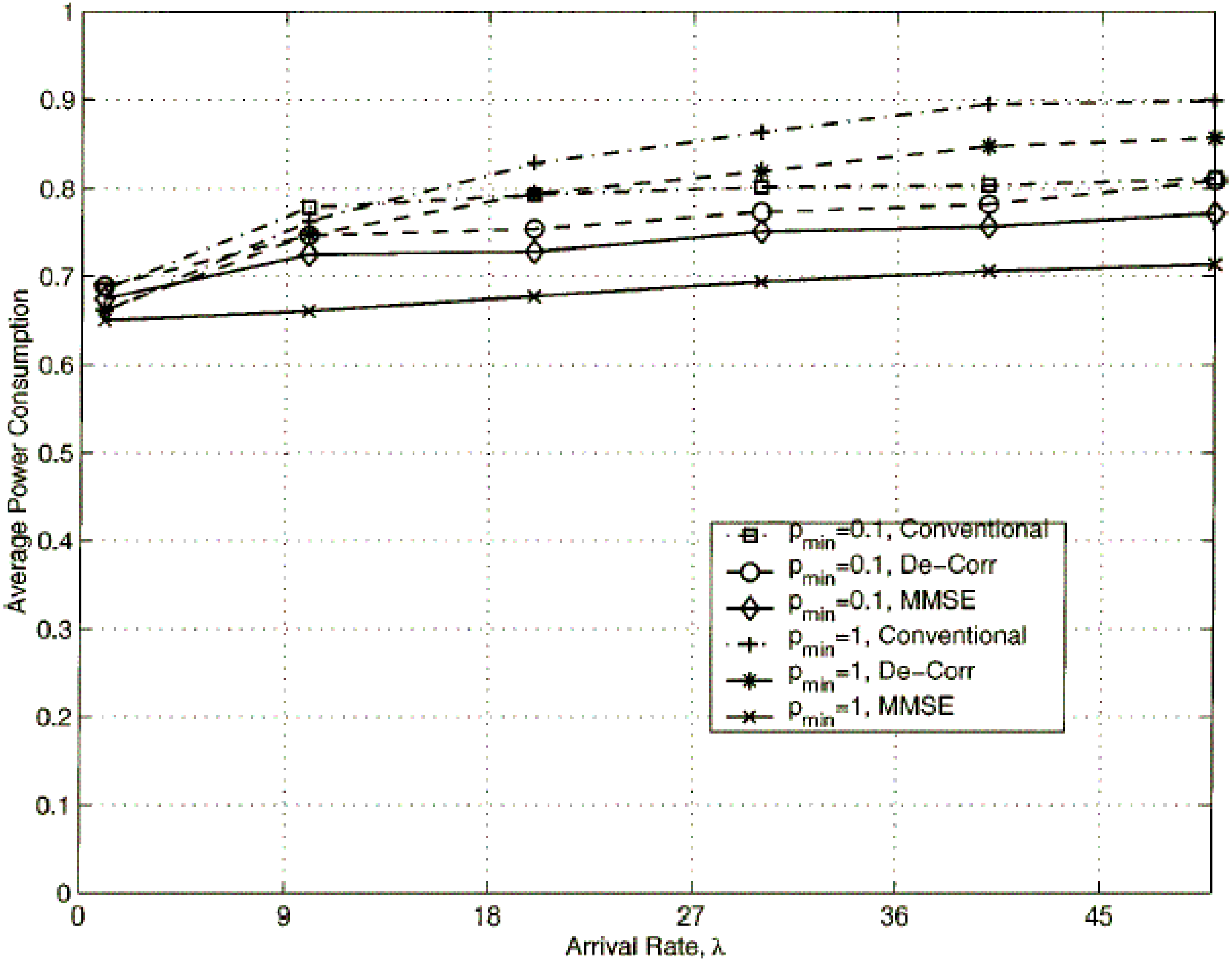
Power control

- Similar to the model in [iv], power control for multicast sessions, require that a node meets target SIR requirements for many outgoing links
  - weakest outgoing link must meet the target SIR
  - We have already seen that this problem can be mapped into a standard power control problem (standard interference function) -> the power control can be implemented iteratively and distributively
  - Similar analysis as in [iv] but without the joint optimization of the routes

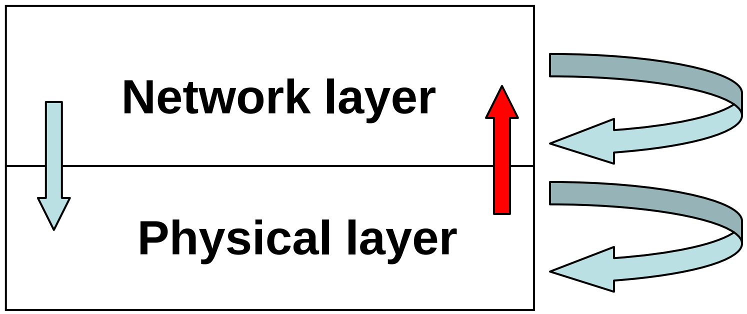
Some performance results



Average power



How this example fits into our general cross-layer design framework?



Admission control
Routing

Power control
Receiver design $\Rightarrow \{p_{\min}, p_{\max}\}$

Current session allocations for each node

Action: new residual capacity and new power bounds are determined

Power bounds $\{p_{\min}, p_{\max}\}$

– influences the admission control and the network topology

Action: admission control considers these power bounds

References

- [i] M. Sanchez, "Multiple Access Protocols with Smart Antennas in Multihop Ad Hoc Rural-Area Networks", Licentiate of Technology thesis, KTH, Royal Institute of Technology Sweden, June 2002.
- [ii] W. H. Yuen et all, "**A simple and effective cross-layer networking system for Mobile ad hoc networks**", PIMRC, 2002
- [iii] T. ElBatt and A. Ephremides, "**Joint scheduling and power control for wireless ad-hoc networks"** IEEE INFOCOM 2002., vol. 2 , pp. 23-27, June 2002
- [iv] C. Comaniciu, H.V. Poor, "QoS Provisioning for Wireless Ad Hoc Data Networks (invited paper)", 42nd IEEE Conference on Decision and Control, December 2003.
- [v] C. Comaniciu, N.B. Mandayam and H.V. Poor, "Wireless Networks: Multiuser Detection in Cross-Layer Design", Springer, May 2005.
- [vi] *Sankaran, C.; Ephremides, A.,* **The use of multiuser detectors for multicasting in wireless ad hoc CDMA networks**, IEEE Transactions on Information Theory, vol: 48 Issue: 11, pp. 2873 -2887, Nov. 2002
- [vii] R. R. Choudhury, X. Yang, R. Ramanatham, N. Vaidya, "Using directional antennas for medium access control in ad hoc networks, ACM Mobicom, Atlanta, September 2002.