Routing and Cross-Layer Considerations in Wireless Mesh Networks

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Routing in wireless networks

- Primary objective
  - Find path(s) from source to destination
- Is this good enough?

Depends!!

On the network under consideration and objectives

Wireless networks: Classification

Mobile ad-hoc networks
- Medium to high mobility
- Lack of infrastructure support
- Ad-hoc peer to peer communication

→ **Network Objectives**
- Maintain connectivity
- Minimize maintenance overhead
- Handle mobility and link outages

Sensor networks
- Fixed deployment
- Battery operated
- Sensors to data collection portal

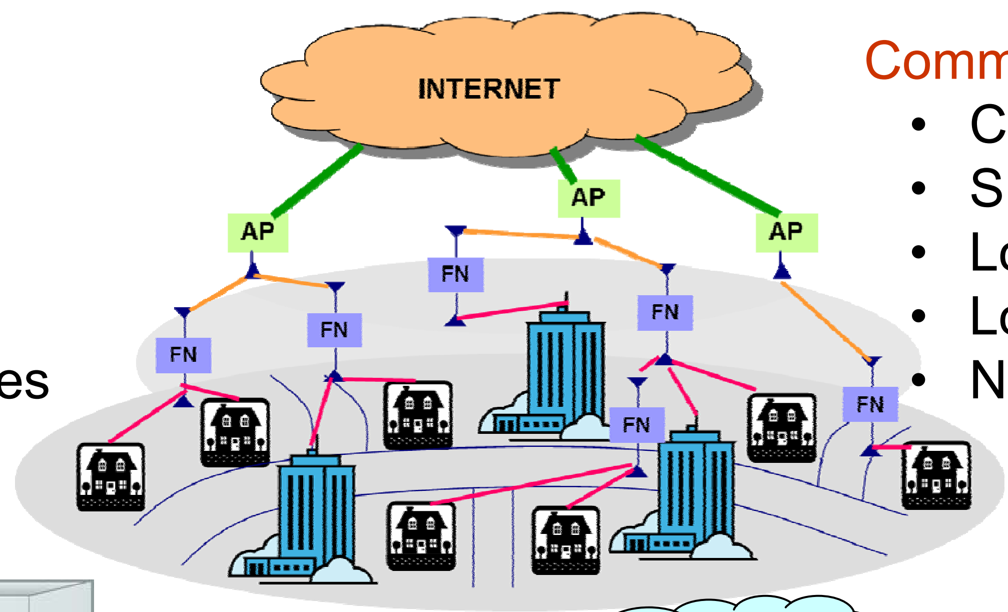
→ **Network Objectives**
- Minimize energy consumption
- Handle infrequent bursts of traffic

Wireless Mesh networks
- Fixed deployments
- Ad-hoc + infrastructure links
- Client to gateway
- Medium to high node density

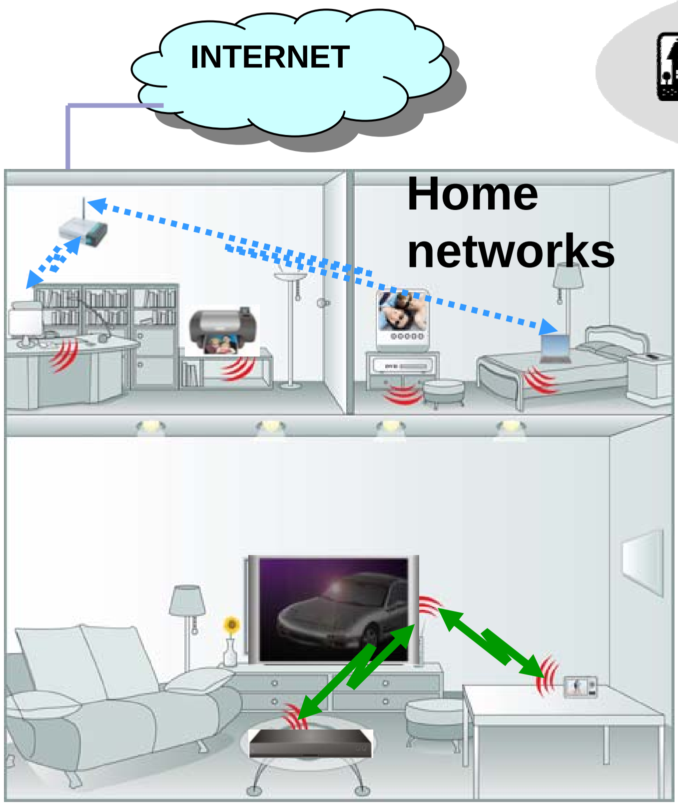
→ **Network Objectives**
- Maximize throughput
- Minimize latency
- Use all available frequencies efficiently
- Handle interference

Wireless mesh networks (WMNs)

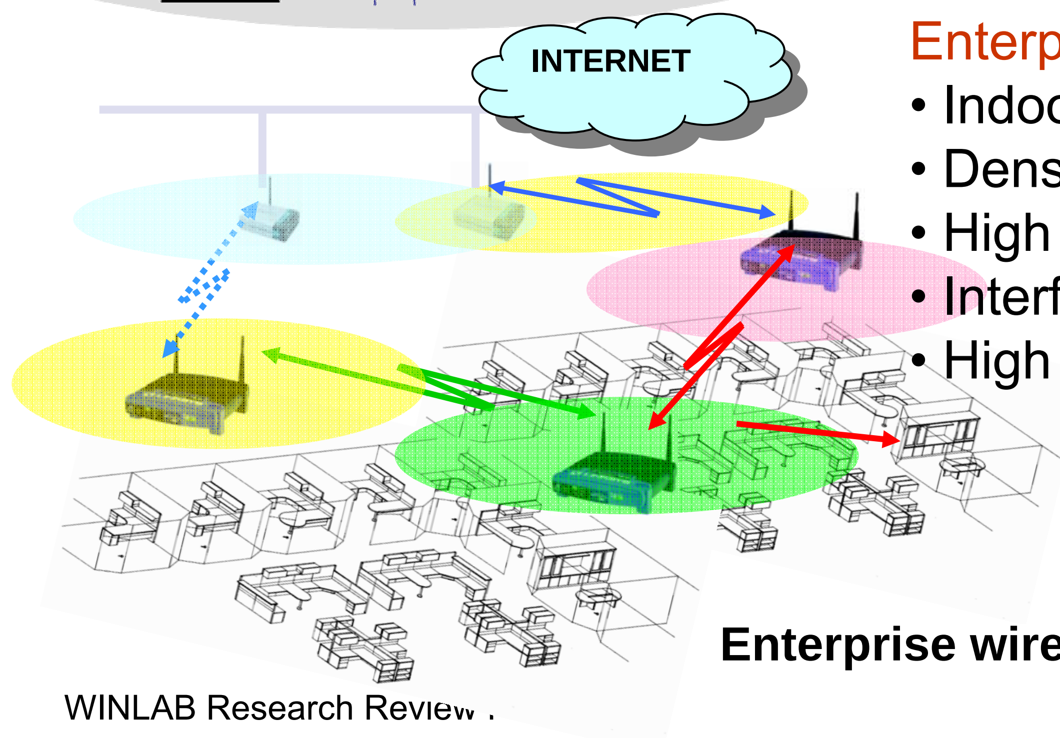
Home Networks
- Indoor coverage
- Sparse topologies
- High bit rate links
- Interference from µwaves, cordless phones



Community wireless
- City wide coverage
- Sparse topologies
- Low bit rate
- Lossy links
- Noise



Enterprise
- Indoor coverage
- Dense topologies
- High bit rate links
- Interference
- High volume traffic



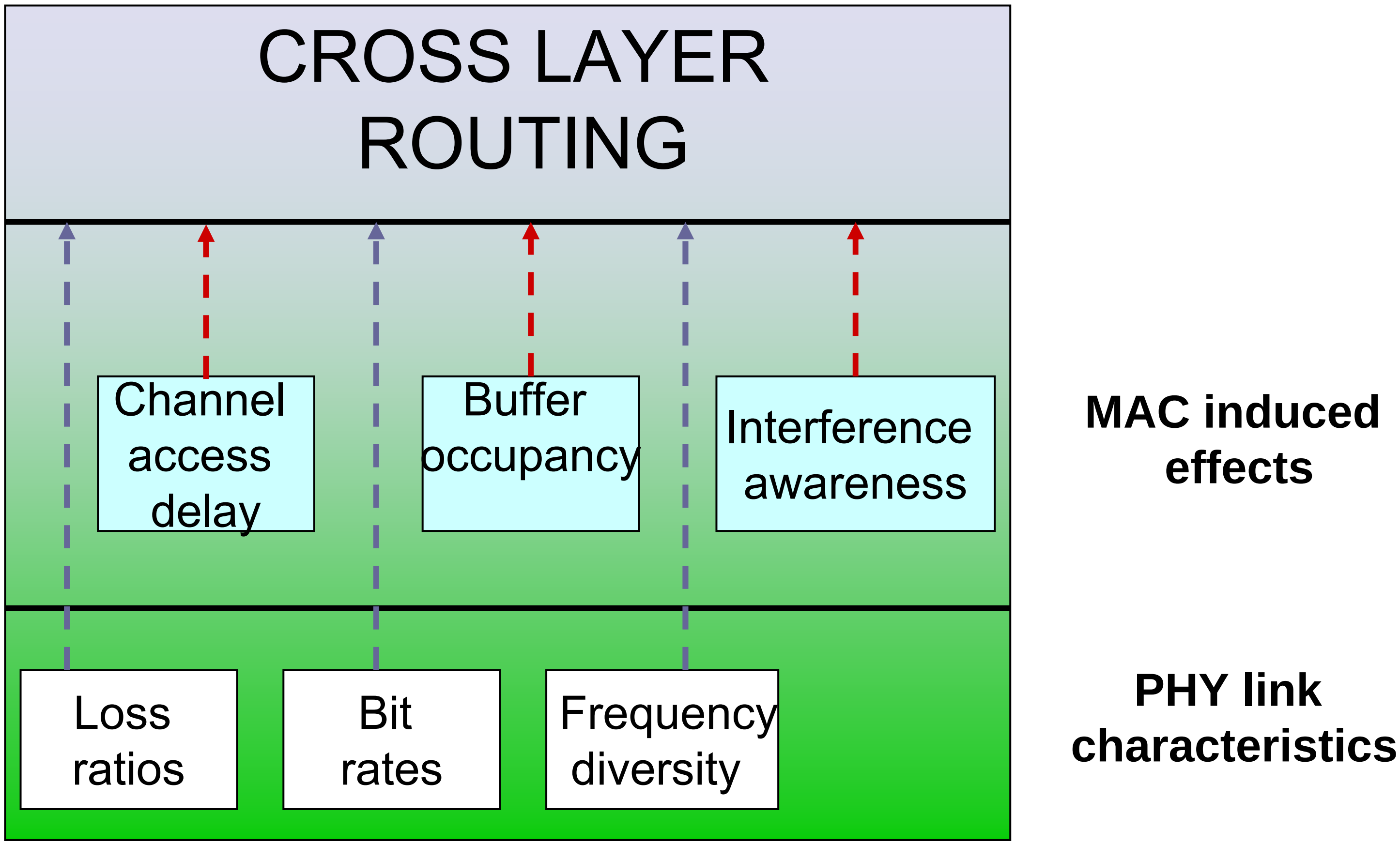
Enterprise wireless mesh

http://www.arcsoft.com/products/mediaserver/images/Digital_Home.jpg

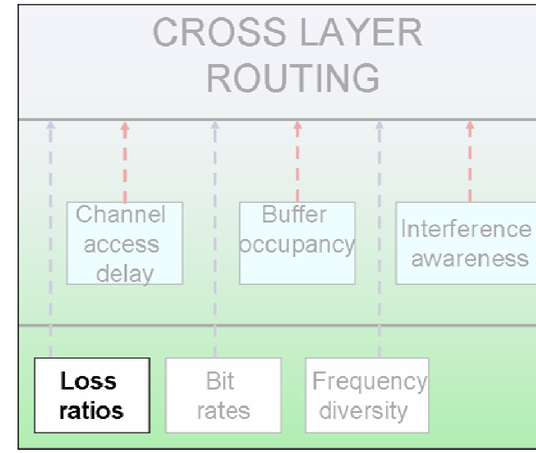
Finding "high quality" routes in WMNs

- Earlier approaches
  - Apply on-demand routing techniques (DSR, AODV) on top of 802.11 DCF MAC
    - Uses hop count based metric
    - Overhead of flooding based route discovery too high for static mesh networks
    - Shortest path not necessarily the best path
- Recent cross layer metric-based approaches
  - Find fundamental parameters that affect end user performance
  - Knowledge of underlying link conditions
  - Knowledge of underlying MAC behaviour

Recent cross-layer considerations



Metric-based routing approaches (1)



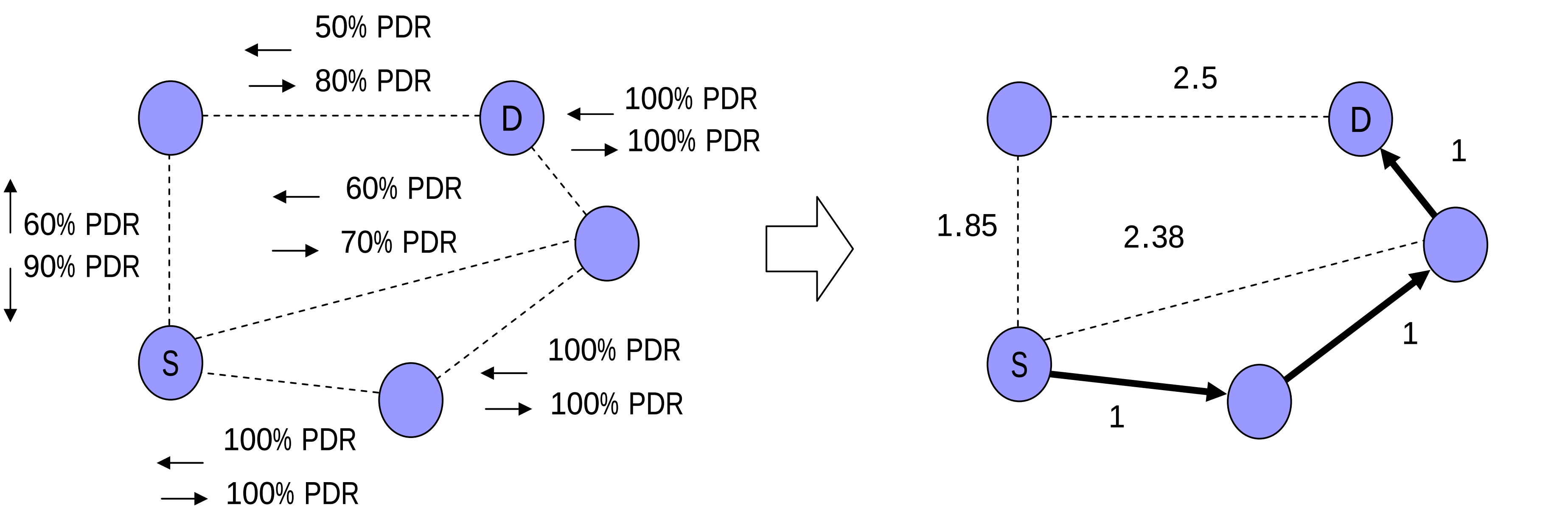
Expected transmission count (ETX) [DeCouto03]

$$ETX = \frac{1}{d_f \times d_r}$$

$$d_f = forward\_delivery\_ratio$$

$$d_r = reverse\_delivery\_ratio$$

Use periodic (100ms) broadcast packets of 134 bytes to estimate d_f and d_r



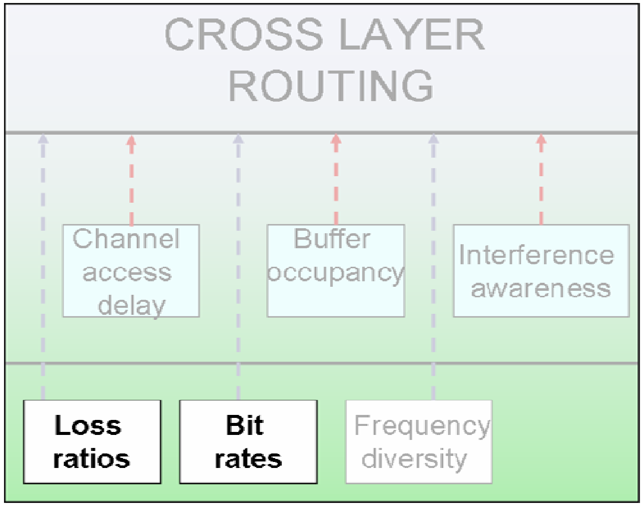
Metric-based routing approaches(2)

Expected transmission time (ETT) [Draves04]

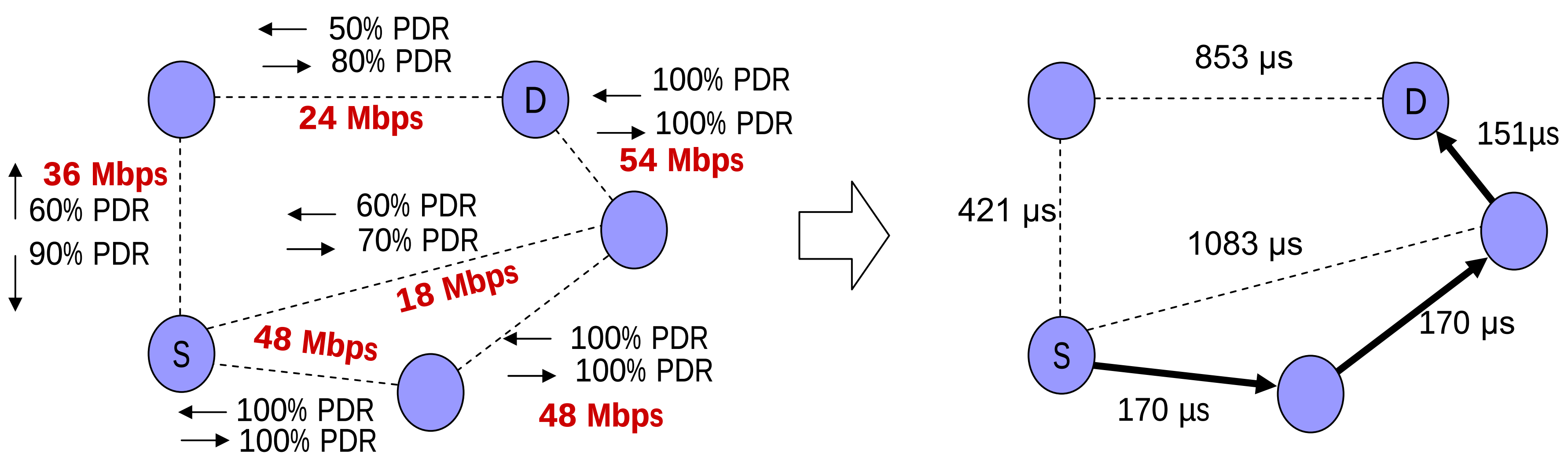
$$ETT = ETX \times \frac{S}{B}$$

$$S = packetsize$$

$$B = linkrate$$



Assuming 1024 byte packet



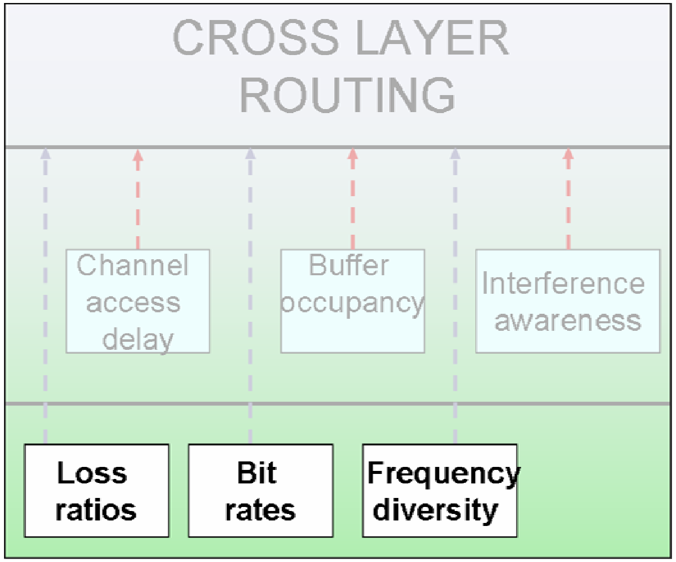
Metric-based routing approaches (4)

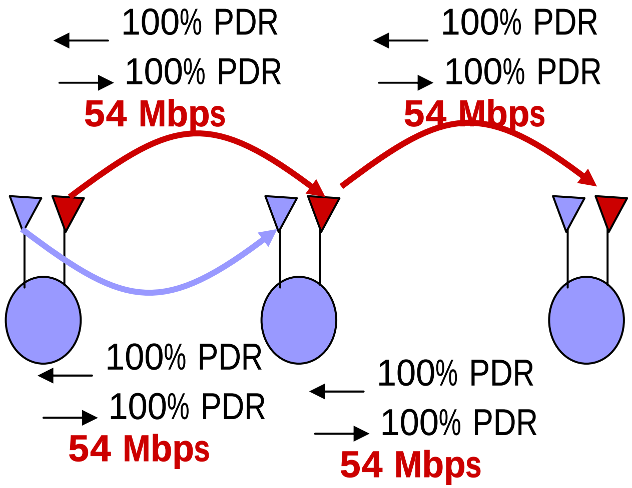
Weighted Cumulative Expected Transmission Time (WCETT) [Draves_04]

$$WCETT = (1-\beta)\sum_{i=1}^{n} ETT_i + \beta \max_{1 \le j \le k} X_j$$

$$where X_j = \sum_{\text{hop } i \text{ is on channel } j} ETT_i$$

$$ETT = ETX \times \frac{S}{B}$$





Channel diversity helps achieve 2x throughput

Path	Throughput	ΣETT
Red-Blue	**~2x Mbps**	**3.02 μs**
Red-Red	**x Mbps**	**3.02 μs**

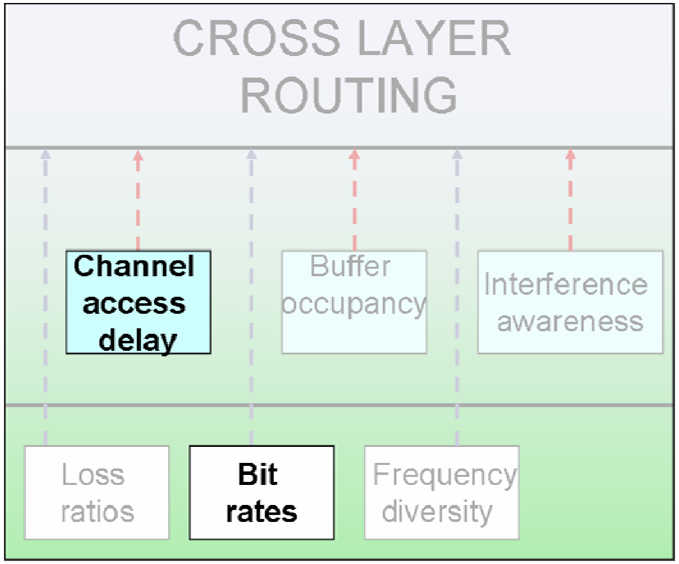
Metric-based routing approaches (3)

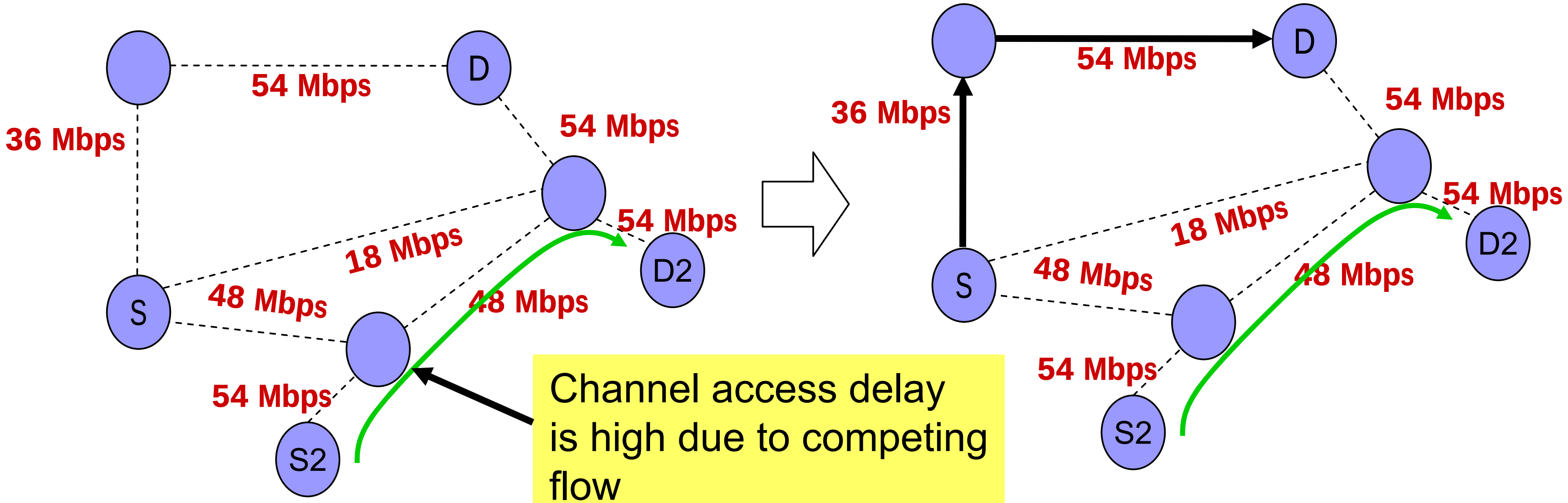
PHY/MAC aware (PARMA) [Zhao05]

$$PARMA = \frac{S}{B} + T_{access}$$

T_{access} = channel access delay

S = payload size, B = PHY rate





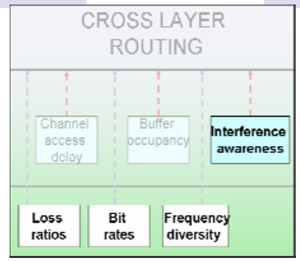
Metric-based routing approaches (5)

MIC [Yang05]

$$MIC = \alpha \sum_{l \in p} IRU_l + \sum_{node, i \in p} CSC_i$$

$$IRU_l = ETT_l \times N_l$$

$$CSC_i = w_1 \_if \_CH(i) \neq CH(prev(i))$$
$$w_2 \_if \_CH(i) = CH(prev(i)); 0 < w_1 < w_2$$



Interference aware Resource Usage
- Scales the ETT with number of interfering links

Channel Switching Cost
- Prefers link with frequency diverse consecutive hops

- Penalizes links with more interfering (irrespective of traffic or SINR at receiver)

iAware [Anand06]

$$IR_i(u) = \frac{SINR_i(u)}{SNR_i(u)}; SNR_i(u) = \frac{P_u(v)}{N}$$

$$SINR_i(u) = \frac{P_u(v)}{N + \sum_{w \in \eta(u)} \tau(w) \times P_u(w)}$$

Takes into account node activity levels

$$IR_i = \min(IR_i(u), IR_i(v))$$

$$iAware_i = \frac{ETT_i}{IR_i}$$

$$iAware(p) = (1-\alpha) \times \sum_{i \in p} iAware_i + \alpha \times \max_{i \leq j \leq k} X_j$$

$$X_j = \sum_{i \in p\_in\_channel_j} iAware_i$$

Interference aware
- Scales the ETT with actual interference measurement and traffic level of interferers

Channel diversity

IEEE 802.11s Standard

- Specifies one of the mandatory protocol and metric for all implementations
- Airtime link metric (C_a)
- Radio aware OLSR or Radio Metric AODV as routing protocols

$$C_a = \left[O_{ca} + O_p + \frac{B_t}{r} \right] \frac{1}{1 - e_{pt}}$$

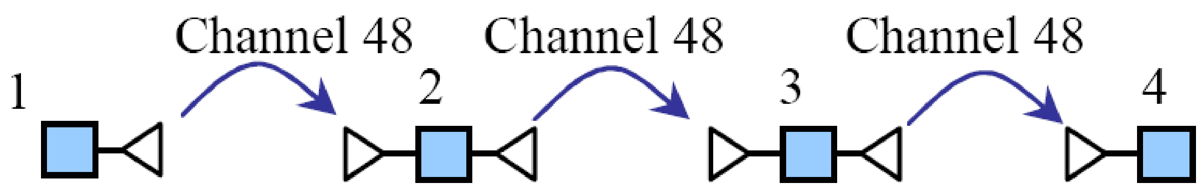
Only variables in the metric

O_{ca}	Channel access overhead (**constant**)
O_p	Protocol overhead (**constant**)
B_t	Packet size (bits) of test frame (**constant**)
r	Bit rate
e_{pt}	Error rate for B_t at r

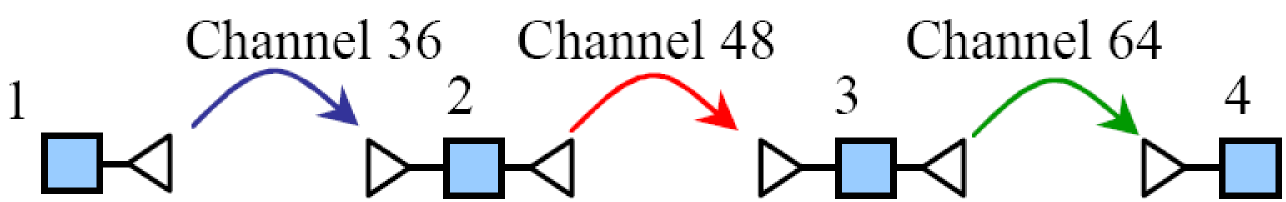
Reading between the lines: Airtime = ETT

ORBIT experimental results

Auto-rate, 1 channel, noise -16 to -5 dBm on Channel 48

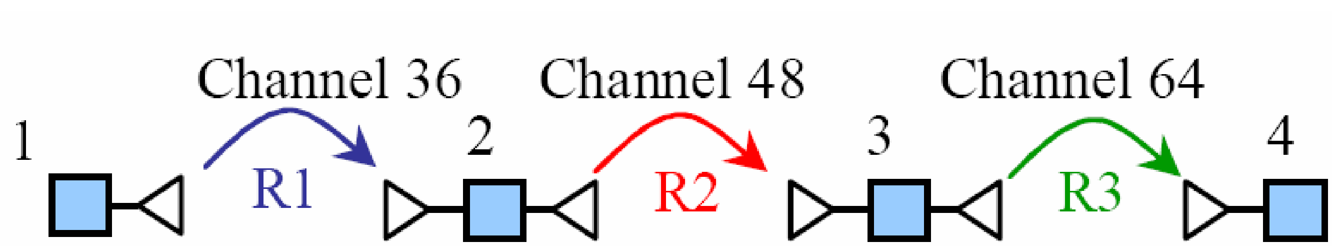


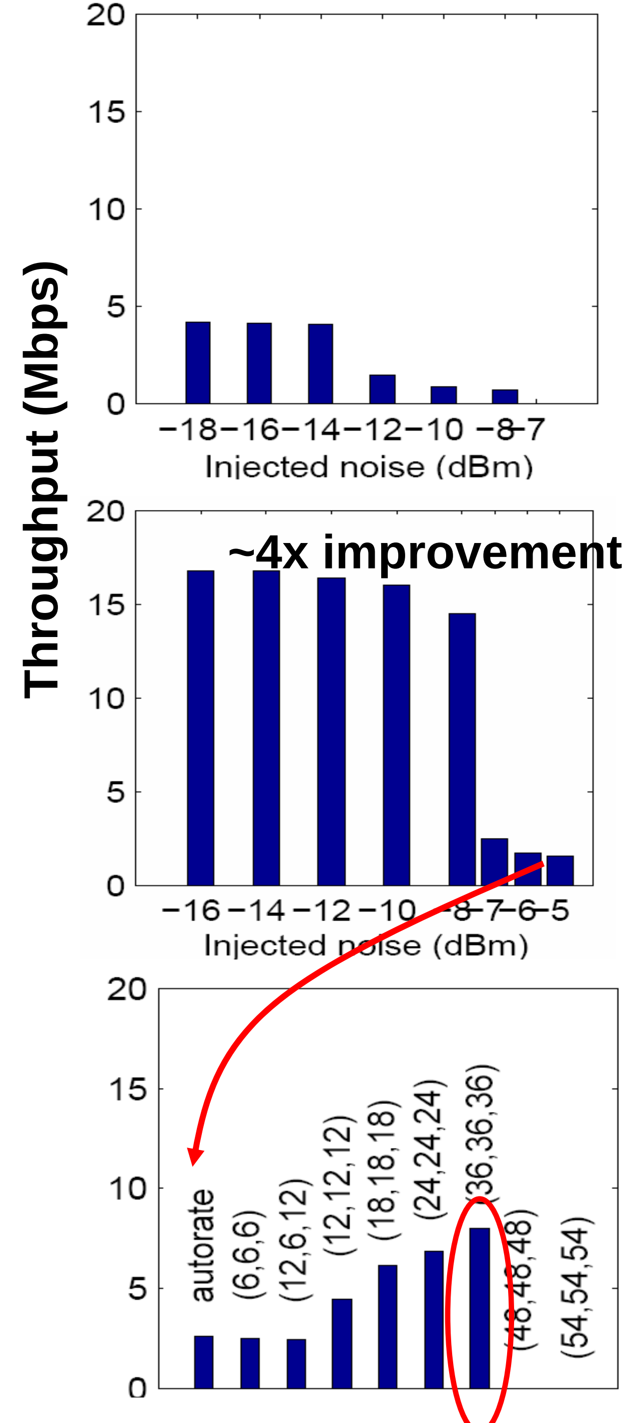
Auto-rate, 3 channels, noise -16 to -5 dBm on Channel 48



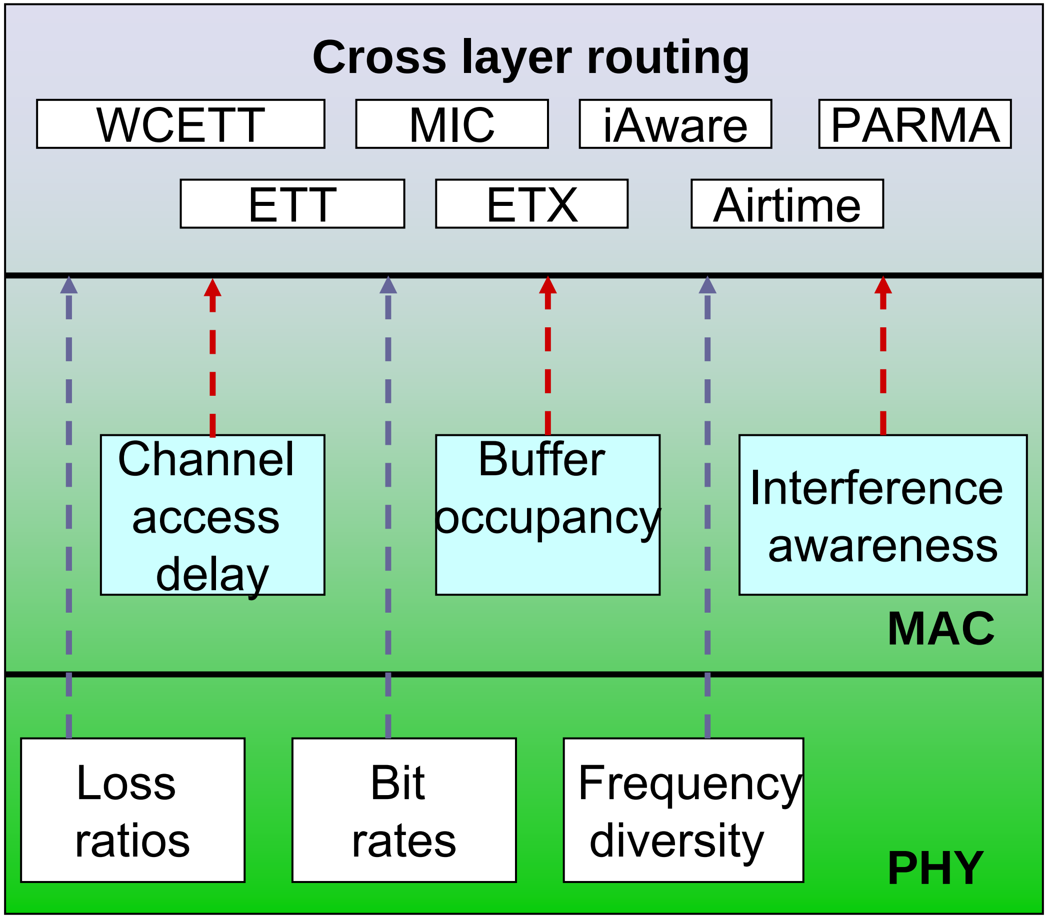
Can we do better??

Specific case: Noise -6dBm, but now with selectable bit rates





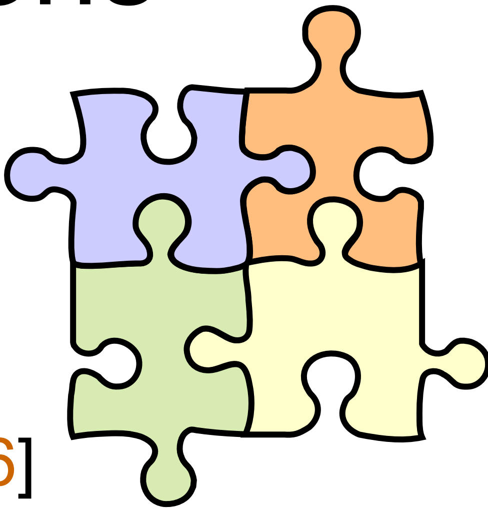
So far.. A layered approach



Mostly API based while still maintaining the strict layering

- Route selection using cross layer metrics
  - Masks the inefficiencies of the MAC
- In-band probing and control messages
  - Inaccuracy in measurements due to use of broadcast probes (of fixed size) for estimation
  - Increased control traffic => disruption of data transfers

The bigger picture: Dimensions



- Addressing MAC issues
  - Scheduling, D-LSMA [Wu04], DCMA [DCMA06]
- Interference mitigation
  - Tune Txpower, CS range [Zhu04, Zhu05, Kim06]
- Multiple frequency – Multiple Radios
  - Channel assignment problems [Kyasunur06]
  - Interface to frequency binding (static/dynamic) [Kyasunur05]
- Route selection
  - Metric-based routing- MAC/PHY/Interference awareness [Draves_04, Yang05, Anand06, DeCouto03, Zhao05]

Joint cross layer approaches

- 2D approaches
  - Joint channel assignment & routing [Raniwala05]
    - No scheduling
  - Interference-aware channel assignment [Rama06]
    - Independent WCETT based routing
  - Joint Transmit power & CS range adaptation [Kim06]
    - Fixed channel assignment

- 3D optimization
  - Joint scheduling, channel assignment & routing [Nandagopal05]
    - Joint optimization - upper bound results

WINLAB: Recent and Ongoing Work

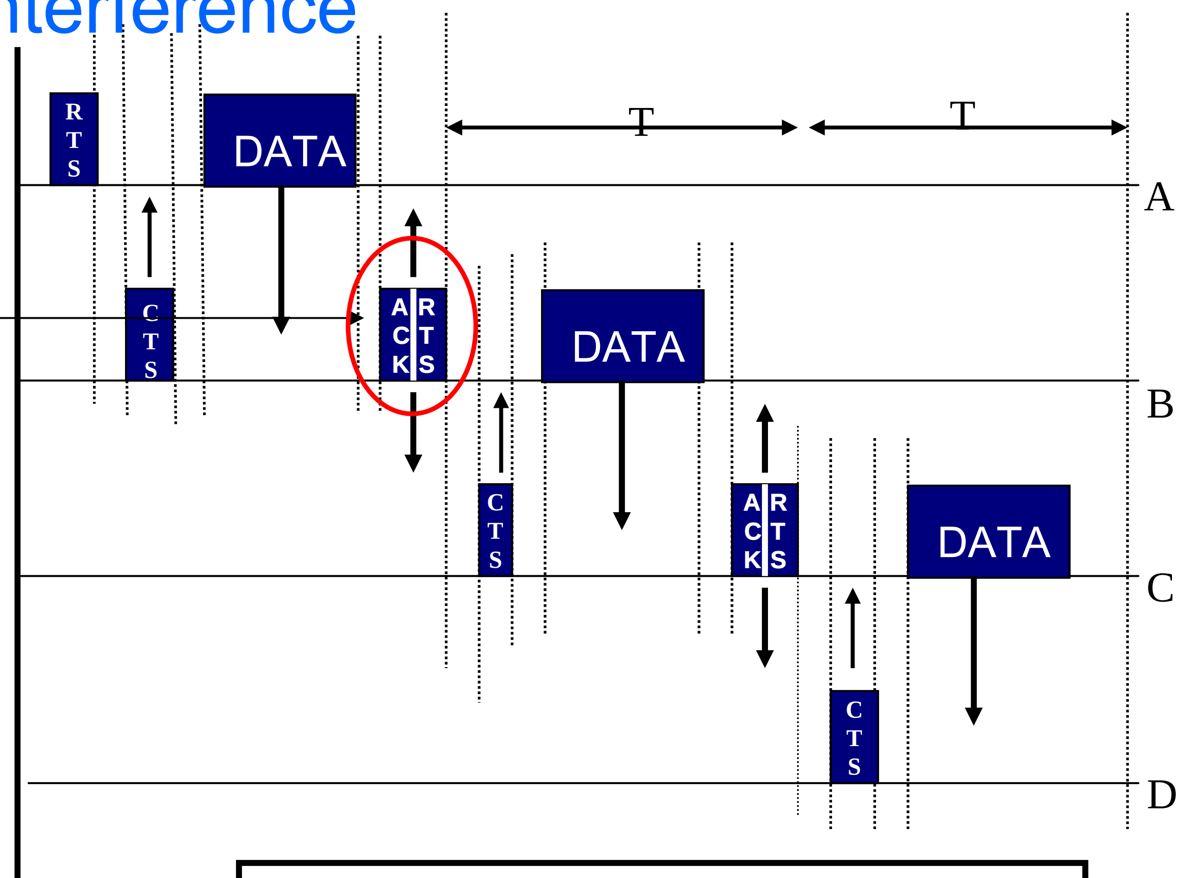
- Flow co-ordination and cut-through forwarding for wireless mesh networks*
  - Cut through forwarding for minimizing end-to-end latencies
  - Flow co-ordination and route selection to minimize interflow interference
- Integrated routing and MAC scheduling (IRMA) using global control plane (GCP)
  - Centralized co-ordination mechanism
  - Global control plane
  - Protocols and system design for IRMA using GCP

* In collaboration with IBM

Cut-through forwarding

- Replace route lookup latencies and CPU handling with label switching
- Reduce independent channel access at each hop
- Reduce intra-flow interference

Combined ACK/RTS which proactively attempts to reserve access for downstream transfer

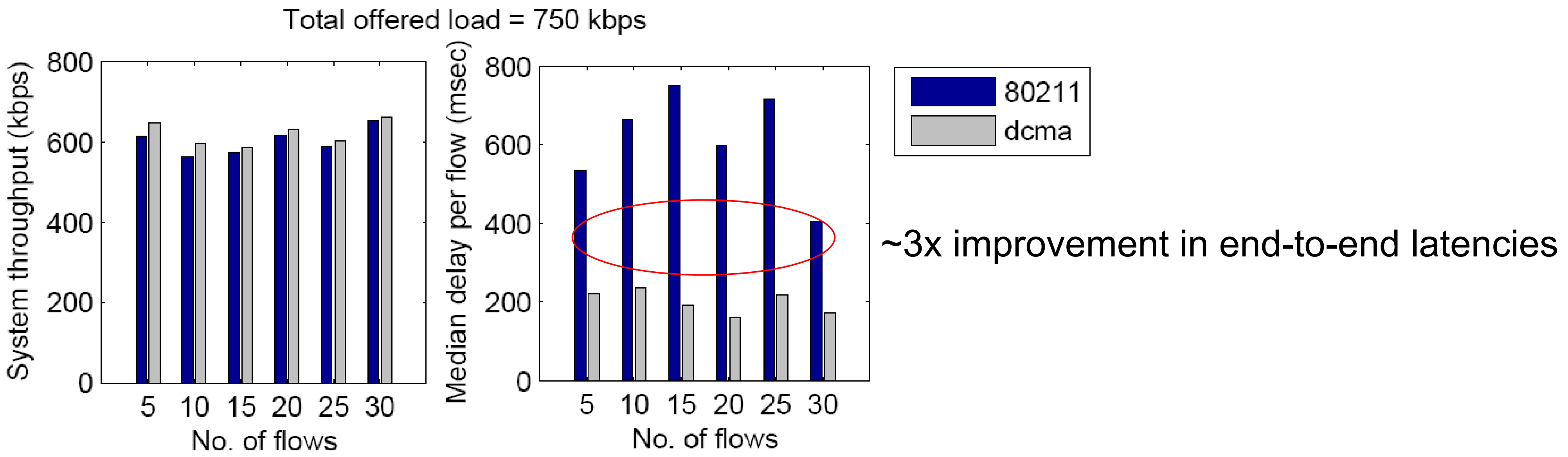


T		
	MAC address	
	MAC address	(out) Label

ACK/RTS control packet

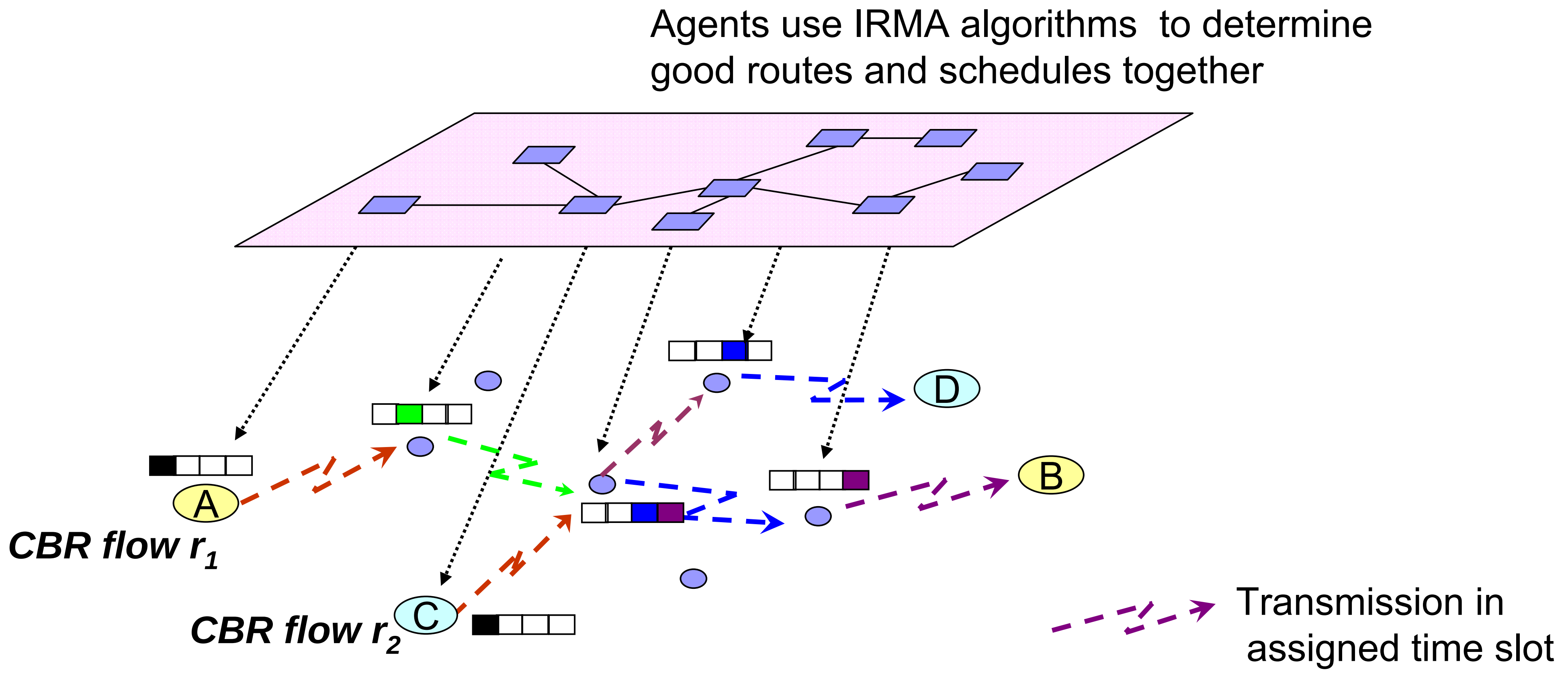
DATA DRIVEN CUT-THROUGH MAC (DCMA)

Ongoing work



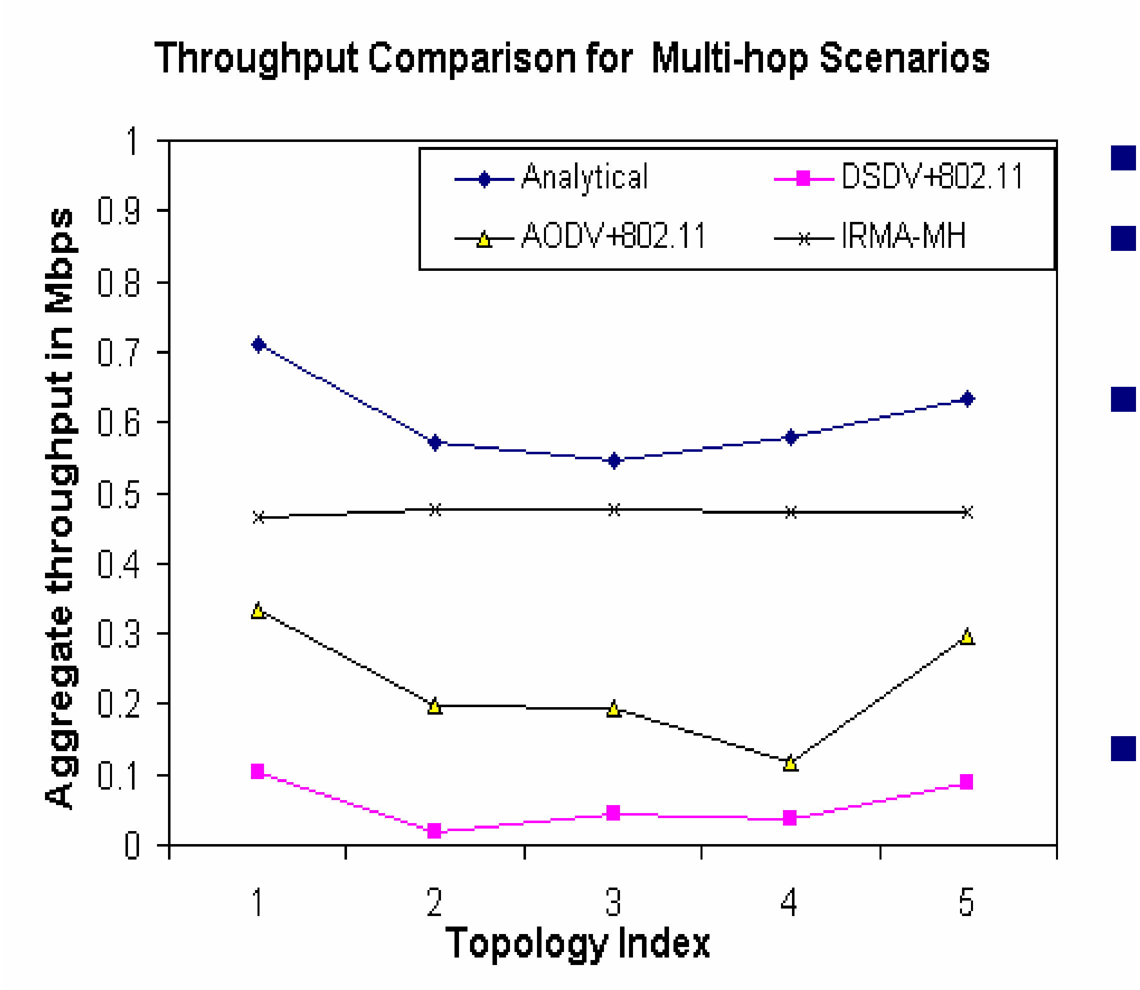
- Cross layer (interference aware) route selection to mitigate interflow interference
- Improved flow co-ordination mechanism to increase the successful cut through percentage

Integrated route selection & MAC scheduling (IRMA) using control plane



- Link transmissions and path assignments jointly decided and scheduled to eliminate interference and maximize spatial reuse

Preliminary results



- 5 Multi-hop flows
- Average Hop length: 3.22

- IRMA-MH algorithm supports much higher throughput (200%-400%) than baseline scenarios with conventional approaches
- Resource utilization is more efficient with conflict-free TDMA scheduling

Details to follow in the afternoon session…

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