Experimentation and Performance Evaluation of Rate Adaptation Algorithms in Wireless Mesh Networks

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Outline

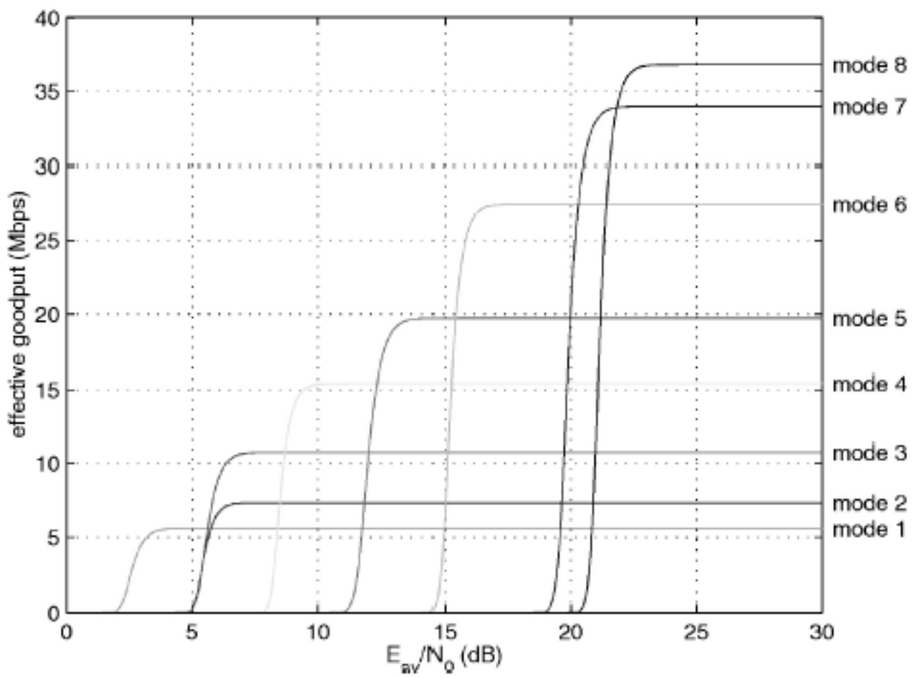
- Why rate adaptation?
- General approaches for rate adaptation in 802.11 networks
- Rate adaptation algorithms in MadWifi driver
  - AMRR
  - ONOE
  - SampleRate
- Indoor experiments
- Outdoor experiments
- Conclusions and ongoing work

IEEE 802.11 Multi-rate capabilities

- The 802.11 a/b/g standards allow the use of multiple transmission rates
  - 802.11b, 4 rate options (1,2,5.5,11Mbps)
  - 802.11a, 8 rate options (6,9,12,18,24,36,48,54 Mbps)
  - 802.11g, 12 rate options (11a set + 11b set)
- Different bit rates are provided by employing different modulation schemes and coding rates
- Rate Adaptation refers to the algorithms used to select the transmission rate that provides the best "*link performance*"
- Rate adaptation plays a critical role to the throughput performance, but it is yet <u>unspecified</u> by the 802.11 standards

Motivations for rate adaptation

- The link-layer capacity at each data rate depends on channel quality, as well as various environmental dynamics, such as:
  - Channel fluctuations
  - Node mobility
  - Medium contention
- In practical settings, wireless channels can be extremely dynamic (e.g., due to multipath fading)



Theoretical MAC layer throughput for an *AWG*N channel versus SNR

(payload:2000Byte, 802.11a modes)

Rate adaptation: general approaches

- Signal strength-based algorithms:
  - Rate adaptation relies on physical layer measurements (SNR, RSSI)
  - They require an accurate channel model
  - Generally not compliant with the 80211 standards (e.g., RBAR and OAR)

- Statistics-based algorithms:
  - Rate adaptation relies on frame transmission statistics (e.g., number of retries, number of consecutive frame successes or failures)
  - Rate is decreased upon severe loss
  - Generally probe packets are used to create long-term statistics
  - Need to differentiate between collisions and channel errors
  - Several examples: ARF, AMRR, ONOE, SampleRate, CARA

Experimental evaluation in real scenarios

- Schemes compliant with 802.11 standards have been implemented in commodity hardware and open software drivers
- Practical investigations of rate adaptation performance
- Available studies have mainly focused on indoor wireless networks, considering:
  - the impact of channel dynamics due to rapid fluctuations of the receive signal strength
  - random channel errors, mobility-induced channel variations, and contention from hidden stations
- Experimental studies have been conducted mostly in small wireless networks consisting of an AP and a few clients

- *How these autorate algorithms cope with moderate to high medium contention levels?*
- *How these autorate algorithms perform on medium-distance 802.11 links?*

MadWifi: Multiple Rate Retry (MRR)

- MadWifi driver enables the network interface to transmit at different data rates the retransmissions of a given frame
- Four rates (r_0,r_1,r_2,r_3) and transmission counts (c_0,c_1,c_2,c_3) are associated to each frame
- Each rate r_i is tried c_i-times before using next rate
- $c_0+c_1+c_2+c_3$ is the maximum number of allowed retransmissions (<=ATH_TXMAXTRY)
- Several rate adaptation algorithms employ the multiple rate retry capabilities of the MadWifi driver

Adaptive Multiple Rate Retry (AMRR)*

- AMRR sets $c_0=c_1=c_2=c_3=1$, i.e., each rate is tried just once
- Rate r_3 is set to the lowest bit rate (1Mbps in 11b/g and 6Mbps in 11a)
- An heuristic is used to select r_0:
  - If less than ***10%*** of the packet transmissions failed during the last observation period, then increase the data rate
  - If more than ***33%*** of the packet transmissions failed during the last observation period, then decrease the data rate
- Rate r_1, is the rate immediately lower than r_0, and rate r_2 is the rate immediately lower than r_1

**M. Lacage, M. H. Manshaei, and T. Turletti. IEEE 802.11 Rate Adaptation: A Practical Approach. In Proc. MSWiM ’04, pages 126–134, Venice, Italy, 2004.*

ONOE*

- ONOE algorithm is a variant of the AMRR scheme
- ONOE uses larger retransmission counts than AMRR (c_0=4,c_1=c_2=c_3=2)
- ONOE sets r_1, r_2, r_3 bit rates as AMRR
- An credit-based heuristic is used to select r_0:
  - If less than ***10%*** of the packet transmissions failed during the last observation period, then the credits of r_0 are increased by one; otherwise the credits of r_0 are reduced by one
  - If more than ***10%*** of the packet transmissions failed during the last observation period, then the credits of r_0 are reduced by one
  - If r_0 has more than 10 credits, then increase the data rate
  - If more than ***50%*** of the packet transmissions failed during the last observation period, then decrease r_0

**MadWifi driver documentation. Onoe Rate Control. http://madwifi.org/wiki/UserDocs/RateControl.*

SampleRate*

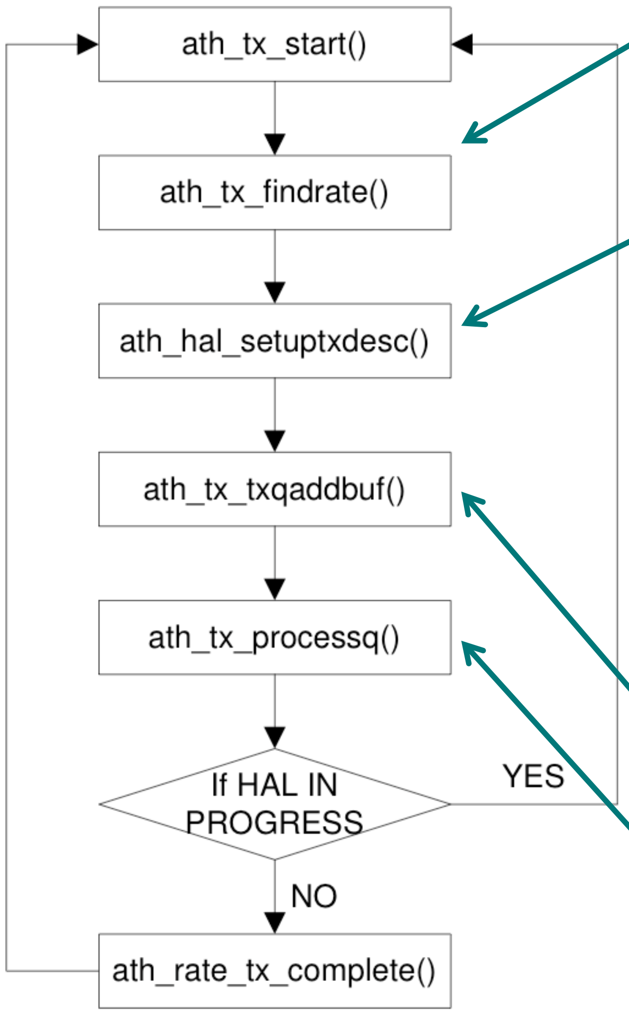
- SampleRate estimates the medium contention level by evaluating the expected transmission time for a frame at different data rates

$$tx\_time(r,n,L) = backoff(n+1) + (n+1)\cdot(\Delta + L/r)$$

- SampleRate transmits each frame at the rate *r* that has the shortest expected transmission time
- A probe packet at a different rate is sent every ten frames
- SampleRate probes only rates with a minimum packet transmission time (i.e., with n=0) lower than the average transmission time of the current bit rate

**J. Bicket. Bit-rate Selection in Wireless Networks, February, 2005. Massachusetts Institute of Technology, M.S. Thesis.*

MadWiFi: frame transmission



Associate a new frame with a transmission rate, which is estimated after the completion of the previous *ath_rate_tx_complete()* function call

Set the properties of the transmit process descriptor

```
ath_hal_setuptxdesc(ah, ds ,
        pktlen/* packet length */    ,
        hdrlen/* header length */    ,
        atype/* Atheros packet type */     ,
        MIN(ni->ni_txpower, 60)/* txpower */ ,
        txrate, try0/* series 0 rate/tries */,
        antenna/* antenna mode */  ,
        ctsrate/* rts/cts rate */     ,
        ctsduration/* rts/cts duration */…);
```

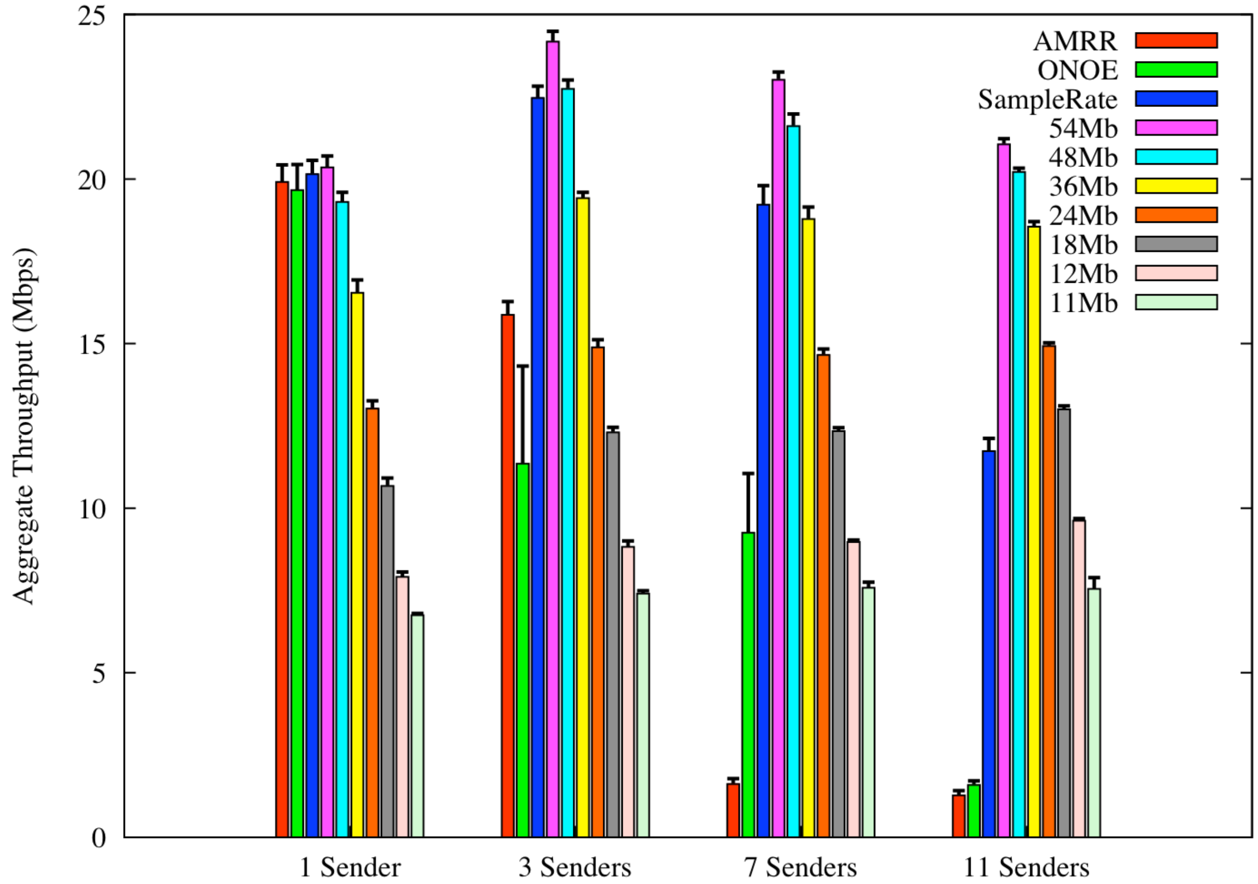
The frame is enqueued into the *ath_txq*, which is hardware queue in the MAC controller

Process the completed transmit descriptors

Indoor experiments

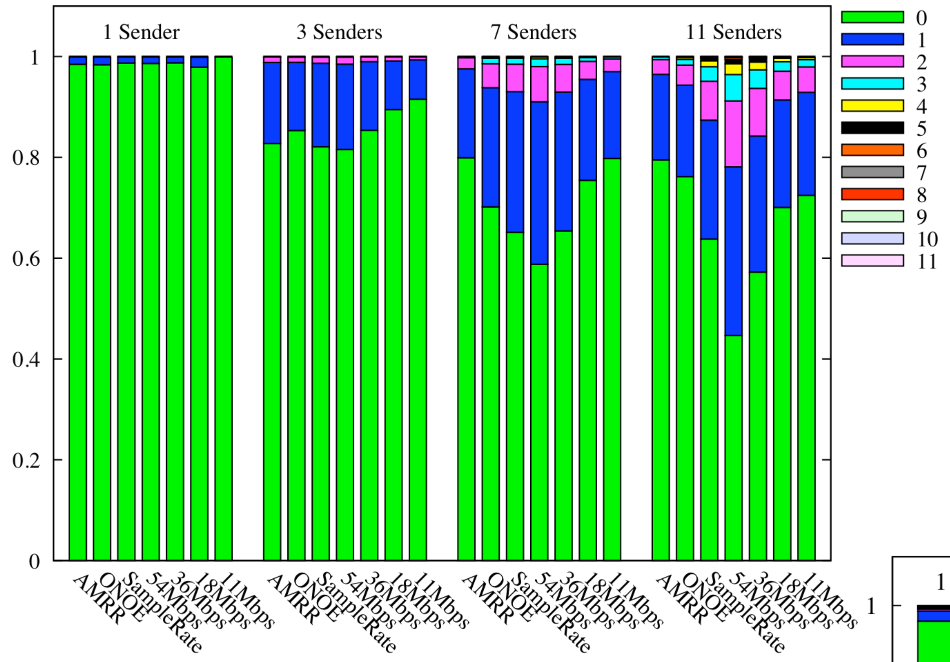
- Indoor experiments aim at evaluating the impact of contention level on rate adaptation performance
- Hardaware/software setup:
  - 12-node network composed of IBM Thinkpad model R50E laptops
  - Each node has one NetGear WPN511 card operating on channel 11 in 802.11g mode
  - MadWiFi driver version 0.9.4
- Traffic configurations
  - UDP traffic generated with iperf (packet size 1500Bytes)
  - Single-hop flows
  - Each test lasts 2 minutes and is repeated five times

Indoor Experiments: Throughput

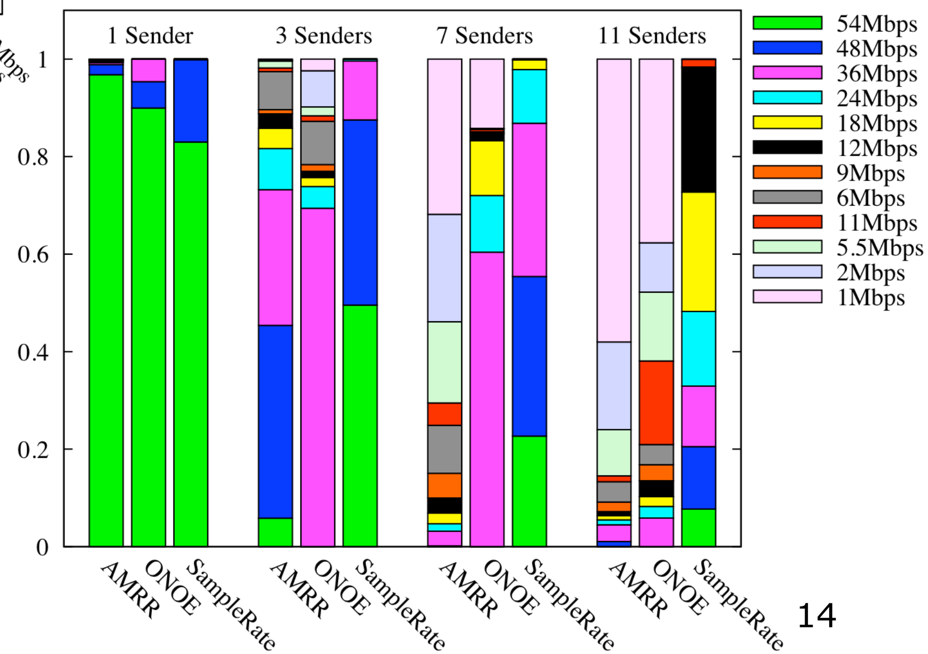


- Maximum throughput achieved with fixed rate at 54Mbps
- Considerable throughput degradation when autorate is used. With 11 saturated stations the throughput achieved with loss ratio threshold-based schemes (i.e., AMRR and ONOE) can be up to ten times lower than the best throughput obtained with a fixed transmission rate

Indoor Experiments: retry and rate distributions

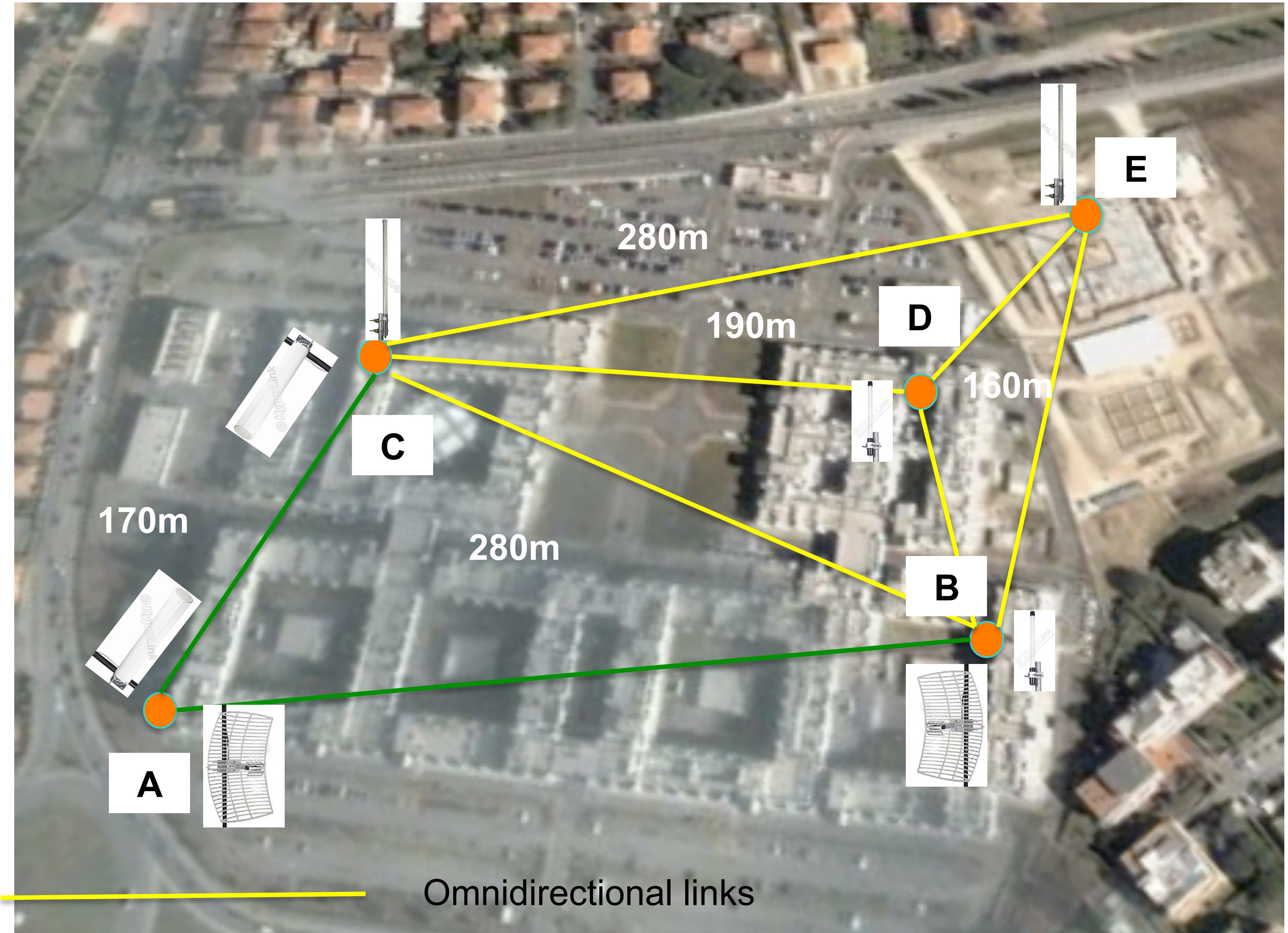


- Channel quality is good
- Contention induces collisions
- More retries with higher data rates and several stations: synchronization problems?



- AMRR adopts small retry limits, which induces high rate variability
- Both AMRR and ONOE operate to keep the frame loss rate below pre-determined and fixed thresholds (33% for AMRR and 50% for ONOE)
- SampleRate overestimates the maximum throughput achievable at the different transmission rates, leading to a conservative rate selection

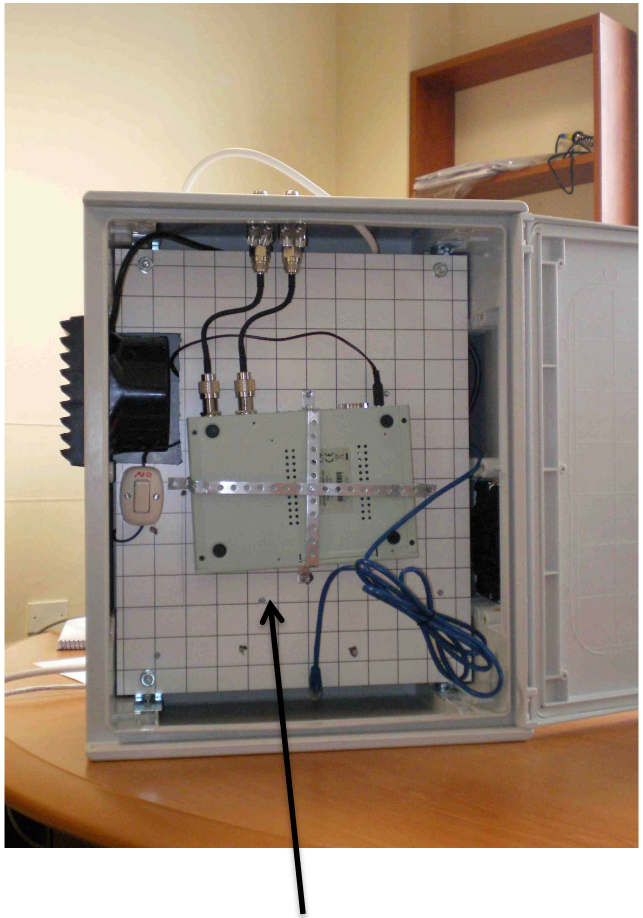
Outdoor Eperiments



Omnidirectional links

Directional links

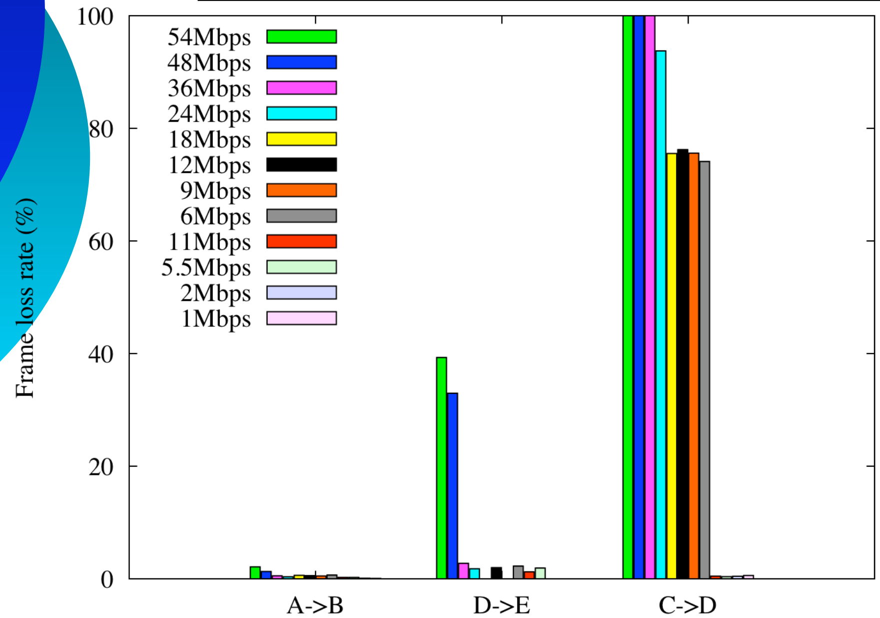
Mesh router



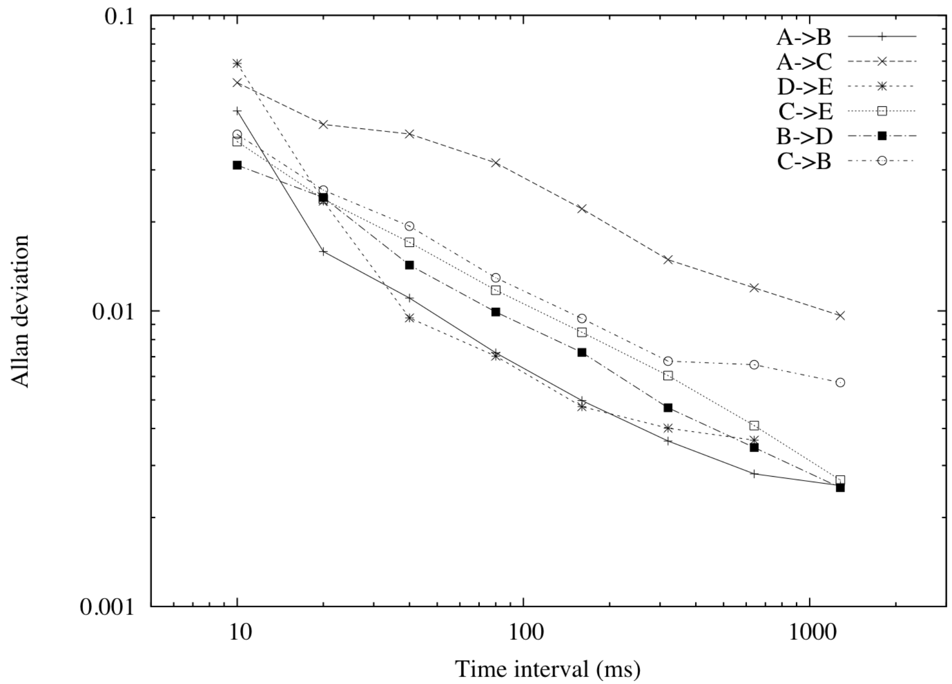
Soekris Board

- Soekris net4801 router
  - 266 MHz NSC SC1100 single chip processor
  - 256 Mbyte SDRAM, soldered on board
  - 100G 2.5" Hard Drive
  - 1-3 10/100 Mbit Ethernet ports, RJ-45
  - USB 1.1 interface
  - Mini-PCI type III socket
  - PCI Slot
  - Two Atheros AR5414 miniPCI modules, 20dBm/100mW, Wireless Super AG, 802.11a/b/g/108Mbps 5/2.4GHz
  - Omni-directional and directional antennas usable in the 2.4GHz band

Outdoor experiments



- Frame loss rates are not uniform over all transmission rates*:
  - Transmission rates with negligible loss rates
  - Transmission rates not working at all
  - Transmission rates with intermediate loss rates

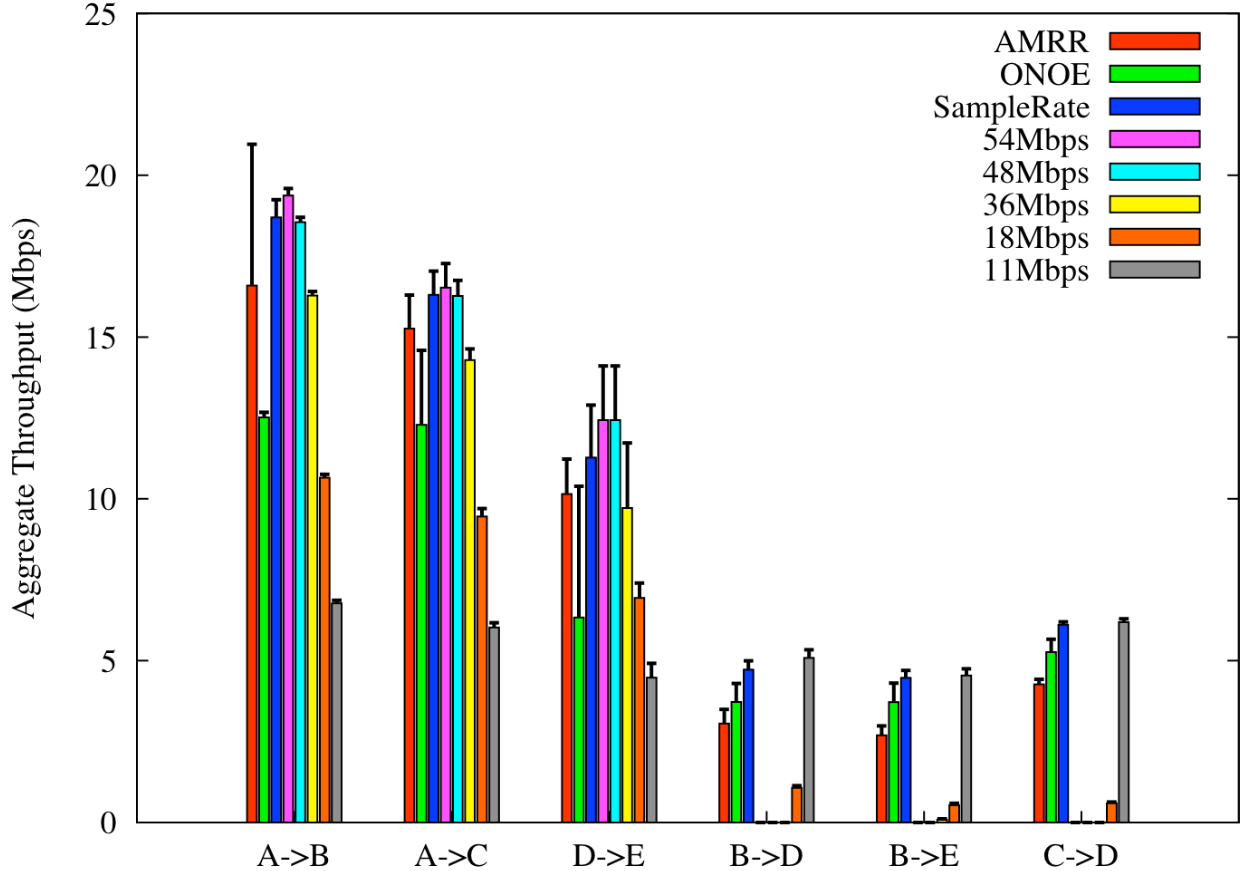


- Allan deviation used to measure the correlation of channel errors.
- X_i is the average loss rate over a time interval T

$$dev = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{i-1})^2}{2n}}$$

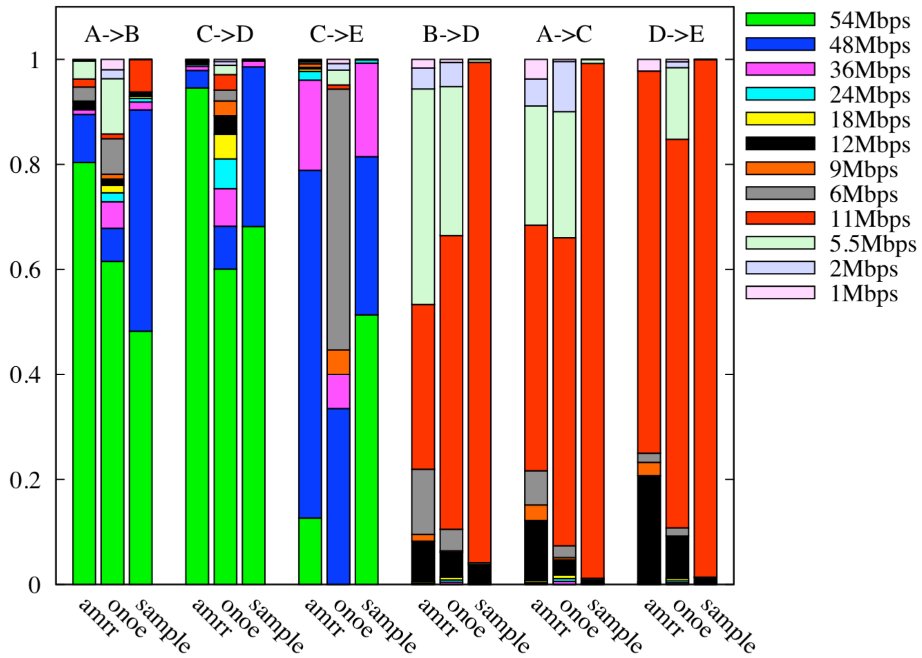
*G.. Bianchi, F. Formisano, D. Giustiniano. 802.11b/g Link Level Measurements for an Outdoor Wireless Campus Network. In Proc. WoWMoM'06, pages 525–530, Niagara-Falls, NY, 2006.

Outdoor experiments: throughput



- In our mesh network, the are transmission rates with negligible frame loss ratios.
- These links are also quite stable, and observation periods of one second give reliable estimates of the long-term average frame loss rate
- Rate adaptation schemes based on loss ratio thresholds will perform reasonable well on these links

Outdoor experiments: rate distribution



- AMRR works reasonably well in both gradual and steep links, but it is worse than SampleRate:
  - AMRR permits only four consecutive retries for each frame
  - AMRR occasionally tries very low transmission rate
- ONOE works reasonably well for steep links (even better than AMRR), but is the worst for gradual links:
  - ONOE is very slow in increasing the rate
- SampleRate seems the best for static configurations with non-bursty links transmission rate

Design guidelines for congestion-aware rate adaptation

- We need more accurate techniques to correctly estimate the medium contention level
  - How to compute the correct time interval between successful transmissions?
- We should make the sampling period used to estimate the long-term frame loss rates adaptive to channel temporal correlations
  - How to measure the channel temporal correlation?
- Minimize the use of probe packets for low transmission rates
- Ongoing activity
  - Design of accurate 802.11 compliant strategies to differentiate collisions from channel errors
  - Extensions of SampleRate to correctly operate in collision dominated environments.

Thanks!

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