Microsoft Research

Dynamic Channel, Rate Selection and Scheduling for White Spaces

Božidar Radunović

Microsoft Research Cambridge

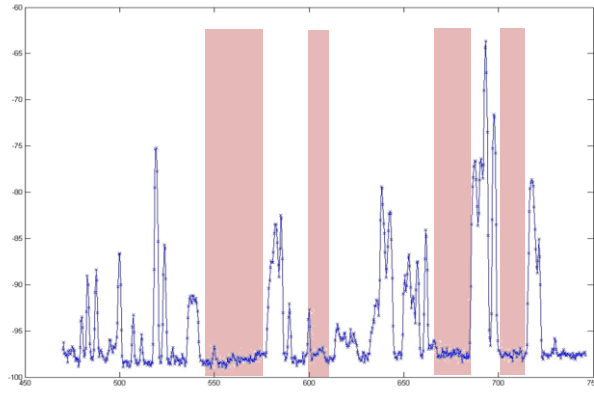
Joint work with Dinan Gunawardena, Peter Key, Alexandre Proutiere

White Spaces

- Only 5% of licensed spectrum is used
- Primary users:
  - Incumbents (analogue TVs, wireless MICs)
- Secondary users:
  - unlicensed users
- White-space regulations (TV bands):
  - Rulings: FCC, OFCOM
  - More to come (Canada, Brazil, …)
- Potentially large number of channels

Exploit Best Channels

- **Problem: channel selection**
  - On average 20 available channels
  - How to use channel diversity?
    - Goal: each link to its best channel



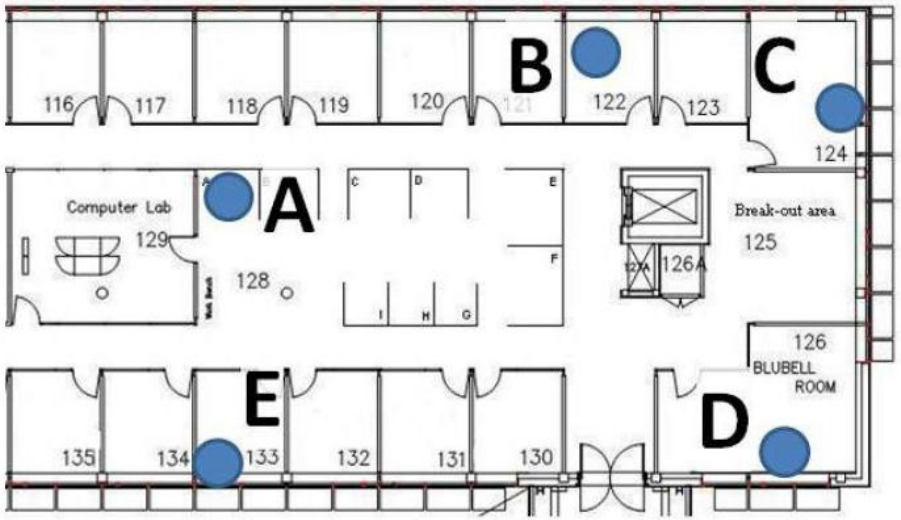
- Primaries specified in geo-database
  - no need for sensing

Our work:

1) Measurements to quantify benefits
2) Algorithm to exploit benefits

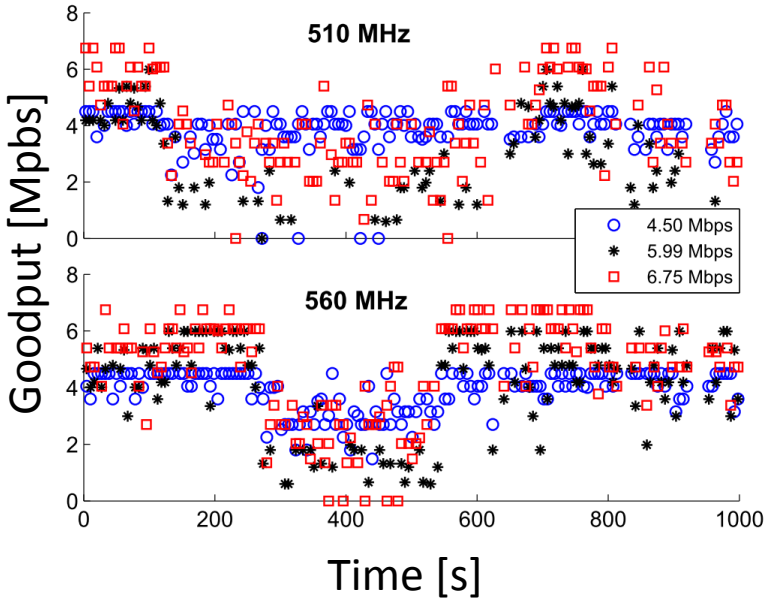
Indoor white-space test-bed

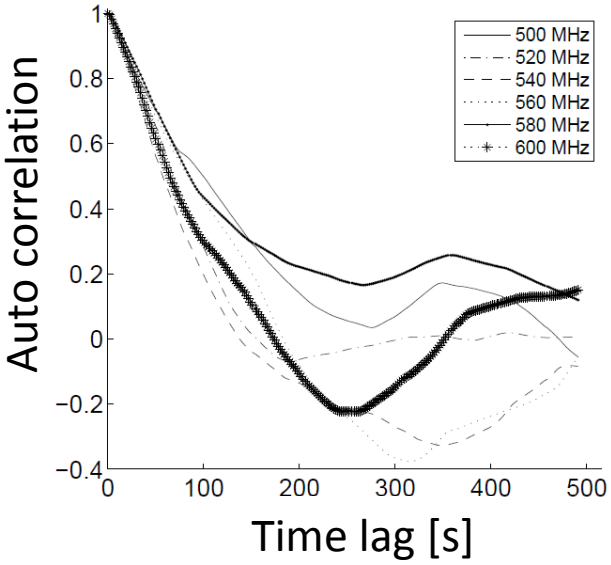
- 5 SDR nodes
- TV Bands:
  - 500MHz – 600MHz
  - 11 channels



- OFDM WiFi-like PHY in FPGA
  - 10 MHz bandwidth
  - 3 QPSK data rate (4.5, 6, 6.75 Mbps)
- Send 10 pkts batch on each rate, in each freq.

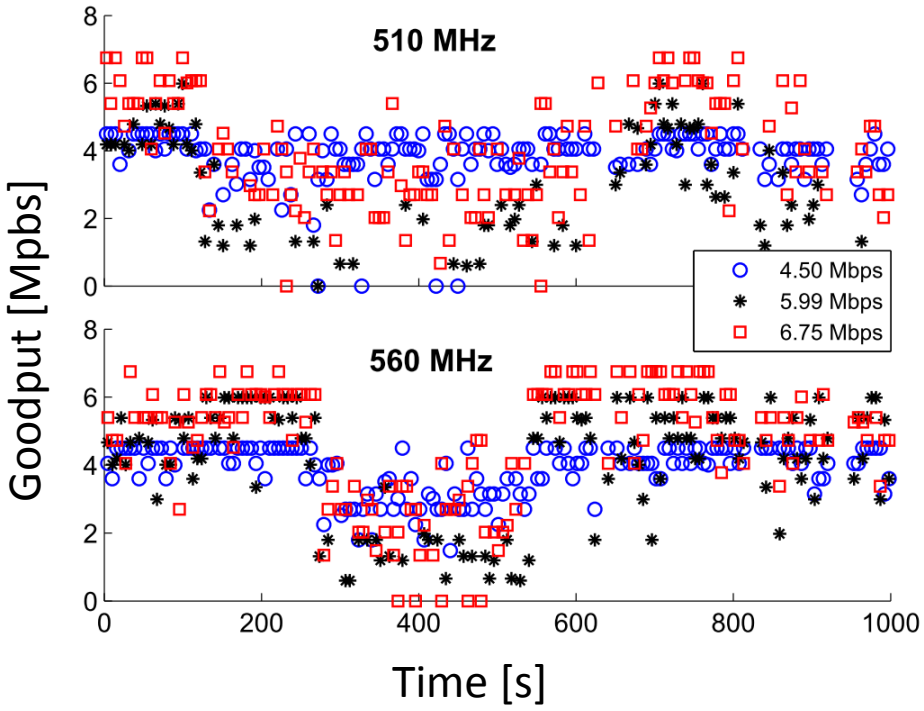
Measurements - Fading





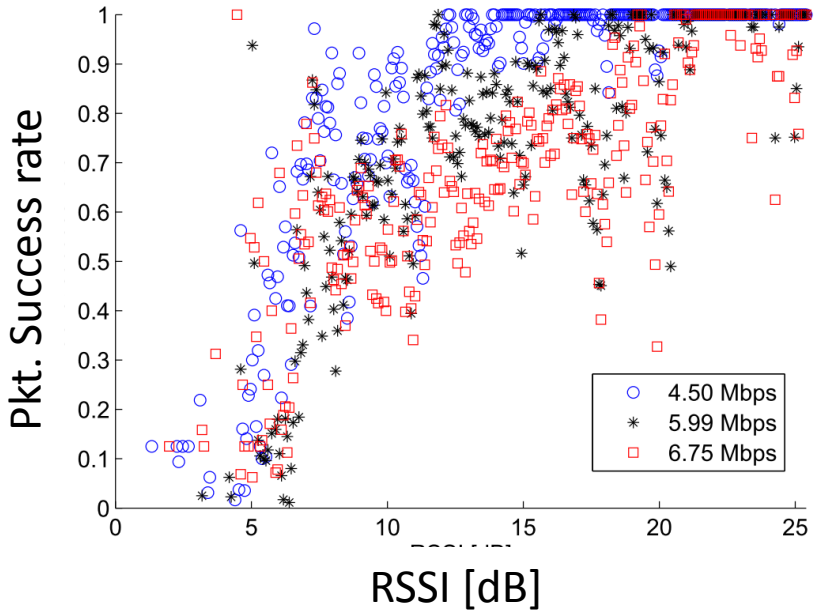
- Fast variations
  - Too fast to track and learn – treat as noise
- **Slow variations** larger than fast ones
  - Time-scale is ~ 10s or more

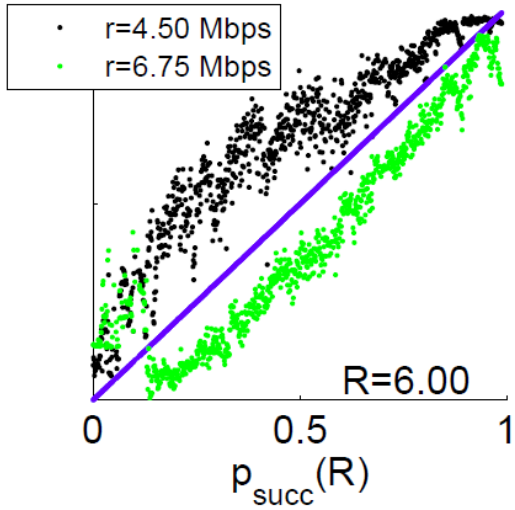
Measurements - Correlation



- Slow fading is not correlated across channels
- It is important to track all channels

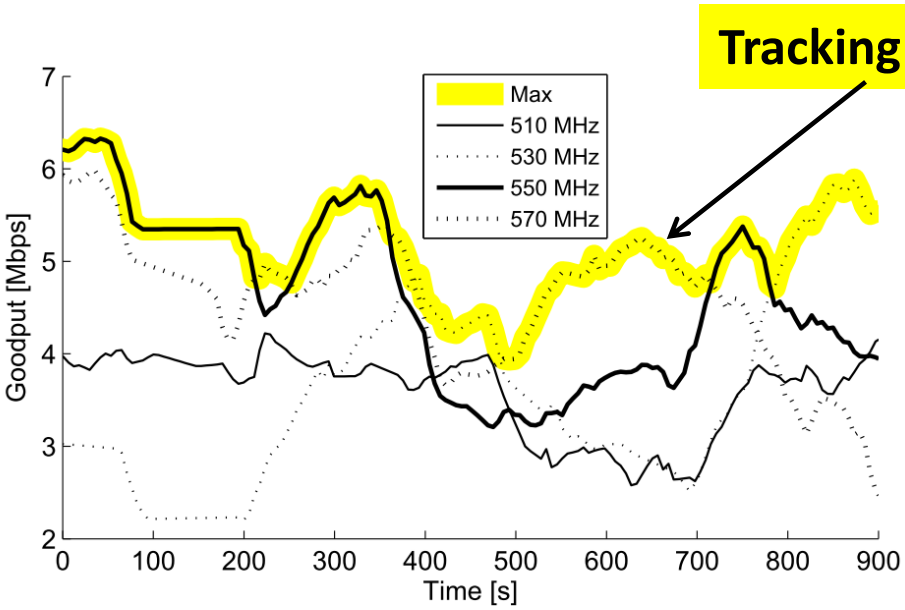
Measurements - Rates



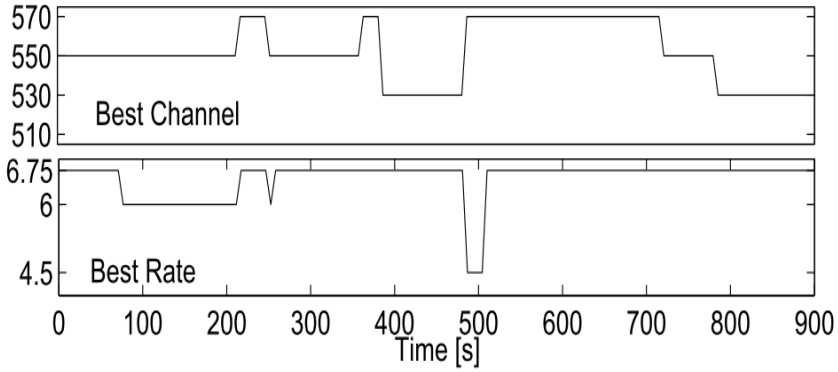


- RSSI does not give accurate channel information
- Difficult to infer success rate at one rate from another

We Gain from Adaptation



Per-channel performance



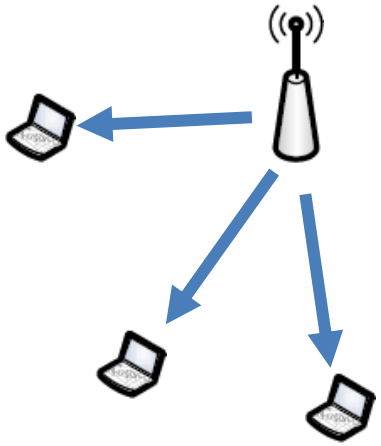
Corresponding
best channel and rate

Channel, Rate and Access Problem

1. RSSI is poor predictor
2. Different channels are not correlated

- Packet loss detected. What to do? Retransmit:
  - at a lower rate?
  - at a different channel?
  - Simple heuristics (SampleRate, AARF) for rate adaptation will not work.
- Periodical probing for changes?
  - When do we have enough measurements to decide?

Learning Problem



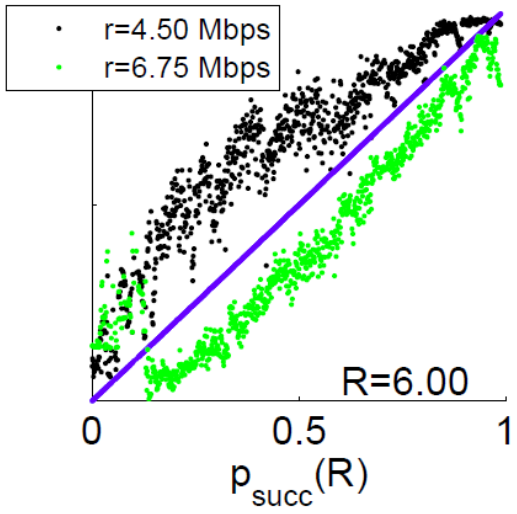
- We consider two scenarios:
  - Single link and AP downlink
- Problem:
  - Given past TX successes and failures
  - Specify the (channel,rate,node) to use next
  - Goal is to maximize network utility
- **Key difficulty** - Large number of states:
  - (11 chan. × 3 rates = 33 states)
  - Slow learning – inefficient algorithm

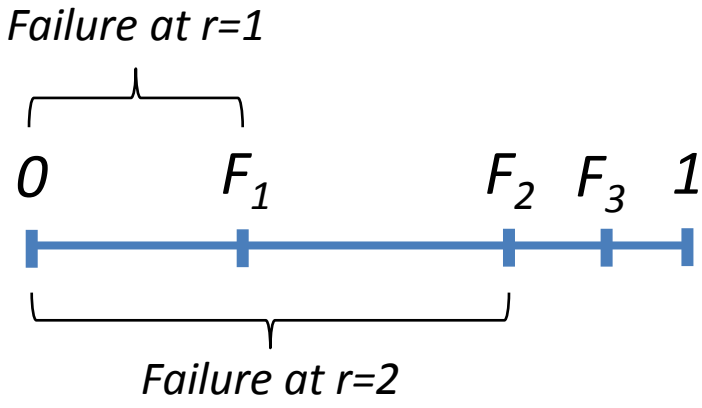
Outline of the algorithm

- Balance exploration and exploitation
  - Adaptation of UCB algorithm for non-stationarity
- **Soft sampling:**
  - Leverage correlation among rates to speed up learning
- Opportunistic channel sampling
  - Speed up learning through overhearing
- Multi-user scheduling
  - Balance opportunity and fairness among users

Soft Sampling

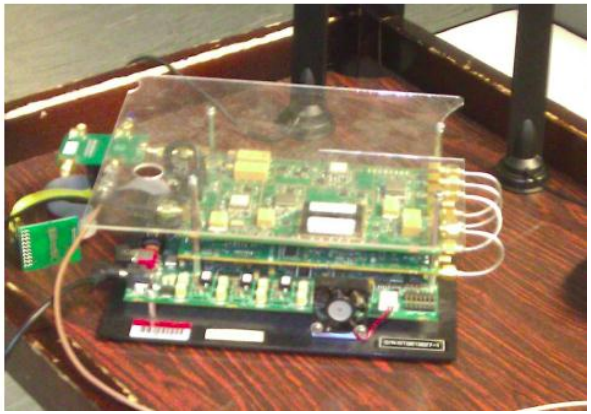
- Success at rate R implies success at all rates r < R
- Failure at rate R implies failure at all rates r > R
- Soft (fake) samples
- Intuition:
  - Failure at r=2 =>
    - SS: Failure at r=3
    - SS: Failure at r=3 w.p. (F1/F2)





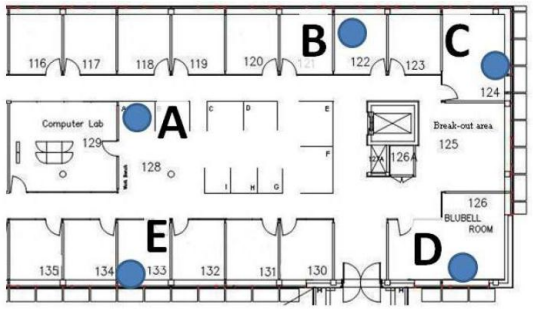
Implementation/Evaluation

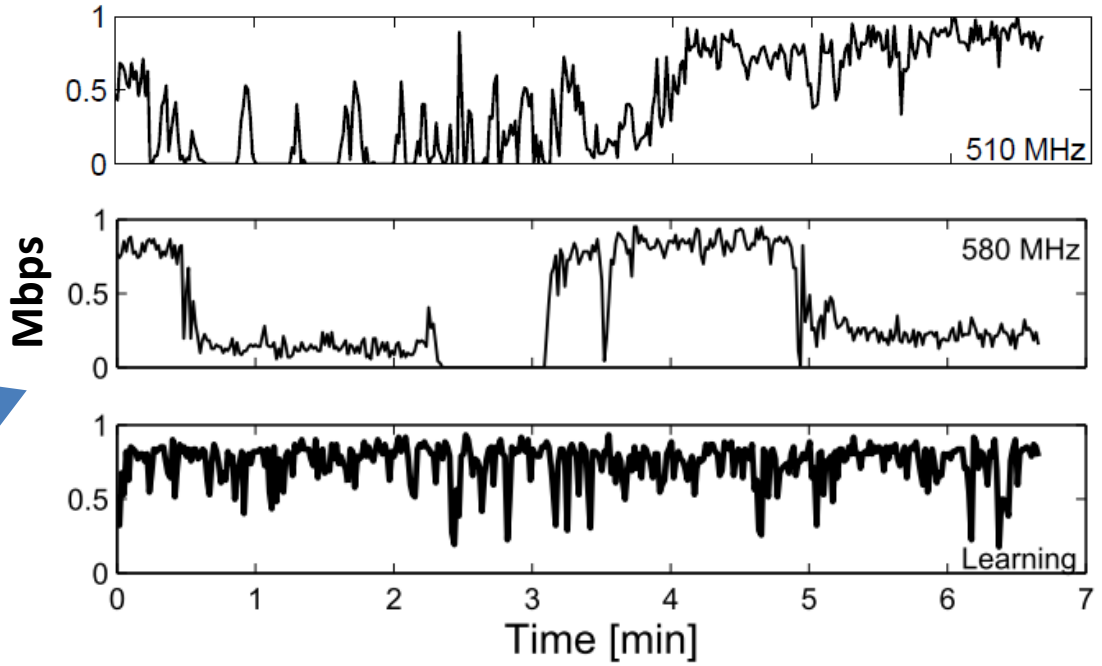
- Evaluated in an SDR testbed
  - MAC implemented in DSP
  - Standard OFDM in FPGA



- Implementation issues:
  - Channel selection and synchronization cost
  - Signaling for opportunistic sampling

Test-bed Evaluation





- Single link:
  - Avg. 35.7%
- Multiple links:

Link	A-B	A-C	A-D	Sum
Goodput [Mbps], Single channel	0.13	0.16	0.23	0.52
Goodput [Mbps], FSS-UCB	0.22	0.19	0.21	0.62
Improvement	63%	23%	-8.5%	19.2%

Conclusions

- Channel and rate selection is challenging
  - Large number of choices
  - Limited prediction information
- Several contributions:
  - Detailed channel measurements
  - Fast estimation algorithm
  - Fair scheduling in conjunction with learning
- Future work:
  - Generalize to different topologies – with interaction