Self-Management in Chaotic Wireless Deployments

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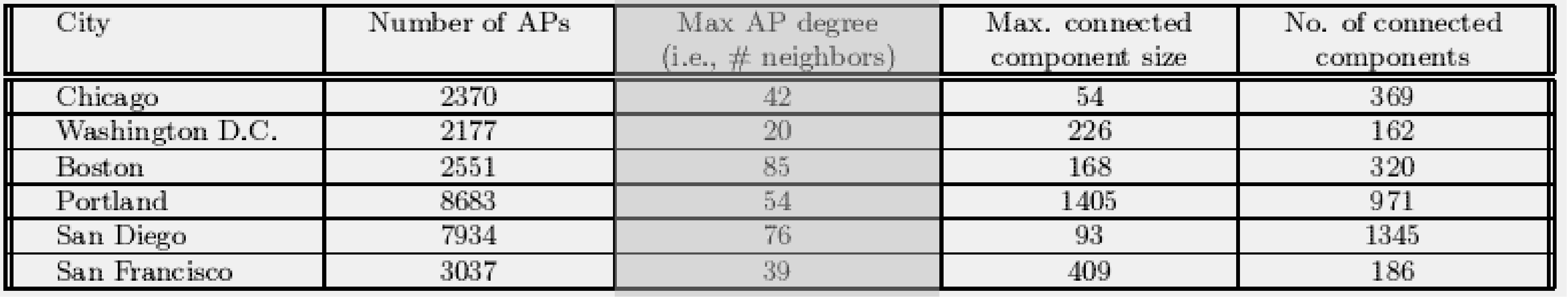
Challenges Facing 802.11, WiFi

- Rapid unplanned and unmanaged growth:
  - 4.5 million WiFi APs sold in Q3 2004, sales to triple by 2009 (free wireless with ISPs, WiFi enabled laptops)
  - Unplanned: Spontaneous deployments with highly variable densities
  - Unmanaged: Power Control, security.
- This is given the term chaotic networks/ deployments
- Goal of paper: to show that interference in such chaotic deployments can significantly degrade wireless performance, and suggest an alternative algorithm, *Power-controlled Estimated Rate Fallback (PERF)*, to more effectively use the available frequency bandwidth to improve throughput.

802.11 Today

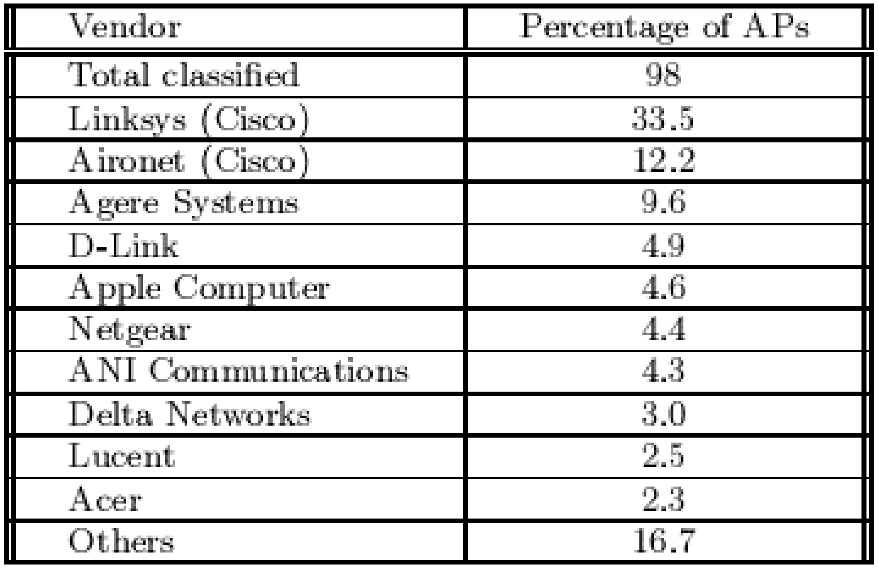
- Power levels and load management already present
  - However, these are for high-end models geared toward large-scale deployments, and are proprietary in nature.
- To analyze data, publishers used data from Place Labs, WiFi Maps and Pittsburgh Wardrive to determine interference levels:



City	Number of APs	Max AP degree (i.e., # neighbors)	Max. connected component size	No. of connected components
Chicago	2370	42	54	369
Washington D.C.	2177	20	226	162
Boston	2551	85	168	320
Portland	8683	54	1405	971
San Diego	7934	76	93	1345
San Francisco	3037	39	409	186

- The table shows multiple interfering signals (>20 in all the major cities above) at each AP.

802.11 Today Cntd…

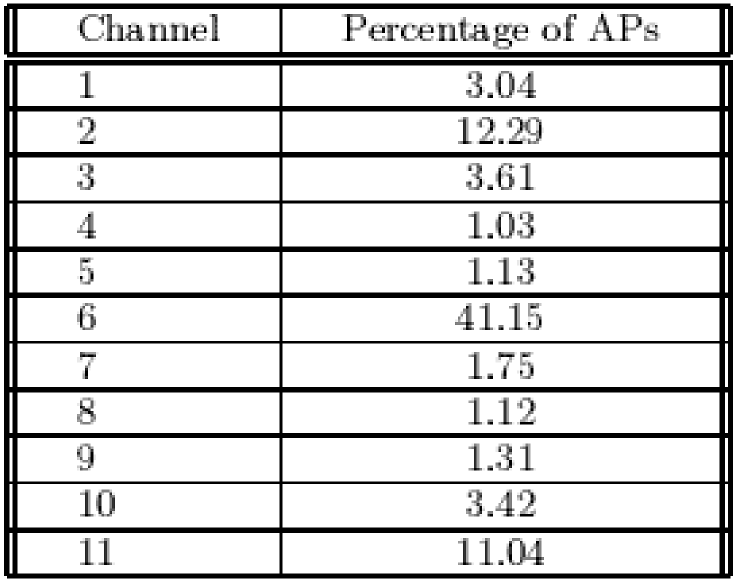


Vendor	Percentage of APs
Total classified	98
Linksys (Cisco)	33.5
Aironet (Cisco)	12.2
Agere Systems	9.6
D-Link	4.9
Apple Computer	4.6
Netgear	4.4
ANI Communications	4.3
Delta Networks	3.0
Lucent	2.5
Acer	2.3
Others	16.7

- Additionally, by looking at the MAC address of the hotspots, it is possible to identify the vendor of the AP.
- The table reveals that in order to implement self-managing software, only 2-3 vendors need to be approached to capture over 50% of the market
- The other vendors in the industry would quickly follow suite if these larger vendors start implementing self-managing APs.

802.11 Today Cntd…

- Table shows how poorly managed APs currently are, with Channel 6 (default channel on many APs) being heavily oversaturated
- Migration towards self-managing small-scale non-commercial APs that are auto-configured needs to be made in order to sustain the growth of WiFi.



Channel	Percentage of APs
1	3.04
2	12.29
3	3.61
4	1.03
5	1.13
6	41.15
7	1.75
8	1.12
9	1.31
10	3.42
11	11.04

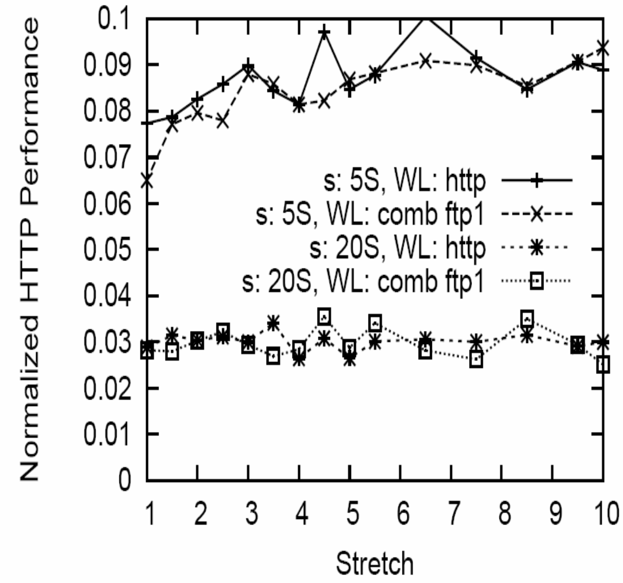
Simulation Parameters

- Each node in the map corresponds to an AP.
- Each AP has D clients (D between 1 and 3).
- Clients are located less than 1m away from their respective APs and do not move.
- APs transmit on channel 6.
- All APs employ a fixed transmit power level of 15dBm.
- All APs transmit at a single rate, 2Mbps.
- RTS/CTS is turned off.
- Use a modified two-ray path loss model for large-scale path loss, and a Ricean fading model with a K-factor of 0 for small scale fading.
- GloMoSim simulator.

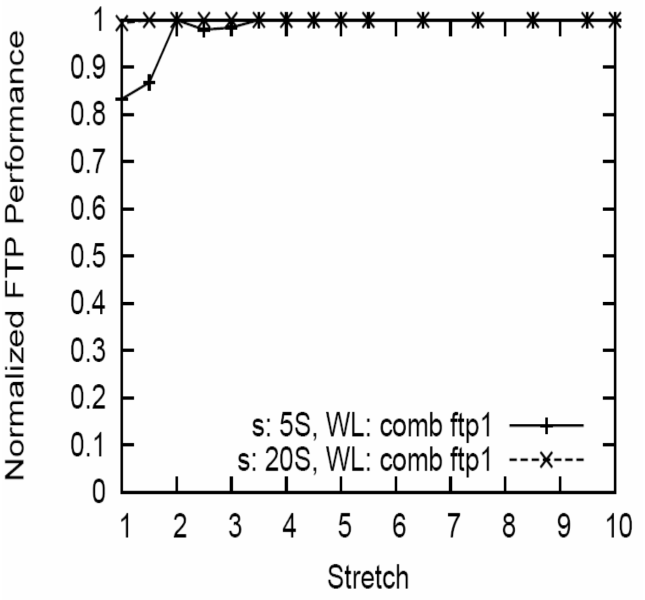
Simulation Runs

- The impact of interference in chaotic wireless deployments depends on the workloads imposed by users.
- Simulate two types of user workload
  - *Http*
    - file size distribution is based on a well-known model for HTTP traffic.
    - think time drawn from a Poisson distribution with a mean of s seconds.
    - Average load 83.3Kbps for s=5sec, 24.5 for s=20sec sleep time
  - *Comp-ftp*
    - i clients in the entire set-up running long-lived FTP flows for the duration of the simulation (0.89Mbps).

Low Client Densities/Traffic Volumes



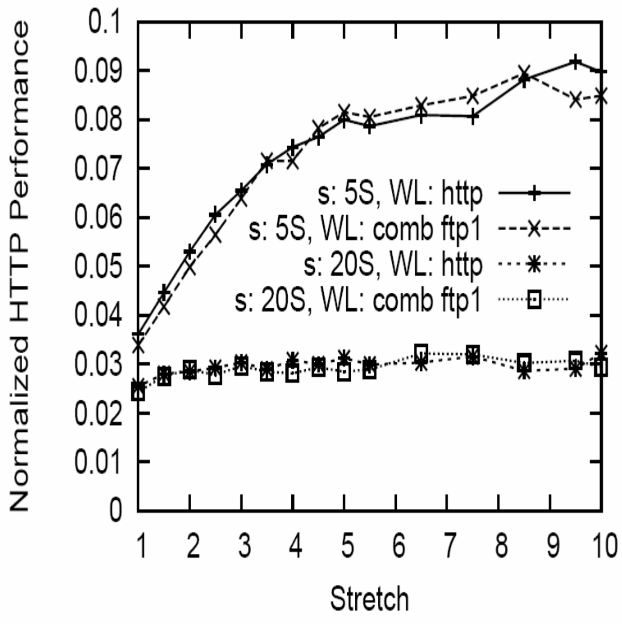
(a) HTTP, $D = 1$



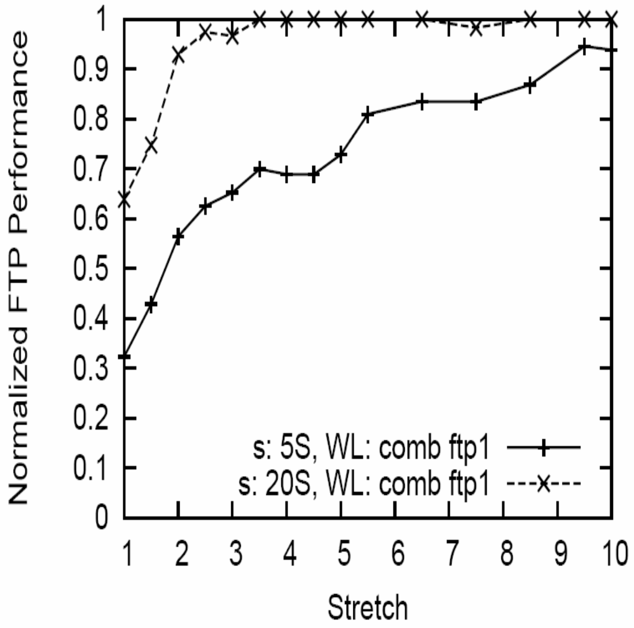
(b) FTP, $D = 1$

- For aggressive HTTP component, the performance of the HTTP flows improves until stretch = 10.
- For less aggressive HTTP workloads the impact on the performance of the HTTP flows is less severe.
- The performance of the FTP flow in comb-ftp1 workload when the HTTP component is aggressive suffers by about 17%.
- With a not so aggressive HTTP the impact on the FTP flow is minimal.

Greater Client Densities (D = 3)



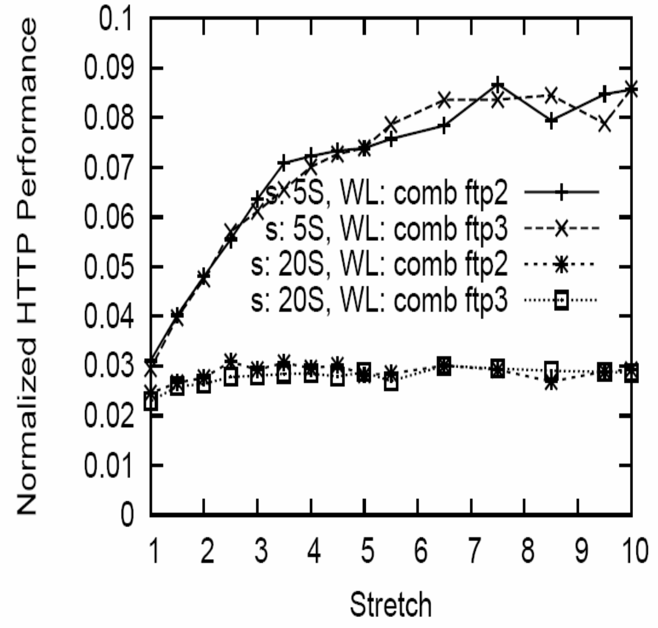
(a) HTTP performance



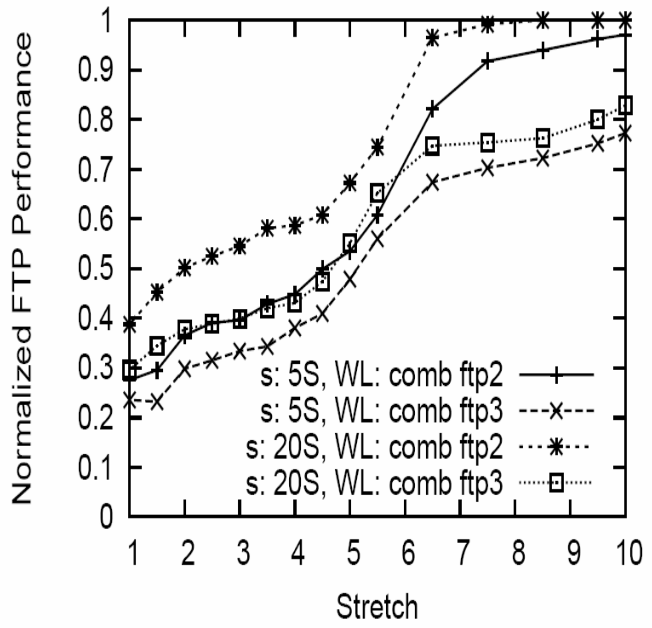
(b) FTP performance

- The performance of both HTTP and FTP flows suffers significantly under high client densities.
- HTTP performance is lowered by about 60% due to interference between aggressive flows.
- For a less aggressive HTTP component the performance of the HTTP flows is ~10% inferior, while the FTP flow suffers by about 36%.

Higher Competing FTP Traffic Levels /D = 3.



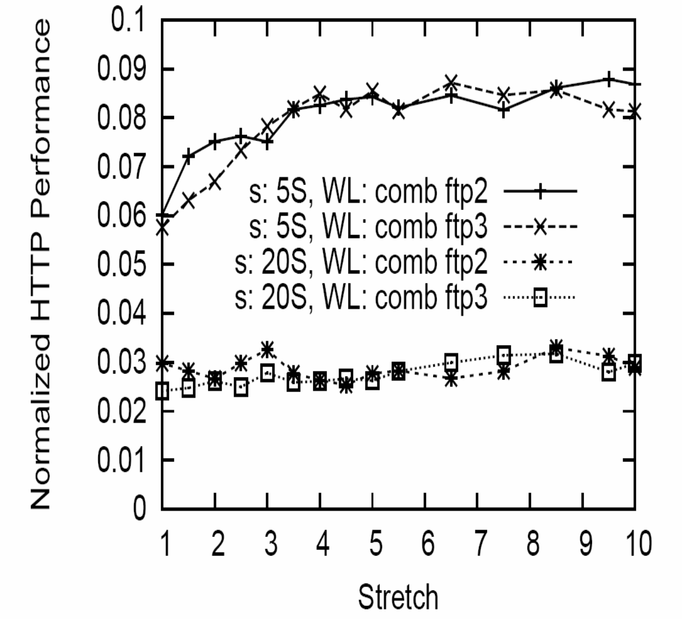
(a) HTTP performance



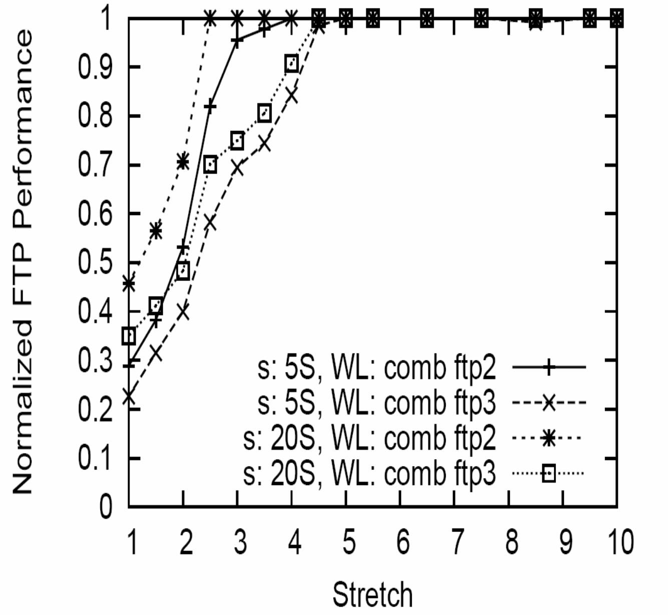
(b) FTP performance

- The performance impact on HTTP and FTP flows is slightly more pronounced

Optimal Static Channel Allocation



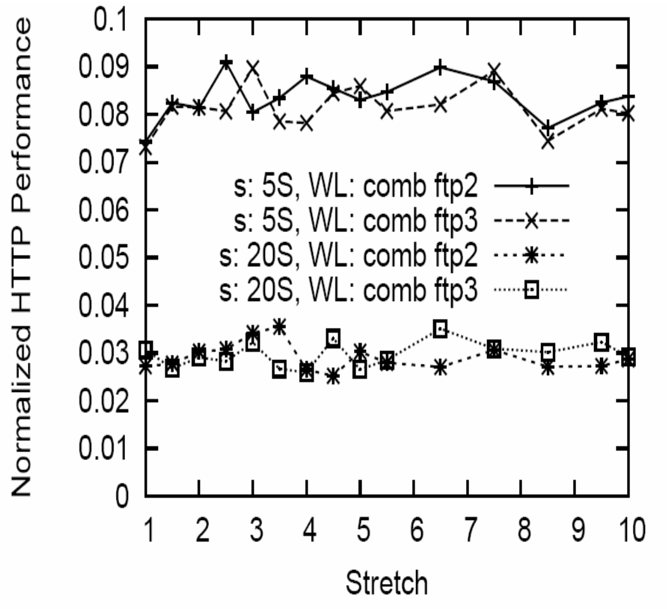
(a) HTTP performance



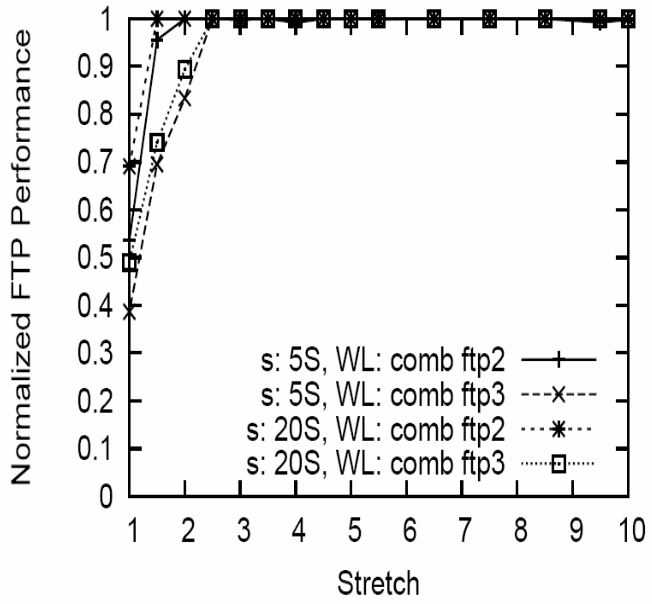
(b) FTP performance

- The APs are statically assigned one of the three non-overlapping channels (1, 6 and 11) such that no two neighboring APs share a channel.
  - The performance curves flatten out earlier.
  - The impact of interference can still be seen.
- Static channel allocation reduces the impact of interference but it cannot eliminate it.

Transmit Power Control



(a) HTTP performance (range = 15m)



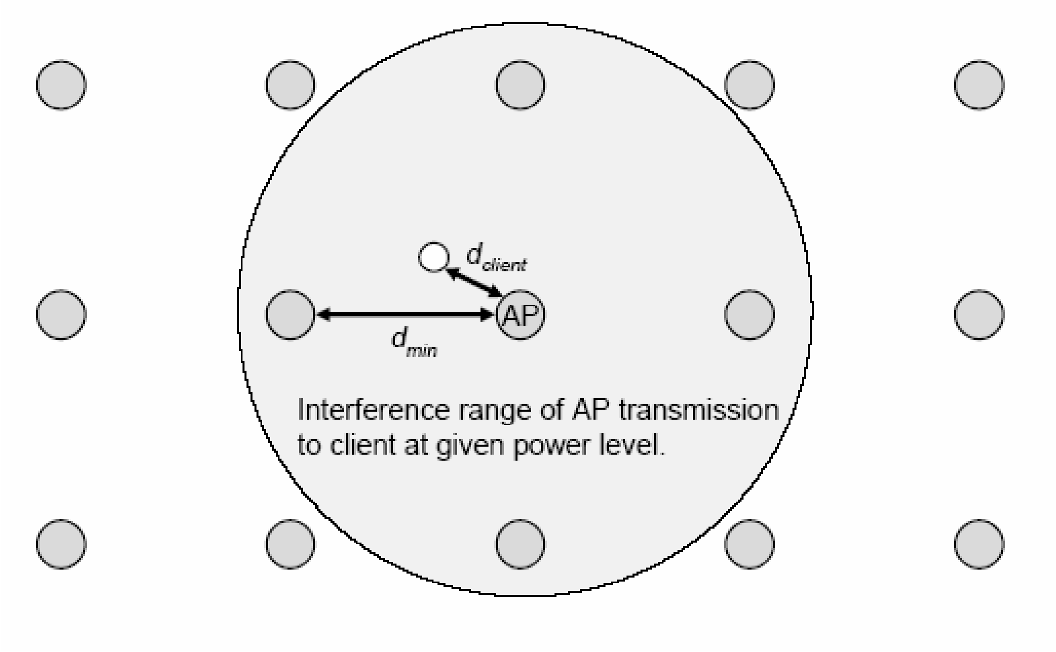
(b) FTP performance (range = 15m)

- We forced the 8 APs to use a power level of 3dBm. This yields a transmission range half the range from using the default power level of 15dBm.
- The performance of individual flows improves significantly.
- The interference among nodes is lowered and both the performance curves flattening out at stretch = 2.

Benefits of Transmit Power Reduction

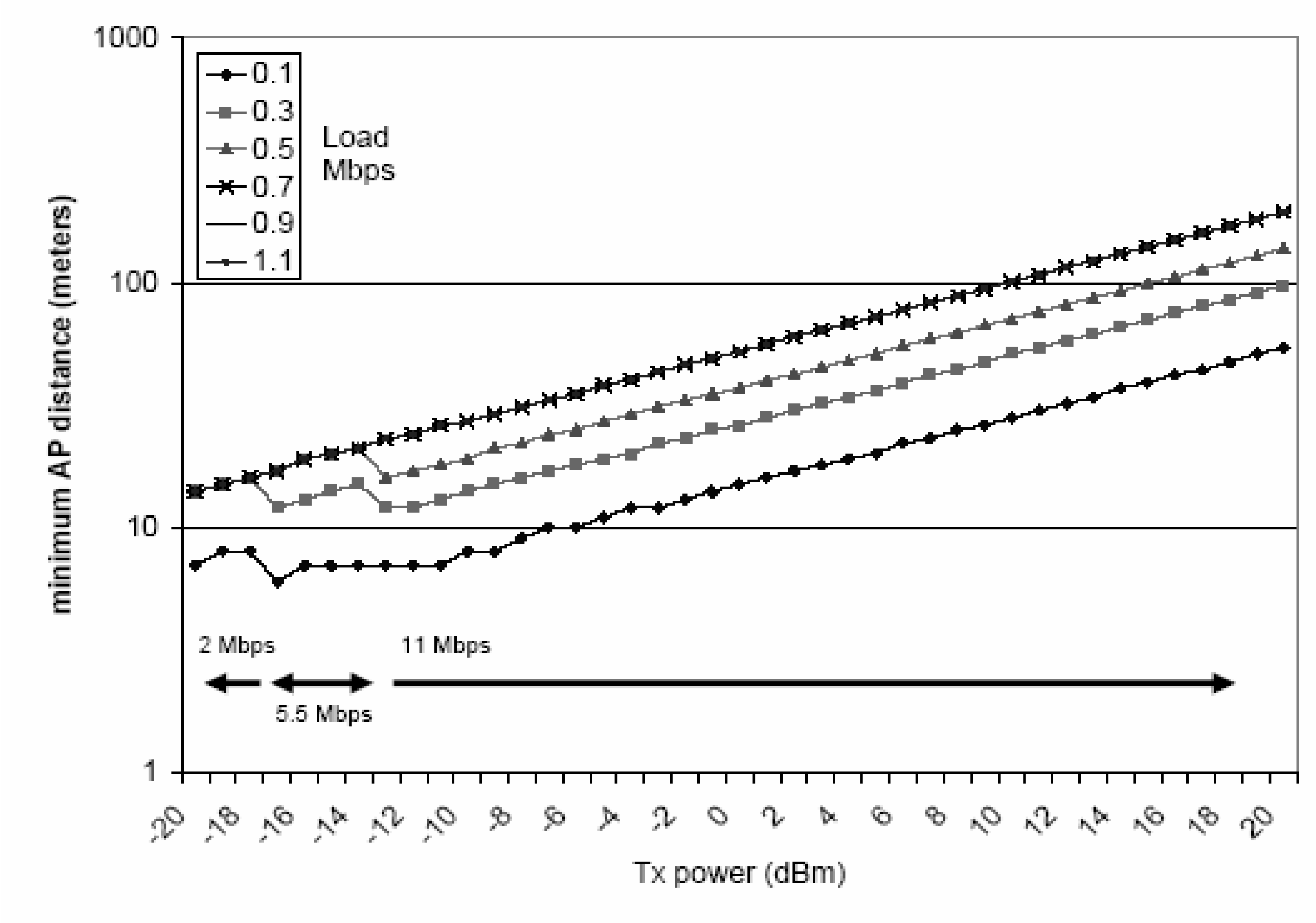
Two-dimensional grid topology model:

- One client per AP, d_{client}=10m



- For each transmit power level and traffic load pair determine the minimum physical spacing required between APs (d_{min}) to support the specified load

Benefits of Transmit Power Reduction



Minimum AP distance vs. Tx power

Key Conclusions

- Minimum distance between APs that can be supported decreases as the transmission power is decreased
- High AP density and higher loads require transmit power levels below 0 dBm
- The highest densities require the use of very low transmission power, forcing nodes to use a transmission rate under 11 Mbps

Deployment Challenges

Reducing the power on a channel:

↳ can improve performance for other channels by reducing interference

↳ but it can reduce the throughput of the channel by forcing the transmitter to use a lower rate to deal with the reduced signal-to-noise ratio.

- Chaotic networks: independent users or organizations (often 1 AP) that want to transmit always at highest power with suboptimal results in terms of performance
- **Solution**: “socially responsible” power control algorithms that would work well in chaotic environments and act for the good of the entire area

Fixed-power Rate Selection Algorithms

- **Auto Rate Fallback (ARF)**

  Used by most 802.11b implementations

  – Attempts to select the best transmission rate

  - If a threshold number of consecutive packets are sent successfully
    → the node selects the next highest transmission rate

  - If a threshold number of consecutive packets are dropped
    → the node decrements the transmission rate

  - If no traffic has been sent for a given amount of time
    → the node uses the highest possible transmission rate for the next transmission.

Fixed-power Rate Selection Algorithms

- **Estimated Rate Fallback (ERF)**

  hybrid between pure SNR-based and ARF-based algorithms

  - estimate the SNR with which each transmission will be received
  - determine the highest transmission rate that can be supported for this SNR
    - If the estimated SNR is just below a rate selection decision boundary

      → after a given number of successful sends, try the rate immediately above the estimated best transmission rate
    - If the estimated SNR is just above a decision threshold

      → after a given number of failures, use the rate immediately below the estimated best transmission rate
    - If no packets have been received from the destination for a given interval

      → begin to fall back towards the lowest rate until new channel information has been received.

Power and Rate Selection Algorithms

- **Power-controlled Auto Rate Fallback (PARF)**

  at the highest rate, after a given number of successful sends
  → reduce transmit power by a fixed amount

  repeat until:

  - either the lowest transmit power is reached

  - or the transmission failed threshold is reached
  In the latter case → raise the transmit power is a fixed amount

  If failures continue, raise the transmit power until the maximum transmit power → then begin rate fallback

- **Power-controlled Estimated Rate Fallback (PERF)**
  - compute an estimated SNR at the receiver
  - if the estimated SNR is a certain amount above the decision threshold for the highest transmit rate

    → lower the transmit power until

$$\mathit{estimatedSNR} = \mathit{decisionThreshold}+\mathit{powerMargin}.$$

Performance Evaluation – Interference Tests

Measured

Aggressive TCP Flow

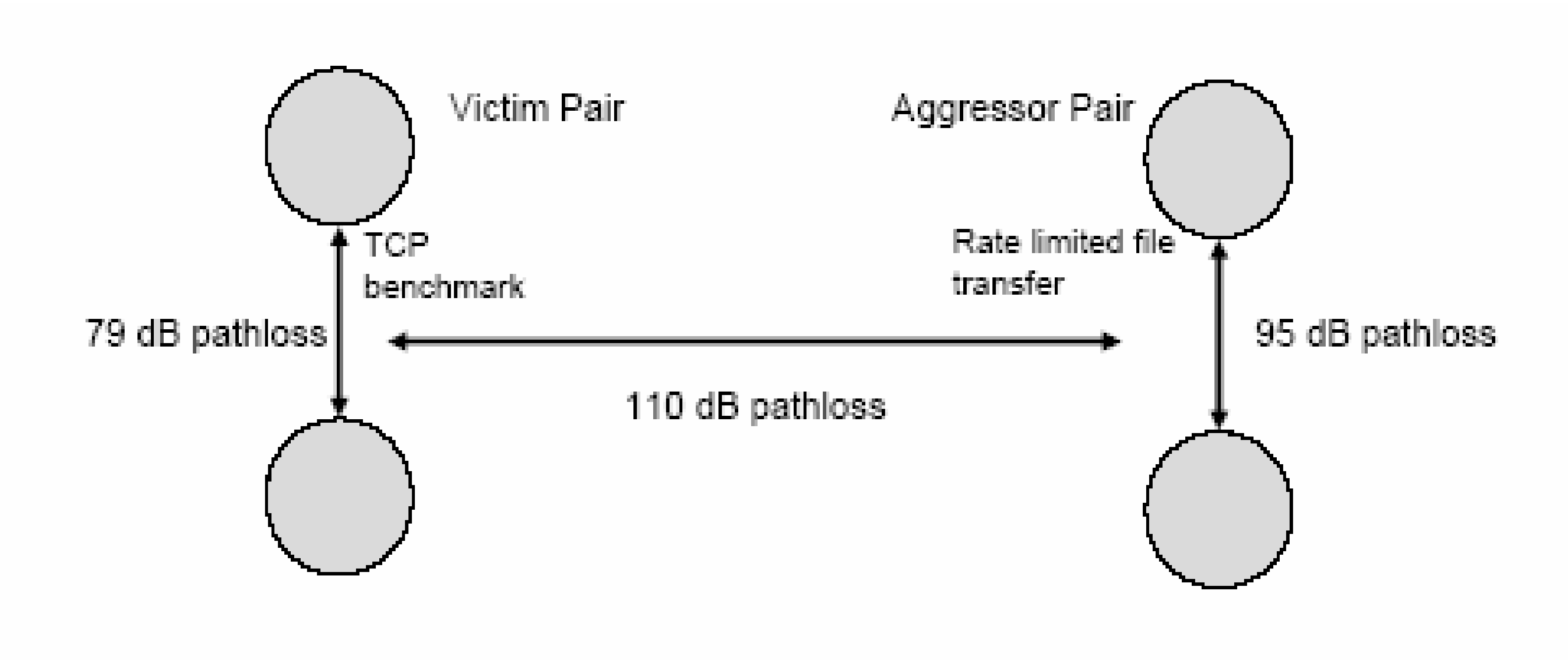
from

Bandwidth Limited TCP Flow

Algorithms

- **ARF**
- **ERF**
- **PERF**
- **PARF – Not Measured: Unstable**

Performance Evaluation – Laboratory Interference



Performance Evaluation – Lab Interference Test

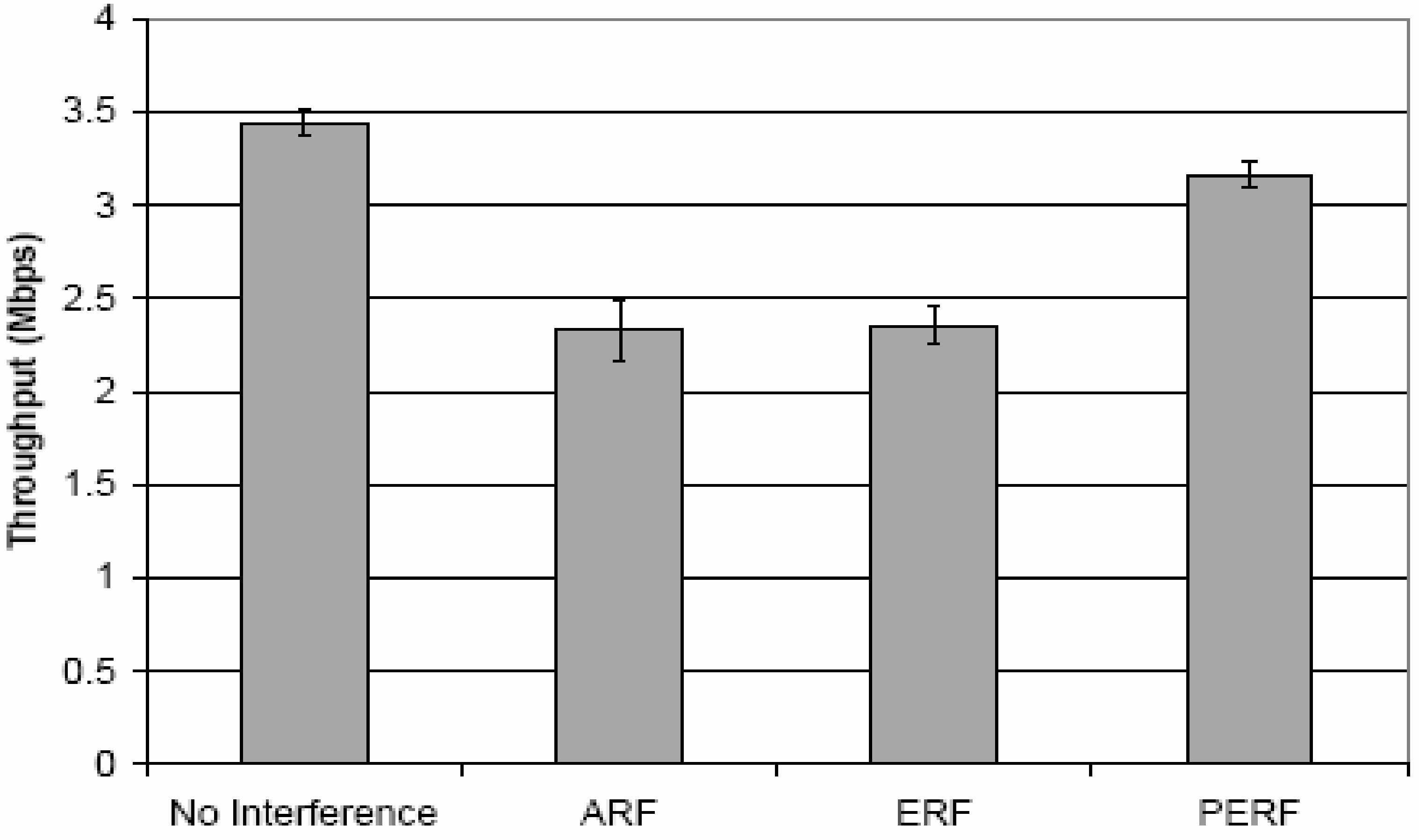
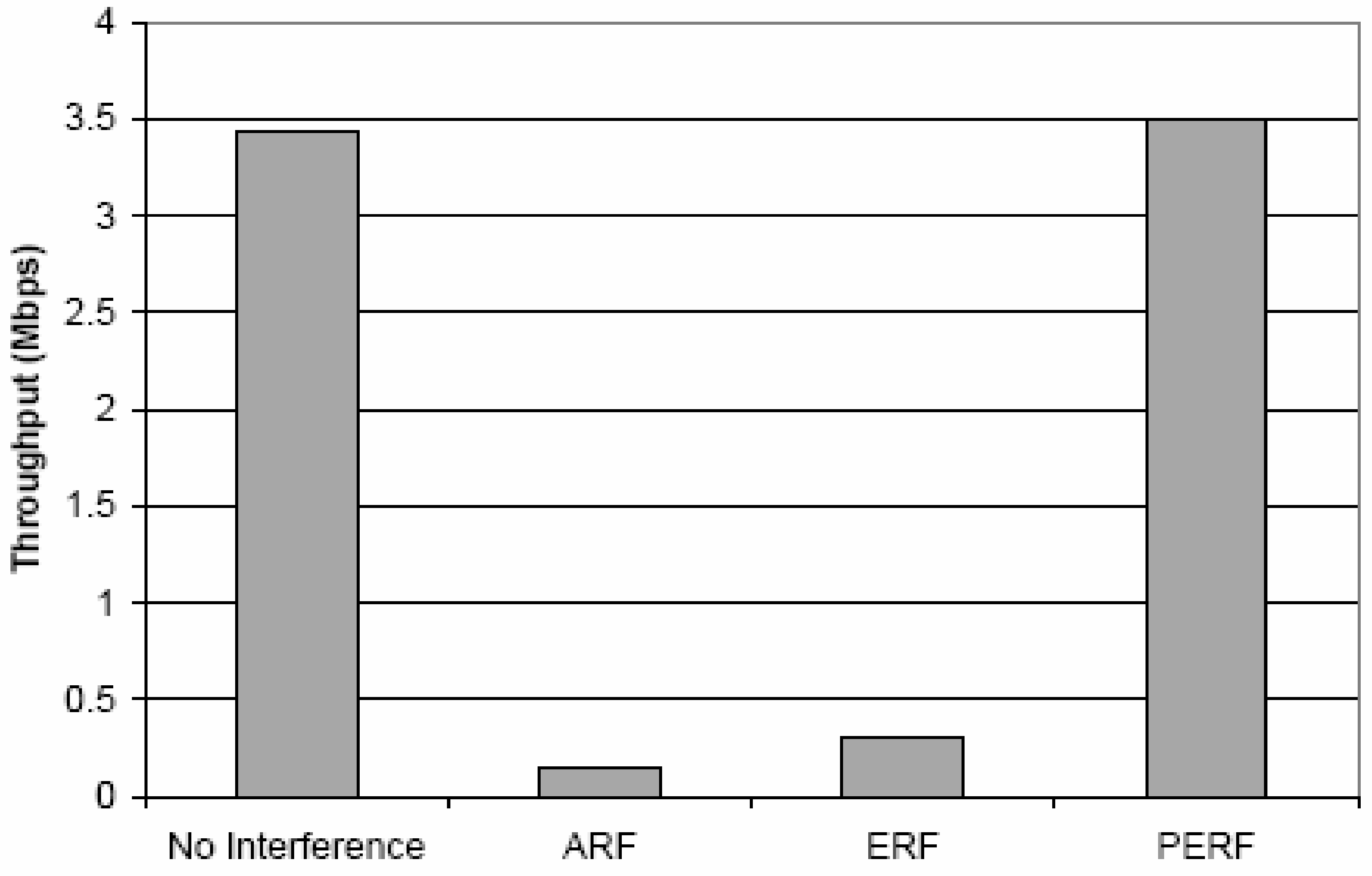
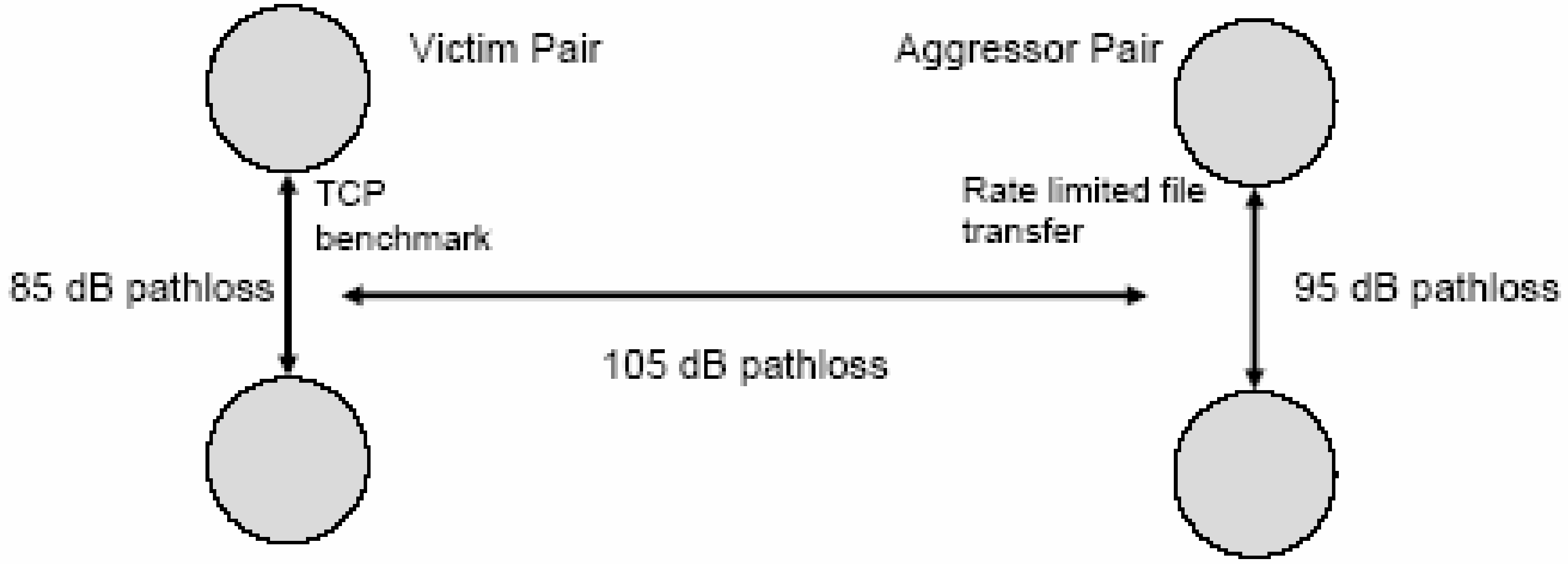


Figure 12: Lab Interference Test

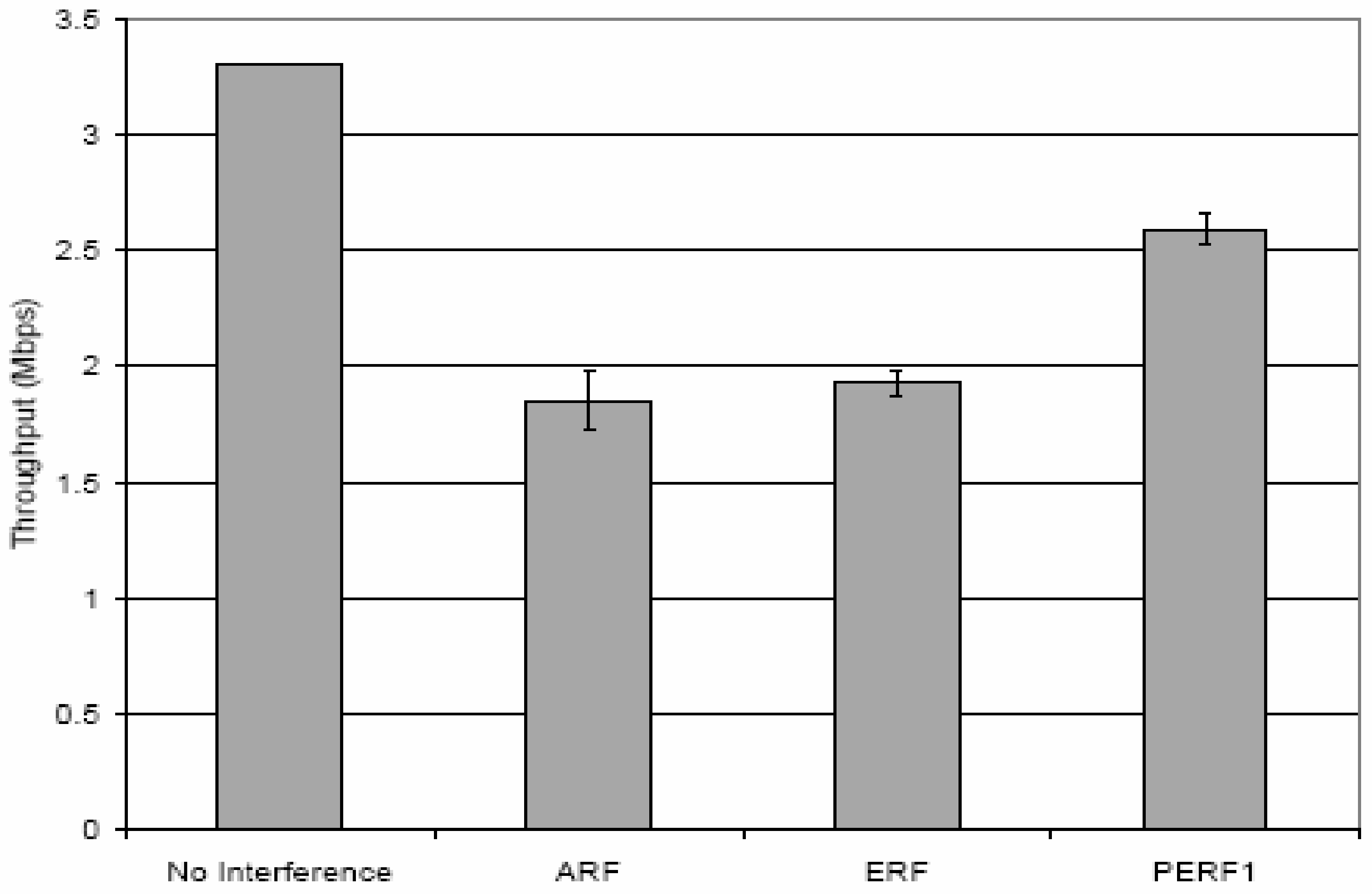
Performance Evaluation – Lab Interference Test



Performance Evaluation – Home Interference



Performance Evaluation – Home Interference Test



Discussion

Load-sensitive **P**ower-controlled **E**stimated **F**allback **R**ate (LPERF)

- High Density AP
- Demand < Selected Transmission Rate
- Accurate Measurements for Received signal strength, noise and transmit power

While the topic of this paper is important in preventing over-saturation of the 802.11 frequency, it does not simulate a real-world environment to fully scope the effectiveness of their protocols:

- The experiments are limited: most of their work is based on simulations
- They do not account for other interfering sources, such as cordless phones and microwave ovens.

Related Work

- *Scheduled Power and RaTe Adaptation* (SPARTA)
  Ramana Rao Kompella and Alex C. Snoeren, Presented at SIGCOMM 2003

  - Shannon’s Law suggests that the energy required to transmit information rises significantly as the desired data rate goes up.
  - Data does not always need to be transmitted at the maximum possible rate, so by reducing the transmission power (and hence the data rate) you can save energy.
  - SPARTA adjusts the transmission rate to as close as the necessary data rate as possible.
  - This can be effective in mobile sensornets where power conservation is crucial.
  - Tests conducted by the researchers showed up to a 50% power saving through the use of SPARTA, with only a 10% increase in the transmission time.

Questions?