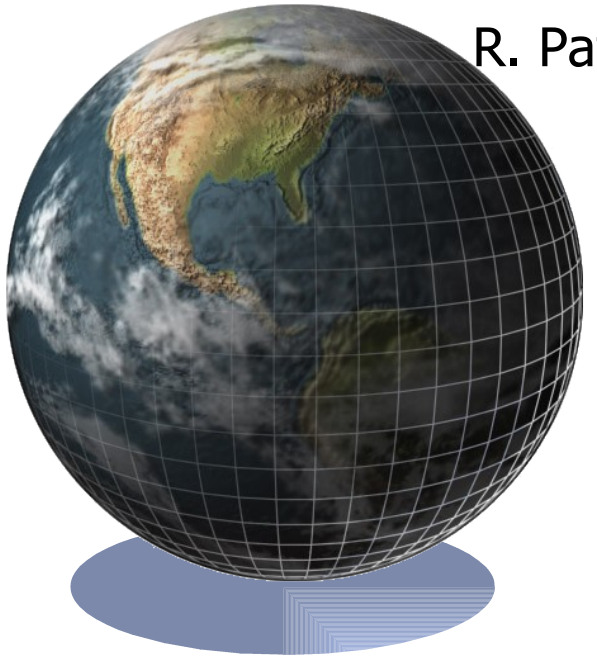
WiLDNet: Design and Implementation of High Performance WiFi Based Long Distance Networks



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Problem Definition

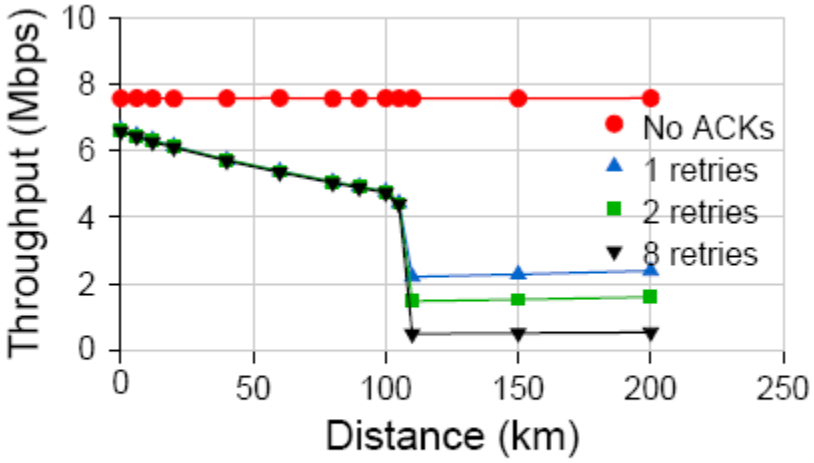
- WiFi Based Long Distance (WiLD) Networks
  - Cheap
  - Unlicensed spectrum
  - Easy to install and use
- Real world deployments:
  - Aravind Eye Hospital,Tamil Nadu,India
  - AIDS Care Training and Support Clinic, South Africa
- Bridging the digital divide

Problem Definition

- Main characteristics:
  - Point-to-point
  - Multihop
  - Up to tens of kilometres
  - Directional antennas
- Other characteristic (not relevant in this work):
  - Unreliable power supply
  - Harsh weather conditions
  - Non-engineering problems

Long Link Performance Issues

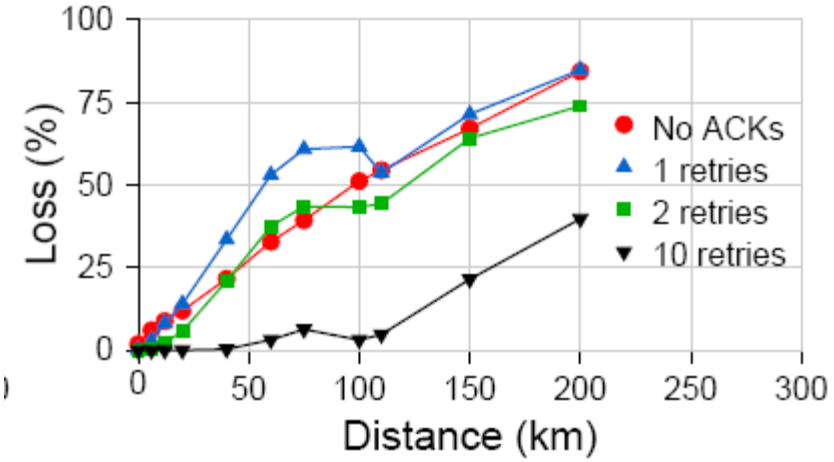
- 802.11 Protocol Shortcomings
  - Link layer ACKs perform poorly:
    - For long distance links sender waits for a longer time for the ACK to return -> decreases utilization
    - For even longer links ACK return time exceeds the ACKTimeout -> unnecessary retransmissions



(a) Unidirectional UDP throughput

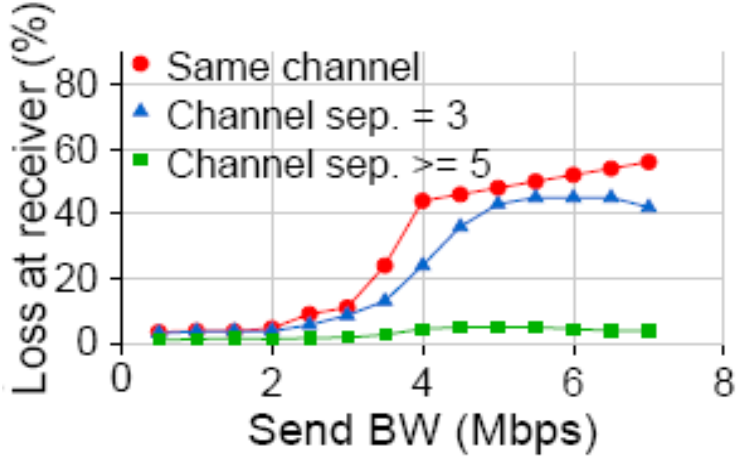
Long Link Performance Issues

- 802.11 Protocol Shortcomings
  - Collisions on long-distance links:
    - CSMA/CA: listen for DIFS time (i.e. 50us) -> if a link is longer than 10km a node would start transmitting unaware of the ongoing transmission at the other end
    - Increasing DIFS is not a solution -> lower utilization



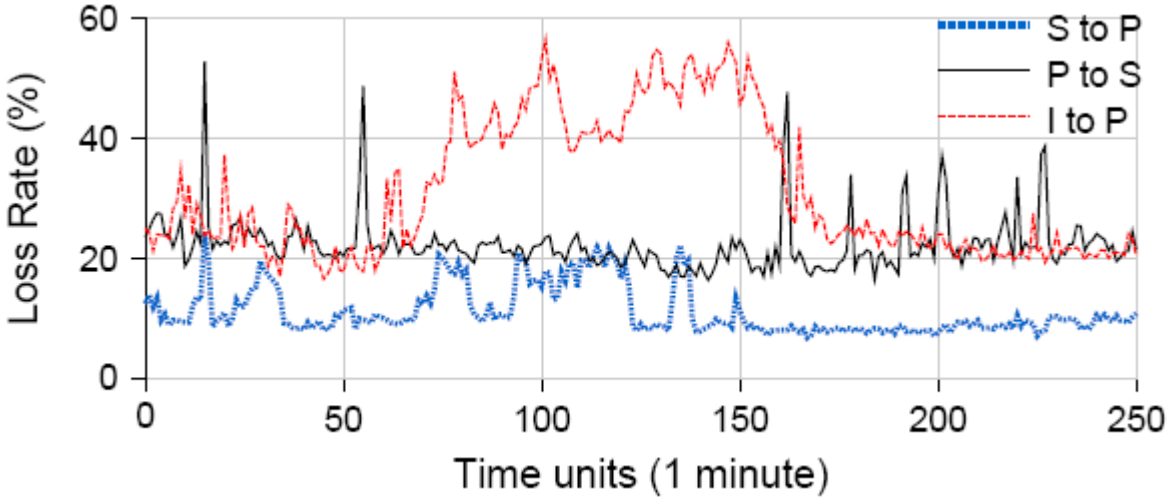
Long Link Performance Issues

- 802.11 Protocol Shortcomings
  - Multiple Link Interference:
    - Adjacent links operating on overlapping channels, may lead to unnecessary backoff
    - CSMA/CA is not well designed for directed transmissions
    - Only three channels per node allow simultaneous transfer -> need synchronized transmission



Long Link Performance Issues

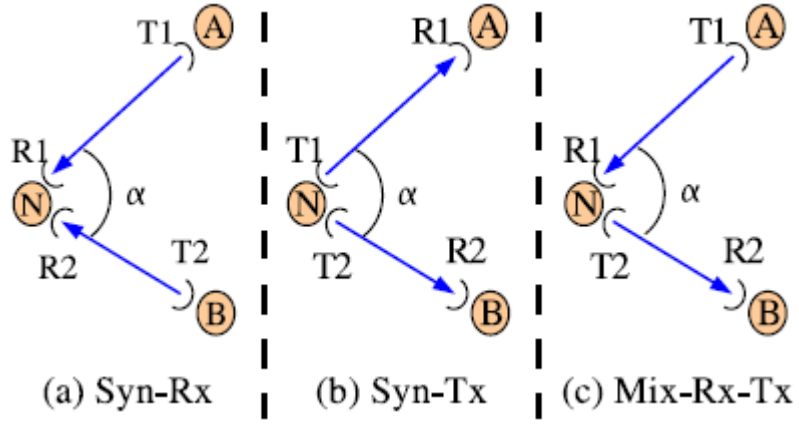
- 802.11 Protocol Shortcomings
  - Channel Induced Loss
    - Loss variation:



    - Sources of loss:
      - Multipath has a very small effect
      - External interference

WiLDNet Design

- Built upon TDMA protocol 2P by B.Raman and K. Chebrolu (IIT Kanpur):
  - Allow simultaneous send/receive on a single node that hosts multiple antennas



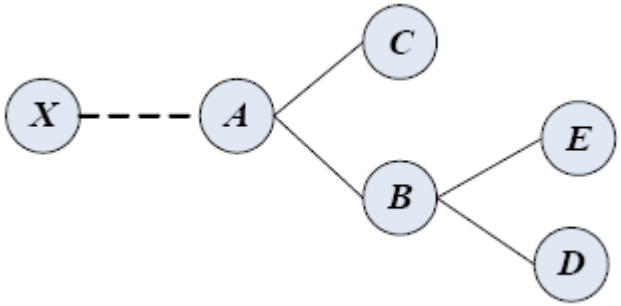
  - Bypassing ACKs and CSMA but needs synchronization methods

WiLDNet Design

- Solve ACK problem:
  - Bulk Acknowledgements:
    - Sliding window based flow-control approach
    - Bulk ACK(aggregate ACK for all the packets received within the previous slot)
      - The sequence number of the last packet received in order and a variable length bit vector for all packets following the ordered sequence
    - Can be piggybacked
  - It has the maximum number of retires set
  - Introduces packet reordering at the link layer

WiLDNet Design

- TDMA in Lossy Environments
  - Use 2P but modify its weak points:
    - 2P explicitly notifies the end of its transmission period by sending a **marker** packet, when the marker is received – phase switching happens. If the marker is lost the other node waits for a timeout
    - Unfortunately this can propagate through the network:



WiLDNet Design

- TDMA in Lossy Environments – Implicit Synchronization
  - Consider a link A(sender)-B(receiver): t_{sendA} and t_{recvB} are start times of the slots
  - All packets sent by A are timestamped with the time difference(δ) between the moment the packet was sent t_1 and the beginning of the slot t_{sendA}
  - When the packet is received B's slot is adjusted: $t_{recvB} = t_2 - \delta$, to accommodate variations: $t_{recvB} = \alpha * t_{recvB} + (1-\alpha)*(t_2 - \delta)$ B starts transmitting at: $t_{sendB} = t_{recvB} + T$

WiLDNet Design

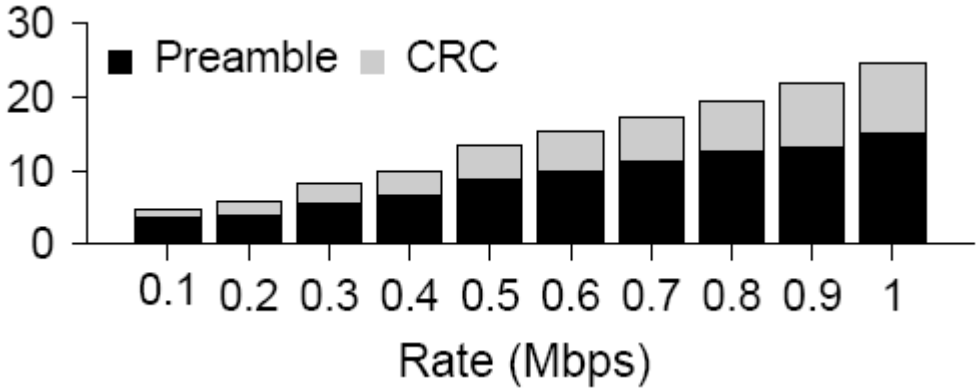
- Adaptive Loss Recovery: Tuning the number of retransmissions
  - For a channel loss rate of *p(t)* we can adjust the number of retransmissions *n(t)* in order to achieve loss-bound of *q* :

$$(1-p(t))^{n(t)} = q$$

  - Minimum throughput overhead but high delay
  - We can have different *n(t)* values for different flows

WiLDNet Design

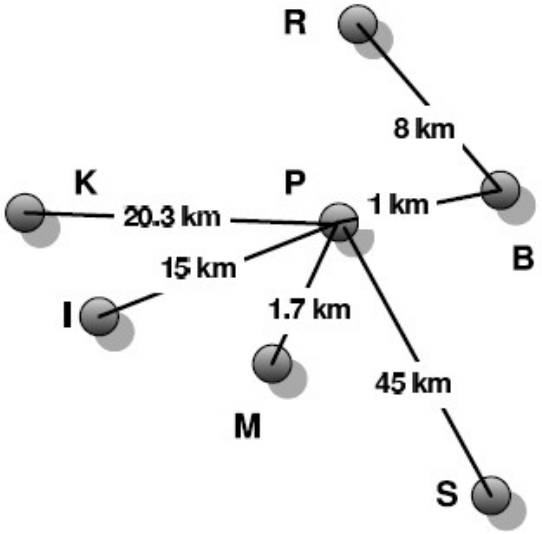
- Adaptive Loss Recovery:FEC-based Recovery
  - Inter-packet FEC



  - For every time slot of *N* packets we add *N-K* redundant packets for every *K* packets
  - Weighted average of the losses observed in the previous *M* slots helps us estimate the needed level of redundancy

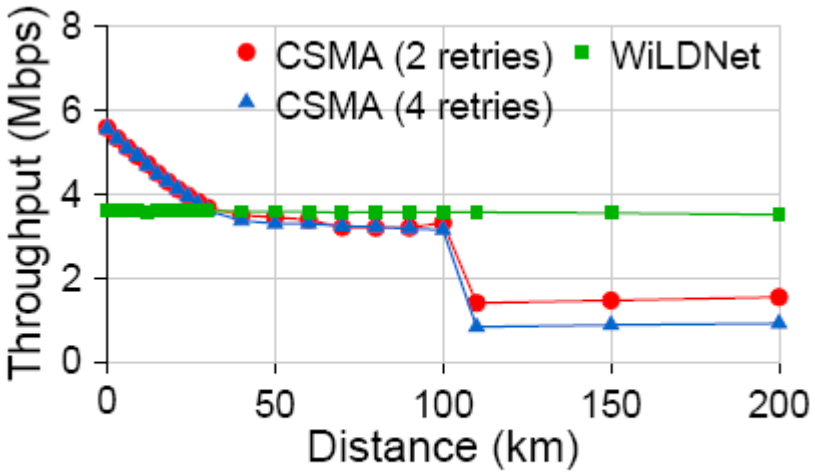
Experimental Setup and Evaluation

- Campus WiLDNet at Berkeley

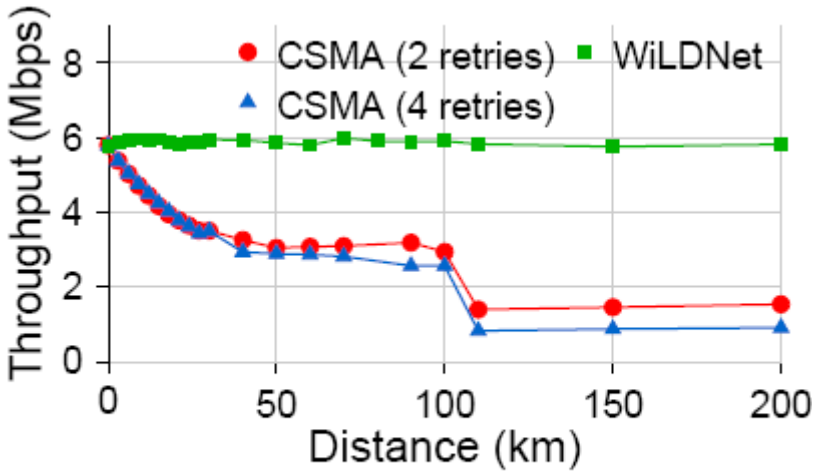


Experimental Setup and Evaluation

- Single Link Without Channel Losses



(a) TCP flow in one direction



(b) TCP flow in both directions (

- Symmetric slots limit unidirectional TCP to 50% (perhaps we should have this in mind when writing applications?)
- After 50km CSMA underutilization is avoided
- After 110km standard 802.11 just retransmits

Experimental Setup and Evaluation

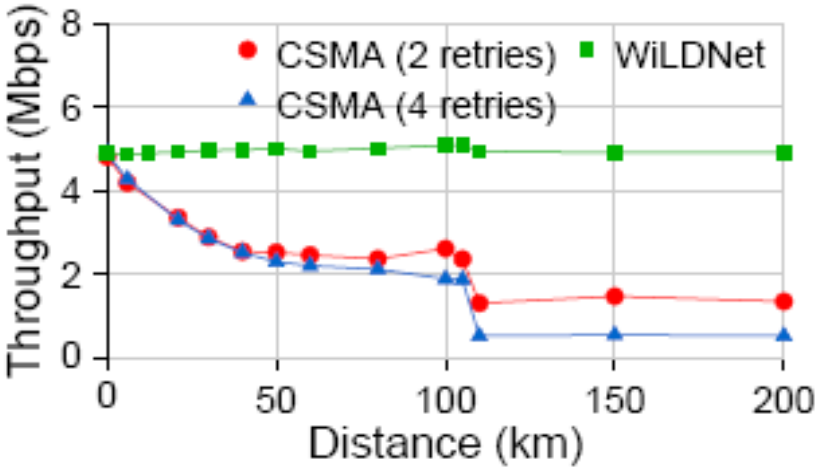
- Multiple Hops
  - Ten one-minute sessions; average results:

Description (Mbps)	One direction	Both directions
Standard TCP: same channel	**2.17**	**2.11**
Standard TCP: diff channels	3.95	4.50
WiLD TCP: same channel	**3.12**	**4.86**
WiLD TCP: diff channels	3.14	4.90

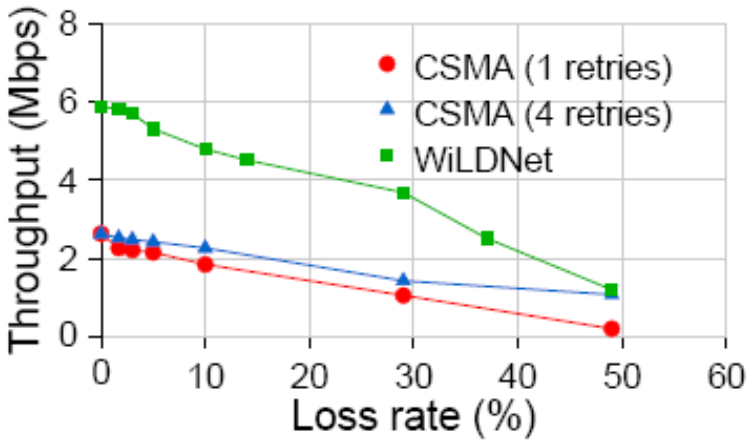
  - WiLD eliminates inter-link interference
  - This makes channel allocations unimportant

Experimental Setup and Evaluation

- Bulk ACK Recovery Mechanism
  - When channel loss exists:

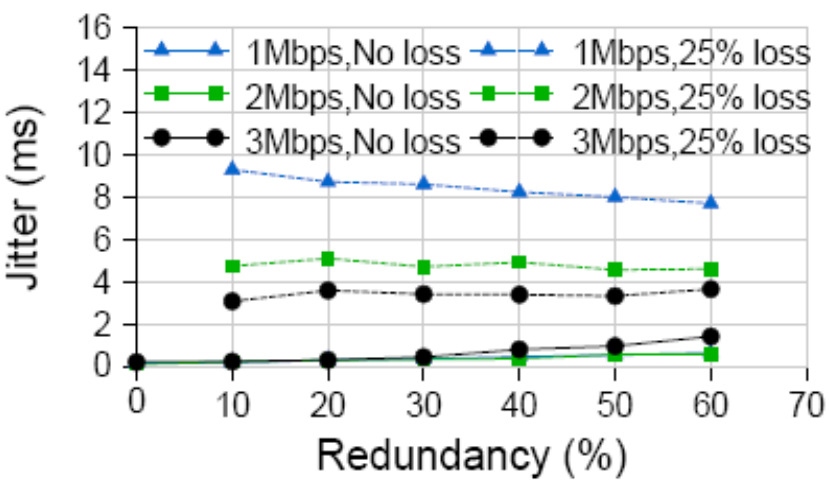


  - Varying loss rate:



Experimental Setup and Evaluation

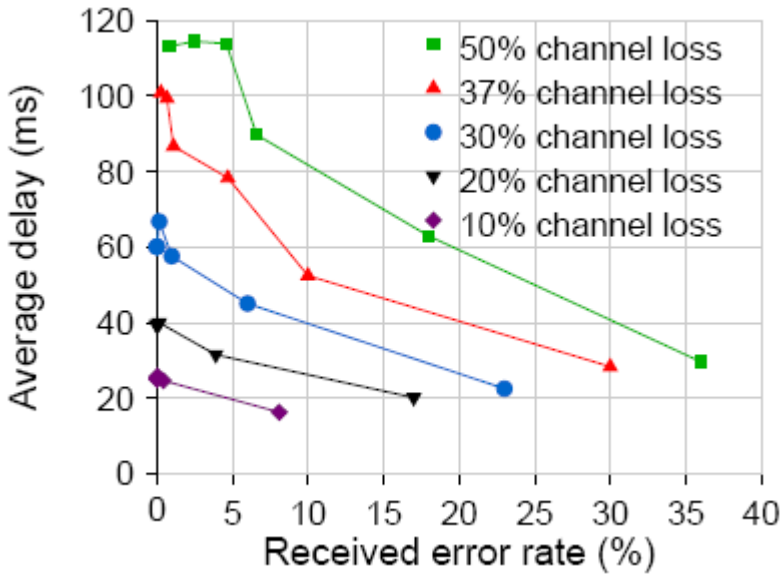
- Forward Error Correction
  - Jitter introduced by encoding/decoding:
    - Encoding introduces only insignificant amount of jitter
    - When decoding takes place it pushes it up to 10ms, which is acceptable



  - Some jitter can be avoided by combination of TDMA and FEC

Discussion

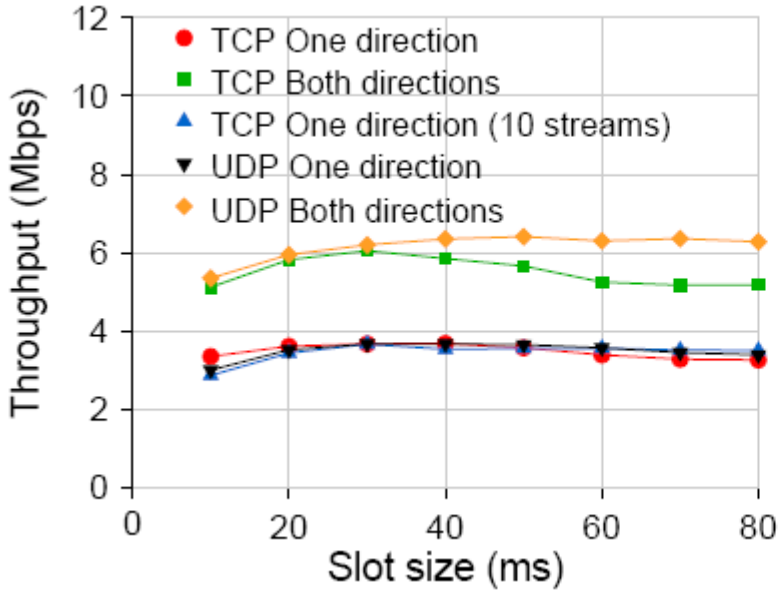
- Tradeoffs
  - Number of retransmissions
    - Retries are increased from 0 to 10 moving from right to left
    - We should balance parameters to satisfy application requirements

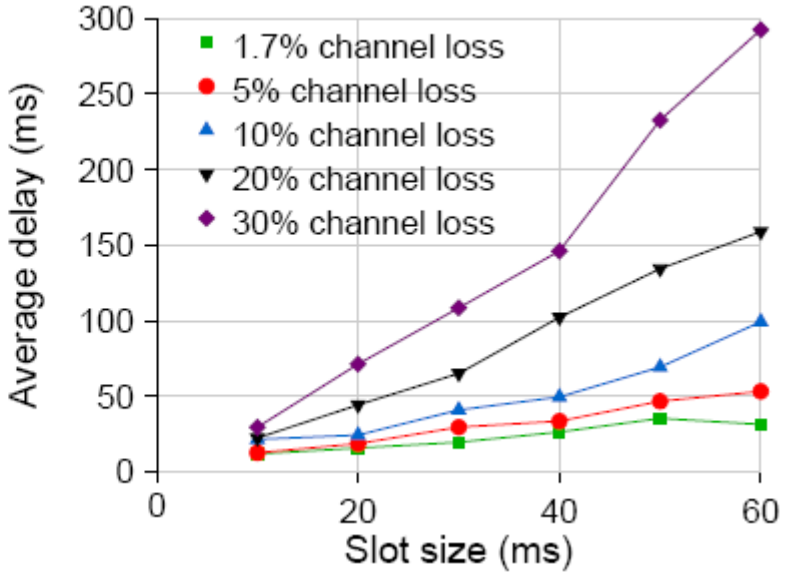


  - Some jitter can be avoided by combination of TDMA and FEC

Discussion

- Tradeoffs
  - Choosing slot size

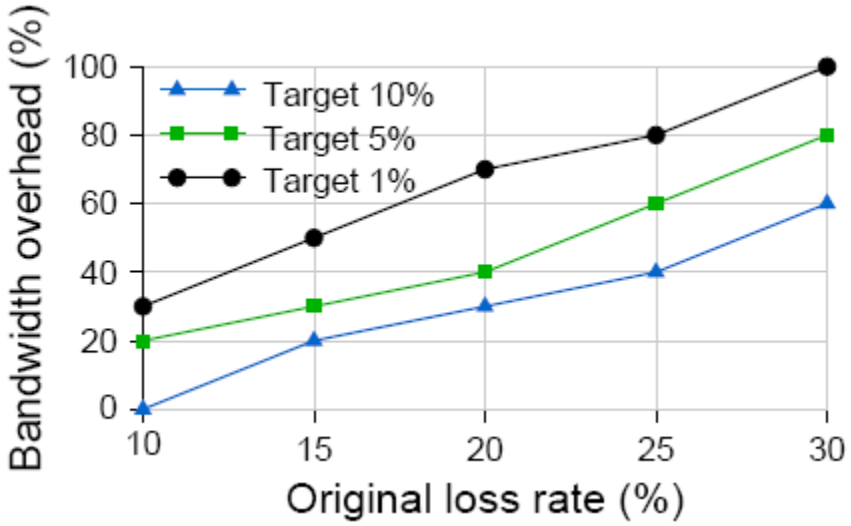




  - Seems that 20ms is a good choice
  - If lower delay is needed we sacrifice some throughput

Discussion

- Tradeoffs
  - Choosing redundancy parameters for FEC



  - These results are given for an emulated link!
  - It's very hard for FEC to achieve arbitrarily low loss rates in case of bursty losses

Related and Future Work

- IIT Kanpur group pioneered in this field:
  - First efforts were just a novel usage of standard 802.11 equipment ("Turning 802.11 Inside-Out",Bhagwat et al. 04)
  - 2P Protocol ("Design and Evaluation of a New MAC Protocol for Long-Distance 802.11 Mesh Networks", Raman et al. 05)
  - Interesting solution for insufficient power supply problem "Wake-on-WLAN", Mishra et al 06
- Berkeley TIER group followed, implemented several WiLD networks in Ghana, India, etc.
- Wireless Africa project

Related and Future Work

- Newer research from the two groups is based on performance evaluation and cost estimation
  - "Packet Loss Characterization in WiFi-Based Long Distance Networks", Sheth et al 07 shows that unlike Roofnet links, WiLD links predominantly suffer from external interference, they categorize loss and propose several remedies
  - "Long Distance 802.11b Links: Performance Measurements and Experiences", Chebrolu et al: adjacent links on non-interfering channels may actually interfere; weather conditions are negligible

Related and Future Work

- Some questions are still unanswered:
  - Is 2P like performance satisfying?
  - Channel assignment (graph colouring)
  - What about the energy consumption?
  - RF noise pollution

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Thank You

Questions/Comments?