Capacity Improvement and Routing for Wireless Mesh Networks

SSCH: Slotted Seeded Channel Hopping for Capacity Improvement in IEEE 802.11 Ad-Hoc Wireless Networks, P. Bahl, R. Chandra, and J. Dunagan (Microsoft Research)

Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks, R. Draves, J. Padhye, and B. Zill (Microsoft Research)
Wireless Mesh Networks

- Community wireless networks
  - Integration of Ad-Hoc networks and HotSpot

![Diagram of Wireless Mesh Networks]
Wireless Mesh Networks

- Commercial applications of multi-hop wireless networks
  - Microsoft, Nortel, Mesh Networks, Radiant Networks
- Most of the nodes are either stationary or minimally mobile
- Routing focuses on improving protocol capacity
Wireless Mesh Networks

- Cost effective Internet access
- Redundant communication paths
- Community network

Issues
- 1. Capacity and transmission-range enhancement
- 2. privacy and security
- 3. multi-path multi-hop routing
- 4. auto-configuration
- 5. bandwidth fairness
- 6. spectrum etiquette
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Research objective

- To use channelization to increase the network capacity
- To propose Slotted Seeded Channel Hopping (SSCH)
  - Mainly deals with channel hopping scheduling
Assumption

- There exist orthogonal channels in radio band
- **Single** half-duplex single-channel transceiver
  - Switching delay is 80 $\mu$s
- IEEE 802.11a (13 orthogonal channels)
**SSCH: Data structure**

- A distributed channel scheduling protocol
- *Slot*: the time spent on a single channel (10 ms)
- *Channel schedule*: list of channels for each slot
- *List of channel schedules*: for all other nodes

![Diagram showing SSCH channel scheduling](image)
SSCH: Packet scheduling

- Positioned on top of IEEE 802.11 MAC layer
- Per-neighbor FIFO queue
- Limited to use broadcast due to allocation of one channel to one slot
  - Neighbor discovery is affected
  - Additional buffering is needed
- Disabling retransmissions at 802.11 MAC
  - All the packets are retained in packet queue
Each node

- Determines channel schedule by \( x_i \leftarrow (x_i + a_i) \mod 13 \)
- Uses a parity slot to prevent logical partition
  - Every node is supposed to switch a parity slot after each slot traverses every channel available
- *Cycle*: time necessary to traverse both all the channels and slots, plus one parity slot
  - Since SSCH uses 13 channels and 4 slots, \( 13 \times 4 \times 10 + 10 = 530 \) (ms)
SSCH: Channel scheduling

Each node periodically broadcasts each channel schedule and offset within the current cycle

- Employs IEEE 802.11 Long Control Frame Header format
- Broadcast this information once per slot
Each node schedules slot overlapping for each destination when each node has packets for it

1. By synchronizing the beginning of slots (synchronization information)
2. By changing part of one node’s channel schedule to match that of other nodes’

For more elaboration,

- Preserves receiving slots, which receives 10 or more packets in the previous iteration
- Uses *de-synchronization* to prevent channel congestions by choosing a new (channel, seed) pair
- In order to moderate the pace of slot change, update is only allowed for the next slot, and the change of the first slot is only allowed during the parity slot
Simulation: Overhead

- Use a network consists of one sender and one receiver
- Measure moving throughput average over 20 ms
- Observe synchronization overhead and SSCH overhead (switching overhead)
Simulation: Single hop case

- 200 × 200 (m) area, and physical rate is set to 54 Mbps
- All nodes are in communication range of each other
- Disjoint flows (flows not sharing either endpoint)
  ▲ with varying number of nodes from 2 to 30, and varying number of flows from 1 to 15

![Per flow throughput](image1)

Per flow throughput

![Aggregate throughput](image2)

Aggregate throughput
Simulation: Single hop case

- Non-disjoint flows
  - nodes participate as both sources and sinks
  - with varying number of nodes from 2 to 20, and varying number of flows from 2 to 20

**Per-flow throughput**

**Aggregate throughput**
100 nodes are uniformly distributed in a $200 \times 200$ m

DSR is employed

Per-flow throughput vs. the varying number of flows
100 nodes are uniformly distributed in a $200 \times 200$ m

Per-flow throughput and route length vs. node speed in two cases
Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks
R. Draves, J. Padhye, and B. Zill
Motivation

- When network nodes have multiple radios, shortest-path algorithms do not perform well
  - If each node has an 802.11a and 802.11b radio, most of the traffic will be carried over the slower 802.11b links since 802.11b has longer range than 802.11a
  - If each node has two 802.11b radios, one tuned to channel 1 and the other tuned to channel 11, and a network consists of 2-hop paths, throughput of a path in which two hops are different channels is better than than of a path which is entirely over channel 1 or 11

- A new routing metric is required
Previous work: ETX


Use Expected Transmission Count (ETX)

Algorithm

1. Each node broadcasts its probe every second
2. Probe contains the count of probes received from each neighboring node in the previous 10 seconds
3. Based on probes collected, each node computes the loss rate, $p$.
4. ETX is simply $\frac{1}{1-p}$
A New Routing Metric: ETT and WCETT

Elaborate the derivation of ETX

Let $p_f$ and $p_r$ be packet loss probability in the forward and reverse direction (measured with probe packets)

The probability of unsuccessful transmission from $x$ to $y$ is

$$p = 1 - (1 - p_f) \cdot (1 - p_r)$$

$$ETX = \sum_{k=1}^{\infty} k \cdot (p^{k-1} \cdot (1 - p)) = \frac{1}{1-p}$$

Compute Expected Transmission Time (ETT) for link

Let $S$ and $B$ be the packet size and the link bandwidth, respectively

$$ETT = ETX \cdot \frac{S}{B}$$
ETT and WCETT

The expected amount of time to successfully transmit depends on both the link bandwidth and loss rate.

Weighted Cumulative ETT (WCETT) for a path consisting of $n$ hops is computed as follows:

- Estimating the end-to-end delay,
  $$\text{WCETT} = \sum_{i=1}^{n} ETT_i$$

- Taking into account the channel diversity,
  $$\text{WCETT} = \max_{1 \leq j \leq k} \sum_{\text{hop } i \text{ is on channel } j} ETT_i$$

- Finally,
  $$\text{WCETT} = (1 - \beta) \cdot \sum_{i=1}^{n} ETT_i + \beta \cdot \max_{1 \leq j \leq k} \sum_{\text{hop } i \text{ is on channel } j} ETT_i,$$
  where $\beta$ is a tunable parameter s.t. $0 \leq \beta \leq 1$.
Routing Protocol: MR-LQSR

- Multi-Radio Link Quality Source Routing (MR-LQSR)
- A source-routed link-state protocol
- Based on DSR
  ▶ discovers the neighbors of a node
  ▶ assigns weights to the links (ETT)
  ▶ propagates the information to other nodes
  ▶ uses the link weights to find a good path for a given destination (WCETT)
Simulation: Protocol stack and Testbed

- There are 23 stationary nodes equipped with a ORiNOCO and a NetGear
- In case of two radios: a 802.11a radio and a 802.11g

Figure 2: Our architecture multiplexes multiple physical links into a single virtual link.

Figure 3: Our testbed consists of 23 nodes placed in fixed locations inside an office building.

Protocol stack

Testbed
Simulation: Comparison with other metrics

- Observe 100 pairs among 506 sender-receiver pairs ($23 \times 22 = 506$), and only one TCP transfer is active at any time.
- Carry out 200 MB file transfer over 2-minute TCP connection, and there is one minute idle period between successive transceiver (total time is 5 hours).
- Evaluate WCETT in comparison with ETX and shortest path.
- Measure: the median throughput of the 100 transfers.
Simulation: Single and two radios

Median throughput vs. path length

Figure 6: Relationship between path length and throughput of individual connections in the baseline one radio scenario.

Figure 7: Relationship between path length and throughput of individual connections with two radios.
Simulation: Improvement vs. path length

Median throughput improvement vs. path length

Figure 8: Improvement in median throughput over single-radio case for various path lengths using WCETT. The improvement is lower for connections on longer paths.
Median throughput vs. path length according to $\beta$

Figure 10: Comparison of median throughputs of connections grouped by path lengths using various values of $\beta$. 
Propose a wireless mesh network (WMN)

Each wireless router is equipped with multiple NICs

Load-Aware channel assignment algorithm
- aims at both channel diversity and connectivity among wireless access points

Load-Balancing routing
- decides each route in a way that balances the load on mesh network