Multi-rate relaying for performance improvement in IEEE 802.11 WLANs

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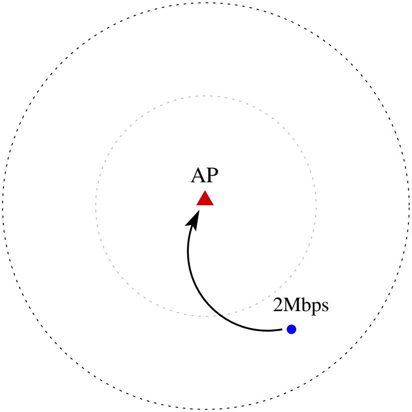
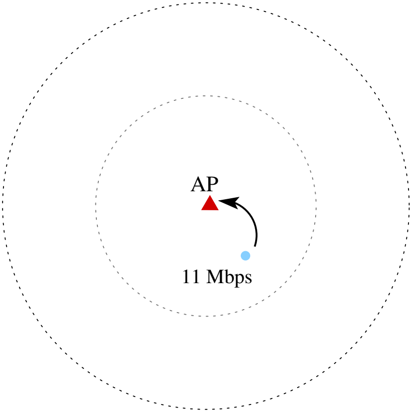
WWIC 2007, Coimbra

Idea



feasible transmit rate depends on SNIR

Idea



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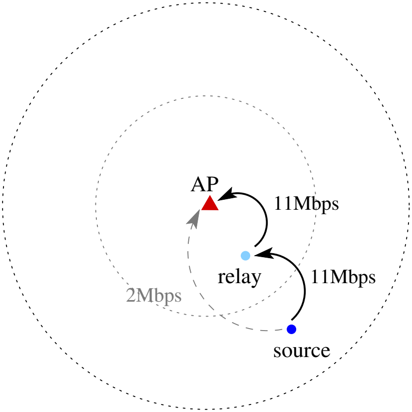
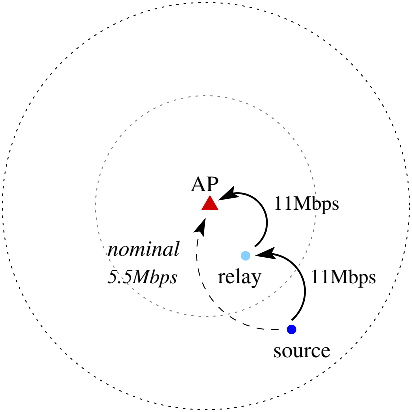
Idea



replace low bit-rate transmission with sequence of high bit-rate transmissions

Idea



increase "effective" transmit bit-rate

Overview

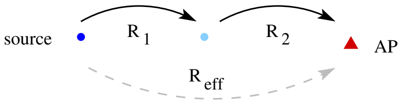
- motivation
- ORP: opportunistic relay protocol
  - source makes frames available for relaying
  - no SNIR-based estimation of inter-node transmit rates
- simulation results
  - up to 40% improvement in throughput
- future work

Motivation

- IEEE 802.11 permits several transmit rates
  - 802.11b: 1,2,5.5,11 Mbps
  - 802.11a: 6,9,12,18,24,36,48,54 Mbps
  - node uses highest rate that gives acceptable loss
  - rate selection mechanism implementation dependent
- nodes using low transmit rate disproportionately affect performance
  - channel contention independent of transmit rate
  - low transmit rate nodes occupy channel longer
- "IEEE 802.11 performance anomaly" (Heusse et.al)

ORP: Opportunistic relay protocol

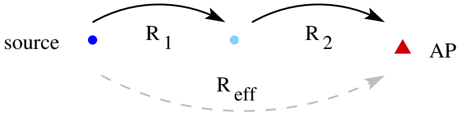
- logical extension to rate selection mechanism
  - source periodically tries to increase its effective transmit rate using relaying



  - rate combinations and effective transmit rates computed offline

R	R_{eff}	R_1		R_2
	2.5	5.5	+	5.5 Mbps
2 Mbps	3.3	11	+	5.5 Mbps
	3.3	5.5	+	11 Mbps
	4.6	11	+	11 Mbps
	5.5	direct		

ORP: Opportunistic relay protocol (2)

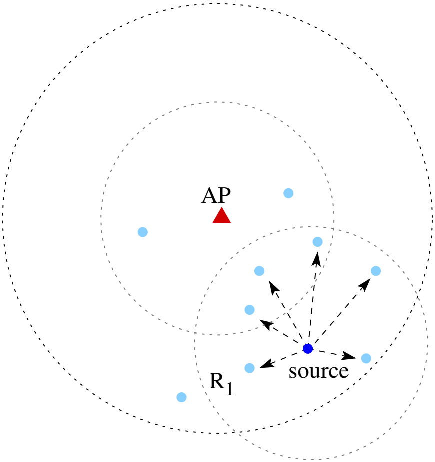


- source completes usual IEEE 802.11 backoff procedure
  - selects rates R_1 and R_2
- source transmits frame at rate R_1
  - doesn't know whether there is a suitable relay node
  - IEEE 802.11 header computed assuming a relay will transmit at rate R_2
- relay must be able to receive from source, transmit to AP
  - potential relays observe relay request implicit in header
  - suitable relay transmits frame at rate R_2
- attempt might not succeed
  - failed attempt to increase transmit rate

Mechanism

- *duration* field of IEEE 802.11 header
  - protects end-to-end **[RTS CTS] DATA ACK** sequence
  - other nodes may not transmit for duration (NAV)
- *duration* field when relaying
  - protects **[RTS CTS] DATA DATA ACK** sequence
  - other nodes may not transmit for duration (NAV)
  - except to forward frame (transmit rate implied by duration constraint)
- maintains IEEE 802.11 semantics
  - does not affect channel contention
  - does not affect collision avoidance (*)
  - ORP and non-ORP nodes co-exist

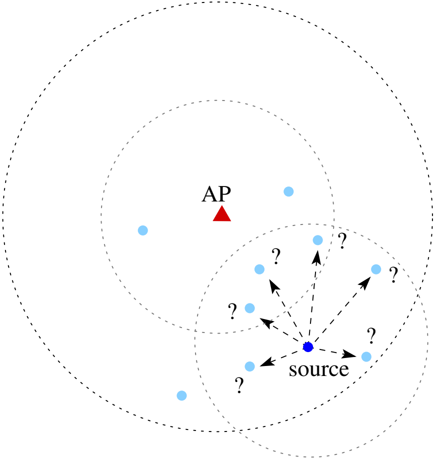
ORP Uplink



$$\text{duration} = +\text{backoff}_{\max} + \texttt{HDR} + \frac{\text{len}}{R_2} + \texttt{ACK}$$

source transmits at rate R_1 (assuming relay at rate R_2)

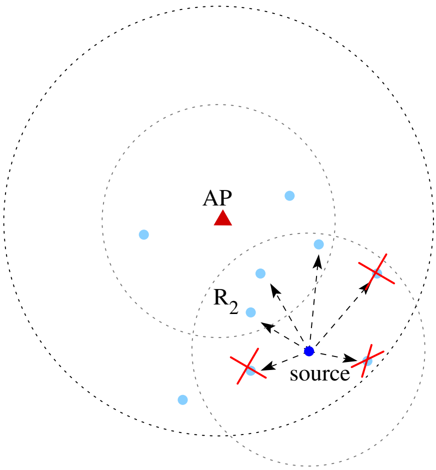
ORP Uplink



$$\text{duration} = +\text{backoff}_{\max} + \texttt{HDR} + \frac{\text{len}}{R_2} + \texttt{ACK}$$

rate R_2 implied by duration constraint

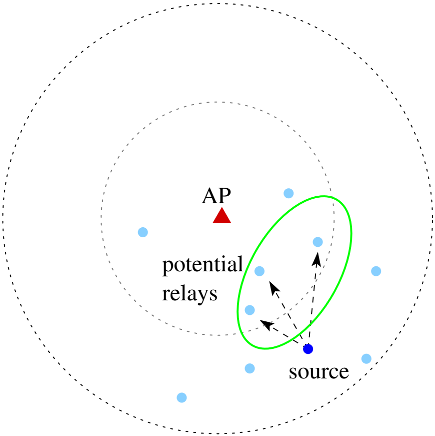
ORP Uplink



$R_{\text{current}} \geq R_2$?

if a node can't forward at rate R_2, it drops frame

ORP Uplink

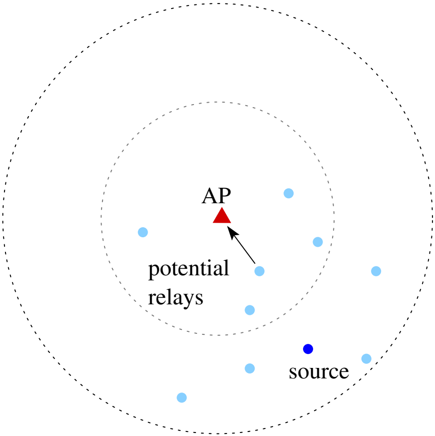


for each potential relay i

$$\mathit{backoff}_i = \mathrm{Rand}(1..\mathrm{max}) * \mathrm{slot}$$

may be more than one potential relay - short random backoff

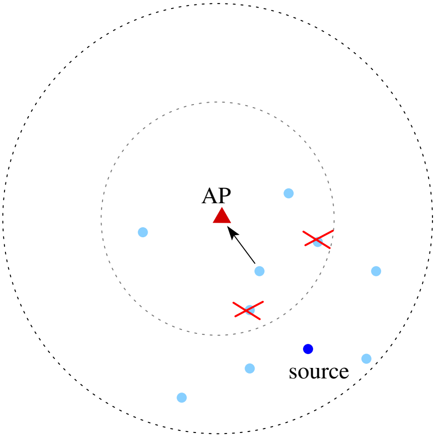
ORP Uplink



for each potential relay i
$backoff_i = \mathrm{Rand}(1..\mathrm{max}) * \mathrm{slot}$

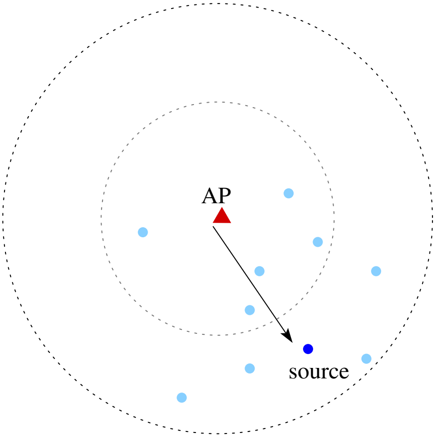
relay with earliest backoff transmits frame at rate R_2

ORP Uplink



other relays detect transmission and drop frame

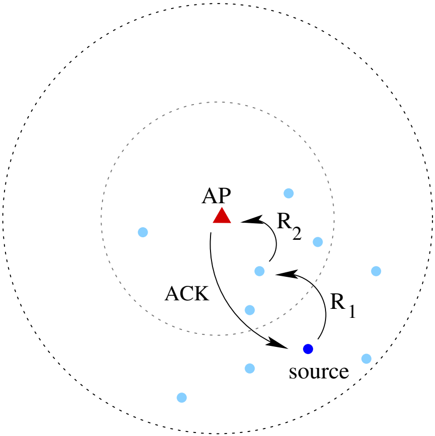
ORP Uplink



$$\text{duration} = 0$$

AP transmits ACK directly

ORP Uplink



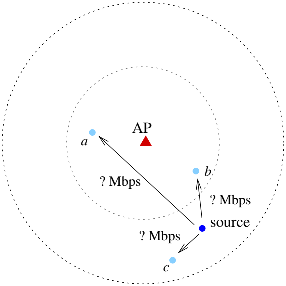
$$\text{time} = \texttt{HDR} + \frac{\text{len}}{R_1}$$

$$\underbrace{+\text{backoff}_{\text{max}} + \texttt{HDR}}_{\textit{overhead}} + \frac{\text{len}}{R_2} + \texttt{ACK}$$

overhead: backoff, HDR, failure

Related work

- previously proposed protocols based on intra-BSS topology
- source addresses specific relay
  - transmit rate from source to each potential relay
  - transmit rate from each potential relay to AP



- estimate inter-node transmit rates from SNIR observations
  - maintaining state information
  - may be easier in simulation than in reality...

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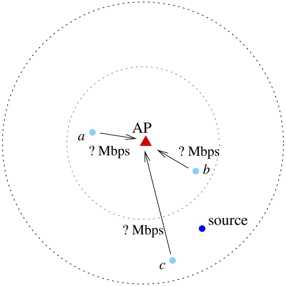

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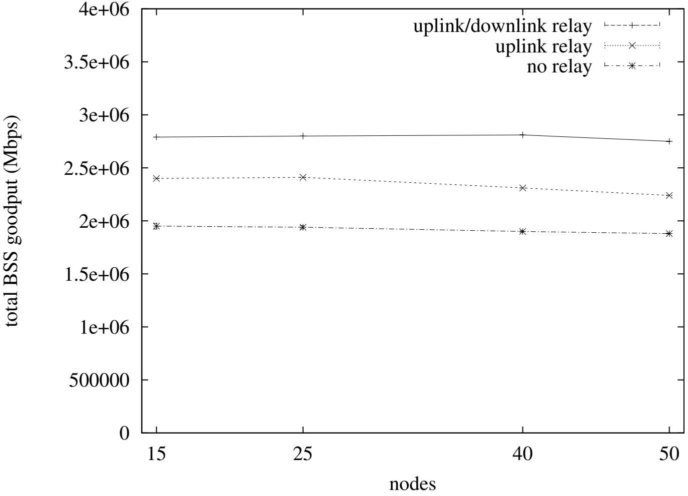
ORP relay discovery

- problem – ORP only works in the uplink direction
  - every node is guaranteed to be able to communicate with the AP
- common traffic scenario is TCP download
  - small uplink frames, large downlink frames
- use ORP as a relay discovery mechanism
  - use ORP on uplink frame
  - AP caches $< source, relay >$ pair
  - AP addresses relay explicitly (Address4 field)
  - no need for `relay backoff`
- standard issues of caching policy
  - how long to keep cached relay
  - current implementation: discover relay each uplink

Simulation setup

- omnet++ (omnetpp.org) and mobility-fw (TU-Berlin)
  - straightforward programming model
  - better channel model than ns-2
- scenario
  - static network, 15-50 nodes, poisson distributed
  - $\text{backoff}_{\text{max}} = 20$ slots (300 μsec)
  - "ping-pong" traffic, 1500 byte frames
- rate selection
  - direct transmit rate fixed (based on distance from AP)
  - 1 Mbps nodes: $R_1 = R_2 = 5.5\, Mbps$
  - 2 Mbps nodes: $R_1 = R_2 = 11\, Mbps$
  - up to 3 relay attempts, every 40 frames

Simulation result



goodput improves ca 40%

Further issues

- rate selection
  - relay source must choose R_1 and R_2
  - usually several possibilities (IEEE 802.11a/g)
  - integrated with (direct) rate adaptation algorithm
- relay caching to improve performance
  - large downlink frames
  - amortize cost of relay discovery over several transmissions
  - usual caching issues...
- scenarios
  - "on-off" mobility: cafe, airport, hotel, home, community, etc
  - unplanned, low cost

Conclusions

- Motivation
  - low transmit rate disproportionately affects performance
- ORP: Opportunistic relay protocol
  - discovers relays opportunistically, by making frames available for relaying
  - increases goodput some 40%
- Advantages
  - simple, low overhead
  - does not require SNIR-based estimate of inter-node transmit rates
  - ORP and non-ORP nodes co-exist
- Future work
  - rate selection mechanism
  - relay caching for better performance