Understanding and Mitigating the Impact of Interference on 802.11 Networks

By

Gulzar Ahmad
Sanjay Bhatt
Morteza Kheirkhah
Adam Kral
Jannik Sundø

Outline

- Background
- Contributions
  1. Quantification & Classification of interferers
  2. Model capturing limitations
  3. Scheme that can withstand strong interferers
- Evaluation
- Critical Appraisal
- Related work
- Question(s) time

Background

- Wireless transmission and RF(Radio Frequency) Interferers:
  - Vulnerable to RF
  - FCC, ITU regulations, users of ISM band and their co-existence
  - Limit transmission power
  - Force nodes to spread signals
  - Does not prevent a range of interference
- Interferes:
  - Cheap 802.11 devices and 2.4 GHz ISM band
  - Wireless jammers
  - Zigbee
  - Cordless phone
  - Disruption in 802.11 operation
  - 802.11 equipment and patterns of weak or narrow-band interference
  - Victim's 802.11 signals and weaker interfering signal

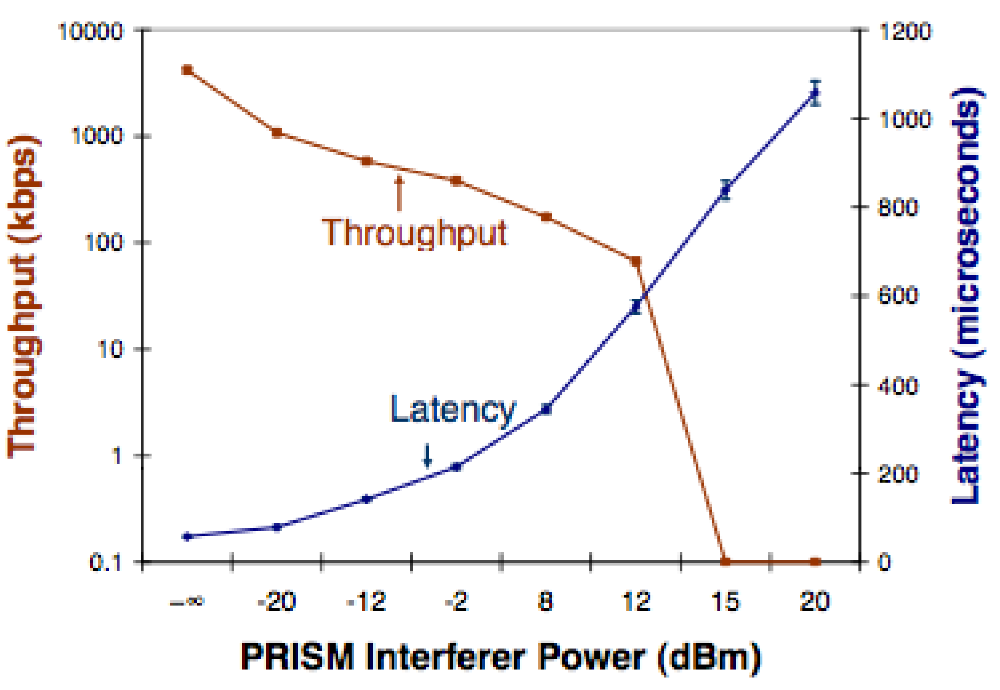
Background Continued

- Types of interferers
  - Selfish Interferers
  - They run own protocol for their own benefit
  - Malicious Interferers
  - They deny service and do not do any useful work
  - Even highly attenuated signals causes severe losses at the receiver
- Current mechanisms to mitigate noise and interference
  - A MAC protocol to avoid collisions
  - Lower transmission rates that accommodate lower SINR ratios
  - Signal spreading which tolerates narrow-band fading and interference
  - PHY layer coding for error correction
- Failure of current mechanisms
  - Do not help due to reception path limitations
  - Fail to tolerate interference gracefully

Background – detecting free medium

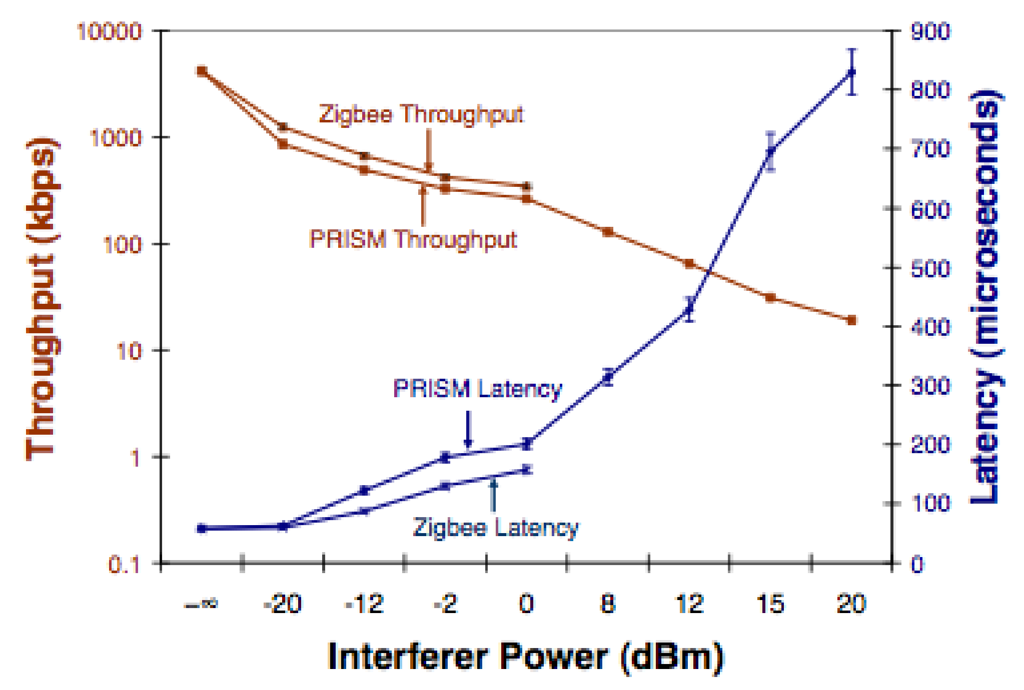
- Device determines free medium in one of three ways:
  1. Energy above an Energy Detect (ED) threshold means busy medium
  2. Valid 802.11-modulated signal detection means busy medium (normally used)
  3. Both 1. and 2.

Timing Recovery Interference



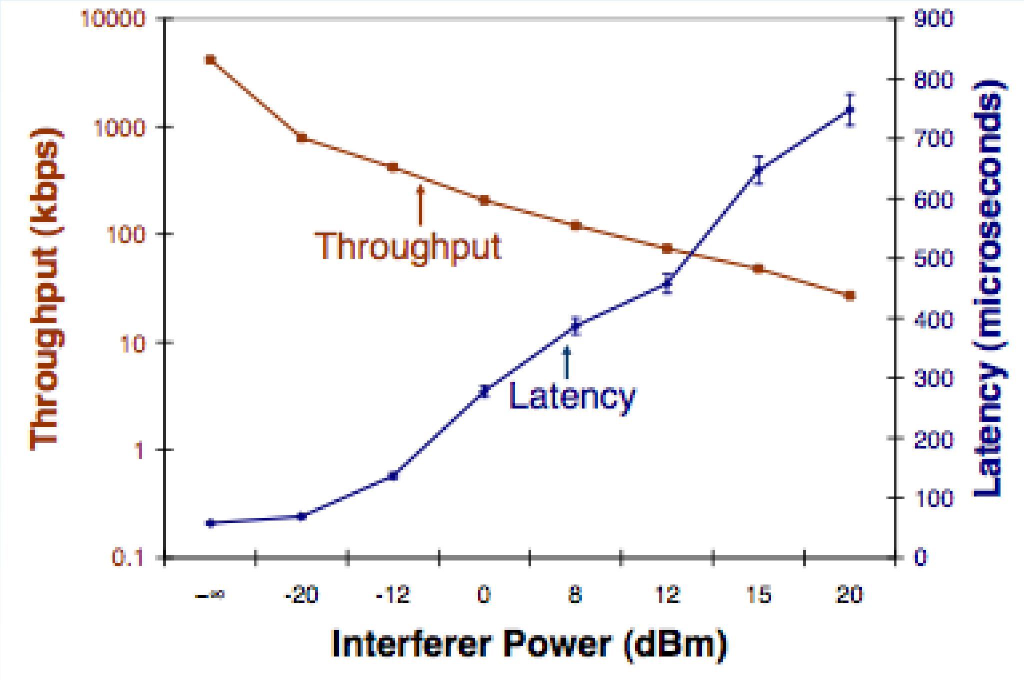
- Receiver uses SYNC pattern from preamble to sync to transmitter's clock
- Interferer transmits SYNC pattern continuously causing receiver to fail to lock onto transmitter’s clock
- Receiver records only energy detection events, but not packets

Dynamic Range Selection Limitation



- Receiver must normalise gain of received transmissions
- Interferer sends random bit-pattern for 5ms and stops for 1ms
- Causes incorrect gain calibration at receiver
- Interference added after gain control can cause sample overflow
- Interference removed after gain control can cause sample underflow

Header Processing Interference

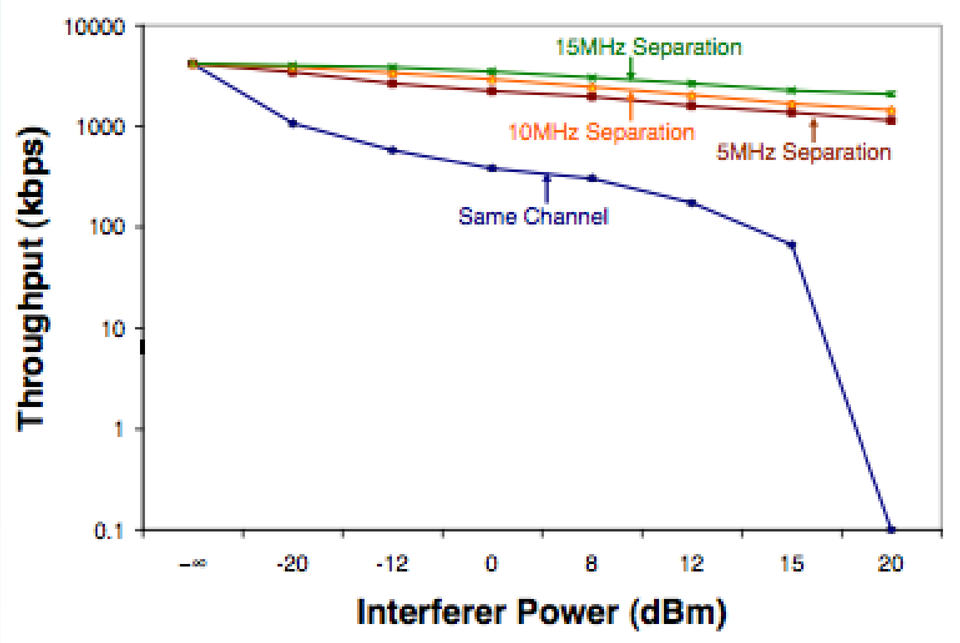


- Start Frame Delimiter field signifies that PLCP header is about to be sent
- If interferer continuously transmits SFD field, receiver believes following bits are the PLCP header
- Causes header to be assembled from wrong samples, resulting in CRC header failure

Impact of Interference on 802.11g/n

- 802.11g and 802.11n are different from 802.11b
- 802.11g does not use a Barker Correlator and uses OFDM
- 802.11n uses spatial coding techniques
- How does interference affect them?
- Authors subjected g and n to similar interference patterns
- Result: still substantial throughput loss
- Cause: same receiver limitations (gain adjustment done once per packet and limited dynamic range)

Impact of Frequency Separation



- RF amplifier sensitivity falls off with frequency separation
- RF filters remove interference power on frequencies that do not overlap the receiver's channel frequency
- Authors moved interferer to adjacent channels which overlapped the AP/client channel frequency range
- Result: throughput increased as interferer moved away
- Conclusion: channel hopping may be a solution against interference

Why do we need better Model of Interference Effects?

- Standard SINR model
  - Basic idea: compute receiver difference between
    - signal power
    - combined interference and noise power
- Doesn’t account for limitations of commodity NICs (covered earlier)
- Example: standard model predicts high probability of receiving packets if signal power is >10dB than interference at receiver
  - Actual observation is high packet loss

SINR - Signal to Interference + Noise Ratio

$$\mathrm{SINR}(\mathrm{packet}_x,\ \mathrm{time}_t) = \frac{\mathrm{Signal}(\mathrm{packet}_x,\ \mathrm{time}_t)}{\mathrm{Interference}(\mathrm{packet}_x,\ \mathrm{time}_t) + \mathrm{Noise}_{\mathrm{Environment}}}$$

$$\mathrm{Interference}(\mathrm{packet}_x,\ \mathrm{time}_t) = \sum_{\mathrm{packet}_x \neq \mathrm{packet}_y} \mathrm{Signal}(\mathrm{packet}_y,\ \mathrm{time}_t)$$

$$\mathrm{Noise}_{\mathrm{Environment}} = \mathrm{BoltzmanConstant} * \mathrm{Temperature} * \mathrm{Bandwidth}$$

Advanced SINR

- Processing Gain
  - Barker Coding (used in DSSS)
  - Adds redundancy => We can do error checks and correction
  - Adds 10.4dB => Signal can be 0.4dB weaker than interferer
- Automatic Gain Control

$$\text{Signal}_{\text{Demodulator}}(\ldots) = \text{Signal}(\ldots) - 30\,\text{dB}; \quad \text{for Signal}(\ldots) > \text{Signal}_{\text{MAX}}$$

$$\text{Signal}_{\text{Demodulator}}(\ldots) = \text{Signal}(\ldots) \qquad \text{for Signal}(\ldots) \leq \text{Signal}_{\text{MAX}}$$

- Ensure signal is in processing range

→Attenuate strong signal: -30dBm

→Minimum SINR: -0.4 dB + 30 dB = 29.6 dB

Advanced SINR

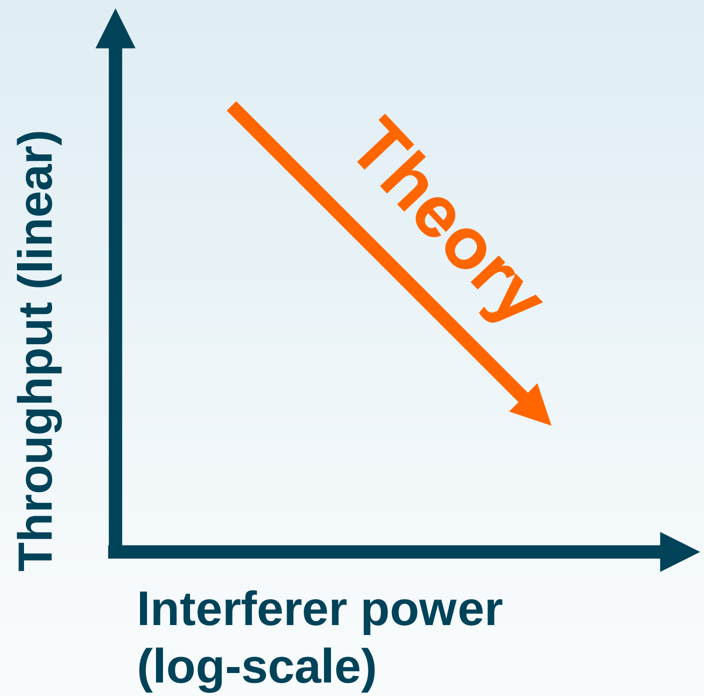
- Non-linear Sensitivity
  - Receiver's amplifier attenuate interference away from the centre

$$\text{Interference}(\text{packet}_x, \text{time}_t) = \sum_{\text{packet}_x \neq \text{packet}_y} \int_{f1}^{f2} \text{ReceiverSensitivity}(\text{frequency}) * \text{Signal}(\text{packet}_y, \text{time}_t)\, d\,\text{frequency}$$

- [f1,f2] frequency range that receiver and interferer overlap
- Sensitivity increases with frequency separation
- -10dB @ 2MHz => SINR increase by 10dB for 2MHz displacement
- -30dB @ 5MHz => SINR increase by 30dB for 5MHz displacement

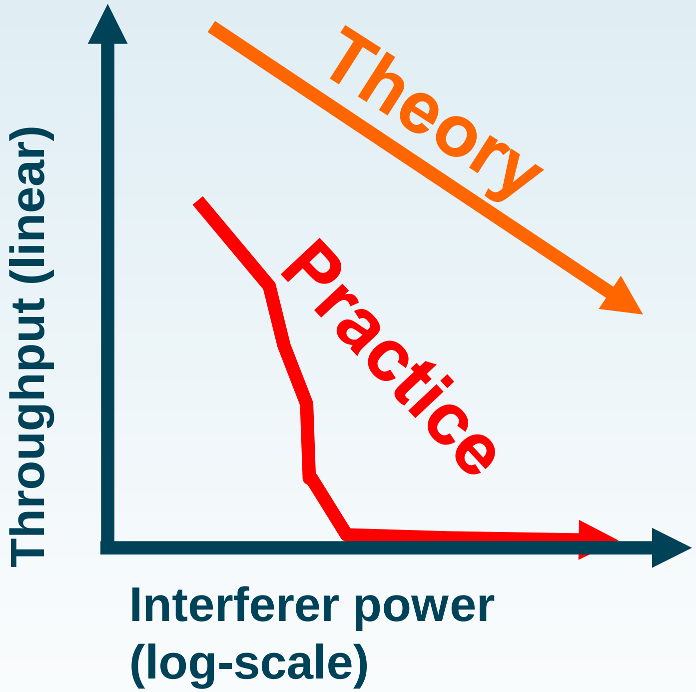
What do we expect?

- Throughput to decrease linearly with interference
- There are lots of options for 802.11 devices to tolerate interference
  - Bit-rate adaptation
  - Packet size variation
  - Forward Error Correction (OFDM,BPSK,QPSK used this technique)
  - Spread-spectrum processing
  - Transmission and reception diversity



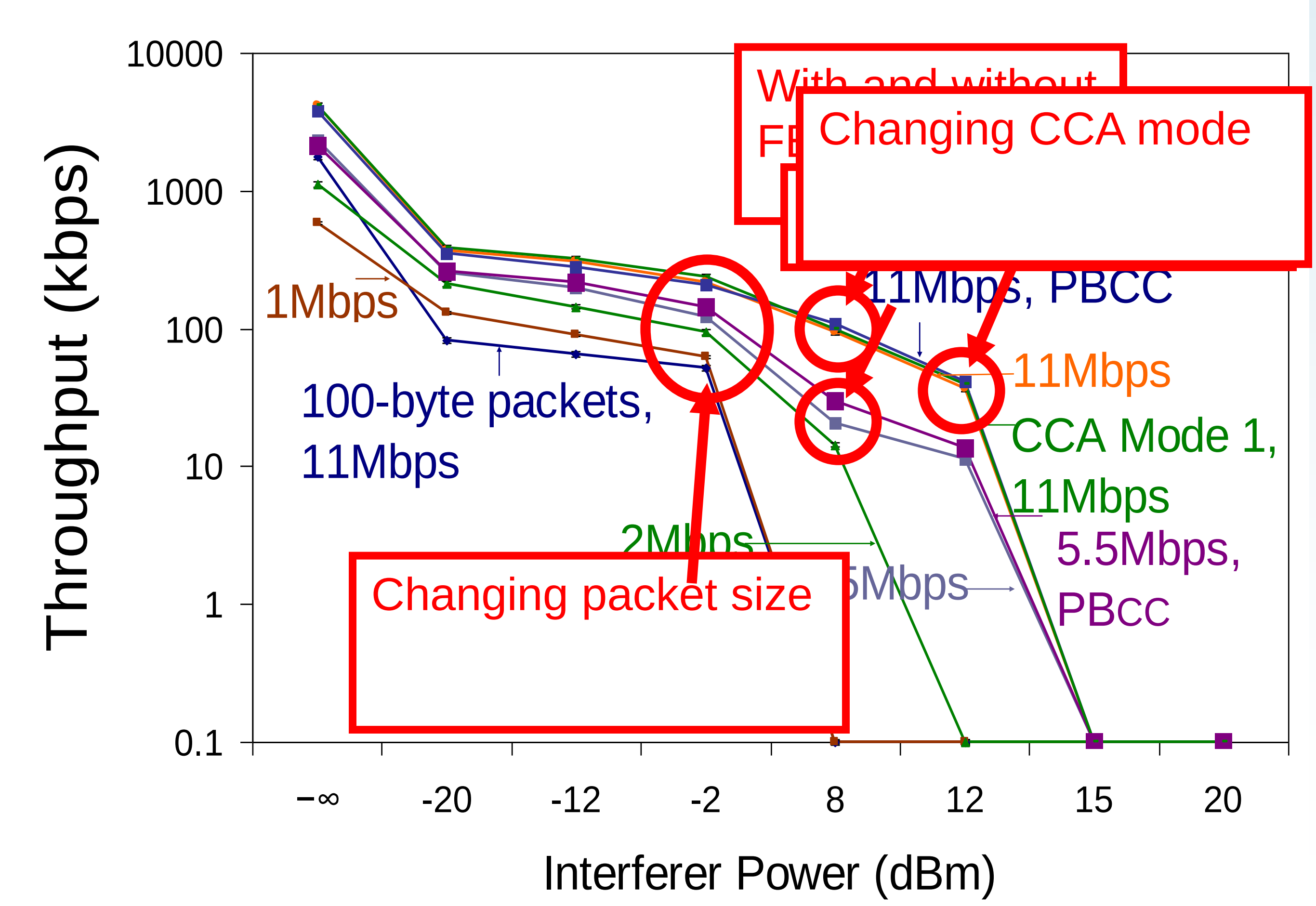
What we see!

- Effects of interference more severe in practice
- Caused by hardware limitations of commodity cards, which theory doesn't model



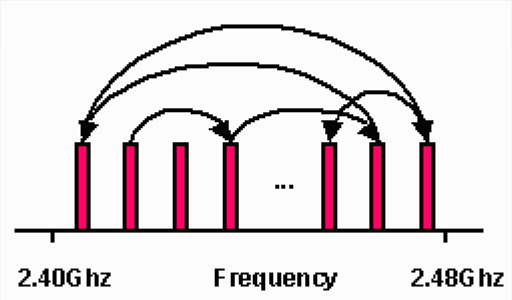
Impact of 802.11 parameters

- Rate adaptation, packet sizes, FEC, and varying CCA thresholds and mode do not help



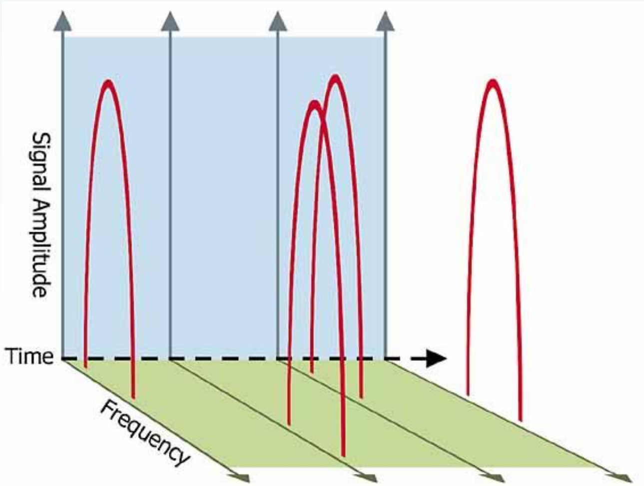
New Scheme Design

FHSS - Frequency-Hopping Spread Spectrum

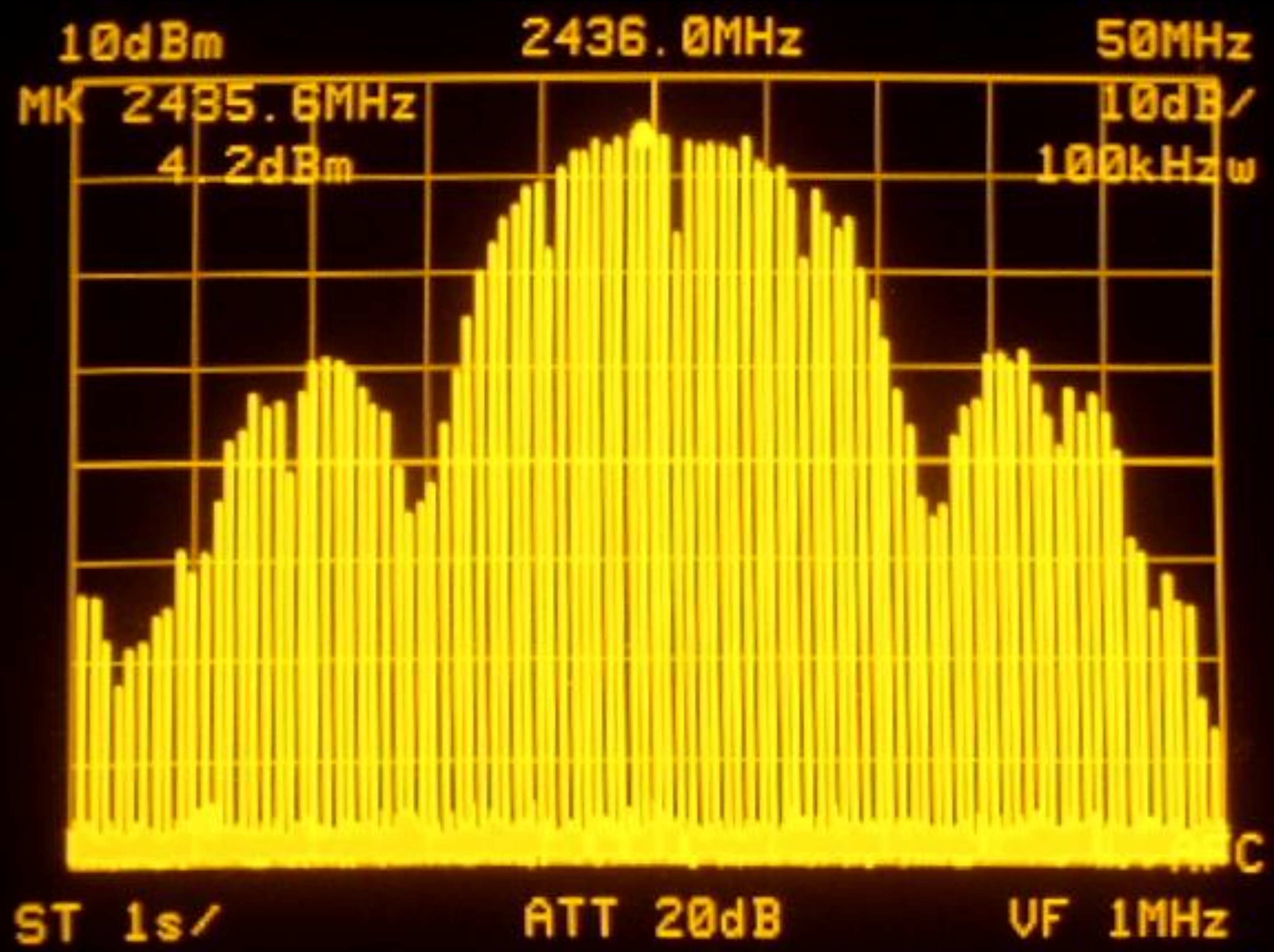


- Split spectrum in channels
  - 802.11 => 79 discrete 1 MHz channels
- Broadcast on one for 400ms and go to another
- Designed for military to prevent listening
  - It's not possible to guess next frequency in short time
  - Now sequence is know & standardised
  - 802.11 uses it for interference reduction
- Too constrained

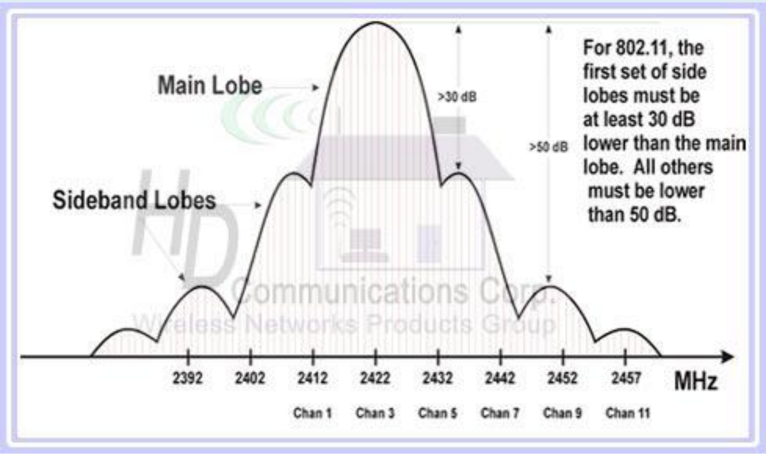
2Mbps

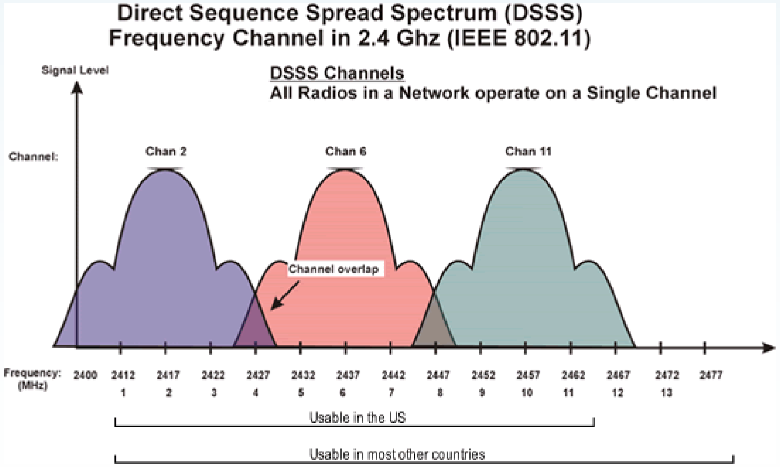


http://www-personal.umich.edu/~csev/hng/book/08wireless/090fhss.gif
http://www.smartcomputing.com/Editorial/article.asp?article=articles/archive/r0602/25r02/25r02.asp&guid=

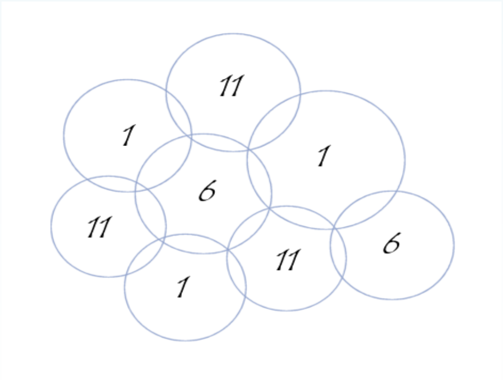

10dBm
2436.0MHz
50MHz
MK 2435.6MHz
4.2dBm
10dB/
100kHz
ST 1s/
ATT 20dB
VF 1MHz

DSSS - Direct Sequence Spread Spectrum





- Barker coding
- Oops, Shanon's theorem:
  - 11Mbps eats 22Mhz
  - Channel overlapping
  - Need 25Mhz separation



http://www.wirelessnetworkproducts.com/index.asp?ID=73&PageAction=Custom
http://www.smartbridges.com/education/print-ready.asp?id=395

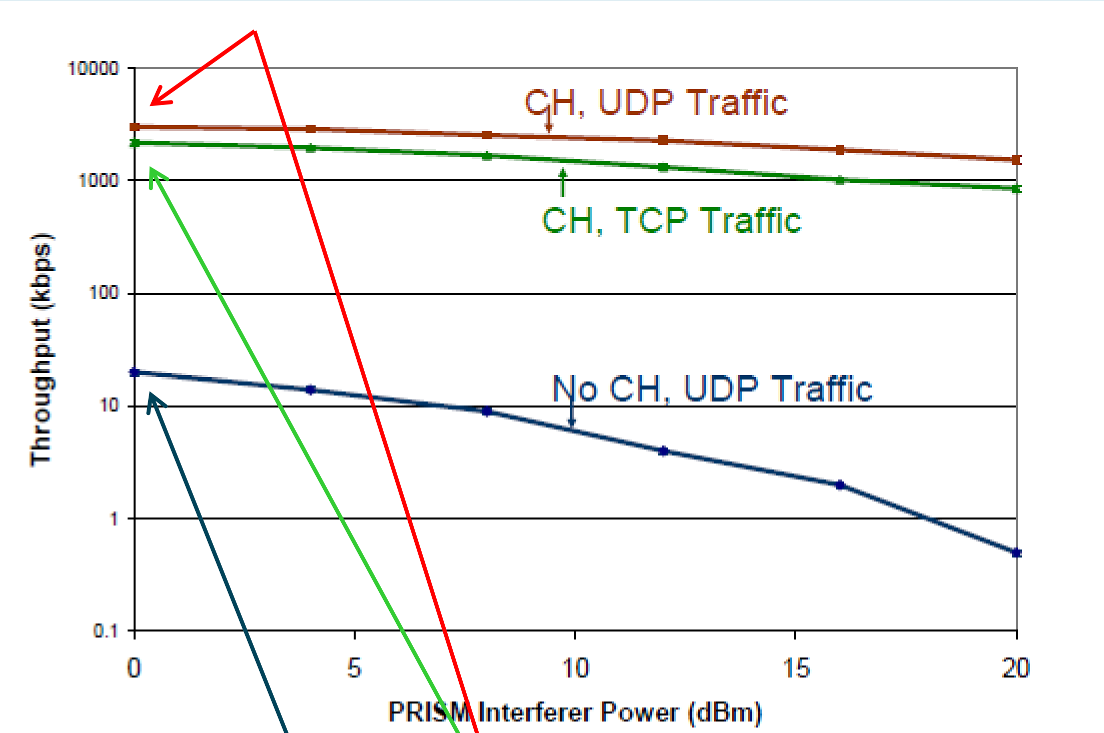
Rapid Channel Hoping + DSSS

- CH+DSSS Goals
  - Withstand malicious interferers => CH
  - Efficient
  - Minimise compatibility issues
- Balance between:
  - Transmission time: 10ms
  - Switching time: 250μs – 500μs   => 2.5% overhead
- Channel Hopping
  - Sequence - MD5 Hash Chain

Evaluation

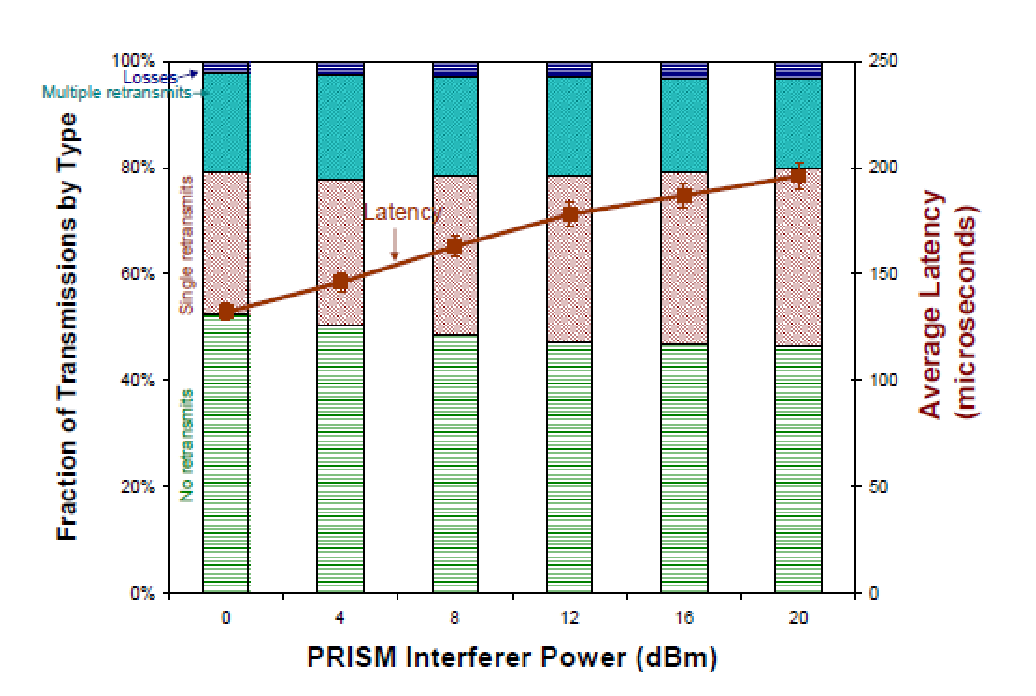
1000 kbps = 1 Mbps

- No interference - benchmark [not shown on graph]
  - No channel hopping (CH) – UDP achieves 4.4Mbps
  - With CH – UDP achieves 3.6Mbps



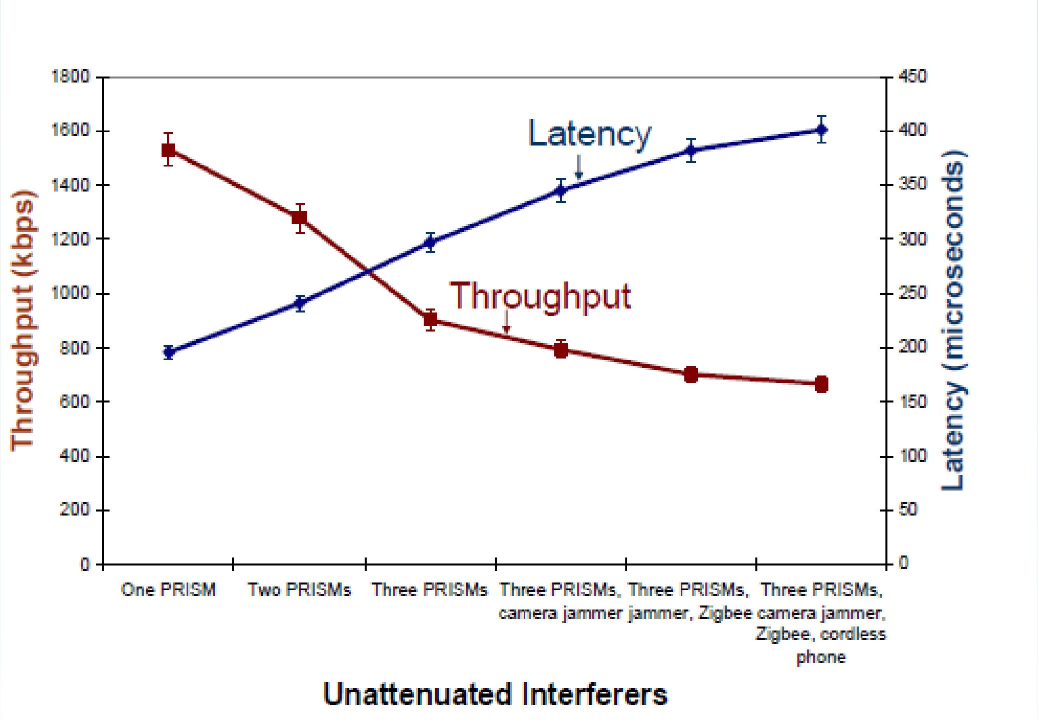
- With interference
  - No CH
    - UDP degrades from around 30 kbps (big decrease)
  - CH
    - UDP degrades from around 3,000 kbps (3 Mbps)
- TCP fails completely with no CH
- TCP gets around 70% of UDP performance with CH

Evaluation



- As interferer power increases
  - Average loss rate stays less than 4%
  - Number of packets requiring one retransmit goes up
  - Number of packets requiring more than one retransmit stays fairly constant
- Reasons
  - Increase in number of single retransmits due to interferer increasing leaking into other bands
  - Increase in latency due to deferrals and losses during times when interferer successful

Evaluation



- Throughput (UDP)
  - falls linearly with more PRISM interferers
  - more gradual decrease with other type of interferers – narrowband
- TCP throughput 20%-40% worse
- Loss rates (not shown on graph) for different types of interferers under 5% due to CH - slots quickly found

Critical Appraisal

- Attacker can use 11 interferers
- Interferer can prevent clients from connecting to AP, hence no channel hopping
- Cryptographic security of the MD5 checksum
- Channel dwell time

Related work

- RF interference and jamming (narrow-band jamming, demodulator interference)
  - We expose additional vulnerabilities in receive path
- 802.11 DoS (e.g., CCA, association, and authentication attacks)
  - We target PHY instead of MAC
- Slow channel hopping (e.g., SSCH, MAXchop, 802.11 FH)
  - Rapid channel hopping uses both direct-sequence and frequency hopping to tolerate agile adversaries

Questions?

Thank you.