Towards unlicensed cellular networks in TV white spaces

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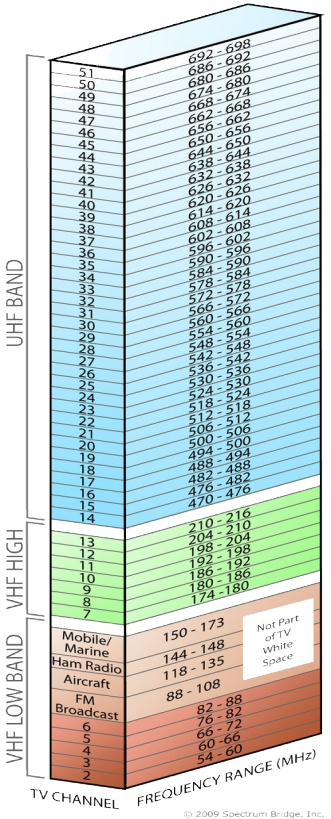
What are TV White Spaces

White Spaces are *Unoccupied* TV Channels

TV

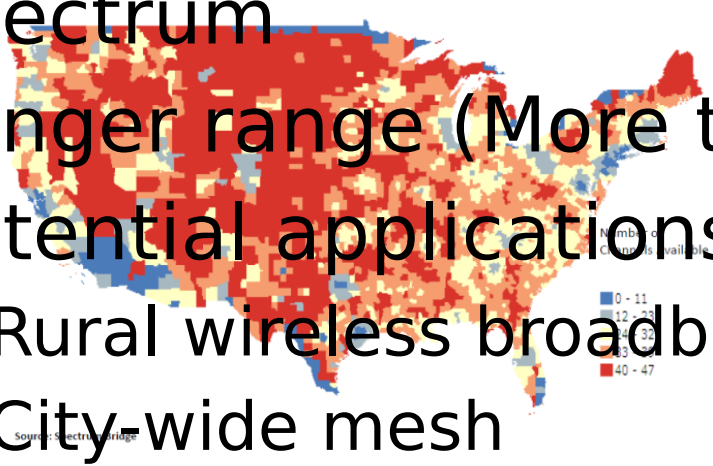
Wireless Mic

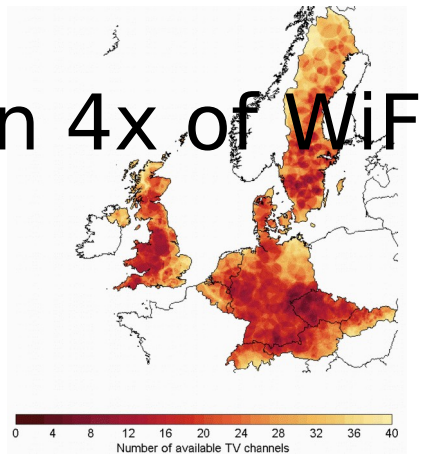


- *Available for Unlicensed use*
  - *Required to sense TV stations and Mics*

Promise of TV White Spaces

- >100 MHz of unused unlicensed spectrum
- Longer range (More than 4x of WiFi)
- Potential applications
  - Rural wireless broadband
  - City-wide mesh
  - IoT applications
  - …





Goal: Design Unlicensed TVWS network

- Long range coverage
- Allows for network co-existence
- TVWS Database access compliance

Are current wireless RATs suitable for TVWS network?

Can we use current wireless solutions in TVWS??

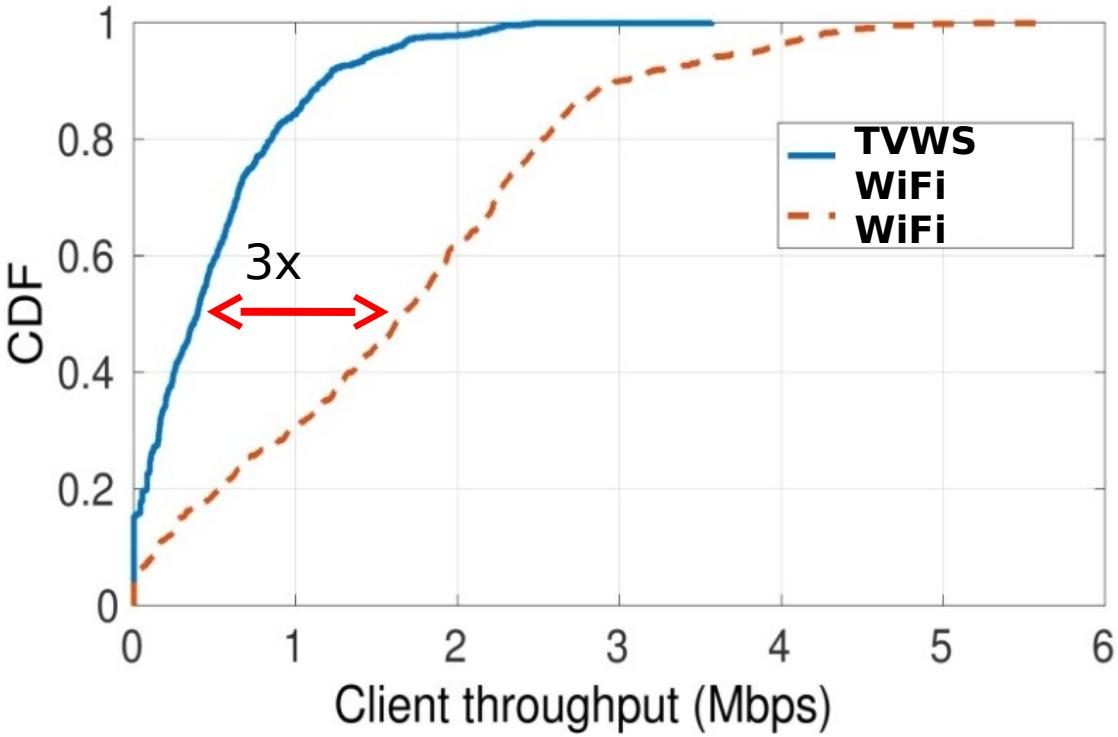
Wifi

LTE/4G

- ✓ Allows for network co-existence in Unlicensed bands
- ✗ Fundamentally difficult to modify for long range – inefficient MAC and PHY

- ✓ PHY layer designed for long range communication
- ✓ Better model for TVWS spectrum access

Wi-Fi MAC performance in TVWS



More MAC inefficiencies due to longer range

PHY layer comparison

	LTE	WiFi
Lowest Coding Rate	0.0762	0.5
Minimum SNR (dB)	- 6.7	2
Hybrid ARQ	Yes	No
PAPR	OFDMA	OFDM

LTE is a better RAT for long range TVWS network

Can we use current wireless solutions in TVWS??

Wifi – 802.11 af

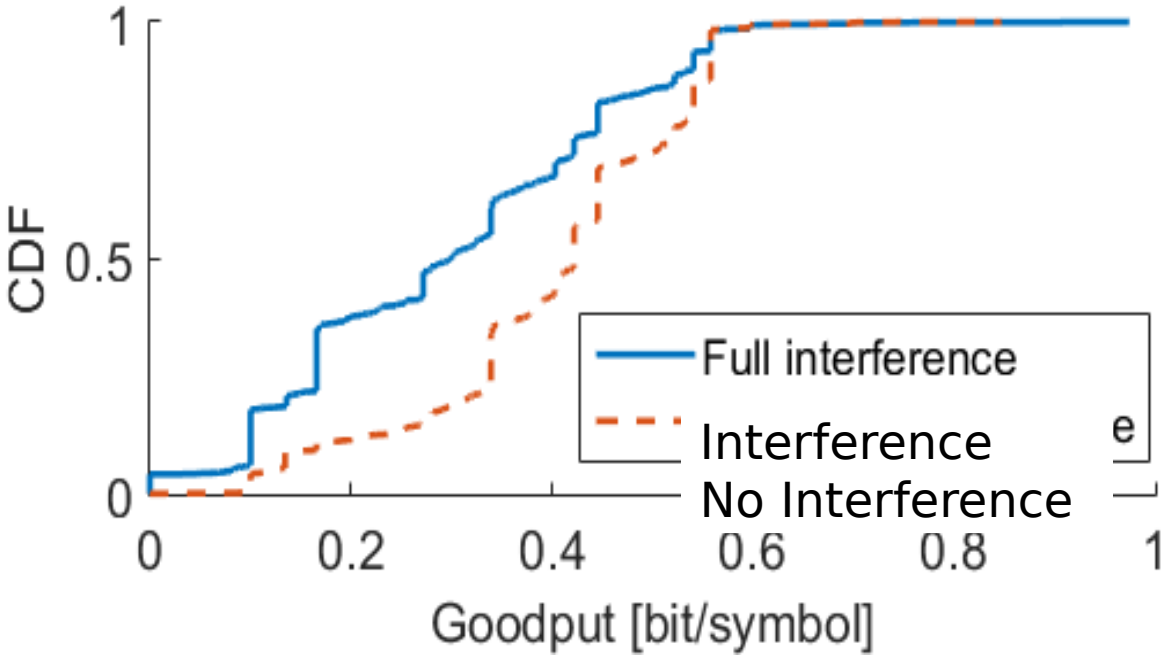
- ✓ Allows for network co-existence in Unlicensed bands
- ✗ Fundamentally difficult to modify for long range – inefficient MAC and PHY

LTE/4G

- ✓ PHY layer designed for long range communication
- ✓ Better model for TVWS spectrum access
- ✗ No mechanism for interference mitigation

LTE/4G – Unlicensed operation

- Frequent disconnections
- 2x throughput degradation when connected



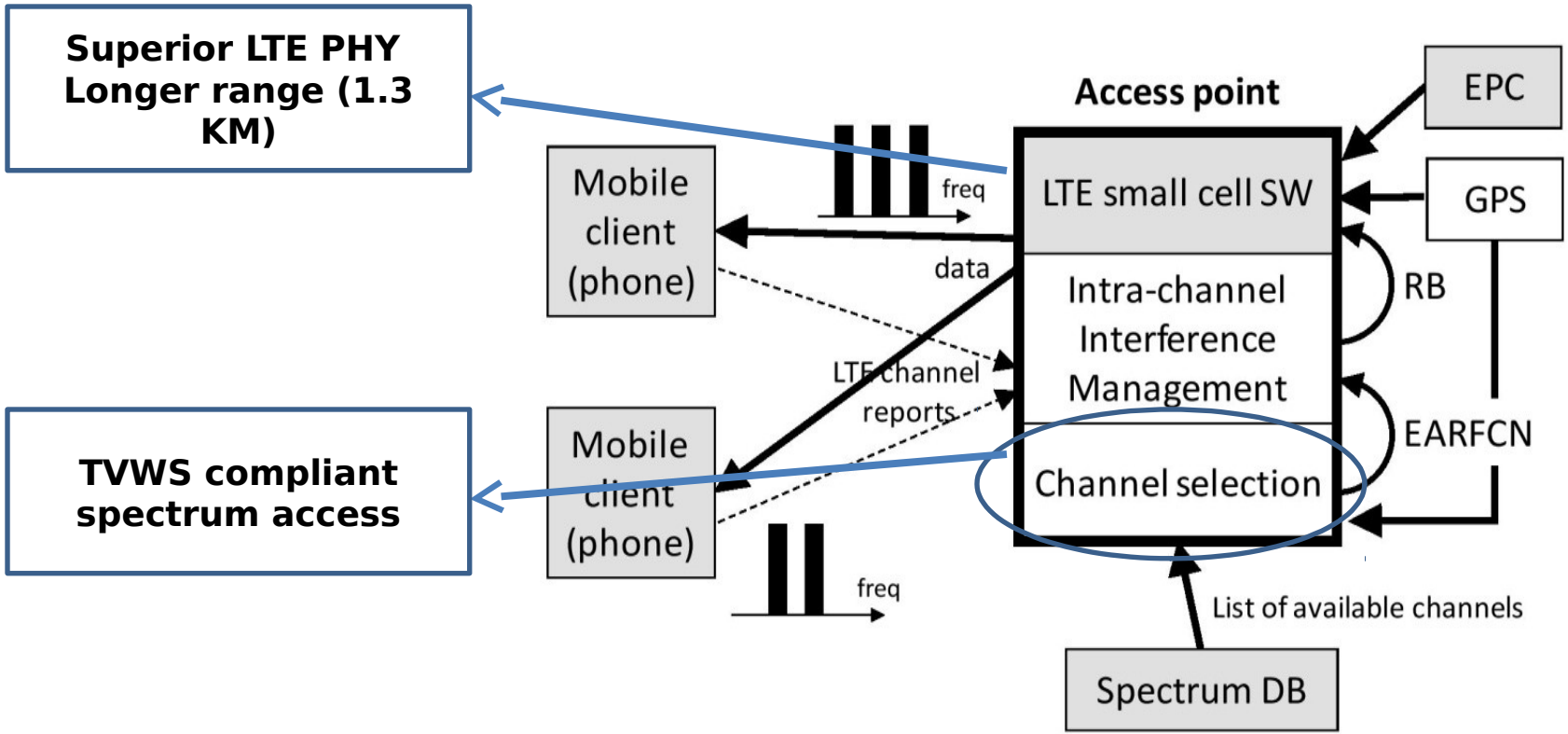
Can we use current wireless solutions in TVWS??

Wifi

LTE/4G

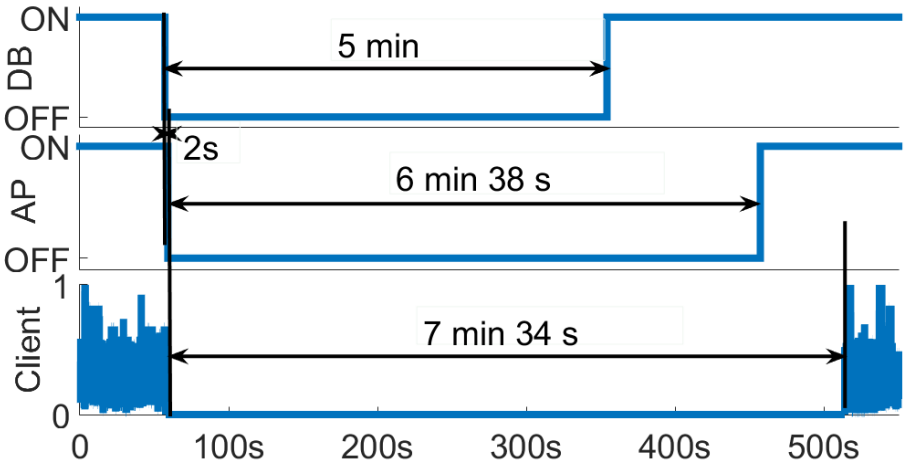
Can we design a new cellular network architecture based on LTE for TVWS?

Cell-Fi System



Channel Selection

- ETSI-compliant TVWS database client
  - PAWS protocol

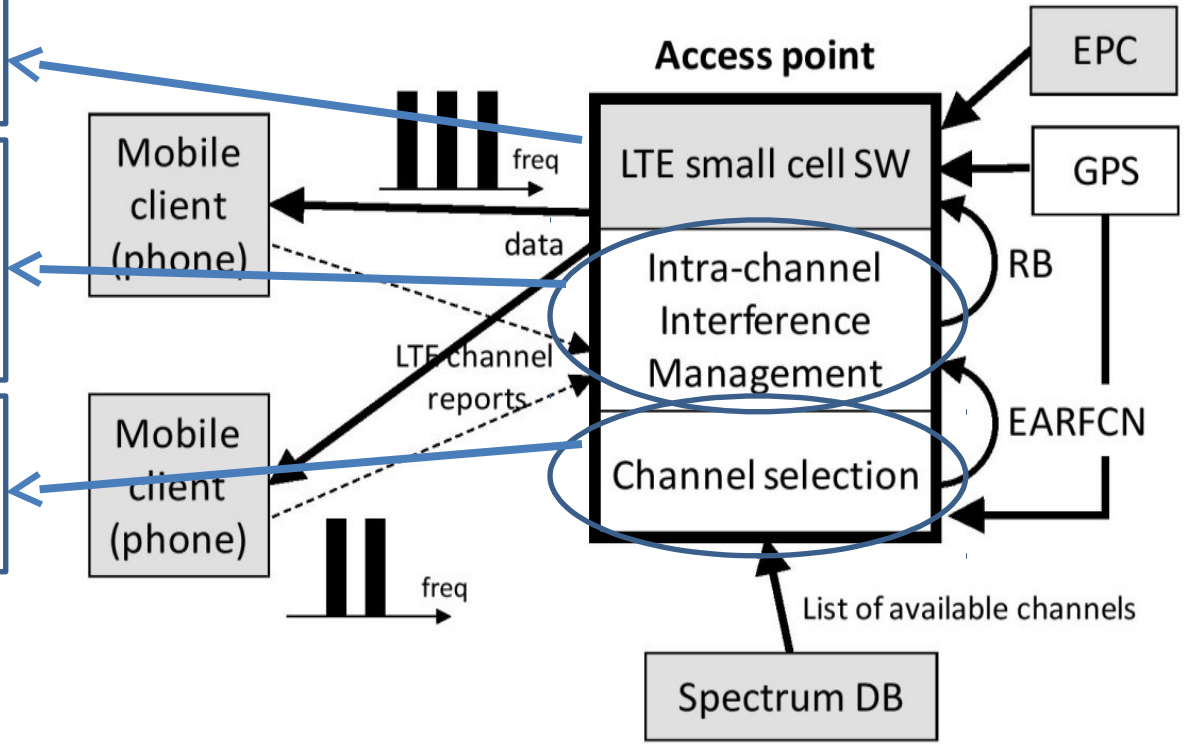


Cell-Fi System

Superior LTE PHY Longer range (1.3 KM)

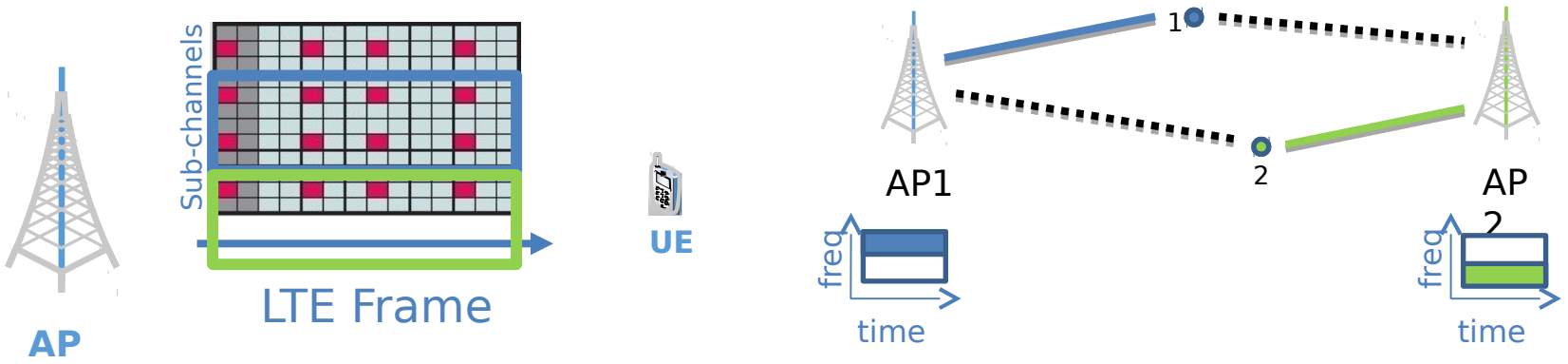
LTE compatible Interference Management among channel sharing nodes

TVWS compliant spectrum access



LTE Resource Scheduling - Idea

- LTE frame is divided into multiple resource blocks
- No overhead for RB schedule change
- Dynamically define multiple virtual channels to share channel in frequency in time



Interference Management

- Ideal - Central resource allocation
  - Multiple operators – No information sharing

Design a de-centralized LTE compatible resource allocation scheme to mitigate interference without any information sharing

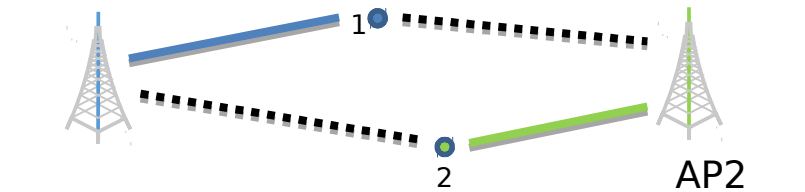
Goal of interference management

- Solve a distributed channel allocation problem
  1. **Share Calculation:** What share of resource blocks should each network?
  2. **Resource Allocation:** Which resource blocks should each access point use and how should it adjust it dynamically?

Share Calculation

- AP's fair share of spectrum

$$A's\ Share(S) = \frac{No.\ of\ A's\ UEs}{No.\ of\ UEs\ in\ A's\ vicinity} \times Number\ of\ SubChannels$$



AP1

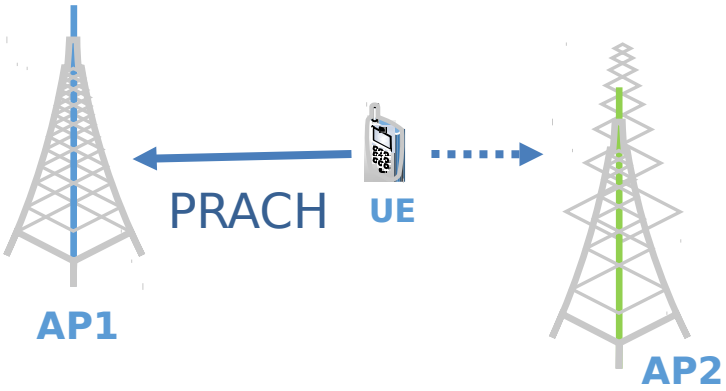
$S_1 = \frac{1}{2} \times 2 = 1$

$S_2 = \frac{1}{2} \times 2 = 1$

How to determine No. of UEs that are effected by *A's* transmission?

Sensing Mechanism

- Unique start of connection signal (PRACH)
  - Any AP in the vicinity can detect it
  - If PRACH is detected client is likely to be affected by AP's transmissions



# of Ues in A's vicinity = # of unique PRACH preambles A detected

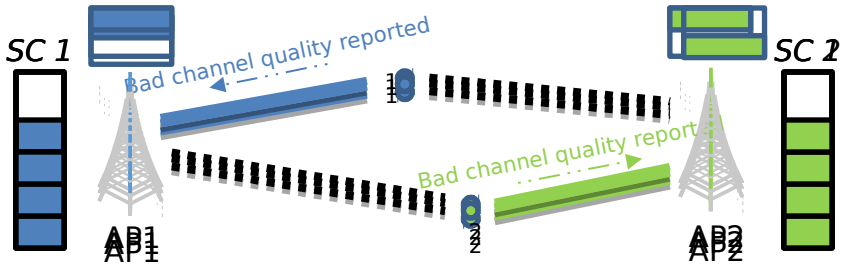
Resource Assignment

Stochastic gradient based resource assignment

Chose S random sub-channels and generate a random (exponentially distributed)
Bucket for every sub-channel

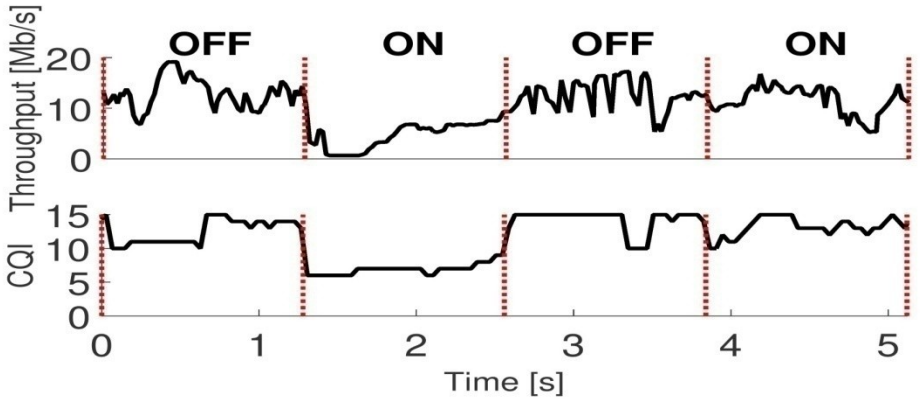
Decrement the bucket if bad channel *quality* is observed

When the bucket for a sub-channel hits zero, hop to another sub-channel



How good is CellFi in estimating interference?

- LTE has CQI reports – channel quality for each sub-channel
- Sub-channel CQI reported every 2 ms
  - Drop of 40% of the max in 10 consecutive reports indicates interference



Estimator works with < 2% false positives and 80% accuracy

Interference management

- Solve a distributed channel allocation problem
  1. **Share Calculation: :** sense active users and calculate your fair share of channels (use LTE PRACH to sense users)
  2. **Resource Allocation:** probabilistically pick some channels to achieve share and keep changing until no interference (use LTE CQI reports to sense interference)

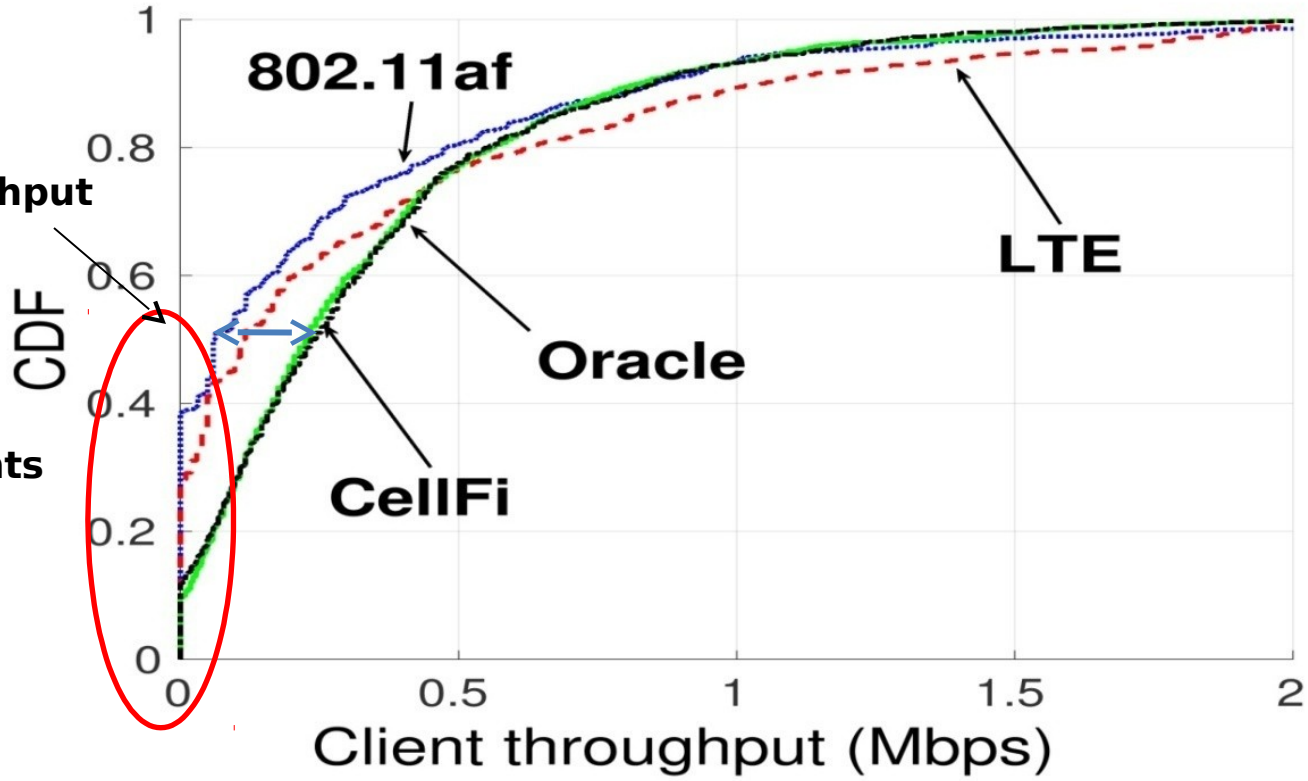
Evaluation

- Real world experiments
  - Measure range
  - Feasibility micro benchmarks
  - Simulation parameterization
    - Control channel Interference, Imperfect Interference detection using CQI, Error in detecting # of users using PRACH
- NS-3 Simulations (detailed LTE implementation)
  - Comparison with
    - 802.11 af
    - LTE
    - FERMI (centralized scheme)

Throughput

2x and 3x median throughput

Starved clients reduced by 70%-90%



Results - Summary

- Real world measurements:
  - Range up to 1.3km with 1Mbps TCP rates at > 85% of locations
- Simulation:
  - Coverage increased by 37% and 16%
  - median completion times reduced by 2.3x compared to Wi-Fi
  - Starved clients reduced by 90%-70%
  - 2x and 3x median throughput gain

Conclusion

- **CellFi**: Unlicensed TVWS Cellular
  - Long-range LTE-based network
  - Compliant with TVWS requirements
  - Decentralized interference management
  - Compatible with the existing LTE network stack