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Challenges in Designing Networks Across Large and Fragmented Spectrum

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Mobile Data Explosion Will Result in Diverse & Fragmented Spectrum

Cisco predicts wireless-data explosion

By Marguerite Reardon, CNET News.com on February 10, 2010

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Summary

Company's mobile data forecast predicts a 39-fold increase in mobile data traffic over the next four years.

If wireless operators thought they'd faced a deluge of data traffic from the iPhone, they haven't seen anything yet, according to a survey from network equipment giant Cisco Systems.

Cisco, which makes the routers and switches that shuttle Internet protocol (IP) traffic around the Internet, has been using its Visual Networking Index to forecast Internet usage. On Tuesday, the company announced results from its Global Mobile Data Forecast for 2009 to 2014.

By 2014, researchers predict, mobile data traffic throughout the world will reach 3.6 exabytes per month, or an annual run rate of 40 exabytes. This is a 39-fold increase from 2009 to 2014, or a compound annual growth rate of 108 percent.

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AT&T Faces 5,000 Percent Surge in Traffic

The nation's No. 2 carrier moves to address huge gains in data traffic, mirroring an industry-wide trend in wireless.

CELL PHONES / VOIP February 24, 2010 10:10 AM

FCC Aims to Free up 500MHz of Spectrum for Broadband

By Grant Gross, IDG News

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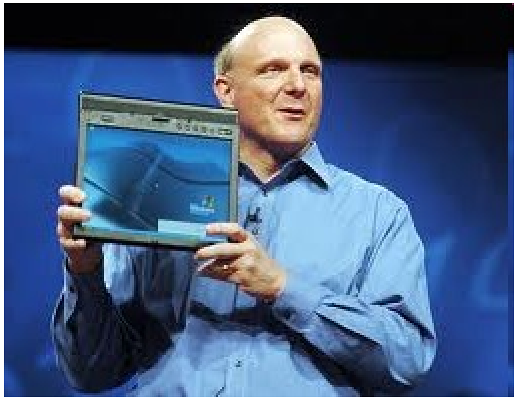
The U.S. Federal Communications Commission's upcoming national broadband plan will ask the nation's television broadcasters to voluntarily give up unused wireless spectrum, in exchange for a share of the profits when that spectrum is sold, the agency's chairman said Wednesday.



Examples:

- AT&T Spectrum in New York – 700MHz band, 800MHz, 1.7GHz and 2.1GHz
- Unlicensed Spectrum in US – DTV Whitespaces (500-700MHz), 2.4GHz and 5.1GHz

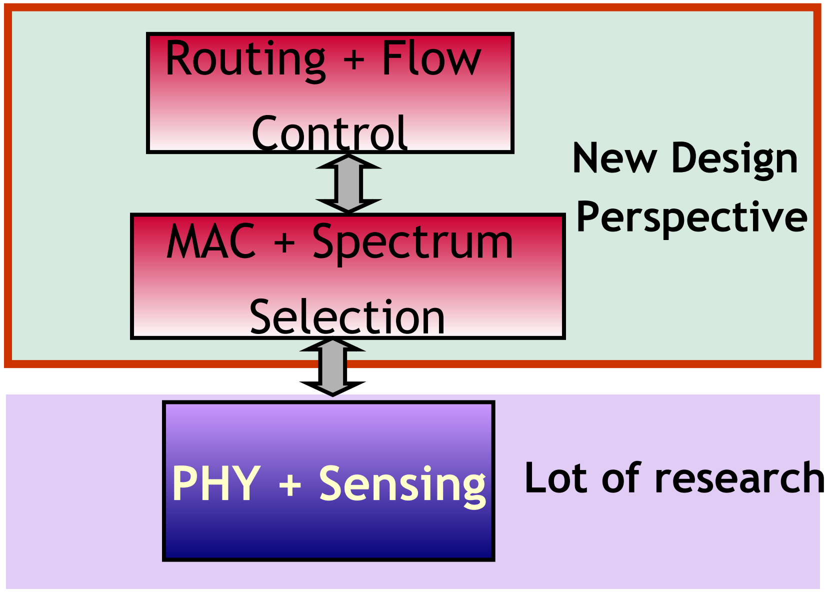
Research Goal

Design a network stack that operates across

1) Fragmented and spatially varying spectrum with diverse propagation

2) Devices with different tunable center freq. and b/w range

- Design of WLAN solutions
- Design of Mesh Solutions
- Implement and test all proposed solutions



So, Why is this Different?

1. Frequency dependent propagation
   - Path loss inversely proportional to f_c^2
2. Out of Band Emission
   - Proportional to PSD
3. Diverse and Fragmented Spectrum

Implications:

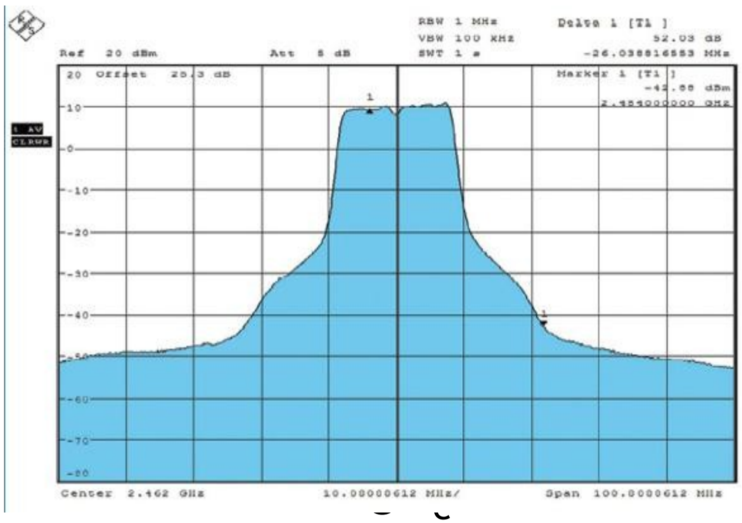
No fixed interference graph (from 1 and 3)

- Implications on architecture and algorithms

Multi-radio solutions may be essential (from 3)

Adjacent channel interference depends on frequency (1 and 2)

- Spectral mask characteristics become important



System designer has to account for freq. dependent Co-channel Int., Adjacent-channel Int, Range

Context of FCC TV Whitespaces Mandate

Usable Free Spectrum: Unused TV channels between 500-698 MHz for unlicensed portable access

- Varies from city to city

Limit Interference to DTV receiver:

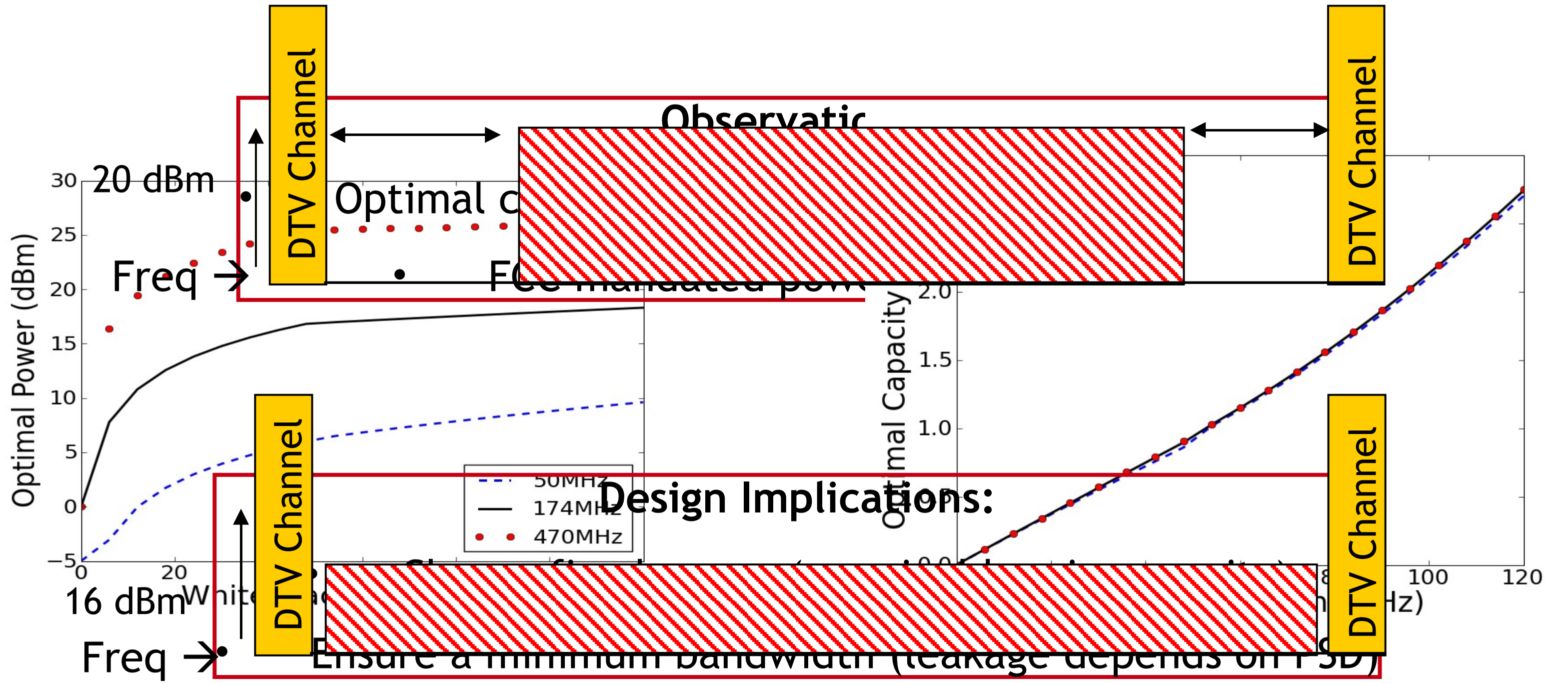
- Tx power: 16 dBm in adjacent band, 20 dBm elsewhere

- Out of Band Emission: Has to fall by 55 dB in the adjacent 6 MHz band
  - Spectrum Mask

FCC Mandate on Power is not overly-restrictive

Fundamental Question: What's the optimal transmit power anyway?

- High power-> lower bandwidth
  - Guard band required to prevent interference to the TV channel
- Low power -> reduced system capacity



Co-channel Interference

Standard Approach:

- Measurement based interference map

But, if the spectrum is diverse …

- Two devices may interfere only in certain frequency bands

<u>Design Principle:</u>

Generate different interference maps for different bands

- Ideally a single control channel

Can use measurements over a single control channel

- $P_r(f_1)$ ¤ $P_r(f_2)$ $20 \log(f_2/f_1)$

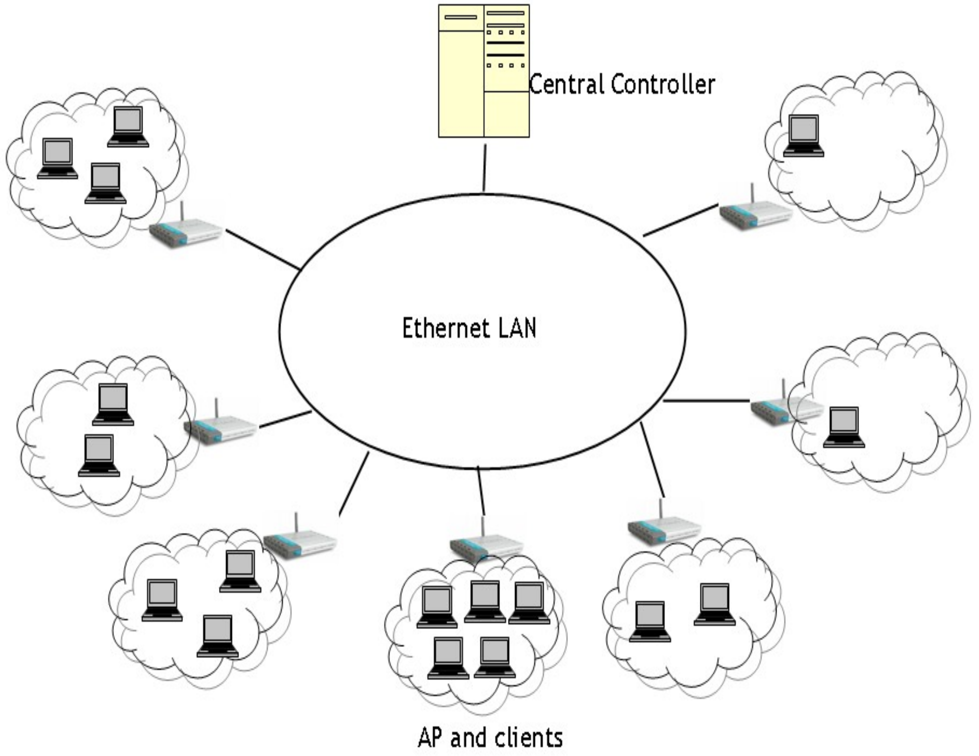
Interference maps in a higher freq. band can be deduced from interference map in a lower band (and knowledge of ambient interference)

Demand Based Spectrum Allocation in Enterprise WLANs

Goal

Design enterprise wireless LAN that operates in DTV-WS and ISM bands

- Centralized architecture
- Adherence to FCC mandate
- Assume good spectrum sensing
  - Knowledge of available white-spaces
- LAN AP's and clients can
  - Tune frequency
  - Adapt bandwidth

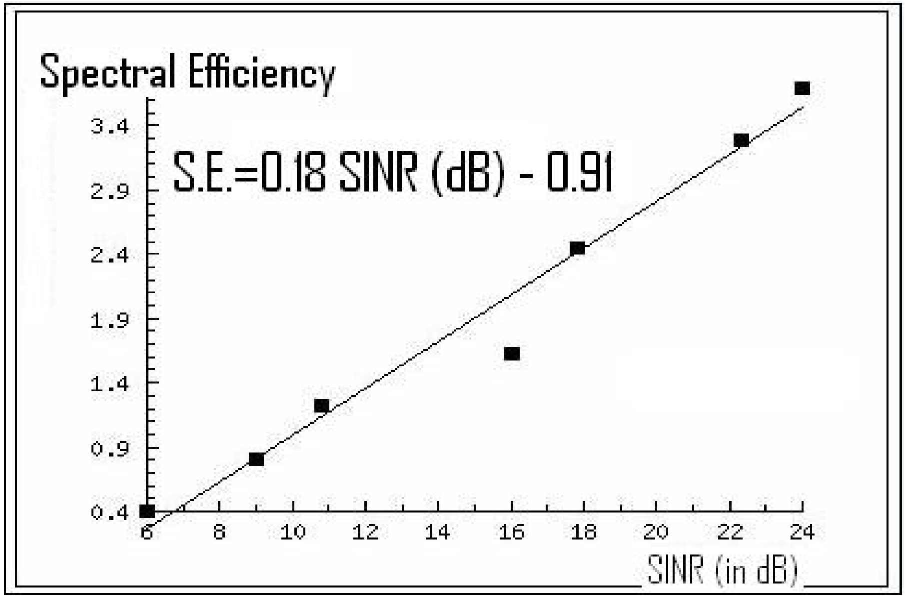


Towards Demand Based Allocation: A Metric for Spectral Efficiency

Motivation: Usefulness of spectrum depends on

- Frequency band
- Client locations with respect to AP

Question: Can we capture these through a unified metric?

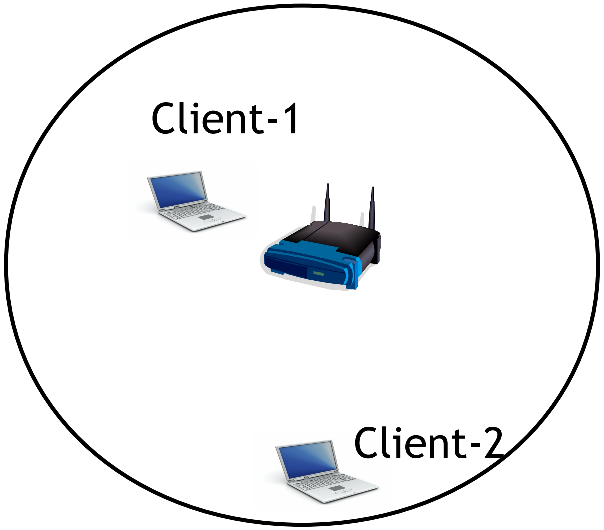


Important Observation:

For most technologies, data rate/Hz depends on SNR as

Data Rate / Hz = a × (SNR in dB) - b

Aggregate Spectral Efficiency (ASE)



ASE = Data rate averaged over all clients / Hz

= a × (SNR averaged over all clients in dB) – b

Depends on freq band

$SNR(f_1)$ È $SNR(f_2)$ $20 \log(f_2 / f_1)$

ASE in f_1 can be generated for ASE in f_2

Design Implication:

Two step ASE generation:

1. Each AP generates ASE in some band.
2. Central controller can deduce the AP in all bands.

Demand Based Multi Radio Spectrum Allocation

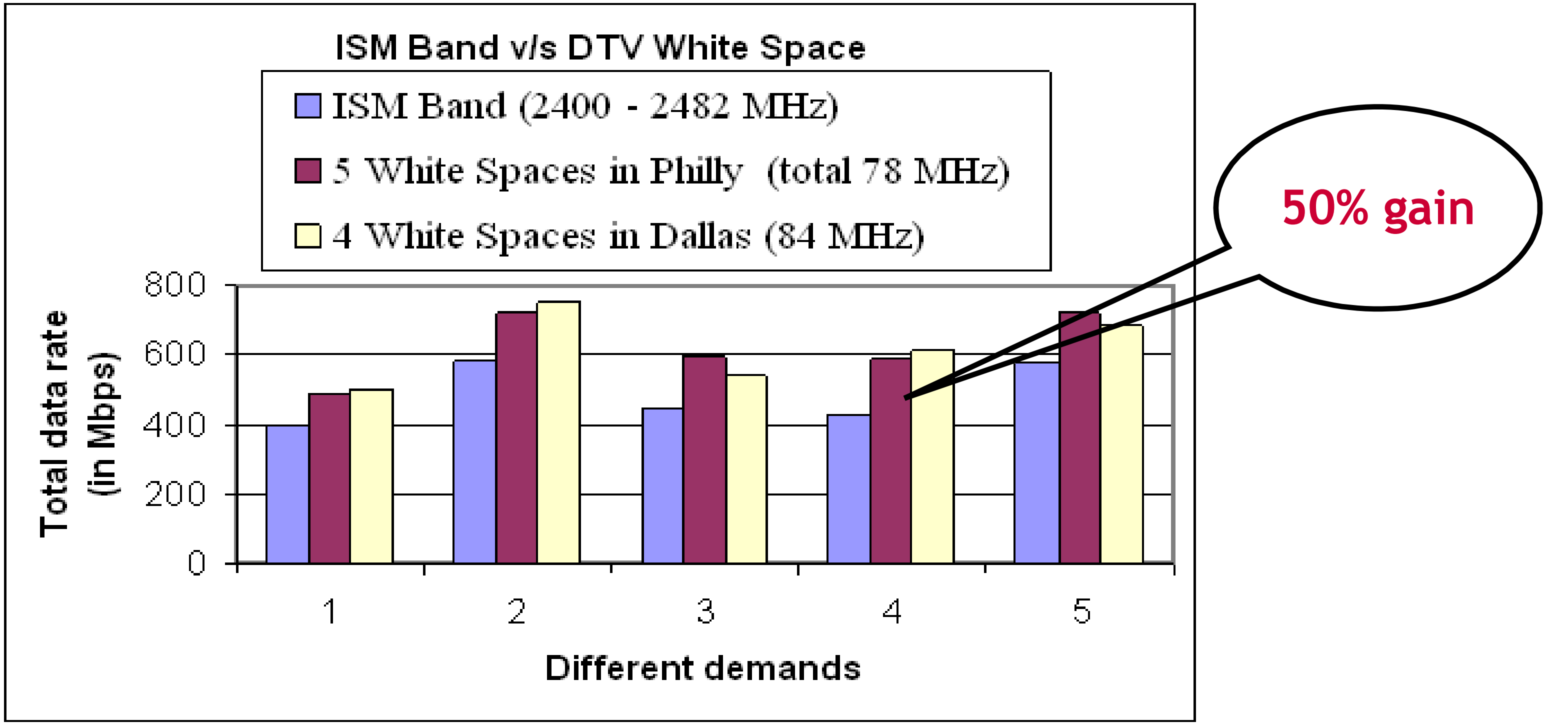
Given: Data rate required by each AP, their spectral efficiencies, and interference maps in different white-spaces

Objective: Proportionally fair spectrum allocation

Constraints:

- Operating spectrum width of each radio of an AP
- Co-channel reuse constraints
  - Depends on operating frequency
- Adjacent channel reuse constraint
  - Depends on spectral mask

DTV Whitespaces are “Wi-Fi on Steroids”



1. Substantial gains in data rate/Hz from Whitespace spectrum
2. Actual gains higher due to larger spectrum

Making it Work in Practice

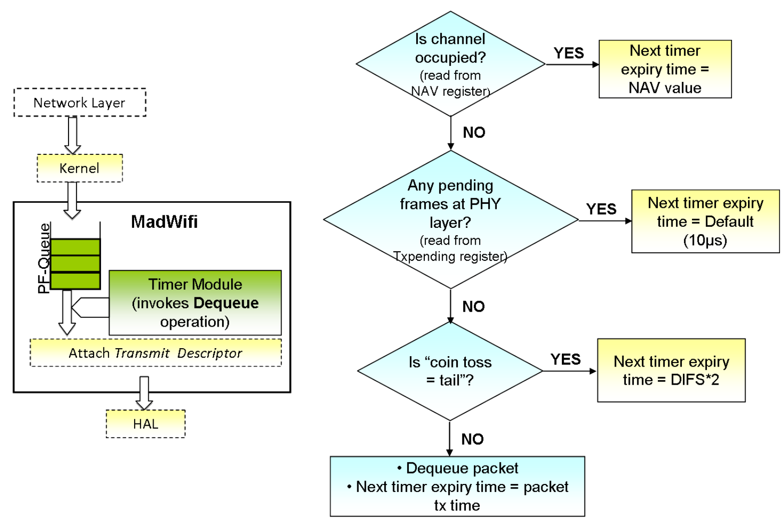
Designed frequency translator with < 2 microsecond switching delay

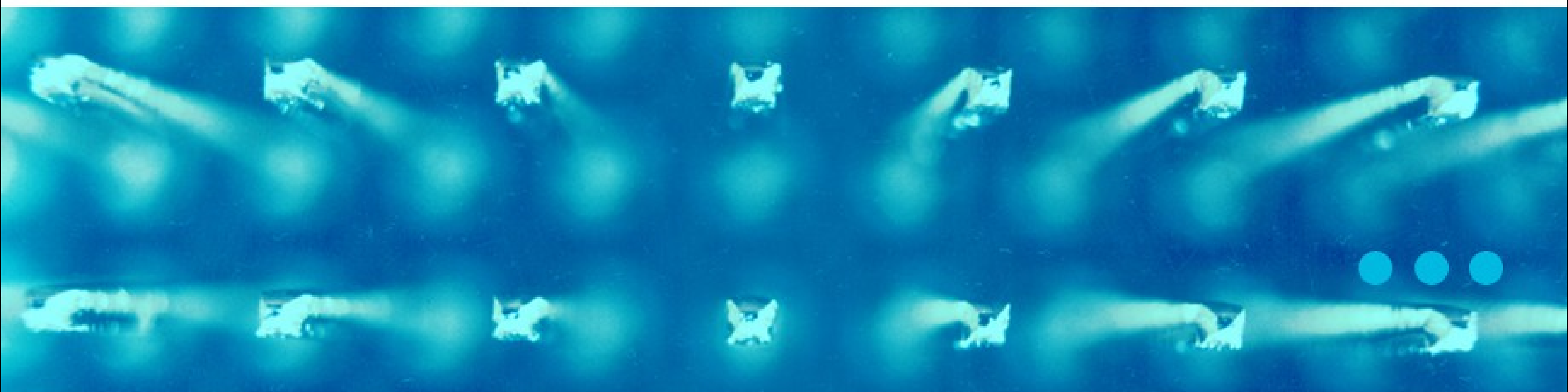
Dynamic range of 100- 900 MHz

Integrates with a WiFi card on Sokeris box

Extensive indoor trials done

Waiting for experimental license for outdoor trials





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