Supporting Demanding Wireless Applications with Frequency-agile Radios

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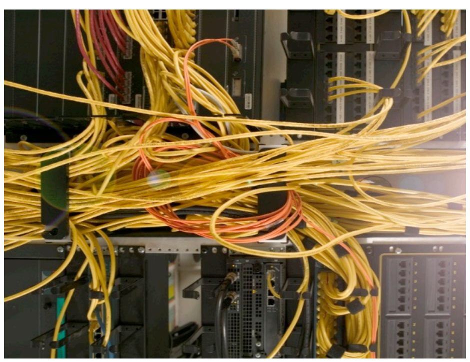
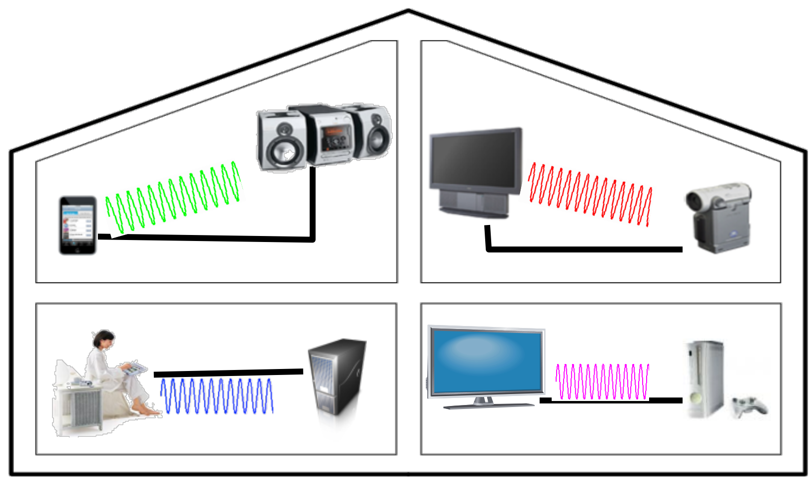
Multimedia Streaming in Home/Office

- Real-time multimedia flows in home/office networks
  - High bandwidth
  - QoS requirements

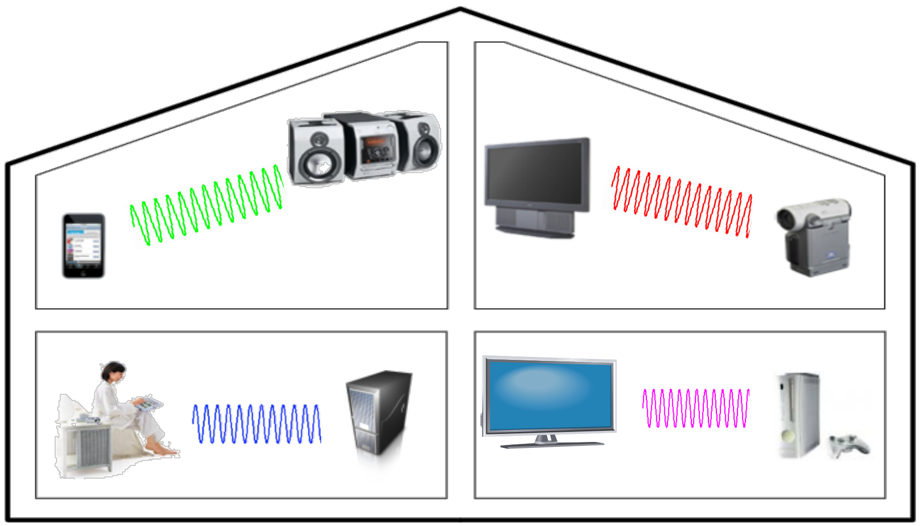
3D TV
DOLBY TRUE HD
dts-HD High Definition Audio
Blu-ray Disc

- No messy wires





Supporting Wireless Media Sessions

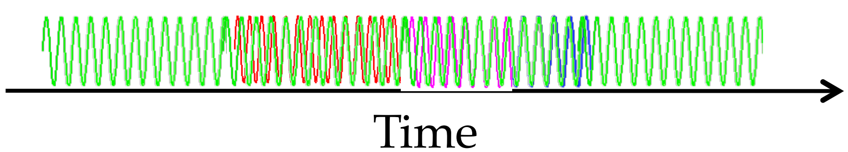


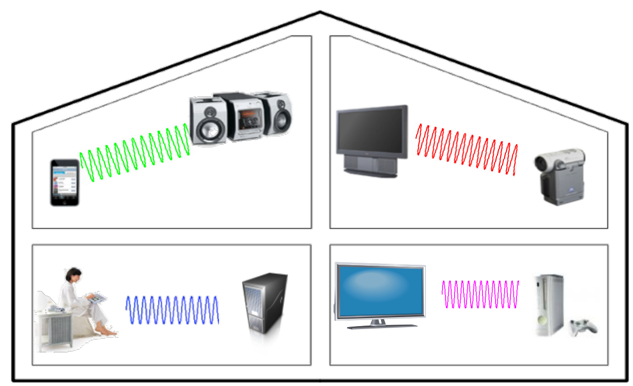
- Desired properties
  - **Continuous access** to radio spectrum, high-bandwidth transmissions
  - Support multiple **concurrent** flows
  - **Adapt** to time-varying traffic demands

Can We Use WiFi?

- The 2.4G/5G ISM band is too crowded → **no dedicated access**

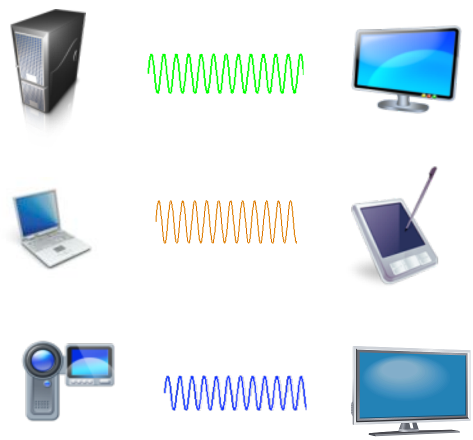
- Per-packet CSMA contention → **frequent & unpredictable disruptions**





Per-session Frequency Domain Sharing

- Simultaneous media sessions work in **parallel** on **isolated** frequencies



No interference

Continuous spectrum access in time

On-demand frequency usage

Is This Feasible?

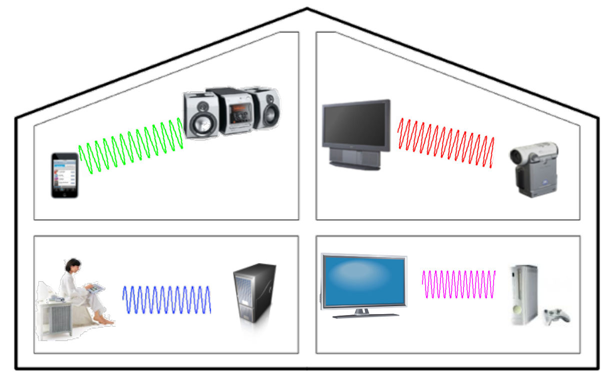
- **Opportunity for new dedicated frequency band**
  - FCC has auctioned & released new spectrum
  - Start from a **clean** spectrum band

- **Opportunity to deploy new access mechanism**
  - The new National Broadband Plan encourages new dynamic spectrum access mechanisms

Our Design: Jello, per-session frequency domain sharing

Jello: Decentralized Home Media System

- **Decentralized** system → wireless home
  - Flexible
    - Support different types of device
  - Self-configuring, self repairing
  - Low cost
    - No extra control radio
    - No central controller



- Utilizing **frequency-agile** radios
  - Flexible, reprogrammable

GNU Radio

SORA

AirBlue

WARP RICE UNIVERSITY WIRELESS OPEN-ACCESS RESEARCH PLATFORM

Jello's Key Components

Spectrum Sensing

Identify available spectrum to avoid interfering with others

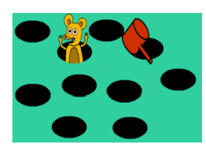
Where is the usable spectrum?

Coordination

Sender receiver coordinate to calibrate sensing results and synchronize spectrum usage

Spectrum Selection

Select spectrum to match traffic demands and utilize spectrum efficiently

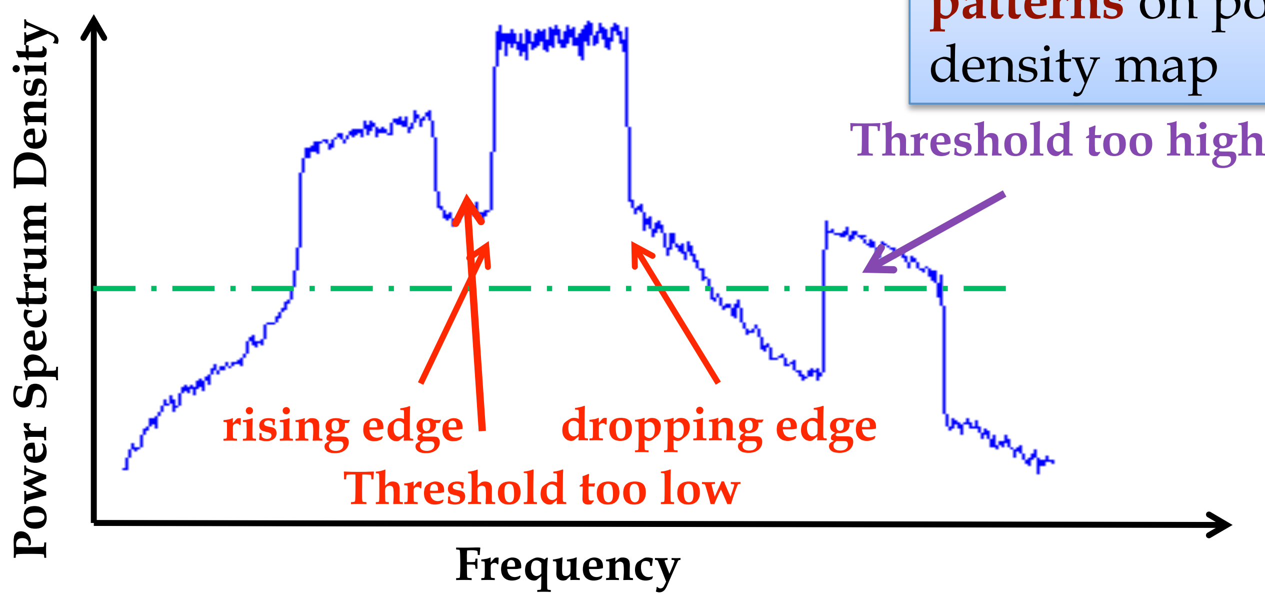


Which frequency band should I use?

How to Identify Free Spectrum?

- Conventional sensing: energy detection
  - **Simple, but unreliable**

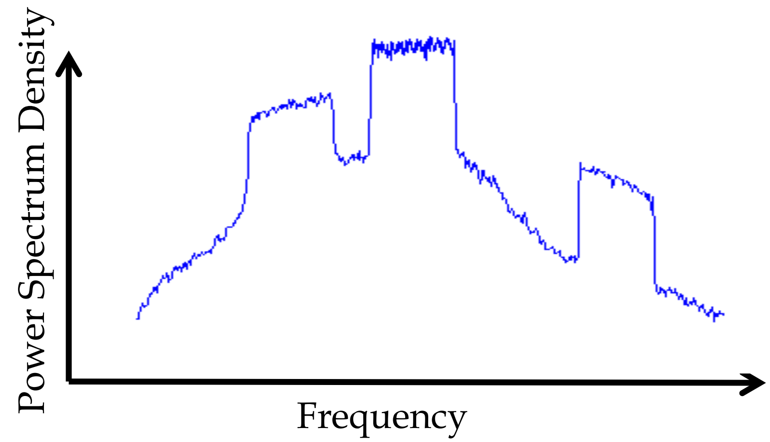
A unique feature: **clear edge patterns** on power spectrum density map



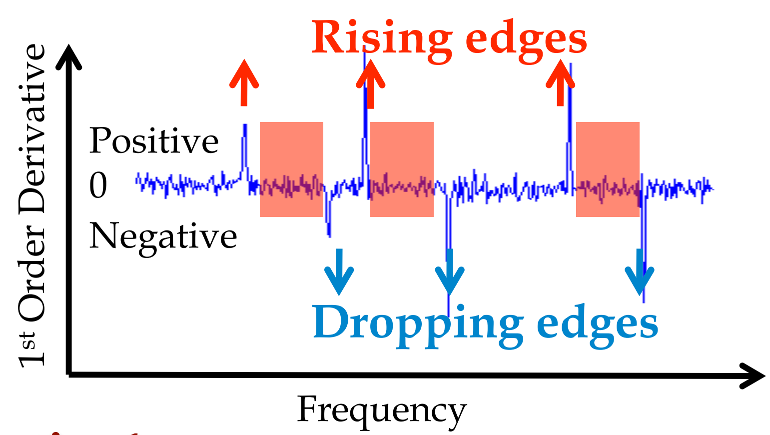
Jello devices identify and use such edge patterns to get better sensing!

Sensing via Edge Detection

- **Step 1: Preprocessing**
  - Smoothing by averaging over multiple observations

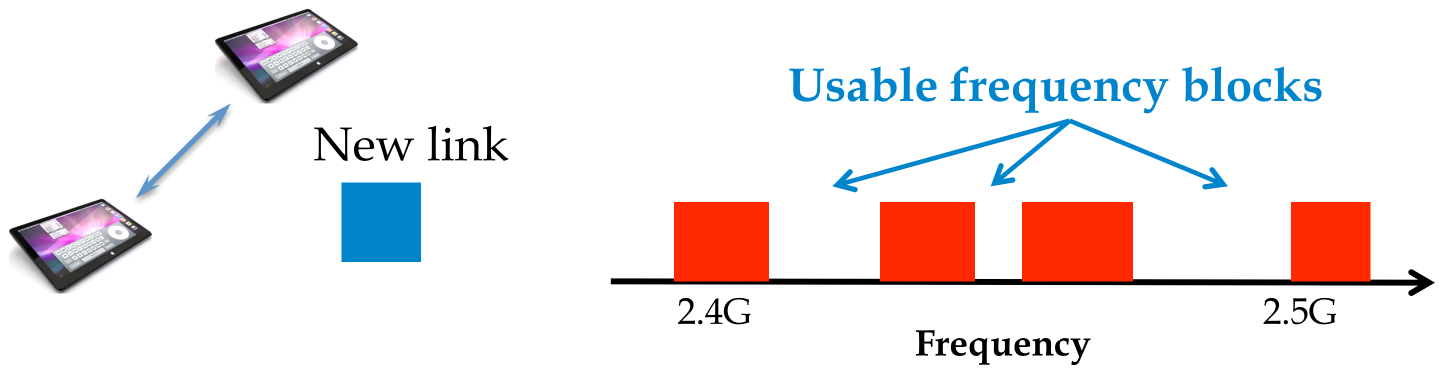


- **Step 2: Detecting edges**
  - Calculate 1st order derivative of the power spectrum map
  - Identify rising/dropping edges



Much more robust than energy detection!

Choosing Frequency Blocks

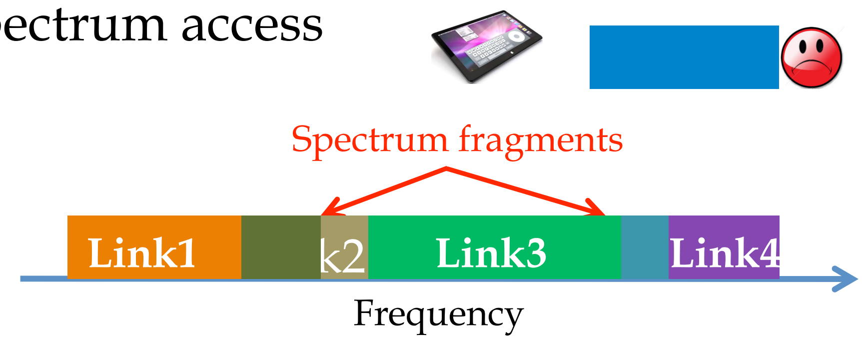


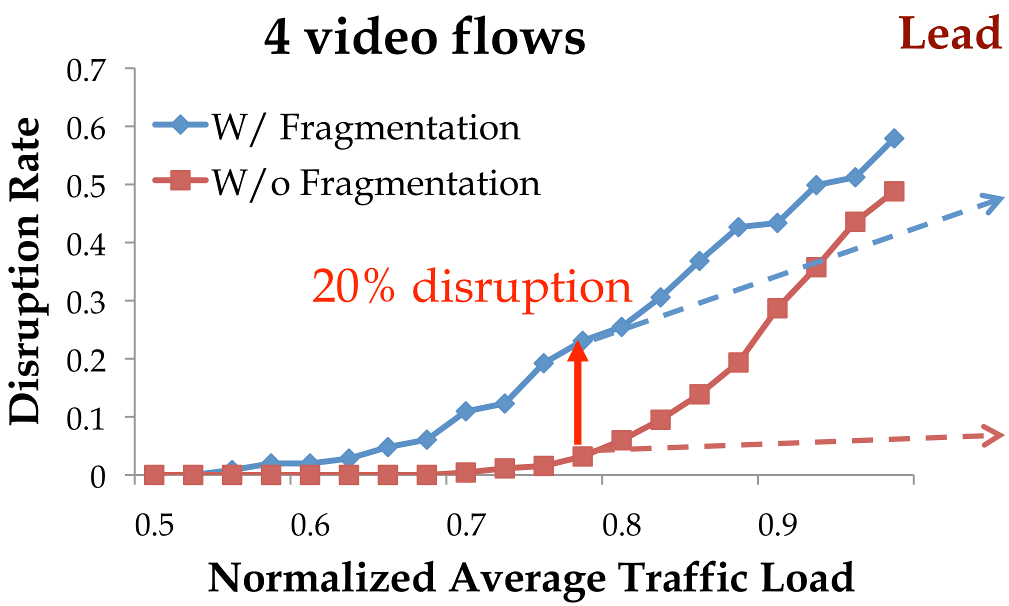
- Online resource allocation problem
  - First-fit, best-fit, worst-fit
- Jello uses **Best-Fit**
  - Selects the smallest available frequency block that can accept the current spectrum request

Our experiments reveal another fundamental challenge …

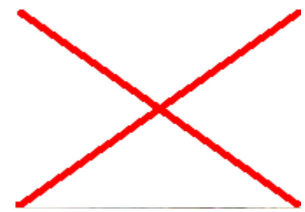
Spectrum Fragmentation

- Like disks and memory, dynamic spectrum access creates **spectrum fragmentation**
  - **Link comes and leaves**
  - **Link changes spectrum usage**

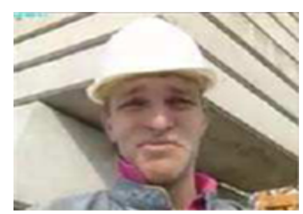




Lead to significant media disruptions!



W/ Fragmentation

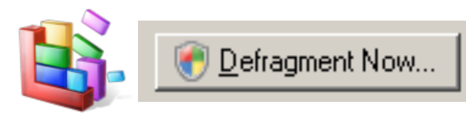


W/o Fragmentation

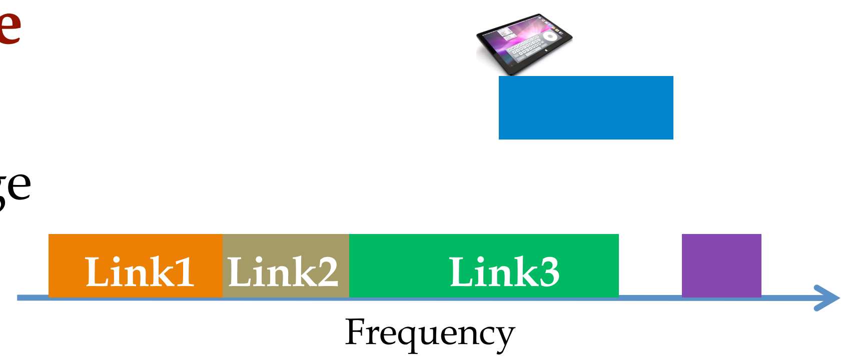
Solution 1: Defragmentation

- Rearrange global spectrum usage

  No, cannot stop all transmissions



- Our solution: **individual online defragmentation**
  - Voluntarily change spectrum usage to reduce fragmentation



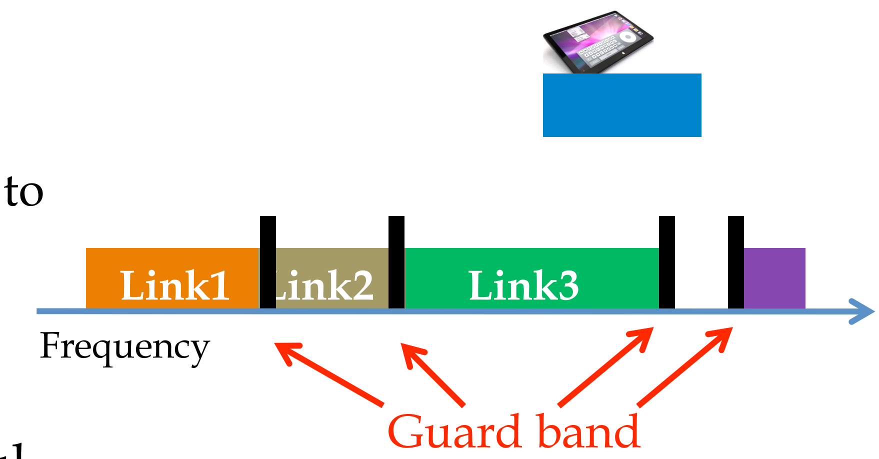
Stays transparent to other links

Self-disruption →Defrag occurs infrequently

Cannot eliminate fragmentation entirely, low levels of fragmentation may still exist

Solution 2: Non-Contiguous Spectrum Access

- Frequency-agile radios→ redesign PHY to support non-contiguous spectrum access
  - Combine multiple spectrum slices to form a single transmission
  - Decentralized OFDMA



- Fragmentation is no longer harmful
- Additional costs
  - Increased frequency overhead

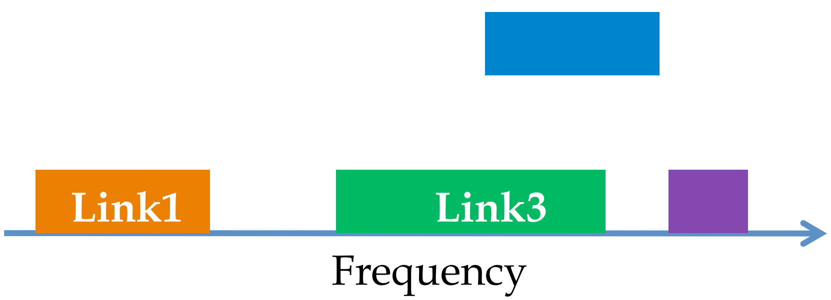
Non-contiguous frequency access reduces the impact of fragmentation, but at additional costs

A Unified Solution in Jello

The two techniques are complementary to each other

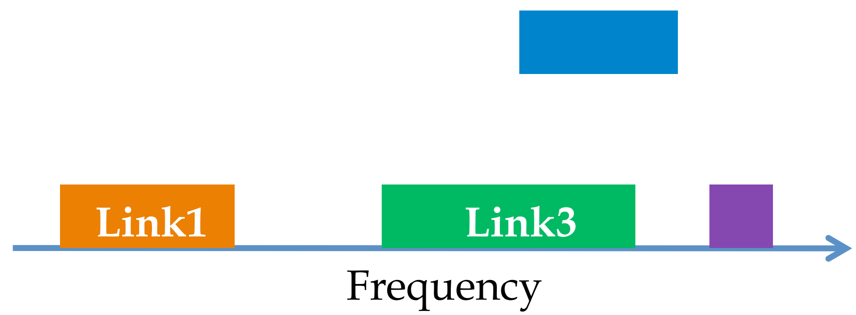
Online defragmentation

- Remove most fragments
- Cannot completely remove fragmentation



Non-contiguous access

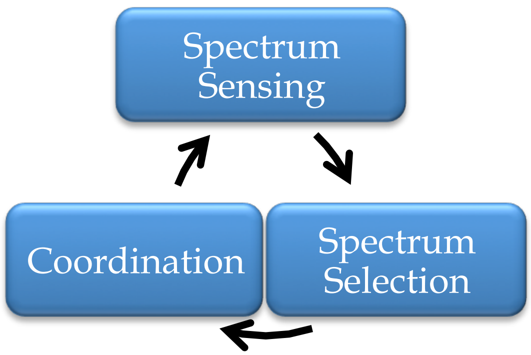
- Effective for low fragmentation
- Increased frequency overhead and hardware complexity



Proof of Concept Implementation

- GNU Radio
  - Software Define Radio
  - USRP frontend at 2.4G
  - Widely available, inexpensive, flexible

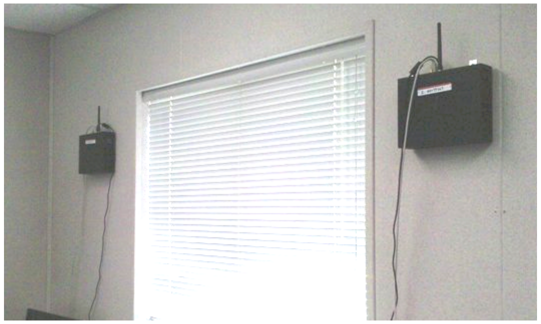
- Hardware limitations
  - Limited bandwidth: 500kHz OFDMA
  - Large and unpredictable proc. delay

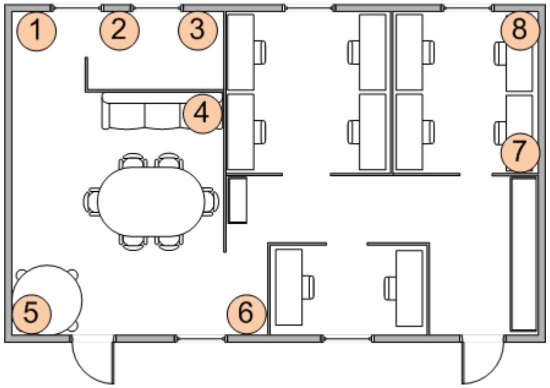


See the paper for detailed implementation

Testbed Evaluation

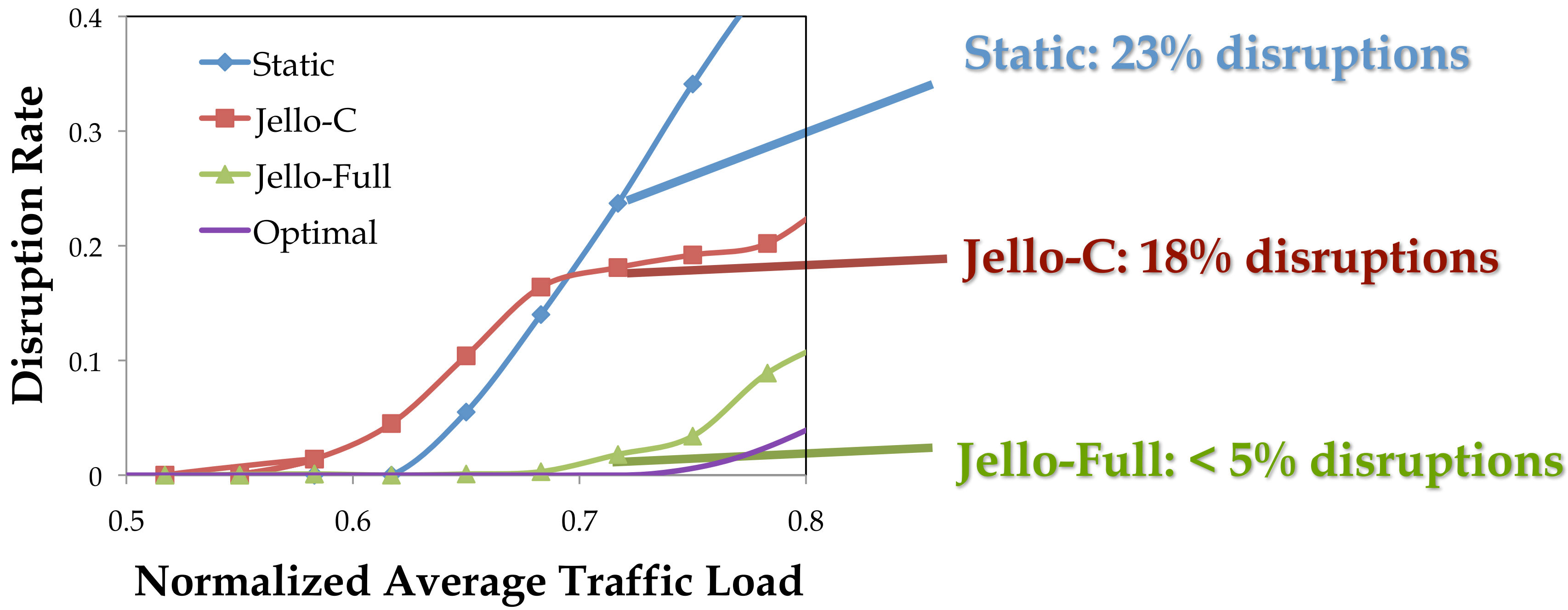
- 8-node GNU Radio testbed
  - 4 concurrent flows
  - 12m x 7m room with various furniture and walls
- Traffic load
  - Video and synthetic traces
- Evaluated 4 systems
  - **Static**: Partition spectrum equally, WiFi-like
  - **Jello-C**: Jello with contiguous frequency access
  - **Jello-Full**: Full version of Jello
  - **Optimal**: Oracle solution w/o fragmentation and overhead





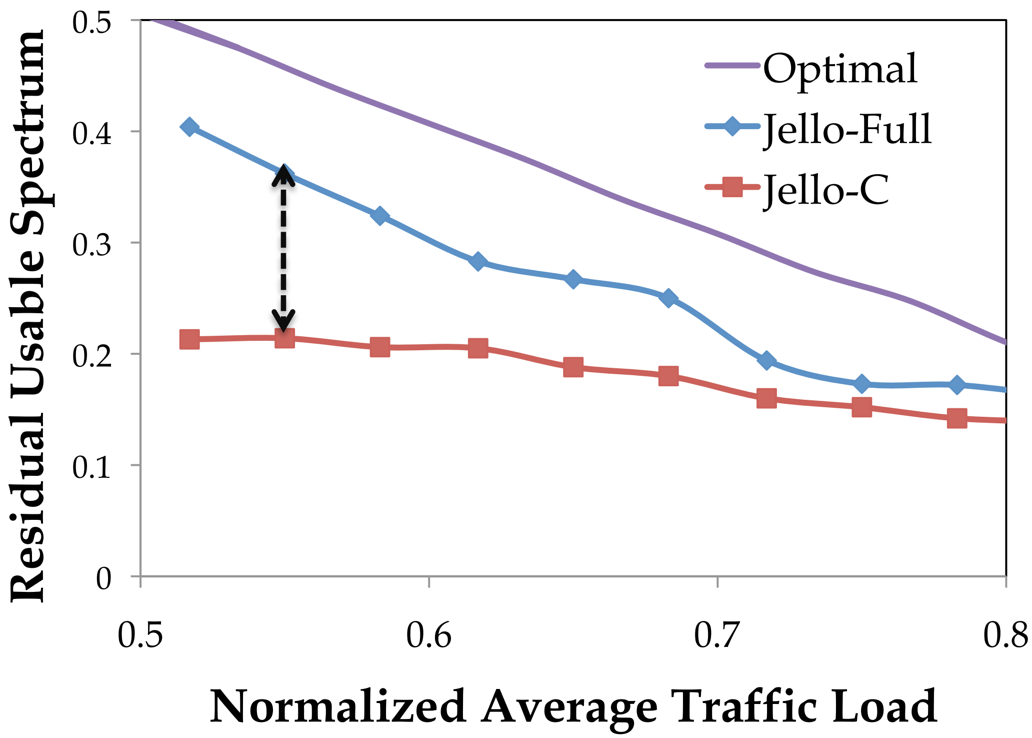
Overall Media Quality

Video Disruption Rate: percentage of time video is disrupted



Spectrum Usage Efficiency

Residual Usable Spectrum: the amount of spectrum a new link can use



45% more spectrum for a new session

Conclusions

- Jello: the 1st system supporting demanding wireless media sessions

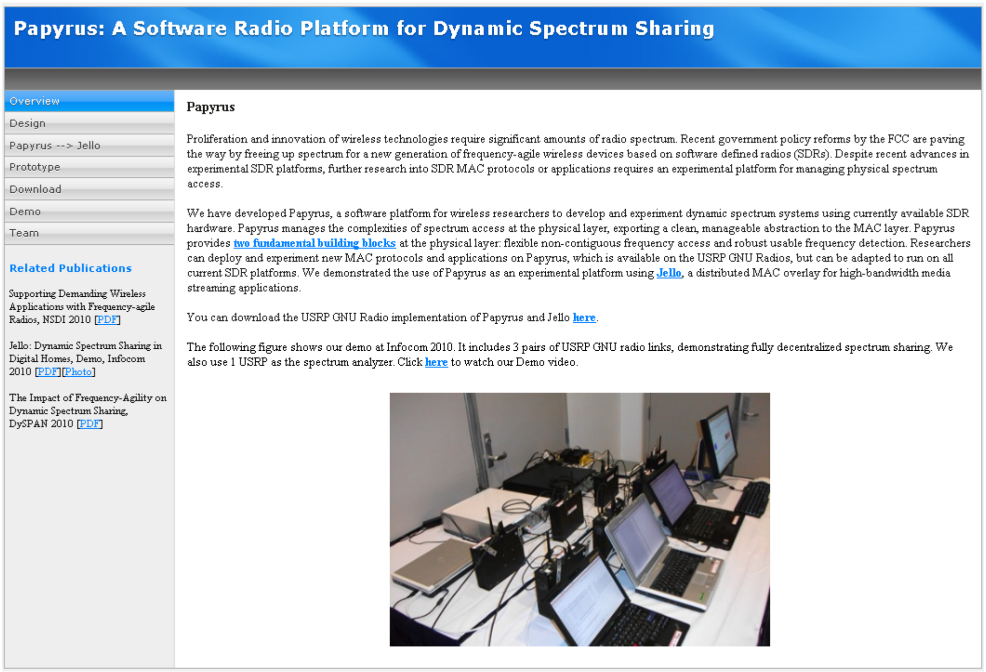
  - **Per-session frequency domain sharing**
  - Detect available spectrum: **Edge-detection spectrum sensing**
  - Reduce spectrum fragmentation: **Non-contiguous spectrum access** + **online defragmentation**
- We deploy Jello on 8-node GNU Radio testbed
  - Support 4 concurrent flows
  - Provide high utilization and adapt to dynamic demands

Full Jello Implementation available @

- http://www.cs.ucsb.edu/~htzheng/papyrus/

Jello Demo available @

- http://www.cs.ucsb.edu/~htzheng/papyrus/detail/demo.html
- http://www.youtube.com/watch?v=-BcycTXh4uc



Questions?