Fixed Wireless Access:
Recent Advances, Broadening Applications

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Three distinct “wireless” use cases

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- The ancient term “wireless” is popularly applied to two-way consumer data access technologies using the radio spectrum
- Two are most commonly known
  - Mobile: Cellular/PCS/AWS provide voice, SMS, and Internet access to hand-held mobile devices
    - Usually licensed; exclusive bands; carrier model
    - Standards bodies include GSMA, 3GPP
  - Wi-Fi: Wireless LAN provides high-speed packet transmission among devices in close proximity
    - Unlicensed, largely using “junque” bands shared with ISM
    - Standardized by IEEE 802.11 subcommittee
    - Some public outdoor Wi-Fi, not very effective

Fixed wireless access is the third use case

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- Fixed wireless access operates over a wider range than WLANs, without overhead of mobility
- Most fixed wireless access network operators are Wireless ISPs (WISPs)
  - Wireless ISP Association (WISPA) has over 800 members
  - Over 3 million WISP customers in the US, many more worldwide
- Most operation is on unlicensed microwave bands
  - Technology must tolerate shared frequencies
  - Low regulatory hurdles, easy market entry, low cost
  - Point to multipoint access using directional subscriber antennas, sectorized base stations

Why use fixed wireless for Internet access?

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- Major market is rural: Fiber is just too expensive when subscriber density per mile is low
- Some urban use too
  - The FCC took away ISPs' access to ILEC facilities (revoked Computer II) in 2005, so often the only surviving competitive ISPs are WISPs
  - Even in urban areas, access to fiber is spotty
- Even incumbents are moving towards fixed wireless
  - Verizon has ended most FiOS rollouts, and will use "densification" of mobile network, and fixed wireless, instead, as they retire deteriorated copper plant
  - You don't really think most of City of Boston will get FiOS fiber, do you?

Other fixed wireless applications

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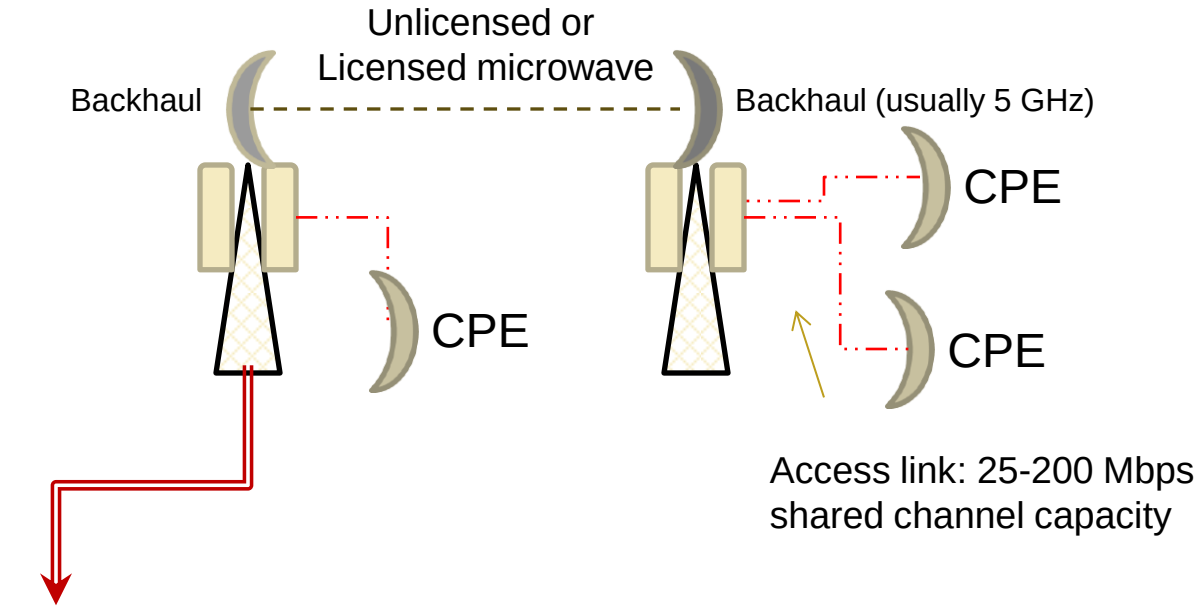
- Besides WISPs, fixed wireless has many other uses
- Security cameras (WISP in reverse: traffic flow is mostly upstream)
- Private/corporate networks
  - LAN extension
  - Feed Wi-Fi access points
  - Interconnect campus buildings where fiber is uneconomic
- Backhaul to cellular towers
  - Heavy use of licensed microwave
  - Licensed links may not be practical for some small cells due to dish size

Typical use case: Microwave PtP backhaul between PtMP base stations



Warning: Do *not* say the 4-letter "m-word" to a WISP!
Backhaul and access are separate!

Fixed vs. mobile wireless

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Mobile	Fixed
Omnidirectional user devices	Directional CPE devices (gain up to +25 dB on 5 GHz, reject off-center)
Indoor and in-car user devices, or if outdoor, hand held	Outdoor CPE devices typically at roof level
Moving user devices (Rayleigh fading)	Fixed user devices (steadier signal, can be tweaked at installation)
Unpredictable user locations (engineer for broad coverage)	Fixed user locations (can be engineered to reach specific sites)
Network core with mobility overhead	No mobility, simple network core (switch/router like any ISP)
Standardized radio interfaces	Proprietary radio interfaces (base station and UE from same vendor)

Traditional unlicensed bands widely used for PtMP access

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- 5 GHz (5150-5350, 5470-5850 MHz “U-NII”) is the WISP workhorse band
  - +36 dBm EIRP allowed on 5725-5850, but very high noise level from Wi-Fi. Slightly less noisy on 5150-5250.
  - 5250-5350 and 5470-5725 require radar detection; EIRP capped at +30 dBm (1W). Much less busy.
  - Sensitive to Line of Sight issues, foliage (but not rain)
- 2.4 GHz sees limited use, mostly rural
  - Extremely high noise level from Wi-Fi in urban areas
- 902-928 MHz best for non-line-of-sight use
  - But noisy due to power meters, other ISM devices
  - Good foliage penetration for rural applications

More regulatory overhead on two other bands

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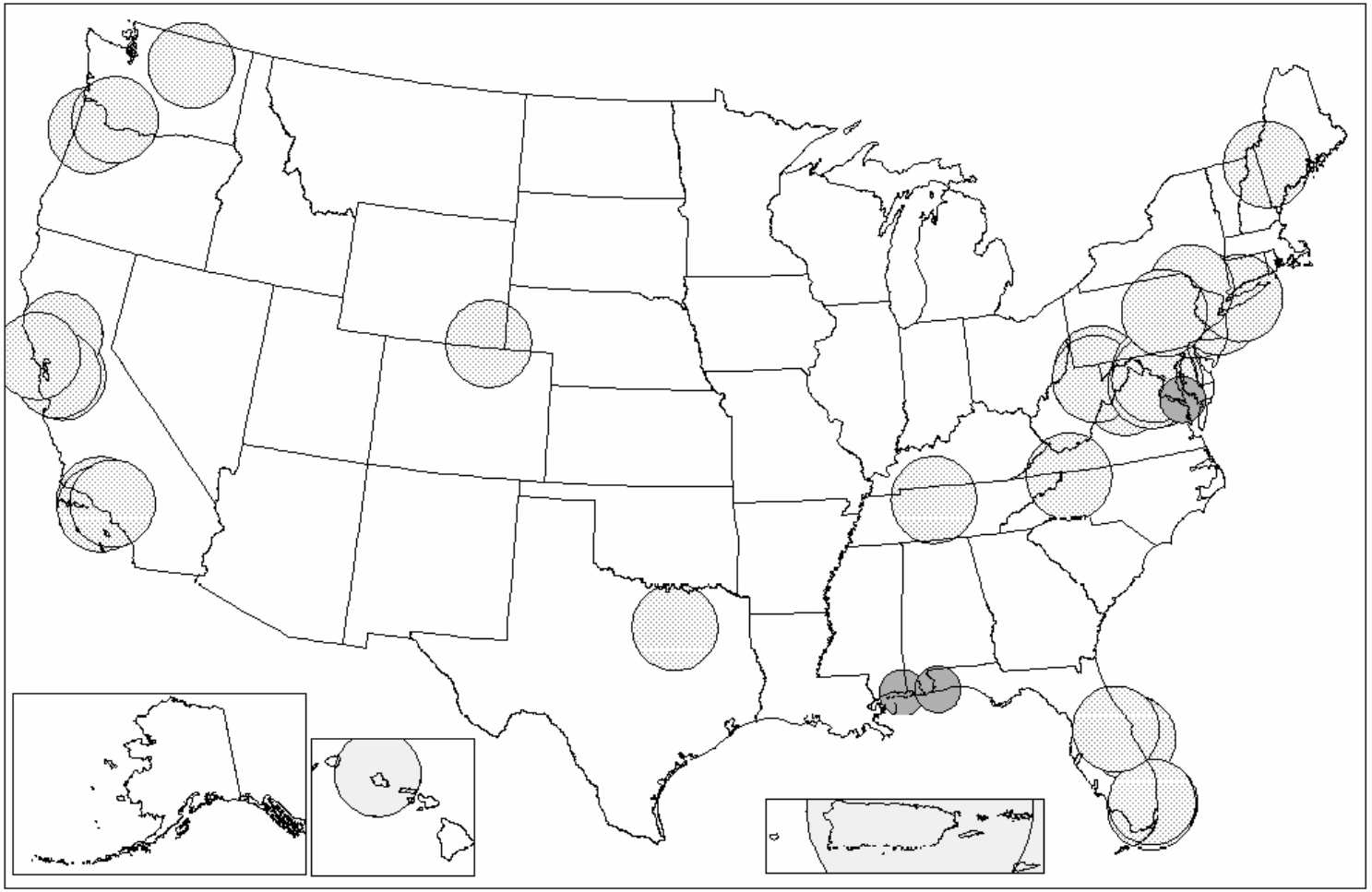
- The 3650-3700 MHz band was available for WISP use, non-exclusive “lightly licensed” requiring “contention-based” operation
  - Most of east coast (but not Massachusetts) and some other areas excluded to protect fixed satellite Earth stations
  - Being merged into 3550-3700 MHz CBRS band
  - Some WiMAX, LTE on this band, as well as proprietary
- TV White Space (470-700 MHz)
  - Primarily available in rural areas for unlicensed use
  - Little deployment to date (NAB resisting all the way)
    - Costly equipment needed to meet strict FCC specifications
    - 802.11af standard may make it easier

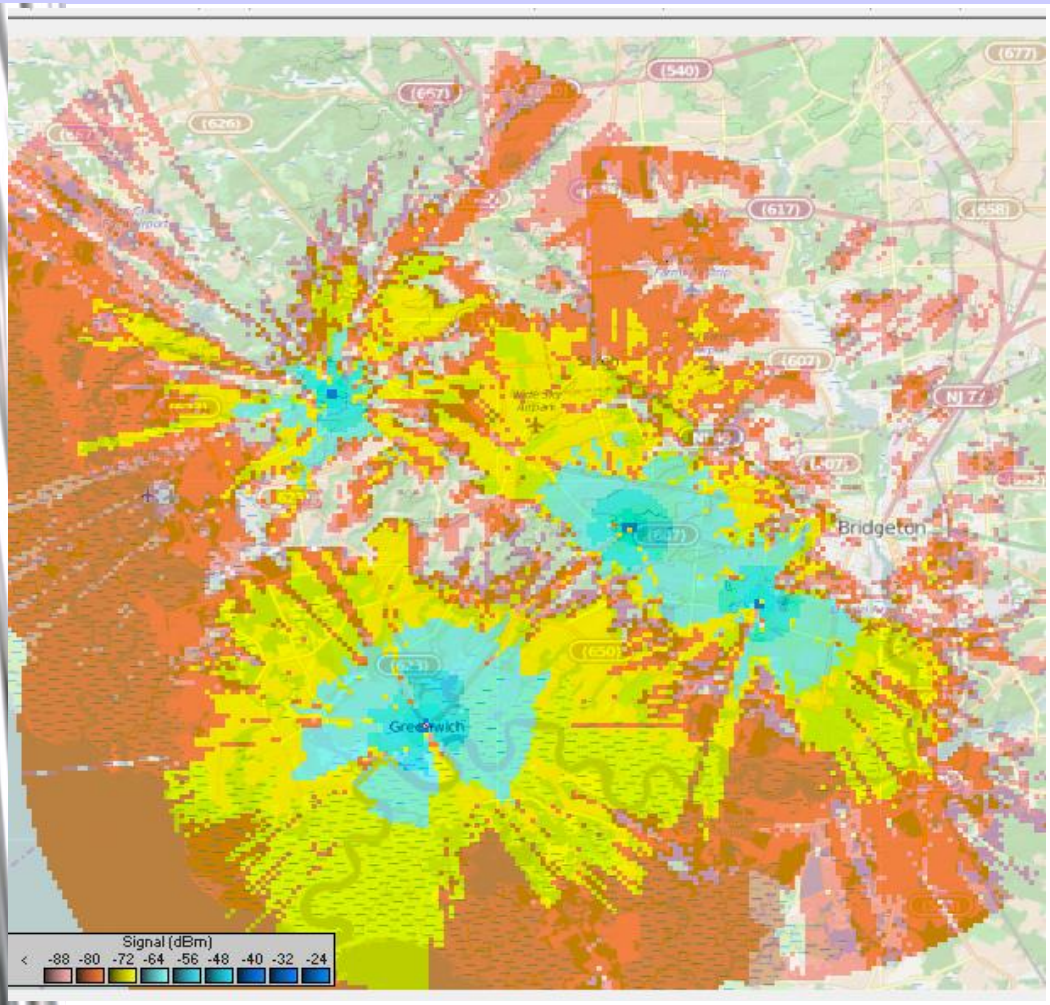
3650 MHz band protection zones



Small dark gray circles = Federal Government stations
Large light gray circles = Grandfathered FSS stations
Not displayed, Guam FSS stations

Federal Communications Commission
Office of Engineering And Technology

Example of WISP coverage (based on Longley-Rice ITM)



A forecast of potential coverage from four sites, each 50 feet tall, in a gently rolling area of mixed farms, forest, and wetland. Coverage with 70% probability of success is plotted to a maximum of 5 miles from each site, to a received signal strength of -88 dBm (pale orange); areas in yellow or blue are most likely to achieve full speed (25 Mbps).

A conventional Wi-Fi outdoor access point model would likely be limited to the areas in blue, largely due to non-directional antennas, especially at the subscriber end.

Point to point microwave backhaul

- A typical WISP will have one or two fiber-connected base stations, with microwave backhaul elsewhere
- Typically 5 GHz unlicensed, usable for 10+ miles
  - PtP power limit is higher than PtMP power limit
    - Primarily limited by Out-of-band-emission rules
    - +50 dBm EIRP or higher is thus possible
  - Proprietary air interfaces, often 802.11n/ac derivative
  - Usually 400cm or larger dish antenna (but smaller than licensed, which requires up to 6' antennas on 6 GHz)
- 24 GHz unlicensed is gaining popularity
  - 33 dBm EIRP, useful to about 2 miles, limited by rain fade
- Licensed microwave has also exploded (fiber did not displace it after all), especially 11, 18, 23 GHz

Generations of WISP radios

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- The WISP radio market is still experiencing rapid improvement
  - Reminiscent of PCs in the 1990s
  - Access fiber, in contrast, has largely leveled off since 2005
- First radios, 1998-2005: 900 MHz and 2.4 GHz
  - Proprietary (like Motorola Canopy FSK), hoppers, or based on 802.11b.
  - Some spread spectrum. Hedy Lamarr was famous again!
- Second generation, ca. 2006
  - 5 GHz caught on, largely OFDM (some 802.11a-derived)
  - Introduction of low-cost radios (<$200) based Wi-Fi chips with LNAs, amps. (Ubiquiti using Atheros chips.)

Later generations of WISP radio

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- WiMAX saw some deployment in 2005-2012 era
  - Often deployed on 3650 MHz lightly-licensed band
  - Also on licensed 2500-2690 MHz (ITFS/MMDS/BRS) bands where leases could be had
    - Clearwire (since absorbed into Sprint) cornered this spectrum
- Third generation, ca. 2010 (*dominant today*)
  - 2x2 MIMO, OFDM (often 802.11n-derived), some 802.11ac
  - Polled MAC to avoid hidden transmitter problem,
  - Higher performance, lower prices (some <$100/radios)
- Fourth generation, 2016+ (premium products today)
  - Higher-order and massive MIMO (eg. 14x14), MU-MIMO
  - Beam steering and null forming sector antennas

Millimeter wave is growing

- 60 GHz band (57-71 GHz) is available for unlicensed use
  - Outdoor power limit is +82 dBm EIRP for 51 dB antenna, reduced by 2 dB for each 1 dB of lower antenna gain
- Cost of 60 GHz gear is falling
  - PtP radios now available around $500 each
    - New WiGig (802.11ad) silicon, repurposed, makes this feasible
- While usually PtP, PtMP sectors are available
  - 15 degree sectors, vs. typical 2-3 degree PtP beamwidth
  - ILECs may use mmWave in lieu of FTTH
- But line of sight is quite literal on these frequencies

Licensed vs. unlicensed microwave

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- Technical characteristics of unlicensed systems differ from traditional microwave in some aspects
- Unlicensed units are packetized,
  - Only transmit when they have data to send, other than beacons/management messages
- Unlicensed units are frequency-agile
  - Some can pick a frequency dynamically
- Unlicensed must tolerate interference on channel
  - Variable bit rate/FEC to adapt, plus local retransmission (often using 802.11-based procedures)
  - Some units have creative OFDM sub-channel masking
  - Clutter is tolerated – NLOS just means more path loss

Flexible high-order MIMO

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- Multiple In/Multiple-Out (MIMO) technology can be deployed in various ways (typically on 2-5 GHz)
  - Wi-Fi and 802.11-derived devices use it to increase capacity on a channel.
  - WiMAX and LTE have a “Matrix A” option that uses it for path diversity; higher-order MIMO could further improve NLOS performance through clutter (trees, buildings)
- Multi-User MIMO allows simultaneous communication with different destinations (space division multiple access)
  - Not in today’s 802.11-based systems but likely to become less costly
- Thank cheap digital signal processing

Beam steering is becoming practical

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- The idea of beam forming, beam steering, null forming and phased antennas is not new
  - AM broadcast stations have been doing beam forming since the 1920s
- The hard part is *dynamic* beam steering, where beams can be computed and changed on the fly, steering as required
  - AT&T Wireless announced it 20 years ago in Project Angel, which failed to take wing
  - Navini had it in 2007 for big $, swallowed by Cisco and rarely seen again
  - Included in LTE specifications but not widely implemented

Uses of beam steering

- Beam forming gain does not exceed sum of gains of component antennas
  - E.g., four 7 dB omnis can potentially steer up to 13 dB gain
  - Not a huge deal on transmit, then, where in any case EIRP may be limited by regulation
- But null forming will be key on unlicensed bands
  - Compute a pattern that reduces unwanted signals to improve signal to noise ratio
  - Shared WISP band capacity is largely interference-limited
- Still relatively expensive but likely to enter mainstream within next few years
  - Beam-steering *receive-only* antenna now a $400 option

Shared spectrum

- The FCC is just starting to rethink its exclusive licensing policies
  - End “spectrum banking”, which leaves massive chunks of spectrum fallow in rural areas because it’s exclusively licensed
  - Make more efficient use, in real-time, of available spectrum
- Two major initiatives: TVWS and CBRS
  - TVWS requries *daily* check on database
- While CBRS is on the short-term horizon, it is likely to be seen as a trial run for future spectrum sharing.
- CBRS will soon make 3550-3700 MHz available for both fixed and mobile use

CBRS Spectrum Sharing

- Fixed devices must be connected to a Spectrum Authorization System (SAS) over the Internet, which authorizes channel and EIRP
  - Standards being written by WinnForum, whose membership shows a strong LTE bias
  - V1 of WinnForum protocols published January, 2017
  - Devices must exchange *heartbeat* with SAS every five minutes to keep their Grants (vs. daily on TVWS)
- Swallows existing 3650-3700 MHz WBS band
- Naval radar is primary user of 3550-3650, and must be protected, as must satellite Earth stations
  - Environmental Sensing Capability (ESC) notifies SAS of radar detection; each ESC needs a protection zone

Three-tier priority use of CBRS band

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- *Incumbents* get highest protection: Federal radar, Fixed Satellite, WBS devices above 3650 that were *registered and in service* by April 17, 2016.
- Priority Access Licenses (PAL) will be auctioned by census tract. Up to 7 10-MHz channels can be used for PAL.
  - PAL grants the right to *not be interfered with* by lower-priority users. SAS keeps track of users to hold aggregate interference below -80 dBm.
- General Authorized Access (GAA) is “licensed by right”. Users are expected to play nicely in the sandbox. SAS protects PALs and Incumbents.

Future directions

- More spectrum needed
  - LTE-U/LAA may severely impair 5 GHz unlicensed band
  - More shared spectrum is being contemplated
    - Current petition to FCC to open 4 GHz band by removing satellite full spectrum/full arc coordination
    - 10 GHz band petition, apparently facing military opposition
    - Expansion of 5 GHz band still open
      - Up to 5925, now little used by DSRC (vehicular service), though DOT proposes making DSRC mandatory in future
      - Share 5350-5470, now some private weather radar
    - More unlicensed Ka-band and millimeter wave bands
- Massive MIMO goes mainstream
- More use of 60 GHz, for both PtP and PtMP
- More recognition!