Future Spectrum Challenges: 6G needs to be “sharing native”

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Spectrum-scape today

- ***Low-band*** is still defined as < 1 GHz, but the definition of ***mid-band*** has been shifting from the traditional definition of 1 – 6 GHz, and FR3 is already being considered, between 7 – 24 GHz.
- ***High-band (> 24 GHz):*** Cellular deployments increasing, mostly in dense urban areas, but performance in real-world conditions has not met the promise of theory, yet.
  - Problems due to propagation, obstruction, body blockage, non-existent outdoor-to-indoor coverage etc.
  - Very limited outdoor coverage, handset constraints limit achievable sustained throughput.
- ***Unlicensed:*** Up to 1.2 GHz of additional spectrum in 6 GHz, shared with microwave incumbents, enabling both Wi-Fi and cellular. Rules allow low-power indoor operation with no requirements to access a sharing database.
- ***New spectrum:*** 12.2 GHz – 12.7 GHz being considered in the US, shared with satellite, NOI on 12.7 – 13.25 GHz, R&O and FNPRM on sharing with Public Safety in 4940 – 4990 MHz.
- ***> 95 GHz:*** Spectrum frontiers

Spectrum evolution of the Gs

Generation	Frequency bands, low, mid and high MHz	Bandwidths	TDD/FDD
≤ 2G	800, 850, 1900	< 1.25 MHz	FDD
3G	800, 850, 1900, 2100	1.25 MHz – 5 MHz	FDD
4G	600, 700, 850, 1700, 1900, 2100 2300, 2500, unlicensed 5 GHz,	5 MHz – 20 MHz	TDD/FDD
5G	600, 3500, unlicensed 5 and 6 GHz, 24000, 26000, 28000, 29000	5 MHz – 100 MHz	TDD/FDD with mid and high-band being TDD
6G?	All of the above + 7 – 24 GHz?	100- 500 MHz?	TDD?

- Key takeaway: every G **has required new spectrum, because the G's are not backward compatible.**
  - This requires new infrastructure roll-out approximately every decade
  - Starting with 4G, unlicensed spectrum has been added into the mix.

Technology evolution of the Gs

Generation	New Techniques	Core Network	TDD/FDD
$\leq$ 2G	Digital transformation begins	Circuit switched	FDD
3G	CDMA/WCDMA	Beginnings of IP	FDD
4G	OFDMA + MIMO + Channel aggregation	IP	TDD/FDD
5G	OFDMA + Massive MIMO +Beamforming	IP, end-to-end-slicing,	TDD/FDD with mid and high-band being TDD
6G?	All of the above + ?	Fully open?	TDD?

- Key takeaway: every G **has added new features that has required new infrastructure**
- This is not always a good thing. For example, sensor networks embedded in infrastructure were often based on 3G: these are being rendered defunct now that 3G is being turned off.
- Verticals often have very different lifetimes: the G's don't take this into account.

6G, the last G?

- New, exclusively licensed spectrum will be increasingly scarce.
  - 6G should be designed to be "sharing native" so that it can be deployed seamlessly in different spectrum allocation regimes: licensed, unlicensed or shared.
- 6G should be designed to be both future proof and backward compatible.
  - Leverage Open RAN architectures.
  - Leverage increased software-ization of the core network
  - Perhaps some decrease in spectral efficiency, but overall utility and sustainability of the cellular networks will be enhanced.
- 6G should not be defined solely by use of higher frequencies
  - Experience with mmWave in 5G should inform the role of even higher frequencies in 6G.
  - Niche use cases are more likely with higher frequencies, e.g., sensing.
  - Higher frequencies can be used for backhaul, but don't need to be labeled as a "G".

Sharing Vs Coexistence: my perspective

- **Sharing:** between "unlike systems", could be co-channel or adjacent channel. Some examples:
  - TV White Spaces: broadcast TV with personal/portable Wi-Fi like devices.
  - CBRS (in the US): DoD radar with mobile wireless.
  - C-band/RadAlts: Radar altimeters with cellular.
  - **RF interference levels are the primary metric of interest, e.g., I/N = -6 dB**

- **Coexistence:** between "like systems". Some examples:
  - Wi-Fi/Wi-Fi in the unlicensed bands
  - Wi-Fi/LAA/5G NR-U in the unlicensed bands
  - Cellular systems co-channel and adjacent channel (e.g. private 5G networks)
  - **Determined by both RF levels and MAC protocols, e.g., airtime fairness.**

Sharing and Coexistence challenges

- Interference is probabilistic, and so is harmful interference. However, most rules consider only worst-case interference to determine protection thresholds: this is very inefficient.

- Databases are usually static, exclusion zones are based on propagation models and are usually over-protective. When sensing has been used along with databases, e.g. CBRS, a separate sensing network has been deployed, with the sensors themselves requiring protection (e.g. whisper zones): extremely inefficient.

- Methodologies for sharing:
  - Lower power, no database or sensing required, but only indoors: used, for example, in 6 GHz.
    - Does not necessarily have to be unlicensed.
  - Spatial rejection: use the Massive MIMO degrees of freedom to null interference.
  - 5G today is not designed for operating well in shared spectrum. Redesign the 5G Waveform and protocol to include coordinated quiet periods for sensing: combined with distributed sensing would allow robust detection of incumbents using ML techniques.

Final thoughts

- New metrics should be applied for 6G: the 10X improvements that were applied to 5G are not sustainable and may not be desirable.

- 6G should have as a goal to connect everyone, everywhere at the minimum broadband rate of 25/3.

- Design and architecture of 6G should enable continuous evolution and ability to operate in all kinds of spectrum: exclusively licensed, shared and unlicensed.

Collaborative research between academia, government and industry needed to take spectrum sharing to the next level.

- NSF in the US launched **SpectrumX:** https://www.spectrumx.org/
- 27 Universities, 41 researchers and staff, led by University of Notre Dame.
- Collaborations with industry, academia and spectrum regulators: MOA between NSF, FCC and NTIA.
- Center vision:
  - Help transform spectrum management into a decentralized, data-driven, automated framework.
  - Enable integrative, convergence research and team science activities.
  - Create compelling spectrum-related education and outreach to prepare the future spectrum workforce.
  - Ensure relevance and timeliness for its efforts through engagement & coordination.