CSMAC Subcommittee 2: 6G

July 18, 2023

Subcommittee Members

- Reza Arefi, Co-Chair
- Carolyn Kahn, Co-Chair
- Michael Calabrese
- Thomas S. Dombrowsky Jr.
- Mark Gibson
- Dale Hatfield
- Jennifer Manner
- Jennifer McCarthy
- Danielle Piñeres
- Glenn Reynolds
- Dennis Roberson
- Jesse Russell
- Steve Sharkey
- Mariam Sorond
- Rikin Thakker
- Jennifer Warren
- Kevin Holmes, FCC Observer
- Richard Orsulak, NTIA Liaison
- Jessica Quinley, FCC Liaison
- Antonio Richardson, Designated Federal Officer

Mandate

- NTIA seeks input on what sort of use cases 6G may entail
  - Importantly, NTIA would like the CSMAC to consider use cases beyond traditional wireless communications including safety, sensor, radar, space and other scientific applications and address 6G's potential impact on federal government users
- When considering spectrum bands that could be used to support 6G, NTIA observes that the THz bands have been identified for potential use
  - How would such use impact government users in that range and what recommendations could be made to help prepare for this
  - Are there other spectrum bands that may be appropriate for 6G and beyond use?

NTIA Clarification: The scope should concentrate on 6G services only. This effort should consider generally the benefits to federal government user, the positives for the federal government as a user or federal equities, and how federal agencies can benefit broadly from 6G.

Schedule

- Kicked off subcommittee: August 2022
- Holding regular subcommittee meetings
- Conducting interviews: December 2022 – June 2023
- Analyzing information and develop a draft report: September 2022 – August/September 2023
- Deliver draft paper and recommendations: September 2023
- Iterate interim findings and conduct follow-on work: September 2023 – December 2023
- Deliver final paper and recommendations: December 2023

Surveys & Interviews*

- Federal agencies
  - AF, Army, **DHS S&T**, **DISA DSO**, DoD CIO, **DoE**, **DoI**, **DoJ**, **DoS**, **DoT**, FAA, FCC (TAC), FDA, NASA, Navy, **NTIA ITS**, NOAA, NSF, NIST, **Treasury**, **OUSD R&E**, **USAGM**, USDA, USCG, USPS, VA
- Industry
  - Service providers: AT&T, BlackSky, **CTIA**, **EchoStar**, HawkEye360, **Intelsat**, Kuiper, Maxar, Planet, OneWeb, **SES**, **SpaceX**, T-Mobile, Verizon, Viasat
  - Cable companies: **CableLabs**, **Charter**, Comcast
  - Equipment manufacturers: **Cisco**, **Ericsson**, **Nokia, Samsung**
  - Chip manufacturers: **Broadcom, Intel, Qualcomm**
  - Hyperscalers: **AWS, Google**, **Meta, Microsoft**
  - Virtualization companies: **VMWare**
- Academia and other non-profit organizations
  - Non-profit organizations: IEEE (Future Networks Initiative), **Next G Alliance, O-RAN Alliance Policy Consortium**
  - Academia: **SpectrumX**
  - International: **6G Flagship, 6GIA**, **B5GPC (Japan)**, **5GForum (Korea), Hexa-X, Networld Europe**

* Surveys & interviews received/completed are denoted in bold font.

6G Use Cases & Applications: Traditional and Non-Traditional*

Traditional (mobile broadband) wireless communications

- **Unlicensed/shared spectrum (slide 8)**
- **Exclusively licensed (cellular, satellite, HAPS)**

Non-traditional (which can integrate with the above) wireless communications

- **Network fabric**
- **Immersive technologies, including AR and VR**
- **Artificial intelligence and machine learning**
- Holograms
- **Digital twinning**
- Ultra-realistic interactive sport – drone racing
- Immersive gaming/entertainment
- **Mixed reality co-design**
- **Mixed reality telepresence**
- **Immersive education with 6G**
- High-speed wireless connection in aerial vehicle for entertainment service
- Personalized user experiences
- Personalized shopping experience

* Not an exhaustive list. Some use cases overlap.
Source: "6G Applications and Use Cases," Next G Alliance, 2022. https://www.dhs.gov/sites/default/files/2022-06/22_0630_st_5G_6G_Horizon_Scanning_Use_Case_Addendum_Infographic.pdf
https://www.ngmn.org/wp-content/uploads/220222-NGMN-6G-Use-Cases-and-Analysis-1.pdf

Note: While federal agencies are expected to benefit from a vast majority of perceived 6G use cases, those captured in bold font are use cases expressed by interviewees as the most relevant to federal agencies.

6G Use Cases & Applications: Safety, Sensor, Radar, Space, and Other*

- **Safety**
  - **National security and public safety applications**
  - **Smart cities/roads**
  - **Field robots for hazardous environments**
- **Sensor**
  - **Synchronous data channels**
  - **Pervasive sensing and tracking**
  - **Connected intelligent machines, including robots, cobots, and IoT**
  - **Autonomous systems**
  - **Online cooperative operation among a group of service robots**
- **Radar**
  - **Integrated communications and sensing**
  - **Automotive radar**
- **Space**
  - **Space-air-ground integrated network**
  - **Communication in space**
  - Commercial space flights and space tourism
  - **Space research**
- **Other scientific applications**
  - **Sustainability**
  - **Smart industry and autonomous supply chain**
  - **Hyper-accurate positioning, localization, and tracking**
  - **Security**
  - **Untethered wearables and implants**
  - **Health care – in-body network**s
  - Teleoperation
  - **Intelligent transportation systems**
  - **Smart agriculture**
  - **Deep sea communications**
  - Mining

* Not an exhaustive list. Some use cases overlap.

Source: "6G Applications and Use Cases," Next G Alliance, 2022. https://www.dhs.gov/sites/default/files/2022-06/22_0630_st_5G_6G_Horizon_Scanning_Use_Case_Addendum_Infographic.pdf
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6G Unlicensed and Shared Spectrum Use Cases & Applications

- Like 5G, next-generation wireless networks will be heterogenous and rely on access to a variety of spectrum bands regulated in different ways and accessed using a variety of technologies
- Proposed unlicensed and shared spectrum use cases include:*
  - **Device-to-device (D2D) communications for home networking, peer-to-peer communications, AR/VR, whole-home video distribution, gaming, telemedicine, enterprise connectivity, training, education, and large venue networking**
  - **Environment sensing, condition monitoring and motion control**
  - **Internet of Things (IoT), Ultra-Reliable Low-Latency Communication transmissions, and private wireless networks to support industrial/smart factory operations**
  - **XR applications requiring very high data rates, low-latency, and synchronized transmissions across multiple devices**
  - **Wireless local and personal area networks and "information showers" relying on mmW unlicensed bands**
  - **Small cell backhaul infrastructure and mmW distribution networks for indoor and outdoor P2P and P2MP connectivity**
  - **"In-X" subnetworks that can operate autonomously when out of coverage of an overlay wide area network, but can benefit from wide area network connectivity where available; these highly specialized radio cells can be installed within the entity where an application runs, in robots, production modules, vehicles, even the human body**

*Some of these use cases could also be covered under a licensed regime

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Suitability Discussion

General dependency of spectrum needs (amount, range) on systems and deployment characteristics

- Suitability from **technical** point of view
  - Amount of spectrum – dependent on applications KPIs
    - Data rate, spectral efficiency, over-the-air latency, range and velocity resolutions, etc.
  - Range, or type, of spectrum – dependent on deployment model and propagation
    - Wide-area vs local area, indoor/outdoor, operation in clutter, LOS/NLOS, mobility, etc.

- Suitability from **regulatory** point of view
  - Dependent on incumbent protection, service rules, and sharing model
  - Time-based sharing; Availability of other spectrum by the same carrier in the same area
  - Location-based sharing; Protection or coordination zones through enforcement of pfd)
  - Frequency-based sharing (e.g., DFS)
  - Time/Location/Frequency-based sharing (e.g., toolbox approach, smart sharing, real-time analytics)
  - Power restrictions (e.g., in 6 GHz); Most suitable for sharing between federal and local-area networks and other short-range services
  - Indoor restrictions (e.g., in 6 GHz, private networks, some verticals); Dependent on deployment model and params, e.g., if possible to maintain certain pfd at the boundary while maintaining system KPIs indoors

Availability of other spectrum resources in the same area, at the same time?

Availability of well-defined KPIs and computing resources for performing the analytics needed to find optimum solutions?

Observations: Technology Development and Migration

- Carriers are still very much focused on deploying 5G and moving on to 5G-Advanced, which will take a few years
- On the other hand, RAN vendors are aggressively defining 6G technology elements and spectrum for 6G
- Carriers and network infrastructure vendors see open networks and ORAN as dominant in the 6G era

Observations: Use Cases

- Clash between visionary ideas and practical realism
- Need to address challenges of 6G (and fill gaps of 5G)
  - Business case/ROI, economies of scale, convergence of vision and path forward, risk of fragmentation and regional divergence
  - Tradeoffs between economies of scale, economies of specialization, and economies of scope
  - Tradeoffs between open architectures and diverse specialized systems
- Currently equipment providers and researchers driving 6G vision, until MNOs provide requirements
- Indicators of use case viability: R&D, TRL progression, proven business case and economic impact, convergence, low barriers to entry, demonstrated impact

Observations: Spectrum

- Most of focus for TN use is now on mid-bands and extending them up to around 15 GHz (vs. MMW or THz); other bands are being considered for NTN
- Interest in sub-THz limited to research areas for mostly short-range communications with a longer associated timeframe for commercial use
- Allow innovation in THz spectrum (localized) for 6G on an exploratory basis
- Lack of suitable dedicated or shared spectrum
- Potential use of spectrum ranges for 6G (including both TN and NTN)
  - Low-band: Not focus for terrestrial 6G; under-utilized spectrum, particularly in large geographic areas with relatively few users, could be pieced together via carrier aggregation and multi-radio connectivity for increased coverage
  - Mid-band: Sweet spot between coverage, capacity, and contiguity
  - MMW: "Information showers" via wireless local and personal area networks for home, office, transportation center, and city hotspot access
  - Sub-THz/THz: Fixed wireless and backhaul; high BW applications if feasible; passive services

Subcommittee Thoughts

- Federal agency engagement early-on will help shape use cases
  - Need to identify R&D gaps for federal agencies use cases
  - Build into a national R&D spectrum strategy and roadmap
  - Influence standards and technology development
- Posture to increase spectrum sharing opportunities, including piecing together available spectrum and using intelligent networks to better leverage spectrum across the G's, and incentives
- Need for more advanced spectrum sharing techniques (e.g., schedulers)
  - Customizing sharing techniques to frequency bands (e.g., mid-band vs sub-THz) and range of incumbent systems
  - Digitized (automated, analytics-based) spectrum sharing for some bands and/or use cases, taking advantage of distributed compute
- Benefits of incorporating interoperability, open APIs, and AI/ML
- Need to invest in 6G research

Back-Up

Interview Questions

Introduction

1. What is your organization's involvement in 6G development?

6G Use Cases

2. What traditional wireless 6G use cases do you expect?
    a. Do you expect federal government users to benefit from these?
    b. If so, how?
    c. If not, why?
3. What 6G use cases do you expect beyond traditional wireless communications including safety, sensor, radar, space and other scientific applications, and any emerging/new use cases?
    a. Do you expect federal government users to benefit from these?
    b. If so, how?
    c. If not, why?
4. What unlicensed 6G use cases do you expect?
    a. Do you expect federal government users to benefit from these?
    b. If so, how?
    c. If not, why?
5. Are there any differences across domestic and international use cases and, if so, what?
6. Do you have any other thoughts or suggestions on how federal government users can benefit from 6G?

Interview Questions

Spectrum Considerations

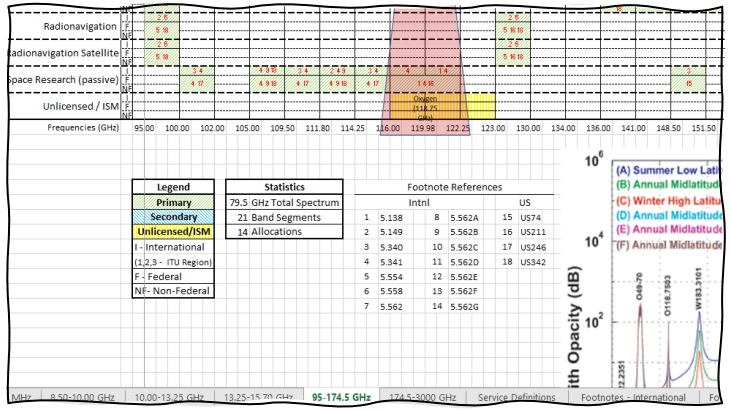
7. How would use of mid-band spectrum for 6G impact government users in that range?
    a. If additional spectrum sharing is required for 6G services, would this be feasible, and why or why not?
    b. If so, in broad terms, what are your thoughts on how this spectrum could be shared?
    c. If not, what are the pertinent obstacles?
    d. What could help prepare for use of mid-band spectrum for 6G?
8. How would use of THz bands (with specific interest above [95 GHz]) impact government users in that range?
    a. If additional spectrum sharing is required for 6G services, would this be feasible, and why or why not?
    b. If so, in broad terms, what are your thoughts on how this spectrum could be shared?
    c. If not, what are the pertinent obstacles?
    d. What could help prepare for use of THz bands for 6G?
9. Do you expect open networks and virtual networks to impact government users and, if so, how?
10. Do you have any other thoughts or suggestions on how to help prepare for impacts to government users?
11. What international spectrum considerations are important?

Other

12. What other national or international considerations are important?
13. What are the most important steps or research needed to make sure your organization's requirements are met?
14. Are there any other thoughts you would like to provide?

Potential Spectrum Bands

- Catalogued 3.1-3000 GHz
- Information collected include:
  - International (Regions 1,2,3) primary and secondary allocations and footnotes
  - Domestic federal and non-federal primary and secondary allocations and footnotes
  - 3GPP bands
  - Unlicensed/ISM bands
  - Bandwidth
  - Atmospheric absorption peaks
- Planned additions:
  - Usage data, if available, e.g., major fixed links bands, federal bands, etc.
  - Bands currently proposed for consideration
    - US/Regional preparations for WRC-23 Agenda Item 10 (WRC-27)
  - External sources, if any, for how much spectrum needed
    - NextG Alliance, Conferences, ITU-R/Regional regulatory bodies
  - More detailed analysis of bands



Uncertainties

- Providing a realistic approach that considers uncertainty, opportunities, and challenges
- Speculation typical in earliest phases of technology development
- 6G remains undefined
- The evolution of the connectivity ecosystem (e.g., satellites, Wi-Fi, cellular)
- Timeline: what is ready by required timeline?
  - What features will be established in a release in an expected timeline?
- Demand for applications and services that are truly 6G
- Regulatory framework and spectrum allocations
- Ability of systems to meet performance requirements in accordance with the expected timeline
- Development of specifications to support use cases, depending on demand/profitability/business model

Challenges

- Research support and strategy
- Security and privacy issues
- Sustainability, including power consumption
- RF exposure
- Dependency of 6G on the pace of development of certain technologies that may be slower/faster (e.g., AI/ML)
- Risk of global standard fragmentation
- Spectrum availability and flexibility
- Capital intensive industry
- System-level challenges in achieving very high reliability/availability (e.g., 99.999%, 99.9999%)

Summary of Responses: Research

- Federal agencies inputs
  - Funding
  - Security and privacy
  - Dynamic Spectrum Sharing (DSS); spectrum engineering with the aim of collating disparate bands across low, mid and high spectrum
  - OOBE; deconfliction strategies
  - Massive MIMO and beamforming capabilities
- Non-federal inputs
  - Industry/Academia/Government partnership; more government funding; NGA model
  - Extended survey of government-controlled spectrum and intensity of use to arrive at sharing targets
  - Private networks to help with monetization of 5G+
  - Specific areas: Connecting intelligence, network of networks, global service coverage, extreme performance, sustainability, and trustworthy
  - Sub-THz and THz applications for 6G
  - Increased densification
  - Vendor agnostic multi-cloud virtualization in distributed cloud environment, AI/ML, serverless deployments
  - CBRS lessons learned