Communication Strategies for Unmanned Aircraft Systems (UAS)

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- Joseph Cramer, Boeing
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The working group gratefully acknowledges the help of the many individuals outside its membership who contributed briefings or other materials.

Stakeholder Priority Topics

- Study the spectrum issues for UAS
  - Including C2, payload, identification, monitoring, collision avoidance
- Address the following specific questions:
  - What frequency bands are available today, and are they sufficient?
    - Consider payload needs as part of this
  - Which UAS activities can be carried out using existing systems or services (CMRS, Land-mobile, Satellite, Aviation, GNSS, etc.)?
  - What are the trade-offs for the various alternative frequency bands?
  - To what extent has loss of communications been a major contributor to loss of UAV?
  - What are the issues of harmful interference to systems on the ground?
  - What new requirements and roles for radar arise from UAS?

Stakeholder Priority Topics (continued)

- Specific questions (continued):
  - What is an appropriate FCC requirement for station ID in UAS transmissions?
  - What is an appropriate FCC requirement for radio certification?
  - What testing facilities are available to evaluate these concepts?
- Make recommendations including:
  - What taxonomy should the FCC use in its regulatory approach?
  - What should the FCC study or do to meet the various spectrum needs for UAS?
    - Considering the need to make efficient use of the spectrum

Briefing Contents

- Systems Analysis: WiFi and Bluetooth for UAS Operations
- RF Analysis Tools and Methods
- Use of Spectrum Designated for Aviation Use for UAS
- New Testing Facility For UAS Spectrum Concepts
- Summary: Spectrum Useful for UAS Command and Control

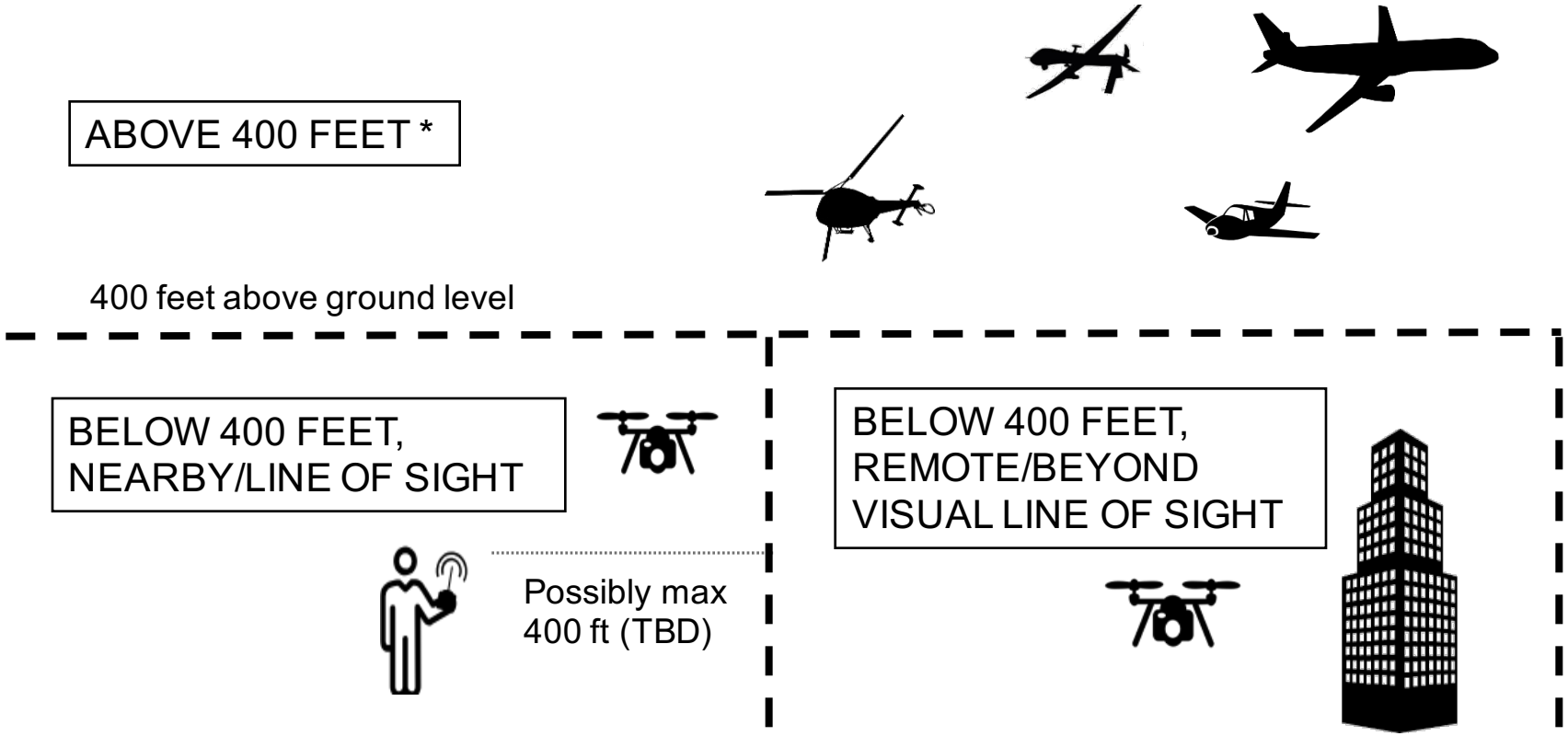
Systems Analysis:
WiFi and Bluetooth for UAS Operations

Project Lead: Stephen Hayes, Ericsson

Systems Evaluation Process

- Conduct a qualitative evaluation of which systems/standards are suited to different categories of UAS
  - This is NOT an endorsement for a particular system
  - Must focus in order to conduct further analysis
- Characteristics of each will be further evaluated in the expected scenarios
  - Availability/Reliability
  - Capacity
  - Coverage
  - Security
  - Integration (systems that fulfil multiple roles are preferable)
  - Latency
  - Deployment issues
  - Cost
- In this analysis, the impact of some safety related issues such as size of the UAV, air traffic zone, etc. were not investigated. These were deemed not to be strictly radio related.

Zone Model



* Systems supporting these aircraft may also need to support low-altitude usage during takeoff and landing.

Unlicensed Analysis

- Selected WiFi (2.4Ghz, 5.8 GHz) and Bluetooth (2.4 GHz) as the two technologies utilizing Unlicensed
  - WiFi is the most common mechanism used for UAV support today for limited operations under FAA Part 107 restrictions
  - Looked at both direct and networked scenarios
- No technology selection at 900MHz since solutions are proprietary
- Looked at the following communication functions towards the UAV
  - Command and Control
  - Backup Command and Control
  - Payload
  - Separation Assurance
  - Broadcast ID
  - Networked Tracking
- Incorporated data from MITRE studies of unlicensed interference and UAVs

Wi-Fi Scenarios

Scenarios Excluded

WiFi enabled phone app

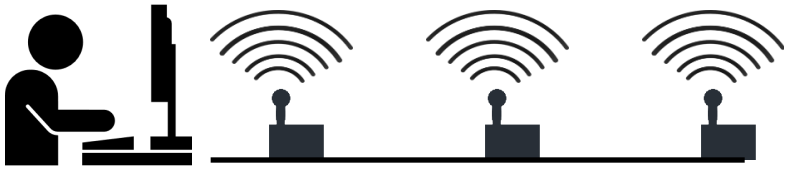
Limited range and commercial usages (primarily a toy)

Scenarios Considered

Dedicated controller with video and extended range antennas

Some commercial usages but BVLOS range limited to 7km

Carrier grade Wi-Fi network (Vantage and Passport certified)



More capable. Not currently deployed extensively outdoors.

Bluetooth (BT) Scenarios

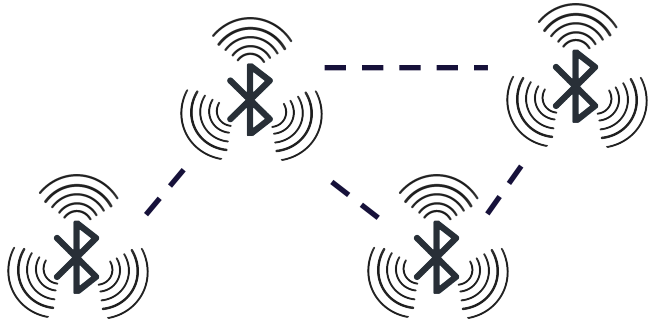
Scenarios Excluded

Bluetooth enabled phone app

Limited range and commercial usages (primarily a toy)

Scenarios Considered

Bluetooth Mesh Network



Can provide wider coverage than standalone BT as well as network connectivity. BT Mesh Networks are typically dynamic and require dense concentrations of participating devices

Unlicensed Analysis based on MITRE simulations and studies

- Conclusions are based on two MITRE reports that looked at unlicensed interference (see below)
  - 900MHz, 2.4GHz (note 5.8GHz not studied)
  - 900MHz not specifically studied since mainly proprietary technologies used for UAS control on this band, however across the board 900MHz had greater degradation than 2.4GHz due to interference.
- Study showed that dense urban environments could lead to loss of command and control
  - Simulations performed for Eugene OR, Brooklyn NY, and Suburban NJ.
    - Severe drops in reliable coverage distance in the presence of RFI in urban areas (350ft was the longest range to achieve 99.8% reliability)
  - The 2008 study found likely interference when using 2006 figures for devices/person in computing interference.
    - Unable to find more recent data (than the 2008 study) for RFI interference towards UAVs
    - The number of devices per capita is now about 10x
    - This will only get worse over time.
  - The studies concluded that local interference had the largest effect, so even if the overall city population density was below the threshold, there would be pockets of high interference
    - Horizontal: congested roads, shopping centers, sporting events
    - Vertical: high rise buildings

Wi-Fi/Bluetooth Conclusions at 2.4GHz*

Population density (persons/square mile)

Interference correlates with population density

0 | 1000 | 3000 | 10000 | 30000

Communications Risk when using Unlicensed Wireless (Wi-Fi/BT)

- Link Range up to+:
  - 7km (Wi-Fi)
  - 200m (BT 4.0)
  - 800m (BT 5.0)
- Video payloads reliably delivered
- Cooperative communications adequate
- Remote ID should work reliably

No hard work/fail boundary.

Depends on factors such as:

- C2 range required
- Automation level of UAV
- Application (e.g., video)

- Link Range greatly reduced
- Payload (e.g., video) may not be received
- Cooperative communications for Collision Avoidance may not work
- Remote ID may not be reliably detected or be received by the UTM

*Data not available for 5.8 + GHz (or 6GHz)

+Optimum unobstructed range (references in reference section)

Technology Comparisons

- 3GPP systems, Wi-Fi and BT can provide the necessary communications to support UAS
- 3GPP Systems may be more robust in some situations since:
  - They operate in protected spectrum
  - Central control allows additional flexibility to overcome interference issues by providing capabilities such as allocating additional radio resources to overcome interference or lowering power levels to reduce interference
- Although 3GPP V2X can potentially provide more robust capabilities for Remote ID broadcast or collision avoidance, it is not currently adapted for UAVs
  - V2X support in LTE is currently being deployed (mainly outside the US), but this is tailored for automotive applications and assumes 5.9GHz
  - Adaptions to V2X to support UAVs is planned for 3GPP R17 (Q2 2021), but it is unclear what frequency band this will use for broadcast.

Recommendations and Future Work

Recommendation 1 [Action] When evaluating the use of unlicensed bands for UAS communications, the analysis should be partitioned into different environments based on the level of radio frequency interference in each environment.

Recommendation 2 [Informational] The TAC anticipates significant reliability challenges when using unlicensed bands for UAS communications for operations in urban environments.

Future Work

- FCC TAC UAS has looked into 3GPP Technologies (2018) and Wi-Fi/BT (2019). In the future it is recommended that the group investigate the applicability of satellite communications for UAS.

RF Analysis Tools and Methods

Project Lead: Reza Arefi, Intel

Scope and Progress

- Appropriate analytic tools need to be identified or created for effective policy making regarding UAS spectrum capacity and requirements
  - Consider both aviation and non aviation bands (including terrestrial mobile and unlicensed)
  - Consider both air to ground and ground to air links
- Key topics for investigation include link, coverage, capacity, in-band and out-of-band interference analysis
- Work accomplished in 2019
  - Focused on CMRS licensed mobile bands
  - Identified likely bands for initial large-scale UAV deployments
  - Identified potential new interference concerns
  - Examined how the interference situations and coverage questions should be analyzed
  - Identified candidate propagation models for use in quantitative analysis

Some bands have Aeronautical Operation restrictions

- UAV deployment in these bands will likely occur after large-scale deployment in unrestricted bands
- Table from UAS-WG 2018 briefing
  - Note 1: This is not a complete list of all bands of interest
  - Note 2: An absence of expressed restrictions on Aeronautical Service in the Table of Allocations (ToA) or in the FCC's service rules for a band does not mean that the FCC has contemplated or analyzed aeronautical or UAS operations for that band.
- Aeronautical restrictions are due to a variety of reasons. Common reasons include:
  - Co-primary Aeronautical or Space Services in the band, or in adjacent bands
  - Sensitive federal systems, e.g. radars
  - Same-area use by FS, especially if used by public safety and/or utilities

Band	Lower (MHz)	Upper (MHz)	Lower (MHz)	Upper (MHz)	Incumbent Services	Regulations	Aeronautical operation
Licensed Spectrum							
Cellular / ESMR	817	849	862	894	FS, MS (land mobile)	allocation, rules, assigned, operational	restricted
AWS	1670	1675	n/a	n/a	FS, MS	allocation, rules, assigned	restricted
AWS	1695	1710	1995	2020	Federal Met-Sat in lower. FS, MSS in upper.	allocation, rules, assigned, operational	restricted
WCS	2305	2320	2345	2360	FS, MS, BSS, RLS	allocation, rules, assigned, operational	Partially restricted
MSS/ATC	2484	2495	n/a	n/a	RDSS, FS	allocation, rules, assigned(?)	restricted
BRS	2496	2690	n/a	n/a	FS	allocation, rules, assigned, operational	restricted
CBRS	3550	3700	n/a	n/a	FS, MS, FSS	allocation, rules	restricted
Frontiers	37000	40000	n/a	n/a	FS, FSS, MS	allocation, rules, partially assigned	Partially restricted (37-38 GHz)
Unlicensed Spectrum							
U-NII-3	5470	5850	n/a	n/a	RLS, MRNS, Met	allocation, rules, operational	unspecified (US), restricted (ITU)
WiGig	57000	71000	n/a	n/a	FS, FSS, MS, SRS, ISS, EESS, RLS, RNSS	allocation, rules, operational	unspecified (restricted in 64-66 GHz)
Under consideration							
UNII-5 to 8	5925	7125	n/a	n/a	FS, FSS, MS	TBD	restricted

Candidate licensed bands for more detailed study

- Focus on low and mid-band, since early large-scale deployment is more likely due to favorable propagation conditions.
- Focus on bands without aeronautical restriction. Network operators plan initial UAV deployment in unrestricted bands.

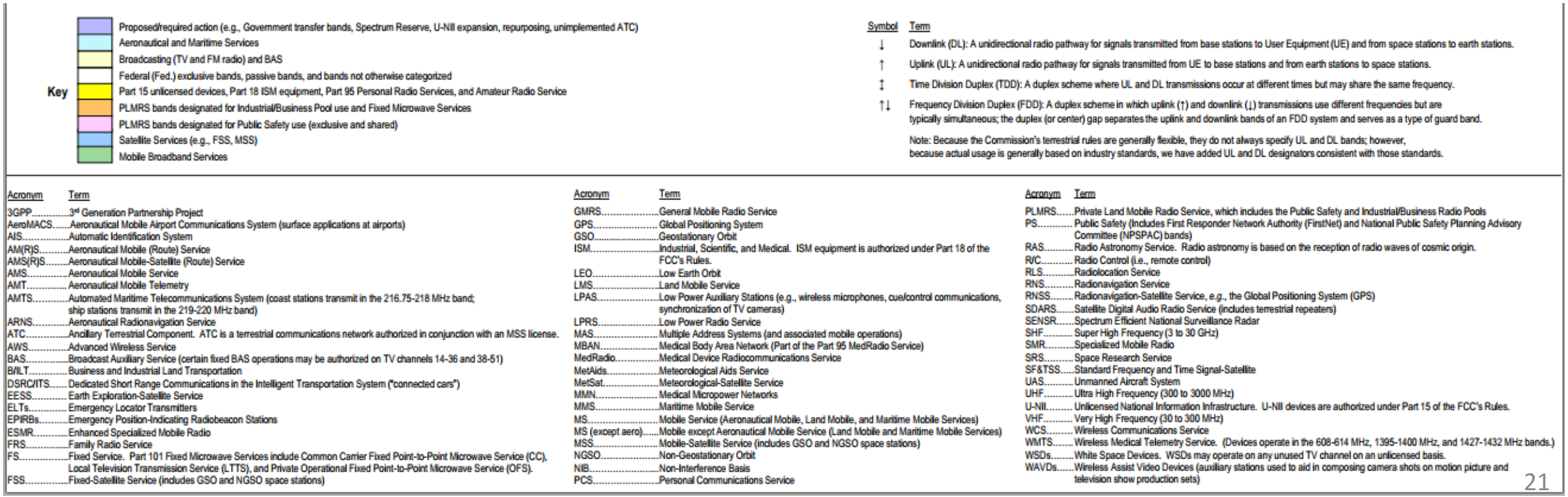
- Candidates for more detailed study:
  - 600 MHz
  - 700 MHz (lower and upper)
  - PCS band
- This list is not exhaustive

Categorization of potential new interference concerns raised by UAV operation in terrestrial mobile bands

- This list is not exhaustive.
- **Category 1** Mobile-Mobile same application
  - Impact of UAVs of a given licensee in a given MOBILE band, with or without aero restriction, on other MOBILE licensees of the same application (e.g. cellular) in same/adjacent bands/area
  - Includes cross-border cases as well as cross-license area
  - Focus on bands without aero restriction
- **Category 2** Mobile-Mobile different application
  - Impact of UAVs in a given MOBILE band, with or without aero restriction, on other MOBILE applications (e.g. public safety) in adjacent bands
  - Focus on bands without aero restriction
- **Category 3** Mobile-Other service
  - Impact of UAVs in a given MOBILE band, with or without aero restriction, on other Services (e.g. fixed service) in the same or adjacent bands
  - **Not considered due to focus on Categories 1 and 2**

Legend for spectrum charts

- The following slides include spectrum charts provided by the FCC
- Charts are zoomed for readability
- This figure is the legend for interpreting colors, symbols and acronyms

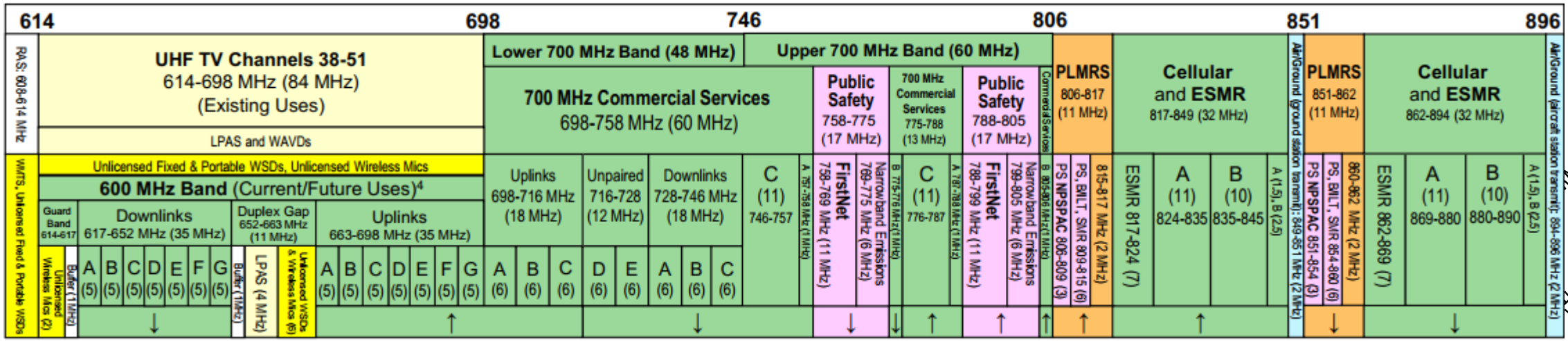


Example of potential Category 1 interference

- Mobile-mobile interference within same application
- Example: 3GPP Band 12 uplink

3GPP Bands in the 614-896 MHz Range

LTE band	NR band	Common name	UMTS band	uplink MHz			downlink MHz			duplex MHz	gap MHz	Band-width	
5	n5	UMTS 850	V	824	-	849	869	-	894	45	20	25	
6	-	UMTS 800	VI	830	-	840	875	-	885	45	35	10	
8	n8	UMTS 900	VIII	880	-	915	925	-	960	45	10	35	
12	n12	UMTS 700 low	XII	699	-	716	729	-	746	30	13	17	Band 12
13	[n13]	700 C-block	XIII	777	-	787	746	-	756	-31	21	10	
14	n14	700 D+F-block	XIV	788	-	798	758	-	768	-30	20	10	
17	-	?	-	704	-	716	734	-	746	30	18	12	
18	n18	?	-	815	-	830	860	-	875	45	30	15	
19	-	?	XIX	830	-	845	875	-	890	45	30	15	
20	n20	EU800	XX	832	-	862	791	-	821	-41	11	30	
26	[n26]	Extended 850 band	XXVI	814	-	849	859	-	894	45	10	35	
27	-	Lower E850 Band	-	807	-	824	852	-	869	45	28	17	
28	n28	APAC 700MHz	-	703	-	748	758	-	803	55	10	45	
44	-	APAC 700 TDD	-	703	-	803	703	-	803			100	
68	-	LTE_FDD_700_ARAB	-	698	-	728	753	-	783	55	25	30	
71	n71	600 USA	-	663	-	698	617	-	652	-46	11	35	
-	n81			880	-	915	-	-	-				
-	n82			832	-	862	-	-	-				
-	n83			703	-	748	-	-	-				
85	-	Extended B12	-	698	-	716	728	-	746	30	12	18	
-	n89		-	824	-	849	-	-	-			25	

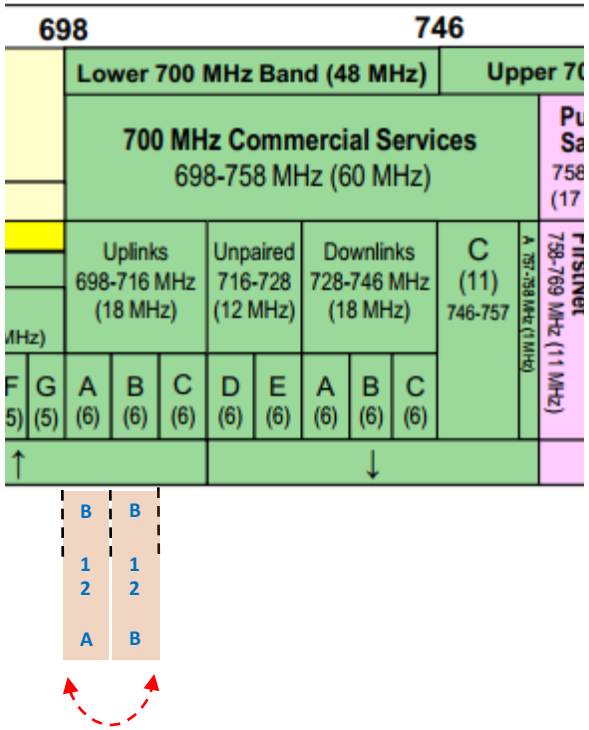


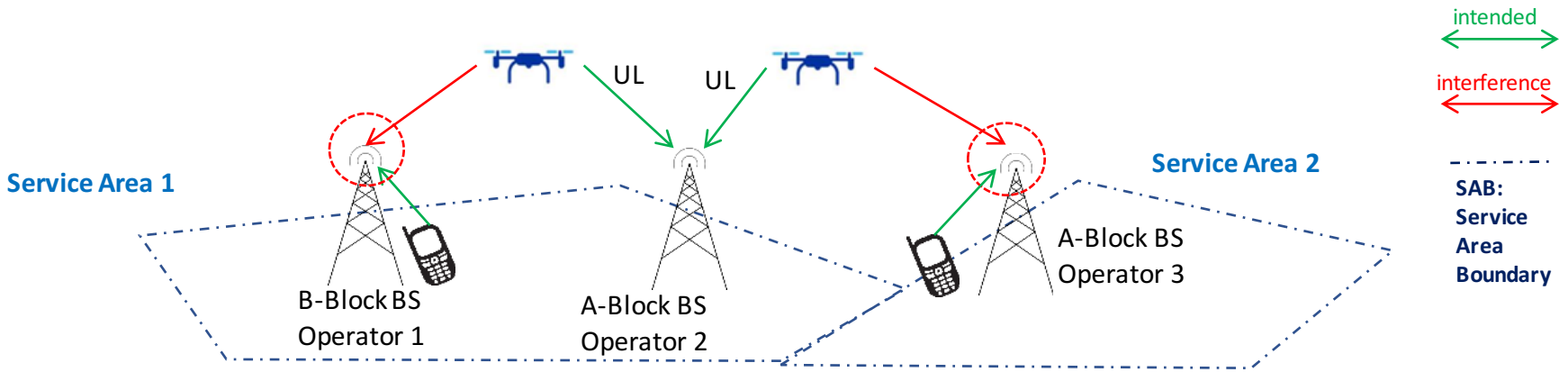
Detail of example potential Category 1 interference: 3GPP Band 12 uplink

Potential for interference from UAV UL to:

a) Adjacent block in same service area

b) Same block in adjacent license/service area





Regulatory issue in Category 1 interference: Service Area Boundaries (SAB)

- In many cases, international cross-border and cross-license area interference is managed by enforcing Field Strength values at the SAB, in some cases at certain heights above ground.
  - FCC Parts 27: 47 dB µV/m, as well as 40 dBµV/m at 1.5 m above ground
  - Field Strength values can be measured using standard probes
  - Specified height above ground related to typical location of user equipment receiver
  - Field Strength limit also prevents from BS in one service area picking up traffic from adjacent service area
- In some cases, e.g. Fixed Wireless Access, other heights have been used, e.g. 10 m

Recommendation 3 [Action] FCC should investigate whether and how the metric enforced at Service Area Boundaries between separate mobile licensees, e.g. field strength of 40 dB µV/m* at 1.5 m above ground**, should be extended to higher altitudes as mobile networks evolve to improve UAV service. For example, a modified metric at the SAB may be needed if the base station's antenna pattern is focused above the horizon.

** For instance, applies to Part 27.55(a)(2), 600 MHz, 698-758, and 775-787 MHz bands.*

*** For instance, applies to Part 27.55(4)(ii)*

Example of potential Category 2 interference

- Mobile-Mobile interference with a different application
- Example: 3GPP Band 13 Uplink-Band 14 Uplink

3GPP Bands in the 614-896 MHz Range

LTE band	NR band	Common name	UMTS band	uplink MHz		downlink MHz		duplex MHz	gap MHz	Band-width	
5	n5	UMTS 850	V	824	849	869	894	45	20	25	
6	-	UMTS 800	VI	830	840	875	885	45	35	10	
8	n8	UMTS 900	VIII	880	915	925	960	45	10	35	
12	n12	UMTS low	XII	699	716	729	746	30	13	17	
13	[n13]	700 C-block	XIII	777	787	746	756	-31	21	10	Band 13
14	n14	D+F-block	XIV	788	798	758	768	-30	20	10	Band 14
17	-	?	-	704	716	734	746	30	18	12	
18	n18	?	-	815	830	860	875	45	30	15	
19	-	?	XIX	830	845	875	890	45	30	15	
20	n20	EU800	XX	832	862	791	821	-41	11	30	
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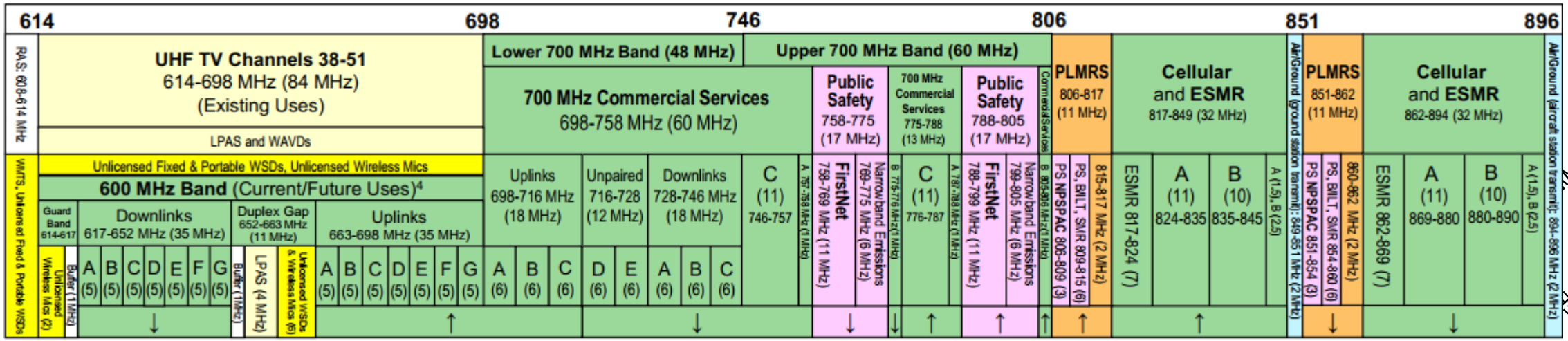
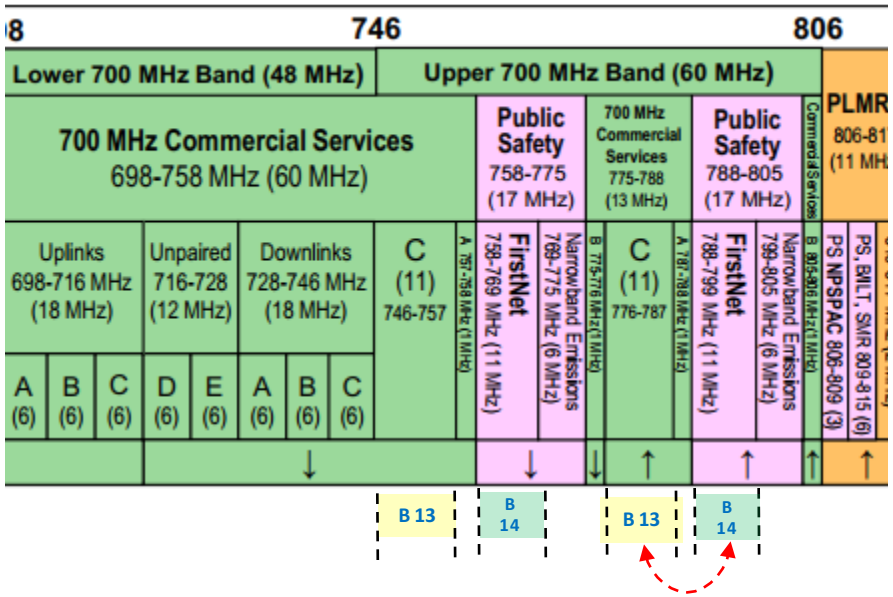
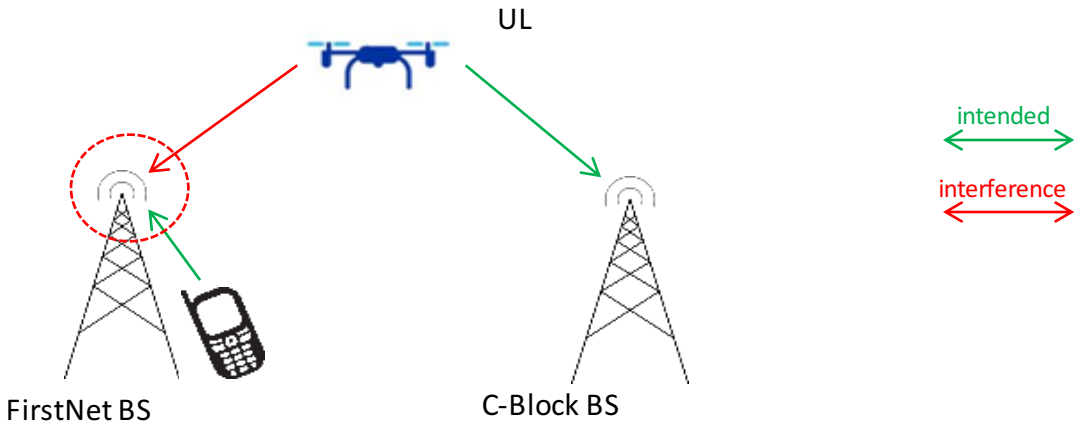
44	-	APAC 700 TDD	-	703	803	703	803			100	
68	-	LTE_FDD_700_ARAB	-	698	728	753	783	55	25	30	
71	n71	600 USA	-	663	698	617	652	-46	11	35	
-	n81			880	915	-	-				
-	n82			832	862	-	-				
-	n83			703	748	-	-				
85	-	Extended B12	-	698	716	728	746	30	12	18	
-	n89		-	824	849	-	-			25	



Detail of example potential Category 2 interference: 3GPP Band 13 Uplink

Potential for interference to FirstNet UL (3GPP Band 14)





Recommended analysis methodology

Recommendation 4 [Action] A quantitative analysis of UAV radio interactions with other services should be carried out before the FCC makes decisions regarding levels of protection*.

Quantitative analysis should take into account the latest system characteristics of systems involved, e.g. enhancements to 3GPP specifications to support UAVs (3GPP 36.777), in cases where sufficient data is available.

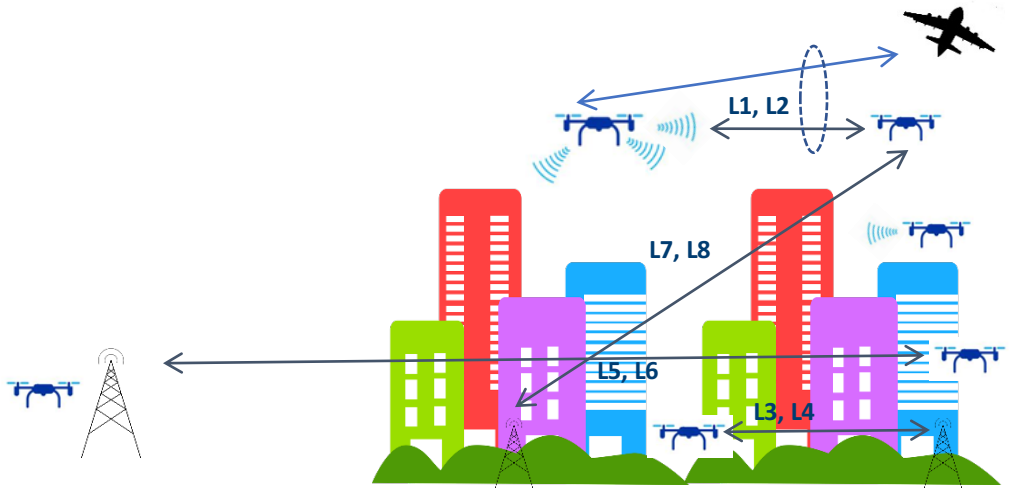
Quantitative analysis of UAV radio interactions should take into account various propagation paths involved, commensurate with deployment scenarios of all systems involved.

** This Recommendation recommends that the FCC apply Principle 9 of the 2015 TAC whitepaper "Principles for Assessing Compatibility of New Spectrum Allocations," which states "A quantitative analysis of interactions between services shall be required before the Commission can make decisions regarding levels of protection."*

Details of propagation paths provided on next slides (not an exhaustive list).

Generalized UAS Operational Environment

- L1: LoS, outside clutter – short paths
- L2: LoS, outside clutter – long paths (incl. atmospheric effects)
- L3: LoS Urban
- L4: NLoS Urban
- L5: L1 + terrestrial clutter loss
- L6: L2 + terrestrial clutter loss
- L7: L1 + slant path clutter loss
- L8: L2 + slant path clutter loss



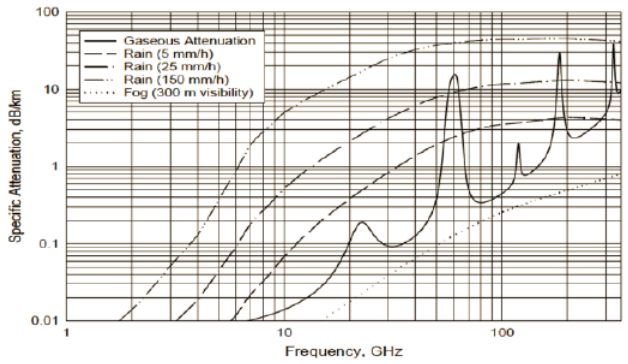


Fig. 1 – Atmospheric attenuation vs. frequency [3]

Propagation Paths (L1, L2)

- L1, L2: Outside clutter, LoS
  - **Short paths (L1) – ITU P.525,** *"Calculation of free-space attenuation"*
  - **Long paths (L2)**
    - Time and location variability
    - **ITU P.525** plus **ITU P.676** *"Attenuation by atmospheric gases"*
    - For interference analyses
      - **ITU P.619** *"Propagation data required for the evaluation of interference between stations in space and those on the surface of the Earth"* - provides methods to predict the propagation losses not exceeded for 0.001%-50% of the time.
        - Includes free space, gaseous attenuation, and other phenomena
      - **ITU P.528** *"Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands"* – applicable to frequencies 125 MHz to 15500 MHz

Propagation Paths (L3, L4)

- L3, L4: Urban/Suburban
  - **ITU P.1411** *"Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz "*
    - Includes site-specific as well as site-general models
    - Site general model, aka ABG model, includes both LoS and NLoS

$$PL(d,f) = 10\alpha \log_{10}(d) + \beta + 10\gamma \log_{10}(f) + N(0,\sigma) \text{ dB}$$

d in meters, *f* in GHz

TABLE 4

Path loss coefficients for below-rooftop propagation

Frequency range (GHz)	Distance range (m)	Type of environment	LoS / NLoS	α	β	γ	σ
0.8-73	5-660	Urban high-rise, Urban low-rise / Suburban	LoS	2.12	29.2	2.11	5.06
0.8-38	30-715	Urban high-rise	NLoS	4.00	10.2	2.36	7.60
10-73	30-250	Urban low-rise / Suburban	NLoS	5.06	-4.68	2.02	9.33

TABLE 8

Path loss coefficients for above-rooftop propagation

Frequency range (GHz)	Distance range (m)	Type of environment	LoS / NLoS	α	β	γ	σ
2.2-73	55-1200	Urban high-rise, Urban low-rise / Suburban	LoS	2.29	28.6	1.96	3.48
2.2-66.5	260-1200	Urban high-rise	NLoS	4.39	-6.27	2.30	6.89

Effects of Local Clutter (L5 through L8)

- Scenarios where one end of the link is surrounded by local clutter, and the other end is not within the same local clutter
- **ITU P.2108**, *"Prediction of clutter loss"* includes three models (Table 1)
  - Height Gain model on ITU P.1812 (limited scope)
  - Horizontal path
  - Slant path

TABLE 1

Summary of Models

Terminal environment	Ref.	Frequency range (GHz)	Description
Terminal below representative clutter height	§ 3.1	0.03 – 3	End loss correction to be added to basic transmission loss calculated to/from the representative clutter height used. Can be applied to both transmit and receive end of path.
Terrestrial terminal within the clutter	§ 3.2	2 – 67	A statistical model which can be applied for modelling the clutter loss distribution for urban and suburban environments. This correction may be applied to both ends of the path.
One terminal is within the clutter and the other is a satellite, aeroplane or other platform above the surface of the Earth.	§ 3.3	10 – 100	A statistical distribution of clutter loss not exceeded for percentage locations for angles of elevation between 0 and 90 degrees.

FIGURE 1

Median clutter loss for terrestrial paths

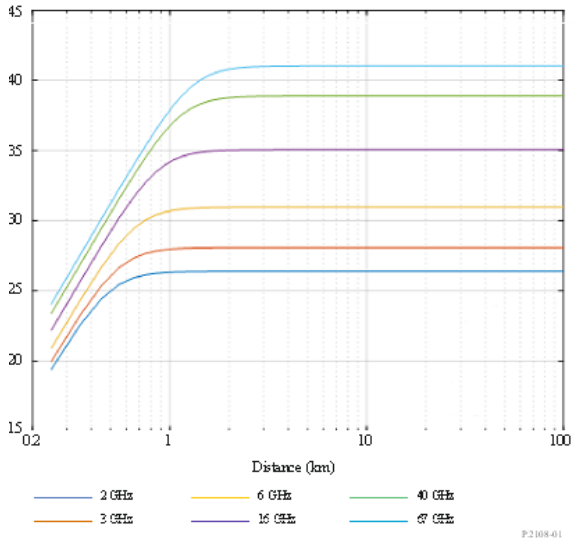
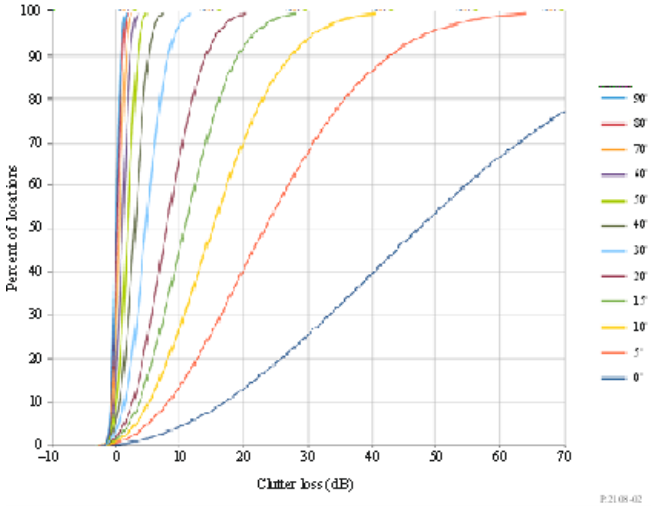


FIGURE 2

Cumulative distribution of clutter loss not exceeded for 30 GHz



Use of Spectrum Designated for Aviation Use for UAS

Project Leads:

Joseph Cramer, Boeing
Scott Kotler, Lockheed Martin

Interpretation of "Spectrum designated for aviation use"

- Consider using spectrum for UAS that supports communications related to the safe operation of or telemetry to/from aircraft.
  - Regulated under Part 87 and Part 25
  - AM(R)S – Aeronautical mobile (route) service intended for communications, including those related to flight coordination, primarily outside national or international civil air routes
  - ARNS – Aeronautical radionavigation service - particularly radio altimeters, traffic alert and collision avoidance
  - AMS(R)S – Aeronautical mobile satellite (route) service intended for communications where terrestrial communications are not available or reliable link via the ground cannot be achieved
  - AMS – Aeronautical mobile service intended to provide telemetry data for flight testing purposes
- Consider certain frequencies available/allocated to aviation services in the range 108 MHz – 5650 MHz
  - SUAS value the low cost and high integration of commercial RF components, available in this range.
  - Antenna requirements become challenging for SUAS below this frequency range

General Potential barriers to use of aviation bands by sUAS

Barriers to using aviation spectrum vary by sUAS use and market segment. Potential barriers for some uses and segments include:

- **Operational Issues:** Using the same spectrum as civil aviation will likely require sUAS platforms to comply with aviation safety standards and FAA technical standard orders related to each band.
- **Cost:** Aviation-grade avionics costs could overwhelm the total cost of the sUAS.
- **Weight and Size:** Avionics available for operation in aviation spectrum could make sUAS too heavy and impact sUAS form factor.
- **Congestion:** Potential large volume of sUAS could place overwhelming demands on aviation bands because aeronautical safety spectrum is already saturated.

General Potential benefits from use of aviation bands by sUAS

- Equipment utilizing aviation frequency bands and certified under Part 87 could benefit from ICAO Convention potentially eliminating need to obtain equipment certification in every country the device operates.
- Equipment could potentially be utilized for larger UAS platforms and possibly aircraft carrying people.
- Interference protection offered by aviation bands make these bands attractive (and mandatory) for “safety related communications” at all altitudes.

Spectrum appropriate for UAS of different sizes and uses

- Because of the need to prevent serious property damage and protect life, aviation frequency bands are likely the most appropriate bands for larger UAVs, UAVs that will transport heavier cargo or people, and UAVs that are most likely to integrate into the national airspace.
  - UAVs operating where there is reliable commercial wireless service may want to leverage licensed commercial wireless bands for some communications functions, and aviation bands for other communications functions.
- Other spectrum options include
  - Fixed and Mobile Satellite Service
  - Mobile Service not including Unlicensed
  - Unlicensed spectrum
- Notes
  - Licensed commercial wireless spectrum is entitled to interference protection, and can offer a high quality of service, similar to aviation bands that are entitled to interference protection.
  - Unlicensed spectrum – WiFi, ISM and Bluetooth – is not entitled to interference protection, and offers no guarantees of reliability or availability, which may pose a number of issues for leveraging these bands for aeronautical systems.

Frequency Band: 108 – 117.975 MHz

- Allocated to Aeronautical Radionavigation Service and Aeronautical Mobile (Route) Service (via footnote 5.197A.
  - Also "allocated on a primary basis to the aeronautical mobile (R) service, limited to systems operating in accordance with recognized international aeronautical standards. Such use shall be in accordance with Resolution 413 (Rev.WRC-12). The use of the band 108-112 MHz by the aeronautical mobile (R) service shall be limited to systems composed of ground-based transmitters and associated receivers that provide navigational information in support of air navigation functions in accordance with recognized international aeronautical standards."
- On a global basis, the band 108–117.975 is used for instrument landing systems (ILS localizer) and VHF omnidirectional range (VOR) and is transitioning the ground-based augmentation system (GBAS) for the foreseeable future. Only GBAS may operate in the band 108–112 MHz to transmit navigational information in support of air navigation and surveillance functions. Any AM(R)S system operating in the band 108–117.975 MHz shall meet ICAO SARPs which are designed to protect FM broadcast stations.

Frequency Band: 117.975 – 121.9375 MHz

- Allocated to Aeronautical Mobile (Route) Service. Footnote information of interest -
  - The carrier frequencies … 121.5 MHz, … may also be used, in accordance with the procedures in force for terrestrial radiocommunication services, for search and rescue operations concerning manned space vehicles.
  - In the band 117.975-137 MHz, the frequency 121.5 MHz is the aeronautical emergency frequency and, where required, the frequency 123.1 MHz is the aeronautical frequency auxiliary to 121.5 MHz
- The band 117.975–137 MHz is the main communications band for line-of-sight air-ground voice and data communications and is used at all airports, for en-route, approach and landing phases of flight and for a variety of short-range tasks for general aviation and recreational flying activities (e.g. gliders and balloons). The use of this band is exclusively for air-ground communications relating to the safety and regularity of flight (ATC and AOC).
- Due to above uses this band is unlikely to be available for UAS use.

Frequency Band: 121.9375 – 123.0875 MHz

- Allocated to Aeronautical Mobile Service. Allocated to non-Federal use. Footnote information of interest –
  - for communications pursuant to flight inspection functions in accordance with the Federal Aviation Act of 1958.
  - The frequency 121.950 MHz is available for aviation instructional stations.
  - The frequencies 122.700, 122.725, 122.750, 122.800, 122.950, 122.975, 123.000, 123.050 and 123.075 MHz may be assigned to aeronautical advisory stations. In addition, at landing areas having a part-time or no airdrome control tower or FAA flight service station, these frequencies may be assigned on a secondary non-interference basis to aeronautical utility mobile stations, and may be used by FAA ground vehicles for safety related communications during inspections conducted at such landing areas.
- The band 117.975–137 MHz is the main communications band for line-of-sight air-ground voice and data communications and is used at all airports, for en-route, approach and landing phases of flight and for a variety of short-range tasks for general aviation and recreational flying activities (e.g. gliders and balloons). The use of this band is exclusively for air-ground communications relating to the safety and regularity of flight (ATC and AOC).
- Due to above uses this band is unlikely to be available for UAS use.

Frequency Band: 123.0875 – 137 MHz

- Allocated to Aeronautical Mobile Service. Footnote information of interest –
- The frequency 123.1 MHz is designated as the frequency auxiliary to 121.5 MHz (ICAO Annex 10, Volume V, Chapter 4, 4.1.3.4). This frequency is used as an auxiliary search and rescue frequency. The Radio Regulations also designate 123.1 MHz for general search and rescue purposes.
- The band 117.975–137 MHz is the main communications band for line-of-sight air-ground voice and data communications and is used at all airports, for en-route, approach and landing phases of flight and for a variety of short-range tasks for general aviation and recreational flying activities (e.g. gliders and balloons). The use of this band is exclusively for air-ground communications relating to the safety and regularity of flight (ATC and AOC).
- The 136-137 MHz portion is available for air traffic control purposes, such as automatic weather observation stations (AWOS), automatic terminal information services (ATIS), flight information services-broadcast (FIS-B), and airport control tower communications.
- Due to above uses this band is unlikely to be available for UAS use.

Frequency Band: 328.6–335.4 MHz

- Allocated to Aeronautical Radionavigation Service. Footnote information of interest –
  - The use of the band 328.6–335.4 MHz by the aeronautical radionavigation service is limited to Instrument Landing Systems (glide path).
- On a global basis, the frequency band 332.8–335.4 MHz is used for the ILS glide path. The signal provides descent information for navigation down to the lowest authorized decision height specified in the approved ILS approach procedure. The glide path projection angle is normally adjusted to 3 degrees above the horizontal plane so that it passes through the middle marker at about 60 m (200 ft) and the outer marker at about 426 m (1 400 ft) above the runway elevation. The glide slope is normally usable to a distance of 10 NM. However, at some locations, use of the glide slope has been authorized beyond this range.
- Further review as to whether this band could be considered is necessary.

Frequency Band: 960 –1164 MHz

- Allocated to Aeronautical Radionavigation and Aeronautical Mobile (Route) Services. Footnote information of interest –
- Footnote 5.327A provides: Limited to systems that operate in accordance with recognized international aeronautical standards. Such use shall be in accordance with Resolution **417 (Rev. WRC-12)**.
- Planned to be used for future air-ground (and air-air) data communications (e.g. LDACS) although achieving compatibility with Distance Measuring Equipment (DME) and secondary surveillance radar (SSR) could be problematic. DME channelization is complicated.
- Automatic Dependent Surveillance – Broadcast (ADS-B) operates in this band (1030/1090 MHz), and is a critical component of aviation detect and avoid requirements.
- The frequency 978 MHz is used for the Universal Access Transceiver (UAT), which provides for ADS-B and up-linking of data messages.
- Due to above uses this band is unlikely to be available for UAS use

Frequency Band: 1164 – 1215 MHz

- Allocated to Aeronautical Radionavigation Service and Radionavigation Satellite Service (space-to-Earth) (space-to-space). Footnote information of interest -
  - Use of the band 960-1215 MHz by the aeronautical radionavigation service is reserved on a worldwide basis for the operation and development of airborne electronic aids to air navigation and any directly associated ground-based facilities.
  - Stations in the radionavigation-satellite service in the band 1164-1215 MHz shall operate in accordance with the provisions of Resolution 609 (Rev.WRC-07) and shall not claim protection from stations in the aeronautical radionavigation service in the band 960-1215 MHz. No. 5.43A does not apply. The provisions of No. 21.18 shall apply. (WRC-07)
- While having no regulatory status, significant DoD communications system operates in this band.
- Used for GPS/Galileo/Beidu/Glonass signals.
- Due to above uses this band is unlikely to be available for UAS use.

Frequency Band: 5030 – 5091 MHz

- Allocated to Aeronautical Radionavigation Service, Aeronautical Mobile (Route), Aeronautical Mobile-Satellite (Route). Footnote information of interest -
  - The use of the frequency band 5 030-5 091 MHz by the aeronautical mobile (R) service is limited to internationally standardized aeronautical systems. Unwanted emissions from the aeronautical mobile (R) service in the frequency band 5 030-5 091 MHz shall be limited to protect RNSS system downlinks in the adjacent 5 010-5 030 MHz band. Until such time that an appropriate value is established in a relevant ITU-R Recommendation, the e.i.r.p. density limit of −75 dBW/MHz in the frequency band 5 010-5 030 MHz for any AM(R)S station unwanted emission should be used. (WRC-12)
  - In the frequency band 5 030-5 091 MHz, the aeronautical mobile-satellite (R) service is subject to coordination under No. 9.11A. The use of this frequency band by the aeronautical mobile-satellite (R) service is limited to internationally standardized aeronautical systems. (WRC-12)
- This band is a potential candidate for UAS C2, especially larger UAS platforms that may require an aviation safety spectrum allocation.

Recommendations

Recommendation 5 [Informational] As UAS operations become more complex, including larger aircraft operating at higher altitudes, flying over people, and carrying passengers, the need to use aeronautical mobile (route) service and aeronautical mobile satellite (route) service spectrum (as defined in Part 87.5) increases for communications impacting the safety of the flight.

Recommendation 6 [Informational] Mobile service spectrum, i.e. Cellular (CMRS), could be an option for safety related communications where the necessary reliability requirements as set by the appropriate government agency(ies) can be met.

New Testing Facility for UAS Concepts

UAS communications testbed announced 9/2019: North Carolina AERPAW

- Built/operated by a consortium led by North Carolina State University
  - One partner is North Carolina DOT, an FAA UAS Integration Pilot Program participant
- Sponsored by Platforms for Advanced Wireless Research (PAWR), a public/private partnership
- AERPAW is a testbed for research that integrates advanced wireless and UAS, including:
  - LTE/5G 3D UAS connectivity
    - Validate analytic predictions in 3GPP documents
    - Interference characterization on cellular network operations
    - Air-to-X propagation measurements and modeling
  - Use of C-V2X technology for UAS applications
  - UAS Traffic Management
  - Spectrum sharing and enforcement
  - AERPAW enables but does not perform or sponsor this research

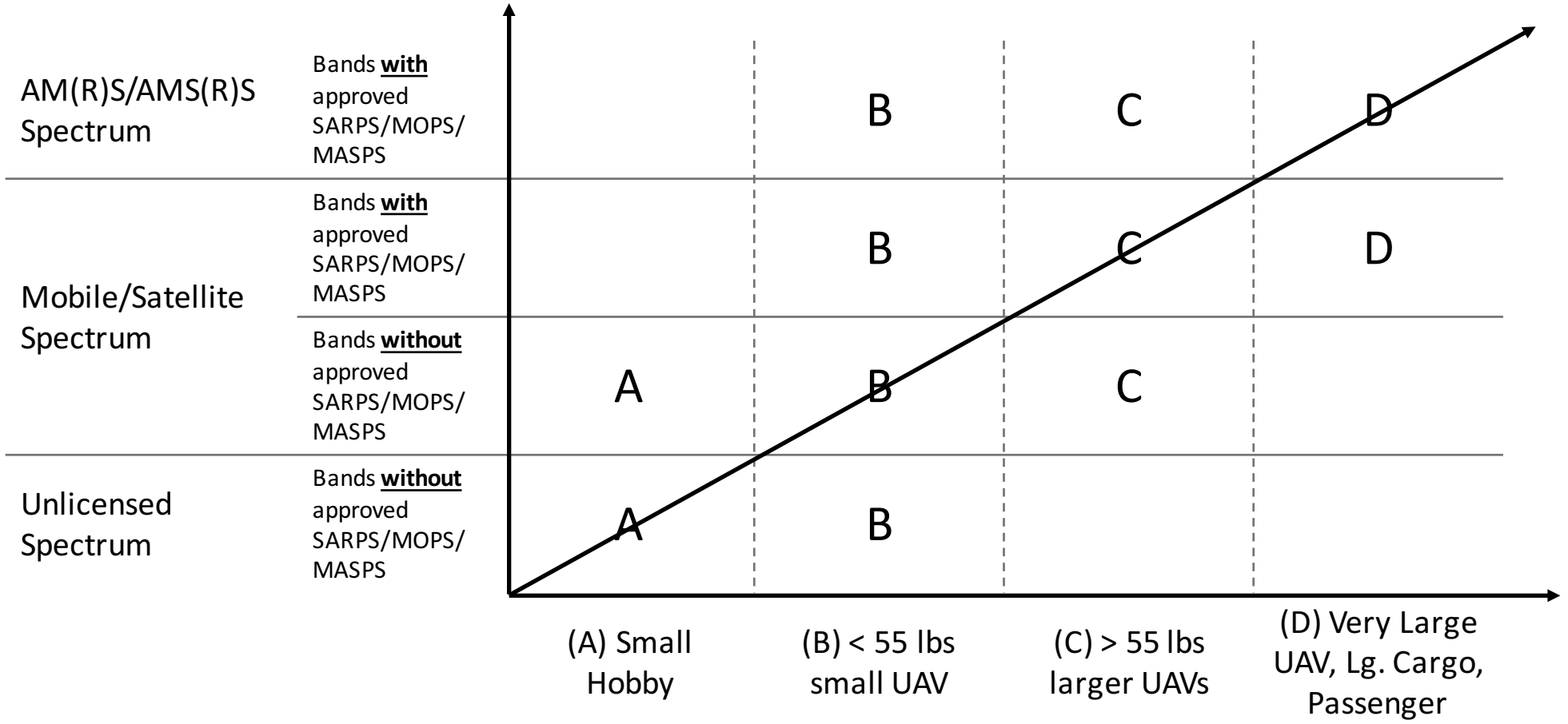
Plans

- Open for experimentation under Part 107 in late summer 2020; BVLOS operations available by 2022
- Tunable radios in aircraft and ground, 70 MHz-6 GHz; mmWave is planned
- Initially 400 ft altitude limit; path to support altitudes over 1000 ft AGL

AERPAW is a new resource for technical studies supporting FCC regulatory decision making

Summary: Spectrum Useful for UAS Command and Control

Recommendation 7 [Informational] Spectrum Likely to be Most Useful for UAS Command and Control Based on Aircraft Size



SARPS – Standards and Recommended Practices
MOPS – Minimum Operational Performance Standards
MASPS – Minimum Aviation System Performance Specification

The FAA is working with RTCA to develop appropriate standards (MOPS/MASPS) for safety-related communications links for large UAV platforms. This strongly suggests that regulations for UAVs > 55 lbs are likely to be based on such standards. As the scope of potential regulation is unknown, mobile/satellite bands where such standards have not been approved are included in column (c) in the chart.

Size of aircraft roughly corresponds to safety requirements. FAA has investigated using maximum kinetic energy rather than weight as a basis for categorization.

Notes for preceding chart. The letter corresponds to the size/type of UAV

A. Small UAVs probably best suited for using Unlicensed bands for operations within Part 107 restrictions, and Mobile Service Spectrum for Part 107 operations and more complex UAS and UAM operations, at low altitude and higher altitudes.

B. Some small UAVs (< 55 lbs.) can use unlicensed spectrum (under certain "non-impactful" conditions).
   - Small UAVs could be permitted to utilize, Mobile Spectrum without developing minimum aviation operational, performance, or international aviation recommended practices (MOPS/MASPS/SARPS).
   - In certain circumstances, even small UAVs might need to utilize very reliable aviation safety spectrum. The option should not be precluded.

C. Larger UAVs (greater than 55 lbs.) presumed to use aviation safety spectrum (Aeronautical Mobile (Route) Service, Aeronautical Mobile Satellite (Route) Service).
   - Should not be permitted to use unlicensed spectrum for safety-related data (C2).
   - Should be permitted to use Mobile Service or Mobile Satellite Service spectrum for safety-related data if the safety-related communications meet FAA requirements (FAA likely to require SARPS/MOPS/MASPS). (The transmitter certification standards under FCC jurisdiction should be based on FAA requirements.)
   - Under limited circumstances (TBD), large UAVs might be able to use Mobile or non-aviation safety Satellite Service spectrum that do not have SARPS/MOPS/MASPS developed.

D. Very Large UAVs (all UAVs that carry people or significant cargo weight) presumed to use aviation safety spectrum for safety communications
   - Should not be permitted to rely on unlicensed spectrum.
   - Can use Mobile or Mobile Satellite Service spectrum if required MOPS/MASPS/SARPS are developed.
   - Preferable using aviation safety service allocations for safety functions

Suggested work items for UAS-WG 2020

- Satellite support for UAS
  - Include standalone satellite systems and hybrid satellite/terrestrial systems
- Peer-to-peer and broadcast UAS communications
  - Applicability of C-V2X technology
    - 3GPP plans to include adaptation of C-V2X for UAS in Release 17, scheduled for Q2 2021
  - Can UAS share the 5.9 GHz band used for intelligent transportation
- RF coexistence analysis for selected bands
  - Analyze selected bands for potential issues
  - Draw on other ongoing efforts such as the one described in:
    Draft Report 309 of Electronic Communications Committee of CEPT
    Use of Mobile/Fixed Communication Networks (MFCN) for the command & control and payload links of UAs within the current MFCN harmonised regulatory framework

References

- MITRE studies on the effect of interference on unlicensed UAS communications
  - Potential RF Interference to Control Links of Small Unmanned Aircraft (2008)
  - Spectrum Planning for Control and Command Links of Unmanned Aircraft Systems (2018)
- Maximum practical ranges for unlicensed devices
  - https://www.dji.com/mavic/info
  - https://www.cnet.com/news/intel-uses-bluetooth-to-keep-flying-drones-from-colliding/
- WRC resolutions related to UAS
  - https://www.itu.int/pub/R-ACT-WRC.8-2007/en
  - https://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.9-2012-TOC-HTM-E.htm
  - See RF Analysis Section for specific resolutions consulted
- Applicability of ITU air-to-ground propagation models for FCC regulatory decision making
  - Letter to UAS-WG from Professor Christopher Anderson, US Naval Academy

Thank you to the Chairman, the FCC staff, all workgroup members and contributors.

Backup: Analysis of WiFi technology for UAS operations

Project Lead: Stephen Hayes, Ericsson

WiFi – Normal C2

- Range
  - Wi-Fi typically limited to about 10km even with range extending antenna
  - Longer range antennas require pointing the antenna at the drone (can be automated)
  - 2.4 GHz often used for increased range
- Throughput and latency meet requirements

Standalone

- Range severely reduced in urban areas (unlicensed interference)
- Does not provide different QoS levels
- WiFi is an access technology and does not by itself provide network connectivity

Networked

- Improved congestion handling, but cannot be eliminated since unlicensed band
- Provides different QoS levels for higher reliability at reduced bandwidth
- AP handovers typically <40ms
- Network connectivity included

WiFi Technology – Characteristics Evaluation for Normal C2

Characteristics	Evaluation	Description
Availability/ Reliability	✔[✔✔]	Vantage networks and 802.11ax improvements help with congestion, but inadequate for safety required for commercial usage in congested urban environments. [In rural environments or where the environment can be controlled (e.g., construction site) it may be adequate]
Capacity	✔✔✔	
Coverage	✔[✔]	For standalone scenarios, typically only near the operator. In urban areas, reliable coverage area may be small. [Networked solutions can cover a larger area, but require new buildout.]
Security	✔[✔]	[Vantage networks are more secure than standalone Wi-Fi usage, however, WPA3 not widely deployed yet.]
Integration	✔[✔✔]	For standalone scenarios, network connectivity must be provided separately. [In managed networks, internet connectivity provided]
Latency	✔✔✔	
Deployment issues	✔[✔✔]	Networked Wi-Fi is not widely deployed outdoors today and would require build out. [For standalone, no infrastructure is required except for internet link]
Cost	✔✔✔	

WiFi – Backup C2

- Backup C2 is a data link meant to assure continued connectivity when the normal C2 link fails
- Same advantages/disadvantages as Normal C2
- Provides technology diversity to a separate primary communications system
  - Technology diversity = Use of an alternate technology for backup improves robustness
- WiFi seems feasible as a backup technology only in networked mode
  - It seems unlikely a new Managed Wi-Fi Network would be built out just to use as backup

WiFi Technology – Characteristics Evaluation for Backup C2

Characteristics	Evaluation	Description
Availability/ Reliability	✔[✔✔]	Vantage networks and 802.11ax improvements help with congestion, but inadequate for safety required for commercial usage in congested urban environments. [In rural environments or where the environment can be controlled (e.g., construction site) it may be adequate]
Capacity	✔✔✔	
Coverage	✔✔	Networked solutions can cover a larger area, but require new buildout.
Security	✔✔	Vantage networks are more secure than standalone Wi-Fi usage, however, WPA3 not widely deployed yet.
Integration	✔✔✔	In managed networks, internet connectivity provided
Latency	✔✔✔	
Deployment issues	✔	Networked Wi-Fi is not widely deployed outdoors today and would require build out.
Cost	✔✔✔	

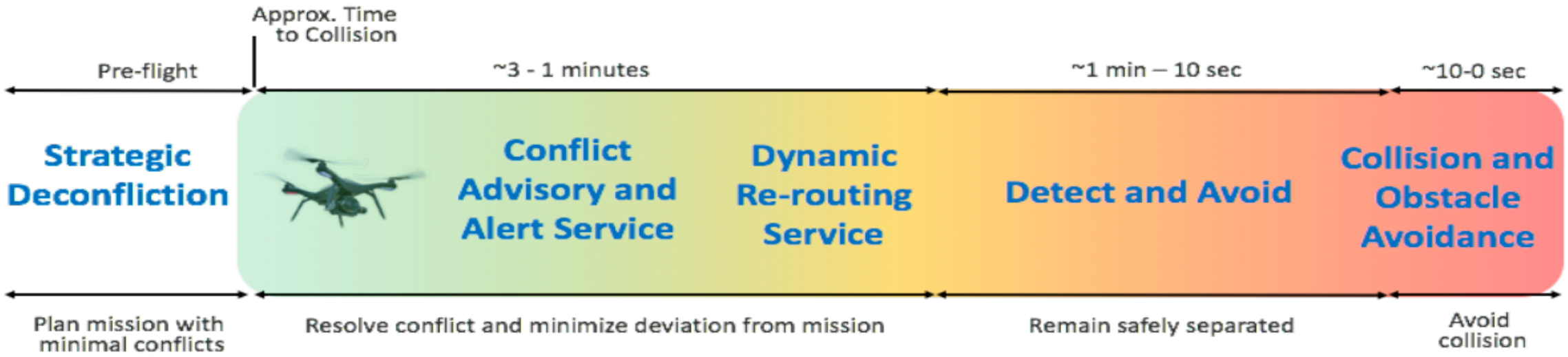
WiFi – Payload

- Payload is considered a non-safety application
- Wi-Fi is well suited for transferring large volumes of data
- Often used in FPV (First Person Viewer) scenarios
- When used in FPV, the video stream must be reliable
- Similar restrictions as for C2 with respect to unlicensed interference

WiFi Technology – Characteristics Evaluation for Payload

Characteristics	Evaluation	Description
Availability/ Reliability	✔[✔✔]	Vantage networks and 802.11ax improvements help with congestion, but inadequate for safety required for commercial usage in congested urban environments. [In rural environments or where the environment can be controlled (e.g., construction site) it may be adequate]
Capacity	✔✔✔	
Coverage	✔[✔]	For standalone scenarios, typically only near the operator. In urban areas, reliable coverage area may be small. [Networked solutions can cover a larger area, but require new buildout.]
Security	✔[✔]	[Vantage networks are more secure than standalone Wi-Fi usage, however, WPA3 not widely deployed yet.]
Integration	✔[✔✔]	For standalone scenarios, network connectivity must be provided separately. [In managed networks, internet connectivity provided]
Latency	✔✔✔	
Deployment issues	✔[✔✔]	Networked Wi-Fi is not widely deployed outdoors today and would require build out. [For standalone, there are no infrastructure required (except for internet link)]
Cost	✔✔✔	

WiFi – Separation Assurance



- Wi-Fi broadcasts may be used as part of cooperative (UAS-UAS) communication
- Wi-Fi must work with maximum expected closing speeds
- Due to potential for interference it is expected that Wi-Fi would only be used with sUAS that pose low risk
- For UTM based separation functions, the issues with network connectivity are the same as described previously

WiFi Technology – Characteristics Evaluation for Separation Assurance

Characteristics	Evaluation	Description
Availability/ Reliability	✔[✔✔]	Vantage networks and 802.11ax improvements help with congestion, but inadequate for safety required for commercial usage in congested urban environments. [In rural environments or where the environment can be controlled (e.g., construction site) it may be adequate]
Capacity	✔✔✔	
Coverage	✔[✔]	For standalone scenarios, typically only near the operator. In urban areas, reliable coverage area may be small. [Networked solutions can cover a larger area, but require new buildout.]
Security	✔[✔]	[Vantage networks are more secure than standalone Wi-Fi usage, however, WPA3 not widely deployed yet.].
Integration	✔[✔✔]	For standalone scenarios, network connectivity must be provided separately. [In managed networks, internet connectivity provided]
Latency	✔✔✔	
Deployment issues	✔[✔✔]	Networked Wi-Fi is not widely deployed outdoors today and would require build out. [For standalone, there are no infrastructure required (except for internet link)]
Cost	✔✔✔	

WiFi – Broadcast ID

- WiFi is one of the technologies defined in the proposed ASTM Remote ID standard
- WiFi has adequate bandwidth to carry certificates and encryption necessary to provide privacy and security for the remote ID information.
- WiFi broadcasts may be hard to detect in congested environments
- WiFi is widely available in handsets

UAS using Standalone WiFi

- Range severely reduced in urban areas (unlicensed interference)

UAS connected to Networked WiFi

- Handset receiving the Broadcast ID is likely not part of the Vantage Wi-Fi network
- Therefore, ability to receive Broadcast ID does not benefit from managed Wi-Fi

WiFi Technology – Characteristics Evaluation for Broadcast ID

Characteristics	Evaluation	Description
Availability/ Reliability	✔[✔✔]	Vantage networks and 802.11ax improvements help with congestion, but inadequate for safety required for commercial usage in congested urban environments. [In rural environments or where the environment can be controlled (e.g., construction site) it may be adequate]
Capacity	✔✔✔	
Coverage	✔✔✔	Broadcast likely covers area around drone
Security	✔✔	Managed network security improvements do not help since receiver likely not part of the managed network
Integration	✔✔✔	Already in handsets
Latency	✔✔✔	
Deployment issues	✔✔✔	No deployment required. Already in handsets
Cost	✔✔✔	

Technological Advisory Council

Antenna Systems Working Group

December 4, 2019

Antenna Systems Working Group

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Antenna Systems Developments

This year the Antenna Technology Working Group continued with two topics that were studied in 2018.

The Working Group made recommendations for action from the FCC on each of these topics:

1. *Incentivize the use of new improved antenna technologies.*
2. *Facilitate a multi-stakeholder group to create guidelines or industry best-practices to improve the aesthetics of 5g/small cell deployments.*

Antenna Systems Developments

- The working group recommended that the FCC institute policies that incentivize the use of new improved antenna systems. The Commission seeks information on the technical characteristics of new systems, particularly, but not exclusively, in the millimeter wave bands, such as:
  - Characterizing and analyzing potential interference.
    - For example, for phased array and MIMO antennas, what assumptions are necessary unique to these antenna systems relative to the gain between in-band and out-of-band emissions?
    - How should antenna patterns and especially dynamic antenna patterns be taken into account in performing such analyses?
    - To what extent can the antenna patterns and gain be used to mitigate interference risks?
  - Trade-offs between performance improvements and interference risks with the increased flexibility of improved antenna systems.
  - Proposed changes in FCC rules that affect advanced antenna systems.

Antenna Systems Technology Developments

- Advanced Antenna Systems (AAS) provide highly focused RF energy.
- Two forms of AAS:
  - **SDMA** (Spatial Division Multiple Access), using MIMO & Multi-User Massive MIMO
    - Also called **Beam Forming** antennas
    - Uses reflections in the environment to focus on a single area in space.
    - More effective at lower frequencies because of insufficient reflections at mm-wave frequencies.
    - As frequencies gets very low, antenna sizes limit the number of elements and the antenna's effectiveness.
    - The sweet spot for SDMA is 2-6 GHz.
  - **Beam Steering** antennas, such as Phased Arrays
    - Most effective at millimeter wave frequencies.
    - Massive MIMO antennas currently have a problem of consuming significant power as the number of antenna elements increases.
    - Power consumption per bit should be a consideration.

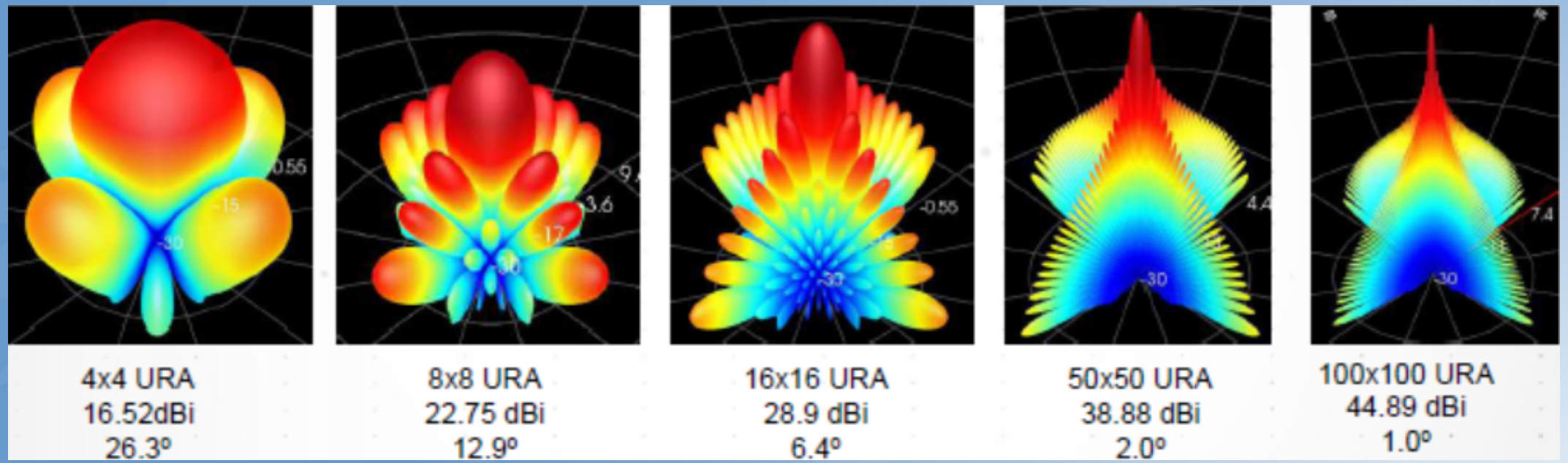
Antenna Systems Technology Developments

- Advanced Antenna Systems are appropriate differently in various frequency bands.

Frequency Range		Probability of deployment	
		Beam Steering	SDMA (Beam Forming)
FR1	< 1 GHz	Not as common due to large antenna array sizes	Not as common due to large antenna array sizes
	2 – 3 GHz	Deployed today with proven 5x gain	Multi-user gains
	3 – 7 GHz	Should be higher gain than 2-3 GHz	Multi-user gains
FR2	24.25 – 52.6 GHz	Essential for realistic operation	Channel sparseness causes limited performance gain over beam steering

Antenna Systems Technology Developments

- Beam steering directionality improves with increasing number of elements



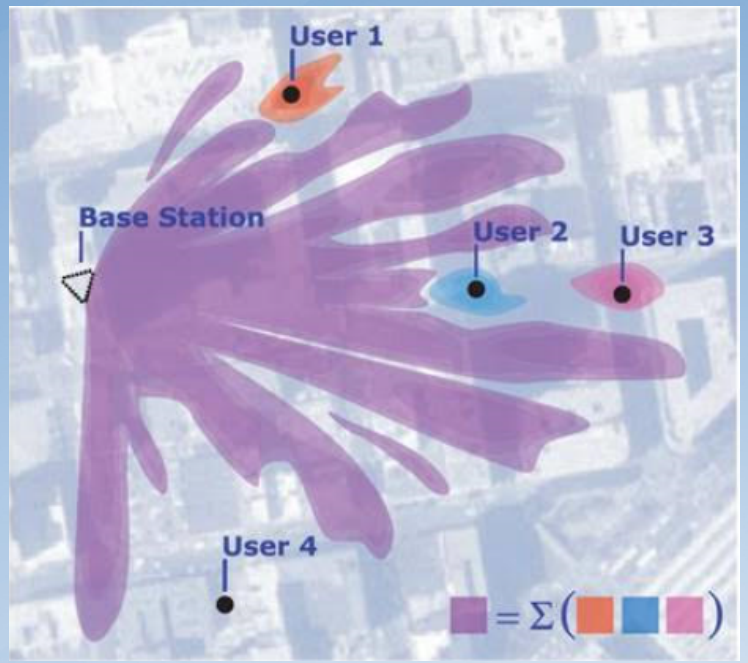
* Images provided by Moray Rumney, Keysight Technologies

Antenna Systems Technology Developments

- Advanced antenna systems:
  - can precisely direct radiated energy to, and receive signals from, specific users. Co-channel sharing is thus possible
  - may reduce co-channel interference with other services through use of highly directional beams in 3 dimensions, limited dwell times at a single location, and low antenna heights.
  - Sharing is enabled through the use of narrow or shaped dynamic antenna patterns (beams and nulls). This may allow enhanced interference management between different services such as Fixed Service, Mobile Service and Satellite Service, and between federal and non-federal systems.

Antenna Systems Technology Developments

- Beam Forming Example:
  - Pattern for a 4 (n) element antenna serving three (n-1) users on the same frequency.
  - The three colored blobs show the energy at each of the served users.
  - The purple is the much lower energy pattern of the total antenna with no processing.
  - All these patterns are continually changing as people move around, as new users come and go, and as the environment changes (moving cars and buses, etc.).



** Image provided by Martin Cooper, DynaLLC*

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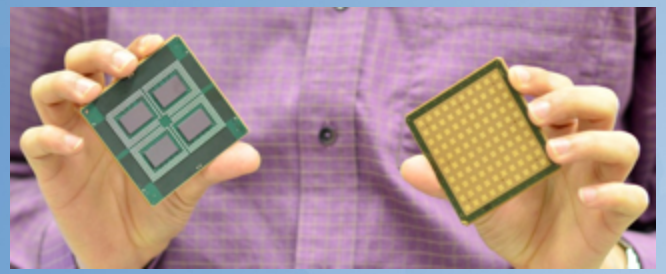
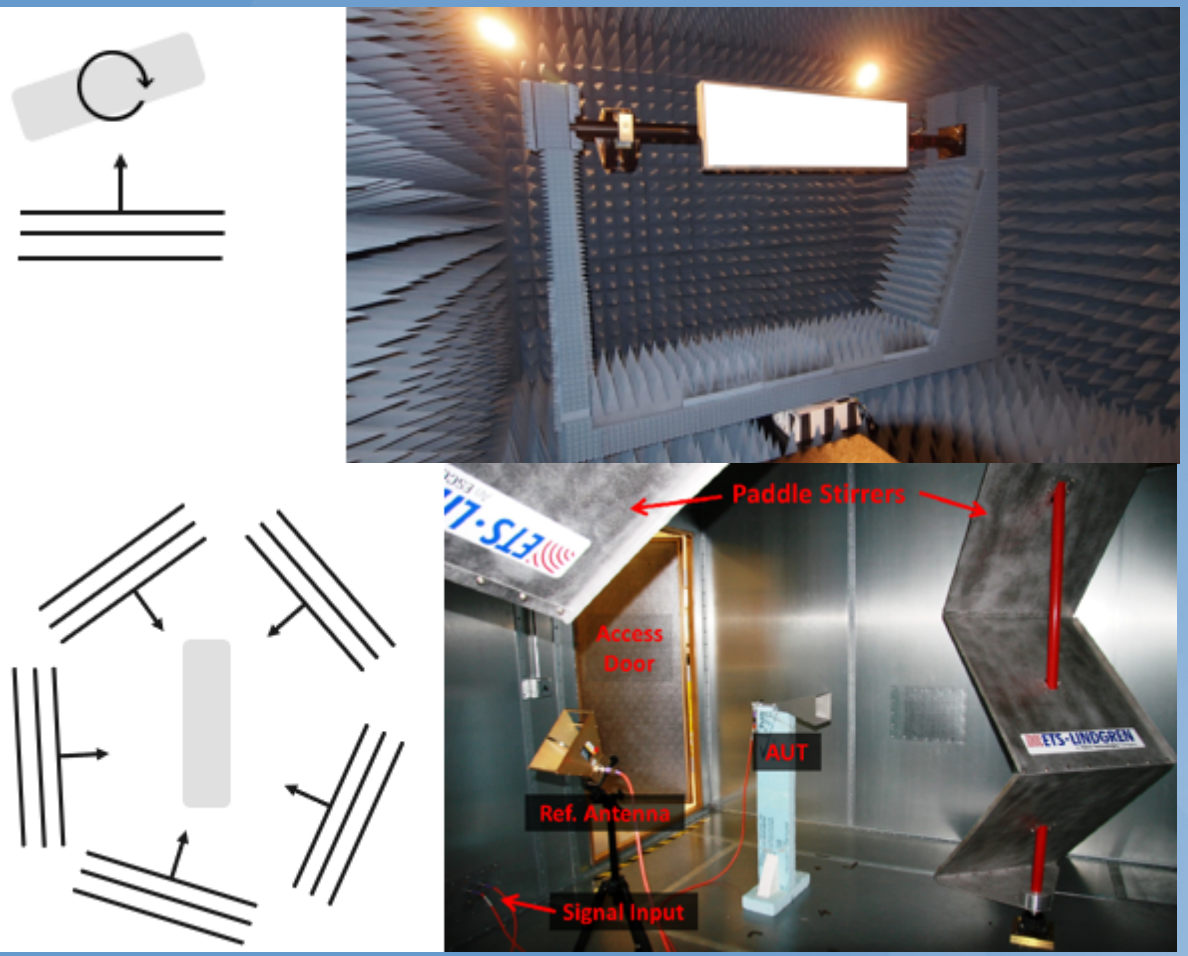
Antenna Systems Testing Developments

- Testing of Advanced Antenna Systems Must Be Different:
  - Incorporation of RF electronics with each antenna element removes the testing ports for both.
  - This type of dynamic antenna cannot be tested with conducted methods.
  - All testing must occur Over-the-Air.



** Image provided by Jonas Friden, Ericsson*

Antenna Systems Testing Developments



- Total Radiated Power (TRP) is being recommended as the preferred testing method.
  - Anechoic chambers complicate such measurements due to longer measurement times and larger chambers needed at lower frequencies.
  - Instead, reverberation chambers are the most efficient way to perform TRP testing, particularly at lower frequencies.

** Images provided by Jonas Friden, Ericsson*

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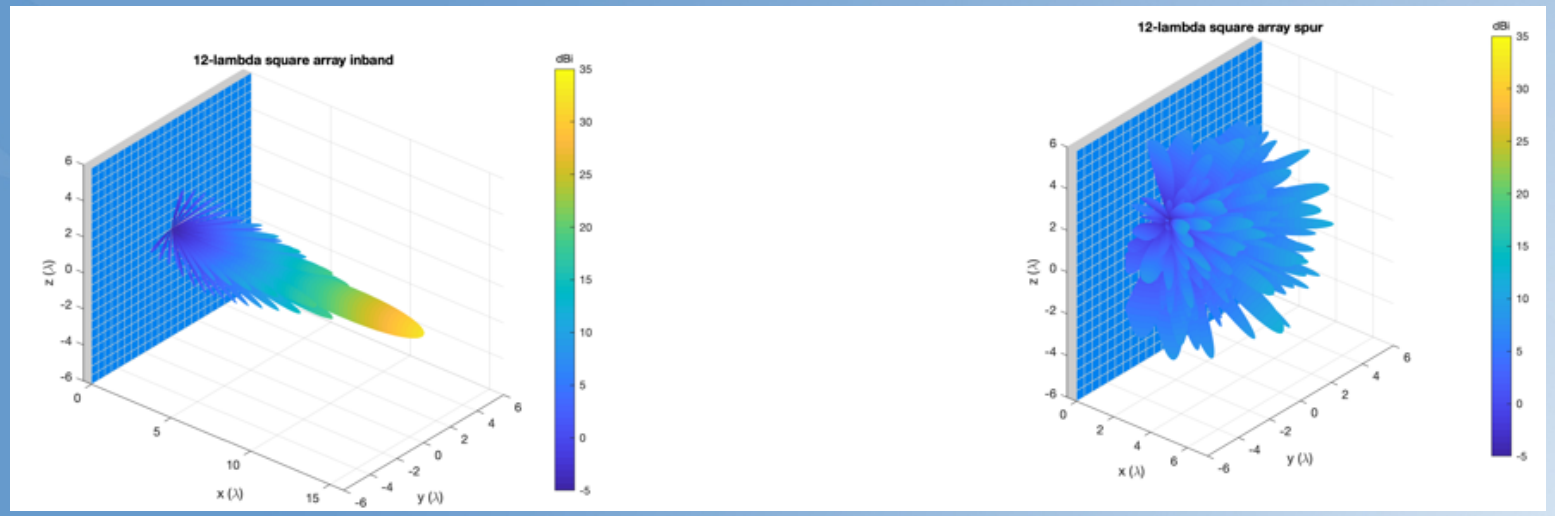
Antenna Systems Testing Developments

- Total Radiated Power (TRP) is better for measuring spurious emissions from AAS.
  - Desired signals are correlated and well focused.
  - Undesired signals (spurs) are uncorrelated and emitted in many directions.



** Images provided by Jonas Friden, Ericsson*

Priorities of 5G Deployment

- In complex communications systems, AAS offers cost, performance and spectral efficiency benefits as compared to passive antennas.
- Emphasis in present deployment plans is on 5G and millimeter wave frequency bands.
- Beam Steering works best at millimeter wave frequencies; SDMA spatial processing offers unique benefits in sub 6 GHz bands.
- It is not generally understood that 5G will deploy in lower frequency bands as well as in millimeter wave bands. Millimeter wave 5G benefits for consumers are expected in the medium term (2-4 years).
- Consumers need lower cost and better coverage in contrast with high speed and low latency that are key 5G benefits.
- Conclusion: direct access of most consumers' devices to millimeter wave technology is not likely for some time and, in rural areas and lesser served constituencies, perhaps never.
- Should the FCC consider using its influence to stimulate a better balance in adoption of advanced technology for existing consumer needs vs. future industrial opportunities. and to educate the public on realistic expectations for 5G?

Myths about 5G and Advanced Antenna Systems (AAS)

Myth	Reality
Advanced Antenna Systems are more costly than traditional passive antennas	Increased capacity and performance more than compensate for increased costs in most cellular systems
Beam forming is lower cost than spatial processing	In high multi-path environments, spatial processing offers higher capacity and more flexibility. At millimeter wave applications, beam steering is superior
5G and millimeter wave applications are synonymous	Millimeter wave application tends to be practical in densely populated areas and impractical in sparsely populated areas (where population includes “things”)
Antenna arrays are impractical at lower frequencies because they are too large	Arrays of as few as eight antenna elements can offer substantial improvements in capacity and performance. Because arrays in spatial processing systems do not need uniform spacing, eight element arrays on towers and building tops are practical
The ability to aim beams is the main advantage of AAS	The ability to aim nulls can have even greater impact in multi-user environments
World leadership in deploying 5G technology is more important than evolving the entire cellular communications network	The benefits of cellular communications for consumers and industry in the fields of health care, education, and enhanced collaboration are only beginning to be exploited in our society. There should be a balance between the **Internet of Things** and the **Internet of People**

Advanced Antenna Systems

- What remains to be seen:
  - How tightly will millimeter wave beams be focused?
  - Sidelobes still exist in all focused beams; how much can they be attenuated?
  - How are spurious emissions propagated in an advanced antenna system?
  - Explore creation of a glossary of Advance Antenna Systems terminology to enhance the continuing discussion of measurement and prioritization related to introduction of this technology.

Advanced Antenna Systems Tower of Babel

Examples of Poorly Defined Terms

Multiple-Input Multiple-output (MIMO)
Massive MIMO (M-MIMO)
Single User MIMO
Multiple-user MIMO (MuMIMO)
Phased Arrays
Remote Radio Head (RRH)
Switched Beam
Beam Steering
Beam Forming
Spatial Processing
Spatial Division Multiple Access (SDMA)
Subarrays
Array Of Subarrays (AOSA)
Antenna vs. Antenna Element

Antenna System Appearance

- The working group last year recommended the Commission facilitate a multi-stakeholder group to create guidelines/industry standards to improve the aesthetics of 5G/small cell deployments to improve public acceptance.
- In examining the long latency of results from the existing 3.5 GHz band multi-stakeholder group, the working group concurs that such a solution may be incompatible with current 5G deployment schedules.

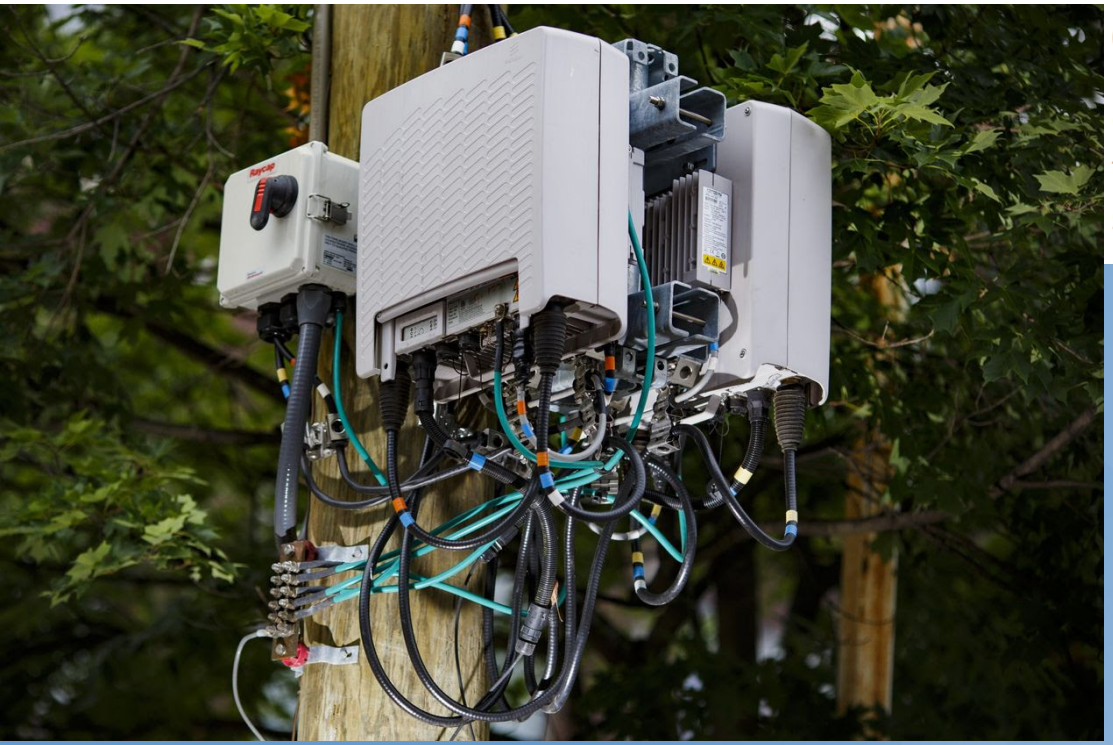
Antenna Systems Appearance

- The Working Group reviewed small cell ordinances from 40 states, cities and towns
  - A lot of commonality
  - Some stark differences
  - Rural vs Urban
- Examples of objectionable installations are self-evident

The Need for Some Intervention to Support the 5G Rollout

THE WALL STREET JOURNAL.

August 24, 2019



Cities Are Saying No to 5G, Citing Health, Aesthetics—and FCC Bullying

Those hawking specious safety concerns about the new technology have found common cause with some of America's most powerful mayors

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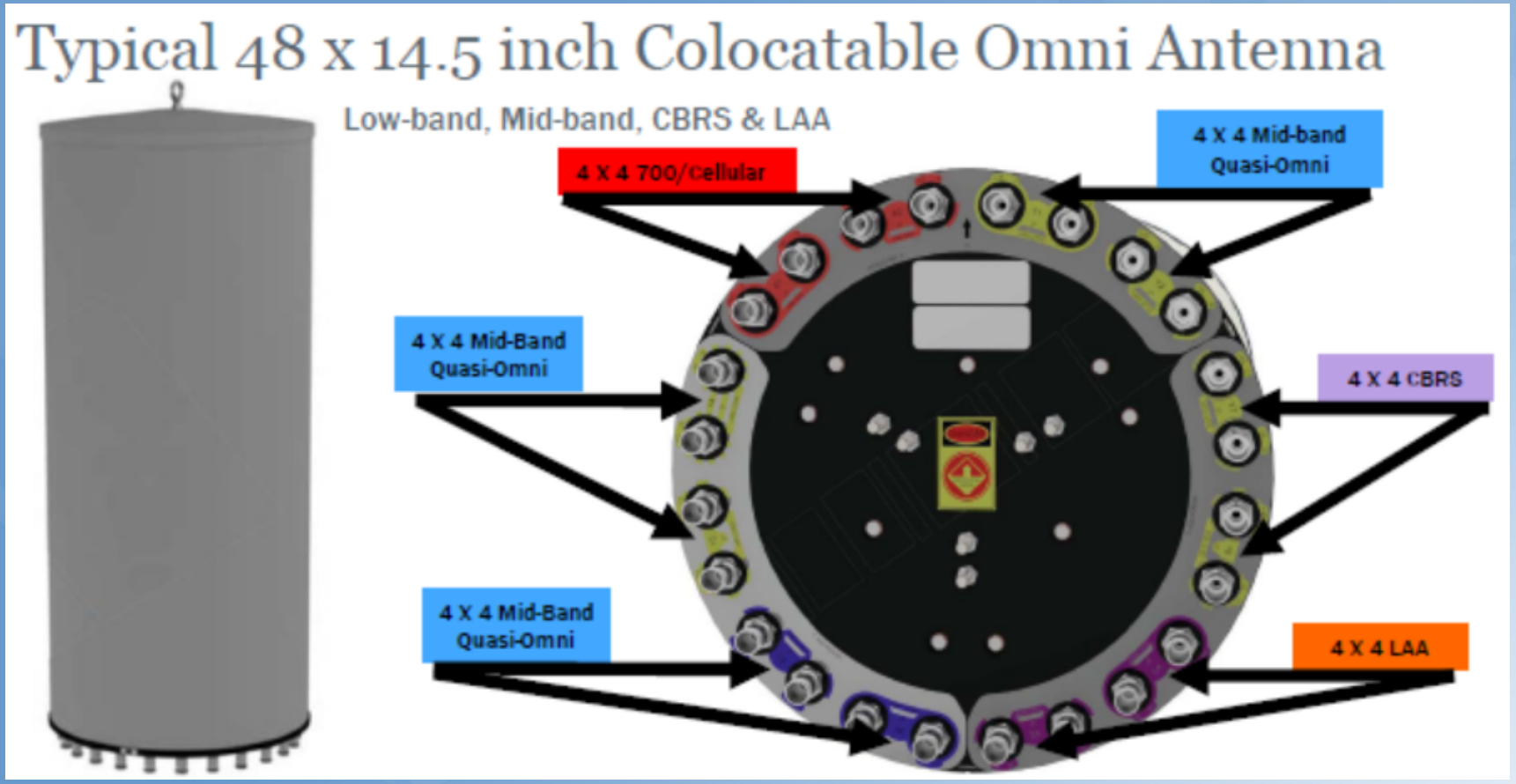
Small Cell Appearance

- An industry Best Practice for installing small cells may help to decrease local resistance to their installation.
- The FCC Broadband Deployment Advisory Committee (BDAC) has addressed interactions between the FCC and local and state governments, but not how to deal with appearance issues.
- The FCC Intergovernmental Advisory Committee (IAC) has not addressed small cells.
- The Antenna Technology Working Group plans to produce a White Paper that summarizes the various zoning regulations across the nation.

Small Cell Appearance

- Trepidation exists about the advent of 5G in less populous communities that expressed fear that their landscape will appear like a forest of small cells.
- Sharing of small cells by multiple vendors can help to reduce the number of small cells that need to be built.
- Antenna canisters that support multiple antennas and frequencies will aid in sharing.

Compound Antennas Improve Cell Appearance



** Image provided by Michael Hughes, Crown Castle*

Cellular Base Station Appearance White Paper

- Regulations and ordinances that affect small cell appearance will be grouped by community size: Dense Cities, Suburban Communities, Rural Areas
- Basic appearance characteristics that apply to all small cells will be summarized.
- The Working Group's goal is to release a document in mid-2020.

Antenna Systems Working Group Recommendations

1. The FCC should stimulate more aggressive deployment of technologies that will provide lower cost and improved coverage to currently underserved communities.
2. The FCC should initiate a proceeding regarding regulation and testing procedures for AAS in sub-6 GHz spectrum and for SDMA beam forming.

Antenna Systems Working Group Continuing Tasks

- The working group, with industry participation, will create a white paper that clarifies AAS terminology to enhance the FCC's collaboration with industry as more complex antenna configurations offer improvements in efficiency and effectiveness while making regulation of radio frequencies more difficult.
- The working group will create a white paper that summarizes zoning regulations affecting small cell appearance from across the nation.
- The working group will continue to explore the different possibilities for testing AAS, particularly SDMA beam forming technologies and sub-6 GHz.
- The working group will explore reports that small cell technology consumes an excessive amount of power.

THANK YOU

5G/IoT Working Group

WG Chairs: Russ Gyurek, Cisco & Brian Daly, AT&T

Date: Dec 4, 2019
Meeting: FCC Headquarters, DC

2019 Working Group Team Members

- Brandon Abley, NENA
- Ahmad Armand, T-Mobile
- Kumar Balachandran, Ericsson
- Mark Bayliss, Visualink
- Marty Cooper, Dyna
- Adam Drobot, OpenTechWorks
- Jeffrey Foerster, Intel
- Dale Hatfield, Univ of Colorado
- Steve Lanning, Viasat
- Greg Lapin, ARRL
- Kevin Leddy, Charter
- Brian Markwalter, CTA
- Lynn Merrill, NTCA
- Robert Miller, inc Networks
- Paul Misener, Amazon
- Jack Nasielski, Qualcomm
- Mike Nawrocki, ATIS
- Arthur Nichols, Windstream
- Madeleine Noland, ATSC
- Hamid Reza, Samsung
- Dennis Roberson, entigenlogic
- Scott Robohn, Juniper
- Jesse Russell, incNetworks
- Travis Russell, Oracle
- Kevin Sparks, Nokia Bell Labs
- Marvin Sirbu, Spec. Gov. Emp.
- Tom Sawanobori, CTIA
- David Young, Verizon

FCC Liaisons: Michael Ha, Padma Krishnaswamy, Nicholas Oros

5G and the Internet of Things WG: 2019 Charter Questions

1. How are low, mid, and high frequency bands being used in deployments, both in the U.S. and internationally?
2. What is the status of deployment of vertical support & services, i.e. energy, transportation, health care, etc.
3. What technical steps are being taken to ensure deployment of 5G services to rural areas, especially those related to low latency dependent applications?
4. How are 5G capacity, speed and latency projections playing out in general and by application and by geography?
5. Considering that a long roll-out is likely, what is the 5G evolutionary path and where will this lead us in terms of new functionality to meet the needs and desires of the citizens of the U.S.?
6. To what extent is 5G making a difference for IoT deployments. How will this evolve?
7. What is the status of satellite offerings of 5G service?
8. What new developments have arisen that the Commission should be aware of and/or address?

Autumn WG Activities

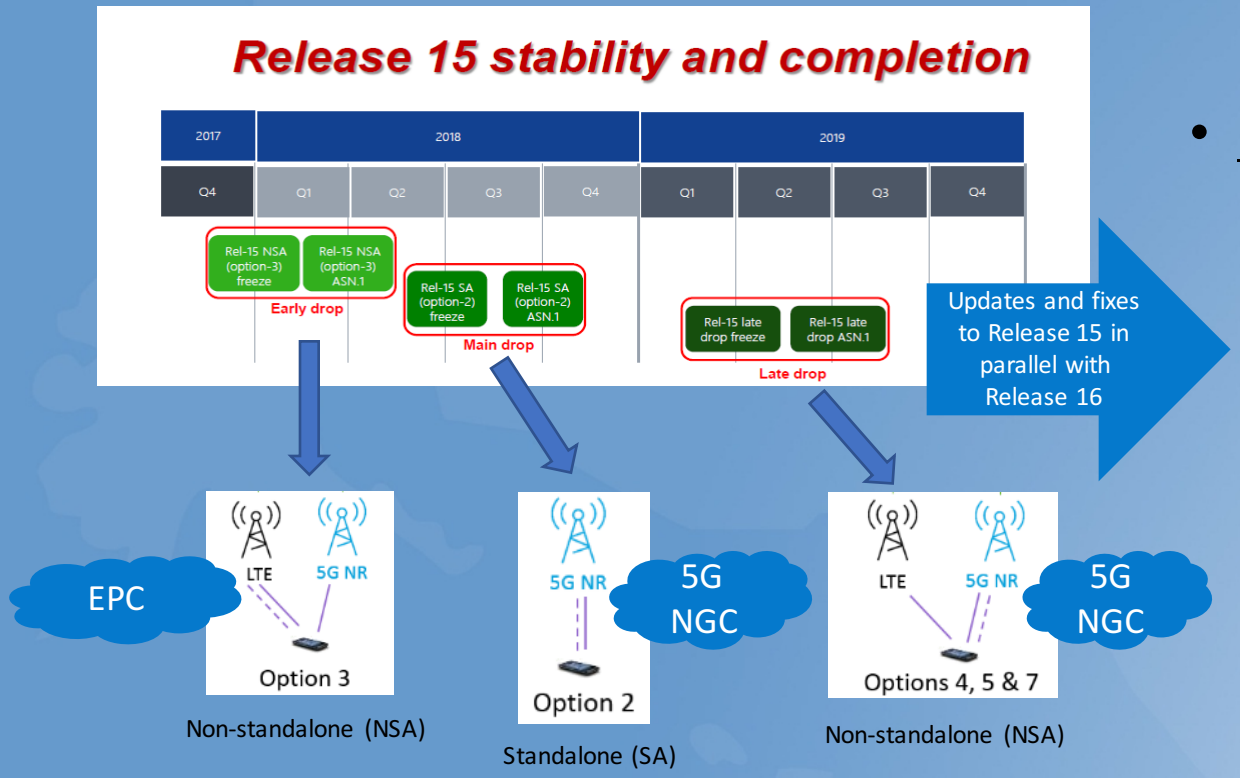
A number of SME speakers

- 5G Standards activities
- 5G/IoT vertical requirements
- Neutral Host deep dive
- Rural SWG: Finalized 2019 learnings and recommendations
- Satellite impact and 5G intersection
- Open Source and O-RAN
- Futures: 6G planning
- Overall spectrum topics: low band to mmWave, shared, licensed needs, unlicensed needs

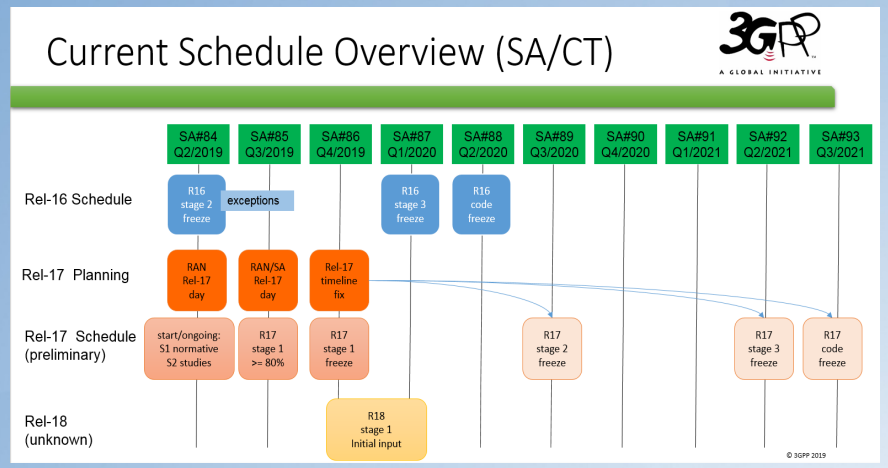
Speaker	Representing	Key Learnings
Steve Lanning	Viasat	• Satellite capacity can be launched and configured to meet the needs of any user • Future capacity is increasing presenting cost effective solutions especially for high cost locations
Paul Smith	AT&T	• O-RAN has potential to open up the RAN to more industry involvement and competition • open source SW and HW reference designs which can enable faster innovation
Dr. John Graybeal	CISCO	• There is an unmet IT need for in-building spectrum • Locally licensed spectrum would fill IT related gap not addressed by SP licensed spectrum • mmWave (~37Ghz) would provide high re-usability and coverage
Mike Nawrocki	atis	• Neutral Host selectively used today for multi-operator deployment in managed spaces • A broader definition includes shared infrastructure currently used in other parts of the world • Technology and business implications need to be assessed (spectrum, shared costs, etc.)
Dale Hatfield		• Wireless systems are inherently open; thereby more attack opportunities • 5G scale and virtualization/disaggregation at various levels creates a greater threats surface
Jennifer Manner	ECHOSTAR	• 5G non-terrestrial networks are being explored in ATIS and 3GPP (Hughes is a contributor) • Satellite will have a greater role in complementing broadband services
Brian Daly	AT&T	• Research related to 6G has started, how does USA remain a leader • FCC should begin understanding 6G technology directions and potential impacts
Joachim Sachs	ERICSSON	• Industrial automation needs spectrum for deterministic and reliable communication • 5G NR URLLC has features for low latency and improved error performance • Distributed Cloud reduces latency by bringing services closer to the user

Industry & Standards

3GPP Standards Update

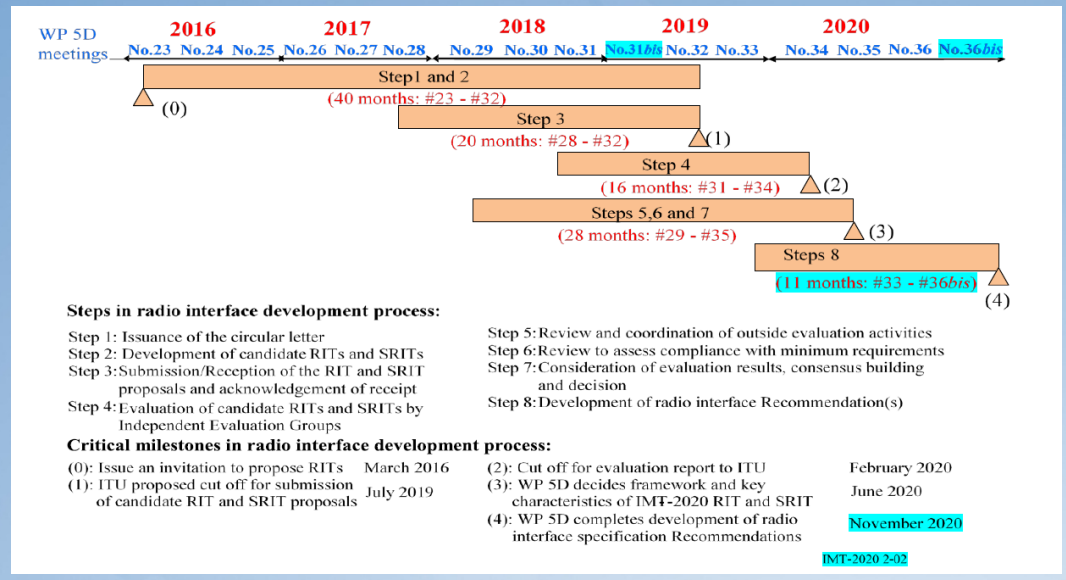


- Rel 16 status (in progress) - Complete March 2020 (ASN.1 in June)
- Rel 17 Final agreement on content & timeline December Plenary



ITU IMT-2020 Submissions (6)

- IMT.2020/3 - ‘3GPP’
  - Two submissions: 3GPP 5G New Radio (NR) and a combination of NR+LTE+NBIoT
- IMT.2020/4 - ‘Korea’
  - In accordance with the latest 3GPP NR Technical Specifications (compliant to 3GPP Release 15 onward)
- IMT.2020/5 - ‘China’
  - 3GPP NR-based
  - IMT-2020 (5G) Promotion Group - promote the research of 5G in China, contribute to 3GPP
- IMT.2020/6 - ‘ETSI & DECT Forum’
  - Digital Enhanced Cordless Communications (DECT) 2020 & Ultra Low Energy (ULE)
  - Target Verticals: Smart Home; Industry 4.0; Audio Industry; Healthcare
  - openD Connect – GitHub, DECT and ULE for mission critical, robust, wireless applications
- IMT.2020/7 - ‘TSDSI’ (India)
  - Low Mobility Large Cell (LMLC), particularly with emphasis on low-cost rural coverage of 5G wireless network services
  - India believes that the process works well only for countries with strong industry presence in 3GPP
- IMT.2020/12 - 'Nufront’ (China)
  - Enhanced Ultra High Throughput (EUHT) developed by NUFRONT



O-RAN

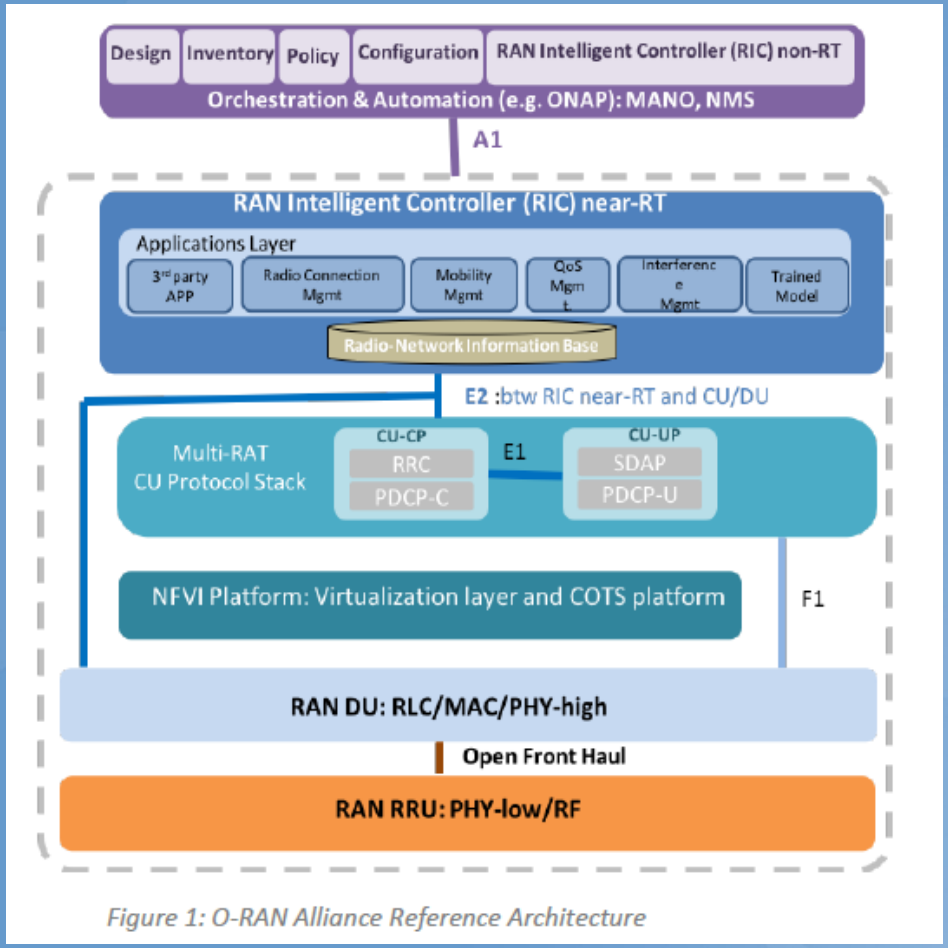


Figure 1: O-RAN Alliance Reference Architecture

O-RAN Alliance → create open hardware specs with open source software running in the equipment

- 107 companies have joined O-RAN; 20 Operators

Open interfaces enable:

- smaller vendors and operators to quickly introduce their own services, or operators to customize the network
- Multivendor deployments, enabling a more competitive supplier ecosystem.

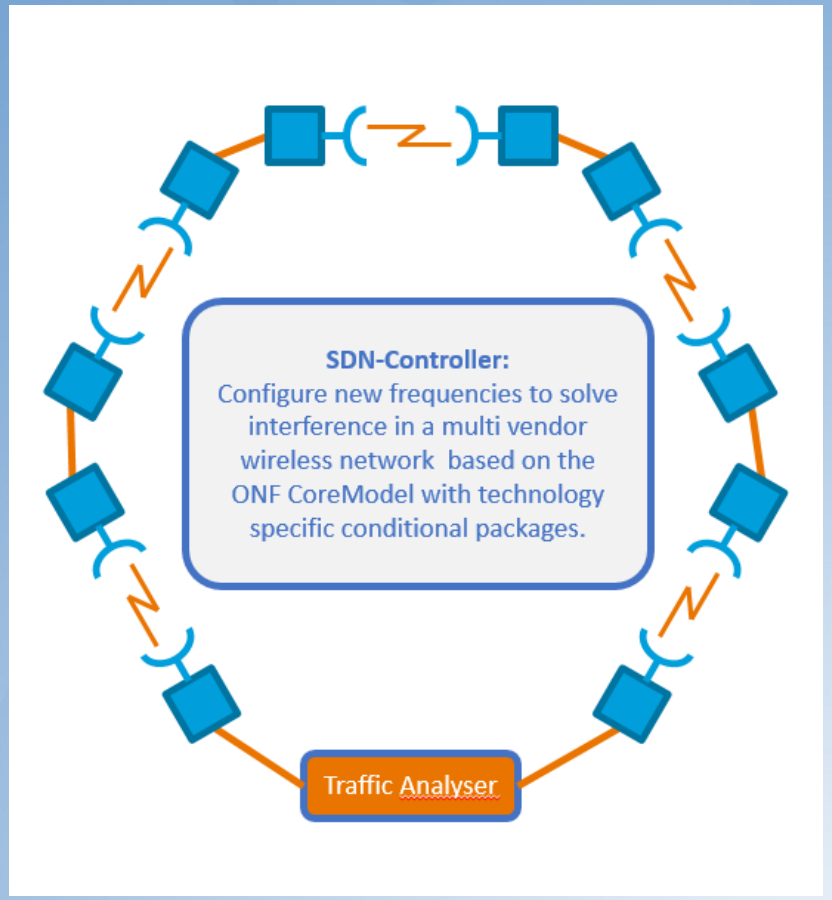
Similarly, open source software and hardware reference designs which can enable faster innovation

O-RAN Specifications

- Use Cases and Overall Architecture
- Non-real-time RAN Intelligent Controller and A1 Interface
- Open Fronthaul Interfaces
- Open F1/W1/E1/X2/Xn Interface
- Cloudification and Orchestration
- Stack Reference Design

O-RAN Example - Shared License /Spectrum Management

- Demonstrate SDN controller (nonRT-RIC) capability of dynamic spectrum allocation using the evolving O-RAN Information Model (OIM)
- One trigger to reconfigure allocated frequency channels for each link in the network in order to mitigate high interference conditions by changing operating frequency channels to another with acceptable lower interference level.
- Change of frequency channel could also be required in response to an external entity (e.g. regulator agency spectrum management and allocation server or database) to evacuate certain frequency channels for other operation.
- Spectrum management use case is applicable to wireless networks operating in unlicensed spectrum, in self-managed block assigned spectrum, or in sharing spectrum such as the CBRS 3.5 GHz band in US.



National 5G Deployment Updates

- **T-Mobile**:
  - 6 5G mobile deployments
  - T-Mobile says 200 million customers will have access to their national 5G network on 12/6/2019
  - National 5G network will cover 5,000 cities and towns covered by YE2019
- **Sprint**:
  - 9 5G mobile deployments
  - As of 10/22/2019, Sprint's 5G network covered approximately 16 million people
- **US Cellular**
  - 5G service expected in parts of Wisconsin Iowa by 1Q2020
- **Verizon**:
  - 20 5G mobile and fixed deployments
  - 13 additional 5G mobile and fixed deployments planned by YE2019
- **AT&T**:
  - 21 5G mobile deployments
  - 2 additional 5G mobile deployments planned by YE2019
  - AT&T plans to cover 200 million POPs with 5G by 2020

Nationwide:

- **57 5G mobile and fixed deployments to date**
- **72 5G mobile and fixed deployments and one nationwide 5G network by YE2019; others in 2020**

International 5G Deployment Updates

- **China**:
  - On 11/1/2019, China's three mobile service providers launched 5G service in 50 communities.
  - Reportedly over 10 million 5G subscribers as of 11/1/2019
  - By YE2019, Chinese mobile service providers plan to expand 5G service to all cities above the prefecture-level.
- **Japan:**
  - Japan's mobile service providers remain in the testing and buildout stage of their 5G networks
  - Reportedly mobile service providers expect 5G service to roll out in 2020
- **South Korea**:
  - Reportedly 85 cities will have 5G mobile service by YE2019
  - Reportedly there were 4 million 5G subscribers in July, with expectations of 5 million 5G subscribers by YE2019
- **United Kingdom**:
  - The UK's three major mobile service providers have 30 active 5G mobile deployments and plan to have 58 active 5G mobile deployments by YE2019
  - According to Ovum, the UK had 110,000 5G subscribers by 9/30 and will reach 1.22 million subscribers by YE2019

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Website tracking 5G deployments WW

DEPLOYMENT TYPES

☑ Commercial Availability	1249
☑ Limited Availability	28
☑ Pre-Release	150

https://www.speedtest.net/ookla-5g-map

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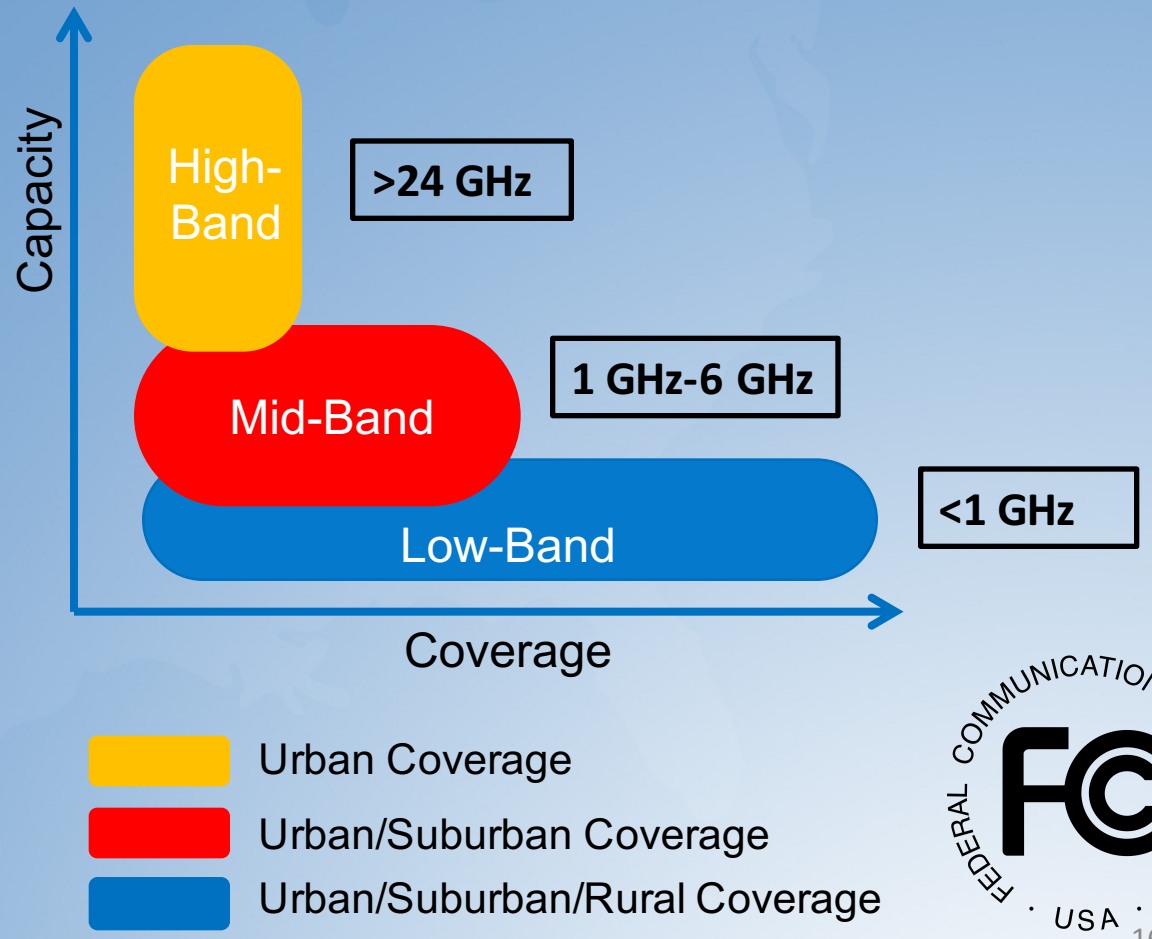
Spectrum Review

Spectrum needs for 5G

- 5G success depends on a mix of low, mid, and mmWave spectrum to support the various deployments and use cases
- Shortage of available spectrum in low and mid bands
- Limited shared spectrum currently available (CBRS)
- Lack of dedicated or locally licensed spectrum
- Q: how to balance licensed and unlicensed spectrum needs?



Additional Spectrum for Consideration

- In addition to the spectrum already allocated and under consideration, there are other bands that could/should be considered for potential use/repurposing for 5G.

Low-Band Spectrum	Mid-Band Spectrum	High-Band Spectrum
• 1300-1390 MHz: There is an ongoing FAA study to determine if 30 to 50 megahertz of this band could be repurposed.	• 1780-1830 MHz: Adjacent to existing AWS allocations; used for commercial mobile services globally. • 3450-3550 MHz: NTIA to issue report about use of this band and its ability to be used for 5G.	• 42.5-43.5 GHz: Internationally used for 5G; could be added to existing 42-42.5 GHz band.

Source: DLA Piper Global Law Firm

Recommendations

Rural recommendation areas under consideration

Licensed Spectrum

- FCC to actively drive more spectrum sharing
  - Rules by region, by time
- Consider optimal license sizes and terms to promote rural deployment

Power levels

- Allow for increased power output levels in 3.5 GHz band, whitespace and un-licensed bands where incumbents can be protected. Explore licenses options
  - provide greater reach for rural/sparse geographies and environments
  - Proposed 2020 effort: TAC to examine increased power for geographies where there are no incumbents

Multi-Operator Shared Infrastructure

- FCC to promote
  - "RAN Sharing" in rural markets
  - shared backhaul/backbone infrastructure
- FCC to explore funding tied to neutral/managed host for rural
- Proposed: TAC 5G/IoT WG to further investigate WW successes of neutral host deployments

Commission oversight

- Recommend BB funding used to encourage high performance networks (> 25Mbs/3Mbs)
  - Enforcement of deployment milestones and performance commitments tied to spectrum licenses

Overall recommendation areas under consideration

Removal of Barriers Recommendation

- FCC program focused on consumer education and acceptance:
  - Radio frequency exposure concerns
  - Densification of new radios/antennas

Spectrum Recommendations

- Recommendation: Additional and potential repurposing: Low/Mid band spectrum- severely short
- The TAC supports 3.7 GHz-4.2G Hz action and would like to see acceleration of shared spectrum in 3.1 GHz – 3.55 Ghz
- Advisement: There is a lack of shared/locally licensed spectrum to meet in-building/industrial/IT needs

Security Advisement

- Radio Spoofing and jamming are issues; FCC should solicit and endorse industry led and other solutions
- As 5G transitions from NSA to SA:
  - Massive IoT connectivity security risks exist – work to be done
  - Devices may open up security threats to 5G network –particularly legacy devices

IoT Advisement

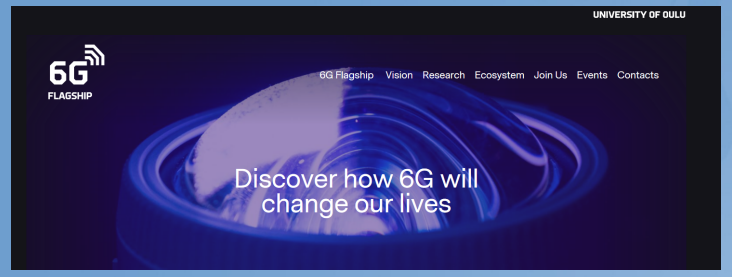
- Leading IoT Use: industrial, transportation and Healthcare
- Statement: CBRS will *not* support industrial automation and control system requirements
  - Spectrum implications: USA needs to compete with WW spectrum options
- FCC plays a key role in expanding IoT deployment
  - Mix of licensed, shared, unlicensed, and locally licensable spectrum needed

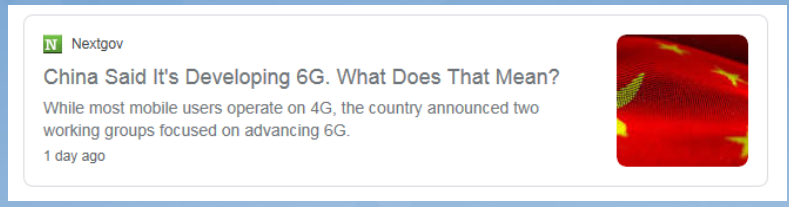
Future WG Focus Areas

2020

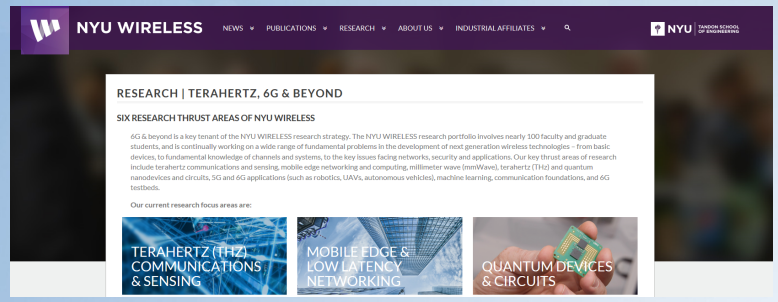
The Path to 6G (it's real)

- Setting the Stage for U.S. Leadership in 6G
  - Academy of Finland 6Genesis flagship program
  - China said it is developing 6G
  - 6G Partnerships being formed
- Cellular generations are ~ every 10 years
  - Does that mean an IMT-2030? With requirements ~2022?
- U.S. faces mounting challenges to its leadership in wireless communications technology
- Growing Chinese clout in international standards-setting poses economic security risks to the U.S.
- China announced plans to launch two separate working groups focused on advancing 6G
  - One composed of relevant government departments, with the intent of promoting the development and implementation of 6G
  - One representing 37 universities, research institutes and enterprises, to provide advice and insights on the technicalities of 6G deployment





- Call for Action*:
  - Expand public funding for research and development of emerging technologies, e.g. 6G Public Private Partnership
  - Promoting more open, more interoperable communications technologies
  - United States must lead in developing secure HW and SW
  - Take steps now to ensure an effective transition from 5G to 6G and reap the economic benefits of these advanced networks



* Source: https://www.lawfareblog.com/setting-stage-us-leadership-6g

What *might* "6G" look like?

- Transmission speeds 10 times greater than 5G, near-zero latency and connection density as high as 10 million devices per square kilometer
- Communications in the high gigahertz (GHz) and terahertz (THz) range
  - frequencies above 95 GHz hold the key to numerous advantages, including strong penetrability (e.g., walls and clothing) and very high bandwidth
- Presence technology and location awareness
  - Working in conjunction with AI, computational infrastructure of 6G autonomously determine the best location for computing to occur

Fig. 1. 6G vision: Applications, trends, and technologies.

Source: "A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems", Walid Saad, Mehdi Bennisy, and Mingzhe Chen, arXiv:1902.10265v2 [cs.IT] 21 Jul 2019

2020 Proposed Areas of Focus for 5G/IoT WG

5G Spectrum

- Explore low and mid band spectrum opportunities
- Locally licensed needs: inside buildings, service fencing
- Optimization and efficiency- the only way to solve limited/lack of spectrum (AAS will help)
- Additional shared spectrum opportunities, and rules
- Unlicensed needs

IoT

- IoT vertical needs and value proposition wrt spectrum; low to mmWave. The related economics tied to spectrum
- Prioritization and timelines (by vertical)
  - Remote Healthcare, Industrial 4.0, transportation, etc
  - Ag: a special case based on BB geography
- Emerging technologies impacting 5G: eSIMs, lower-power

Security

- IoT related impacts; vertical specific needs/concerns
- Industry & Standards: overview of improvements and gaps
- Radio spoofing, jamming, sniffing/interception
- Coordination with CSRIC WG activities

5G & Beyond

- Non-5G options
- Past 5G, 6G planning
- High end mmWave uses
- MEC and slicing impacts as deployments accelerate
- Next wave of deployment: radar, wireless sensing, hi-res imaging/3D

Thank You!

FCC TAC AI-WG
Artificial Intelligence

Chairs: Lisa Guess, Cradlepoint
Adam Drobot, OpenTechWorks, Inc.

FCC Liaisons: Michael Ha, Mark Bykowsky, Bahman Badipour, Eric Burger, Mark Doczkat, Gulmira Mutapaeva

Date: December 4, 2019

2019 Work Group Team Members

- Shahid Ahmed, Independent
- Nomi Bergman, Advance
- Brian Daly, ATT
- Adam Drobot, OpenTechWorks
- Jeffrey Foerster, Intel
- Dale Hatfield, Univ of Colorado
- Lisa Guess, Cradlepoint
- Russ Gyurek, Cisco
- Stephen Hayes, Ericsson
- Mark Hess, Comcast
- Nageen Himayat, Intel
- Steve Lanning, ViaSat
- Kevin Leddy, Charter
- Brian Markwalter, CTA
- Lynn Merrill, NTCA
- Michael Nawrocki, ATIS
- Nimish Radia, Ericsson
- Dennis Roberson, entigenlogic
- Marvin Sirbu, SGE
- Kevin Sparks, Nokia Bell Labs
- David Tennenhouse, VMware

Artificial Intelligence – 2019 Charter

- The Artificial Intelligence (AI) work group is a continuation of the 2018 Computational Power Stress on the Network WG with a focus on artificial intelligence.
- The work group is tasked with providing information on AI and the variety of roles it might play in communications networks and services.
  - Where is AI being deployed in networks today and how will it develop?
  - What benefits and risks does it provide in the broad communications space?
  - Are there Commission rules or policies that are barriers to the introduction of AI?
  - Where might the FCC introduce AI in its own systems and processes to enhance the efficiency and effectiveness of FCC missions?

Artificial Intelligence – 2019 Charter (cont)

- Artificial intelligence is not new and has been around since the early 1960s. However, many view it as a relatively new field that has very broad implications in the communications space. Old or new, the working group has flexibility to determine what might be of most interest and importance and where actionable recommendations might be most valuable to the Commission.

Agenda

- Working Group Composition and Charter
- A bit about Artificial Intelligence
- Application of Artificial Intelligence and Machine Learning to Networks
- Market and National Trends in Artificial Intelligence
- Working Group Results for CY2019
- Suggested WG on AI and Computing Plan for CY 2020
- Recommendations

- Appendix
  - References
  - List of Speakers
  - Background Information

Artificial Intelligence (AI) - A number of views - no general definition!

- Alan Turing launched a debate in the 1940's and suggested a test on how or if a capable computer could be distinguished from a human being, and John McCarthy coined the term" Artificial Intelligence" in 1956. Their view is AI as a capability of using computers to mimic/rival human intelligence and cognition – often called general or context aware intelligence.
- Another broad view – AI as a capability that exploits computers to brings value to tasks that are difficult for humans to perform well or that can be performed better by computers than by humans:
  - Doing repetitive things at a very high volume - humans do not do this well.
  - Automation of routine tasks – bringing economic value and freeing humans from drudgery
  - Dealing with high levels of complexity – where we have difficulty keeping things straight
  - Performing specialized tasks where repeatability and attention is crucial - no distractions!

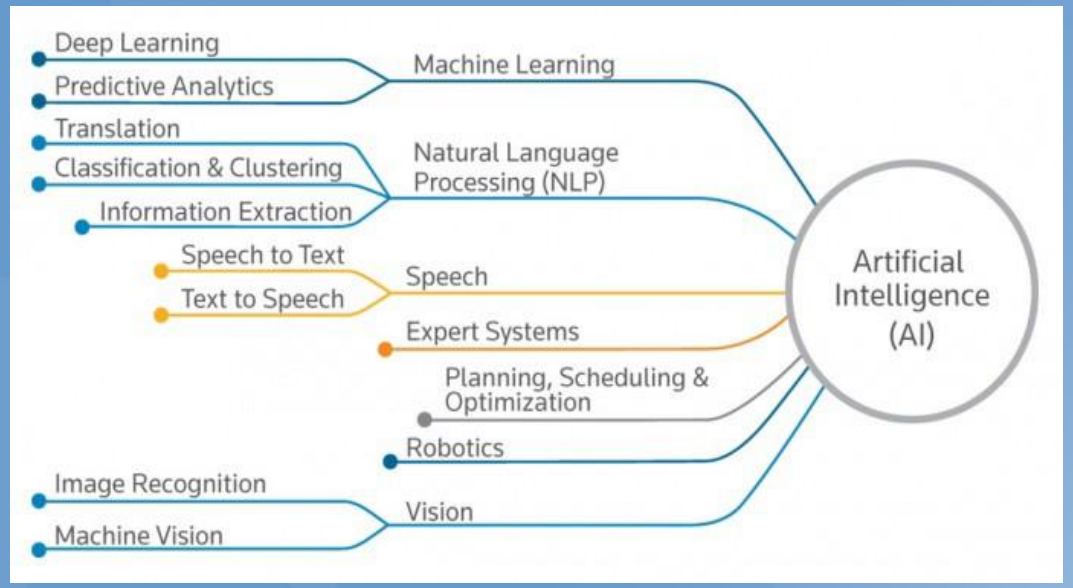
Artificial Intelligence (AI) - A number of views - no general definition!

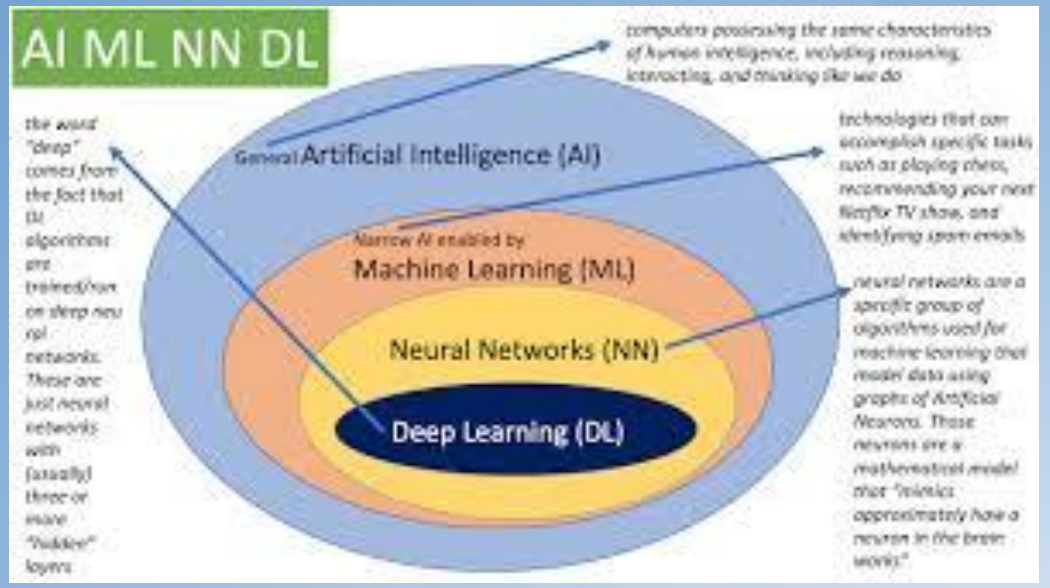
Thinking Humanly	Thinking Rationally
"The exciting new effort to make computers think . . . *machines with minds*, in the full and literal sense." (Haugeland, 1985) "[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning . . ." (Bellman, 1978)	"The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985) "The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992)
Acting Humanly	**Acting Rationally**
"The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990) "The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991)	"Computational Intelligence is the study of the design of intelligent agents." (Poole *et al.*, 1998) "AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998)

Artificial intelligence (AI) as simulated intelligence in machines*

Stuart J. Russell and Peter Norvig, "Artificial Intelligence A Modern Approach," (Third Edition), Prentice-Hall, 2010.

Artificial Intelligence (AI) and the branches within AI

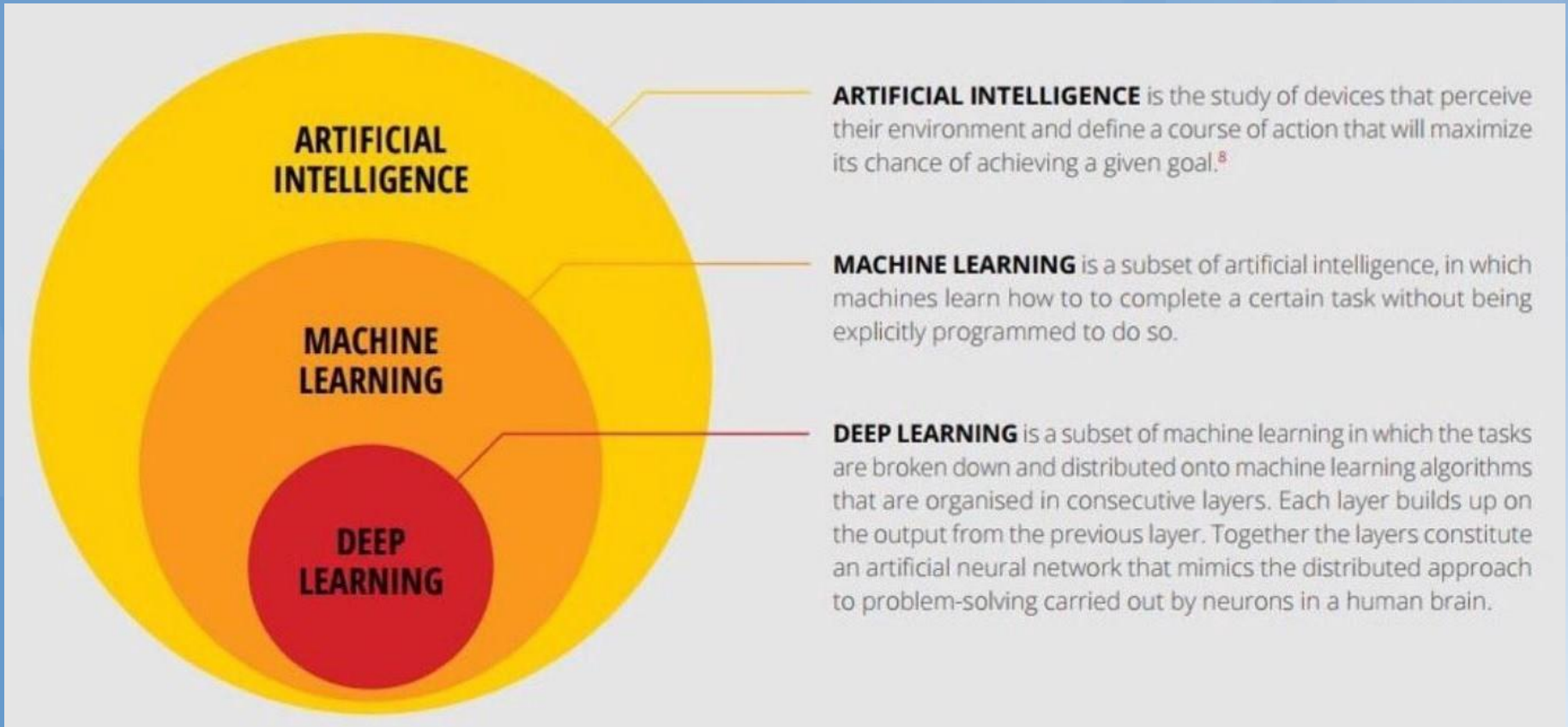




Widely circulated images and explanations on the Web of what Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) entail

Chethan Kumar GN
Data Scientist @Iqreate Infotech Pvt Ltd

Artificial Intelligence (AI) and where ML and DL fit in



Source:
Dhanoop Karunakaran, Deep learning series 1: Intro to deep learning

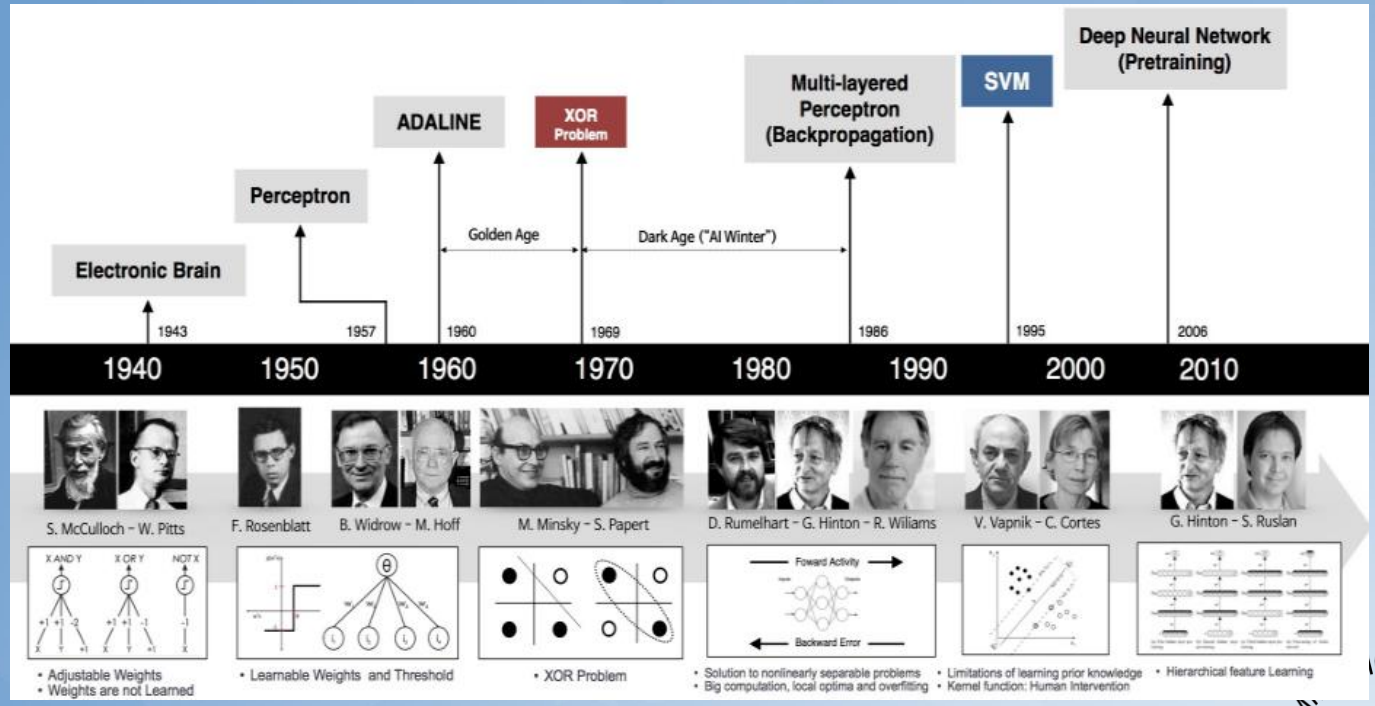
Artificial Intelligence and the Various Components (A partial view)

Methods	Disciplinary Areas
Machine Learning and Deep Learning (Neural Networks)	Natural Language Processing and Understanding (Text Analysis, Automated Translation, …..)
Expert, Knowledge and Rule Based Systems	Speech Recognition and Synthesis
Analytical Techniques and Formal Methods (Algorithms and Heuristics)	Robotics and Machine Systems
Statistical Methods	Vision Systems (Image Recognition and Feature Extraction)
Model Building and Simulations	Automation and Autonomous Control Systems
Classification, Clustering, and Identification (Search)	Predictive Maintenance
Inference, Reasoning, and Problem-Solving	Intelligent Systems
General Intelligence – A long Term Goal	

Artificial Intelligence and Machine Learning

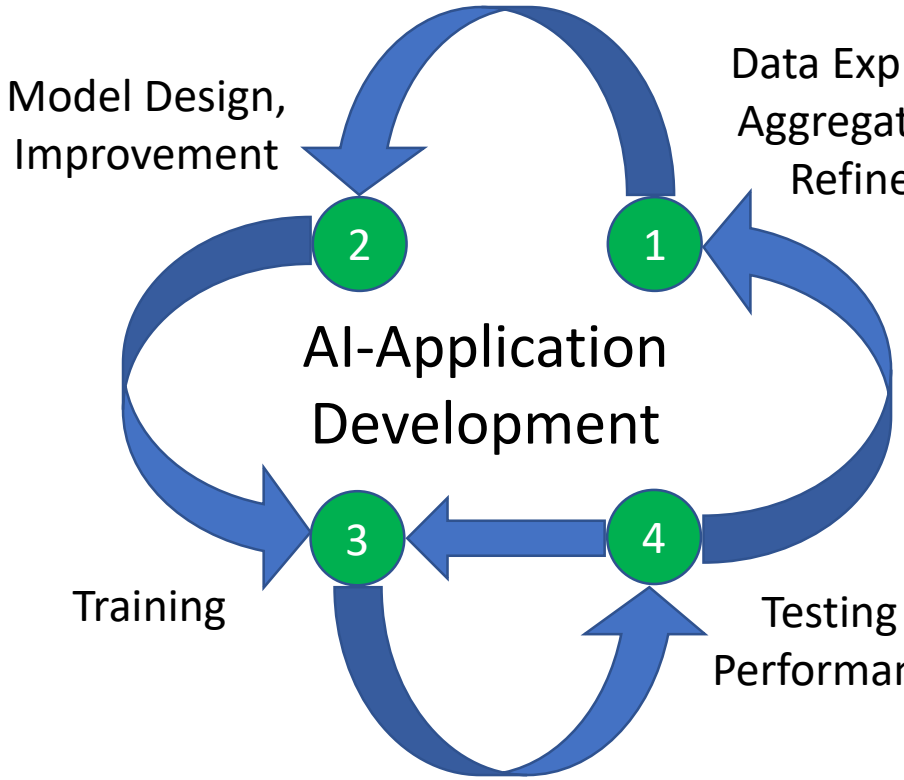
- Three major methods are being deployed
  - Rules-based systems
  - Statistics-based systems
  - Hybrid of both

- Deep Learning
  - Statistics-based using neural networks
  - Requires large volumes of training data
  - Most successful efforts have used supervised learning
  - Unsupervised learning success is an active area of research

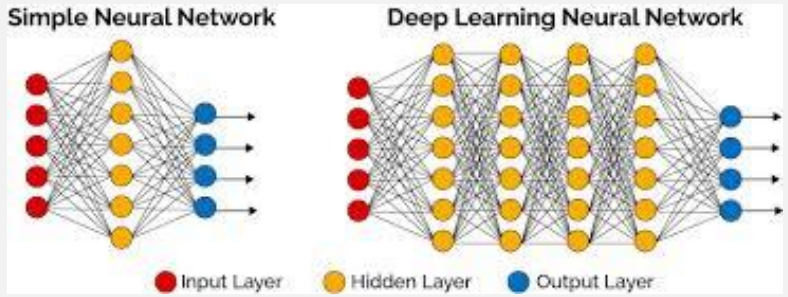


Deep Learning Timeline: Source:
https://beamandrew.github.io/deeplearning/2017/02/23/deep_learning_101_part1.html

Artificial Intelligence – From Development to Operations



Typically done in the Cloud
Communication, Storage
and Compute Intensive

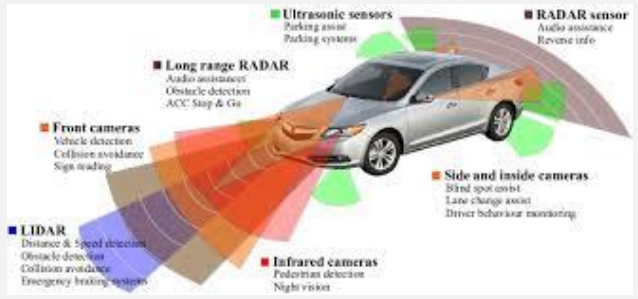


AI-Operation

Source: Patricia Florissi Global CTO Sales, EMC/Dell

Artificial Intelligence – From Development to Operations

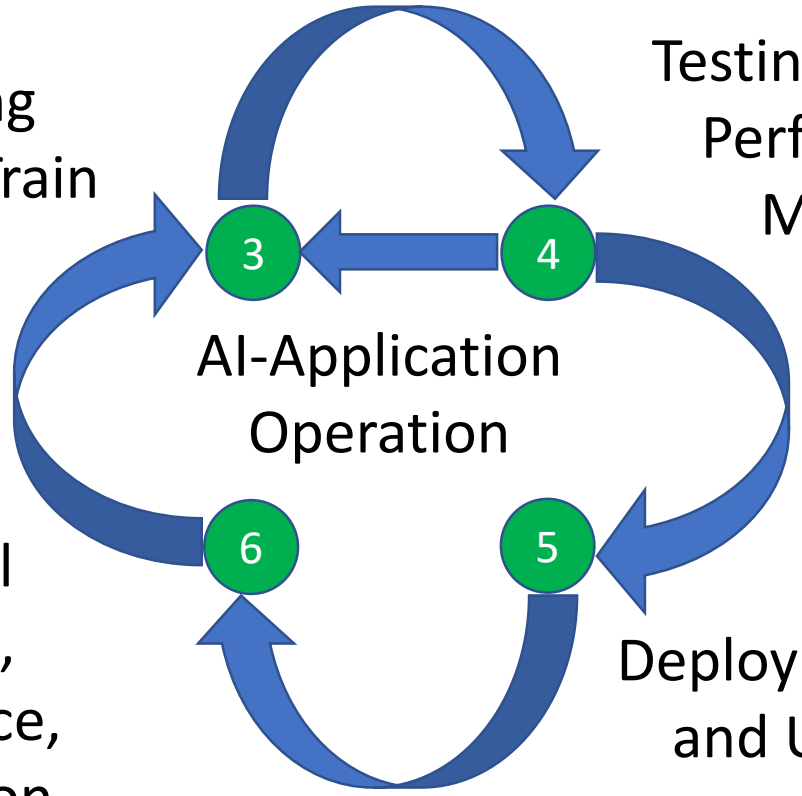
Typically done on the Platform and the Edge
Communication, Storage and Compute Intensive, with input from sensors and commands to actuators



AI-Development

Training
And Re-Train

Testing (Meeting Performance Metrics)



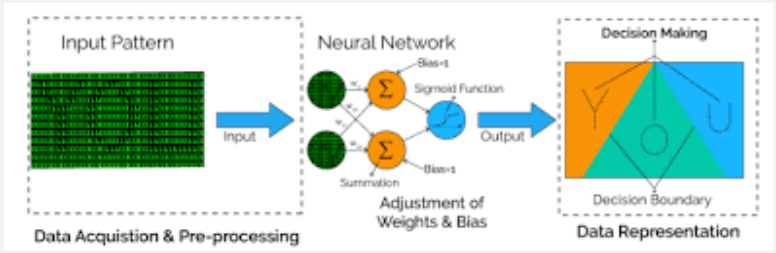
Run Model
- Sensing,
- Inference,
- Actuation

Deploy (Maintain, and Upgrade)

Source: Patricia Florissi Global CTO Sales, EMC/Dell

Artificial Intelligence – From Development to Operations

Typically done on the the Edge and in the Cloud, Communication, Storage and Compute Intensive, with input from sensors.



AI-Development

Train

Adjust Weights

3

7

AI-Application Learning Cycle

AI-Operation

8

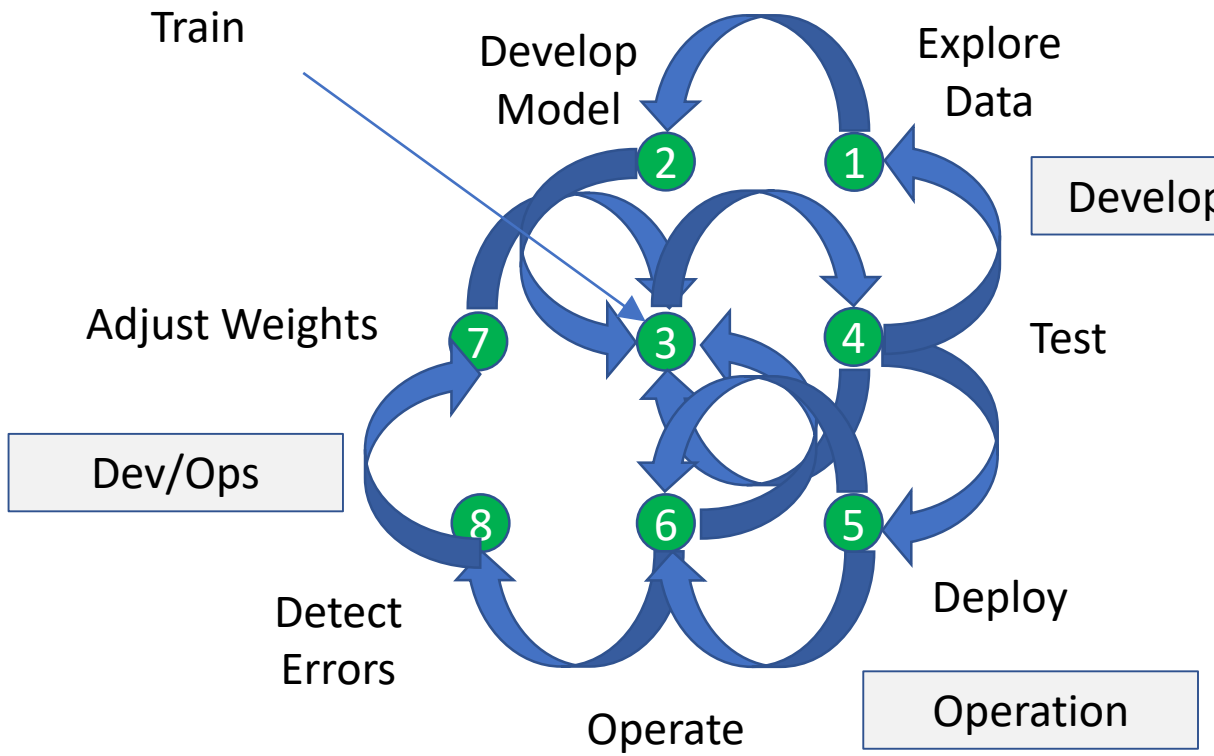
6

Measure Error

Run Model/Operate

Source: Patricia Florissi Global CTO Sales, EMC/Dell

Artificial Intelligence – From Development to Operations



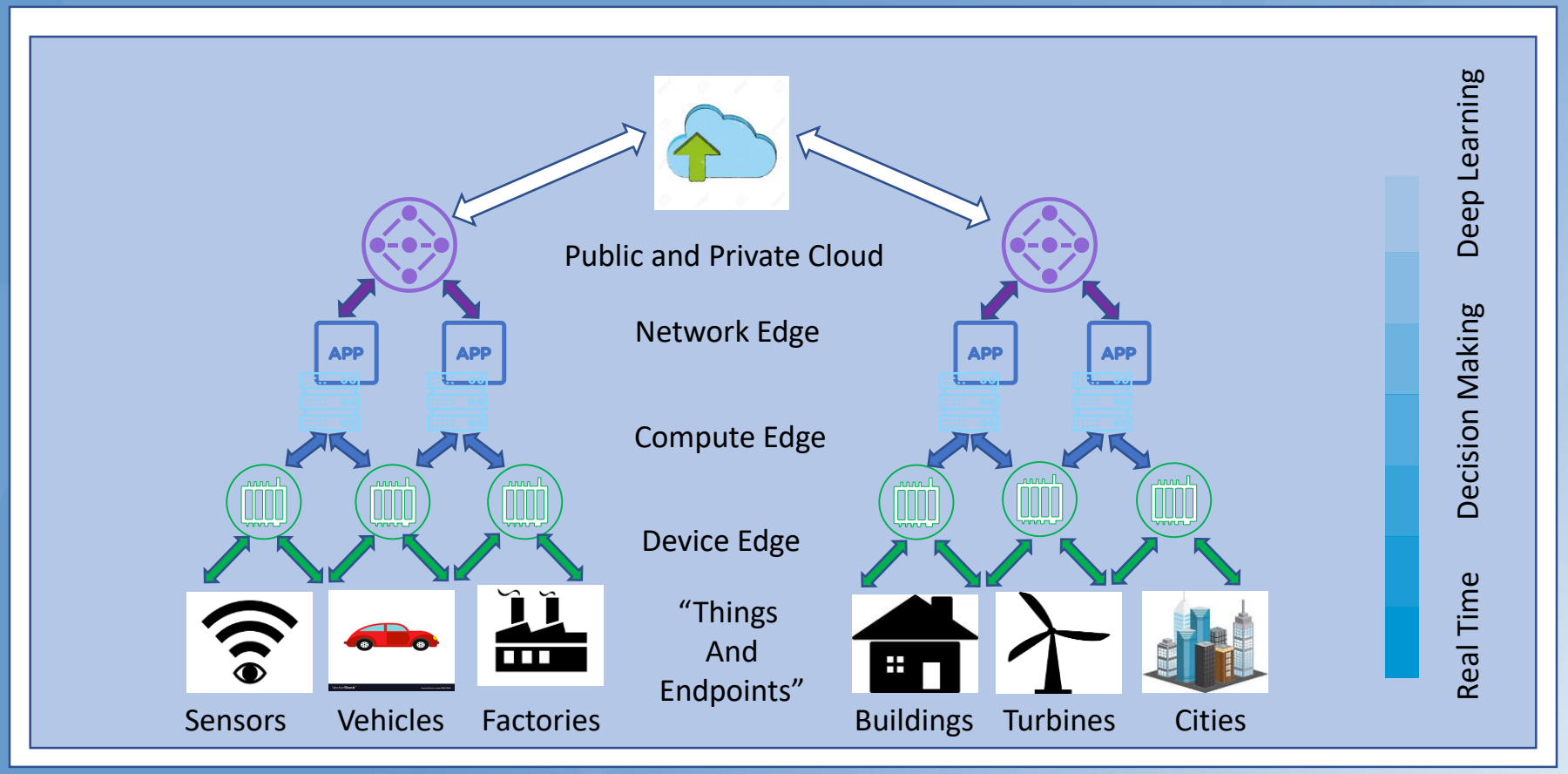
Distributed Resources:
- Computing
- Storage
- Communications

Other Components:
- Sensors
- Actuators
- Human Interfaces

Software

Source: Patricia Florissi Global CTO Sales, EMC/Dell

Artificial Intelligence – From Development to Operations



Influence of Distributed Compute and Storage Requirements on Network Architectures and Resources

Artificial Intelligence – From Development to Operations

The deployment of AI based solutions is rarely stand alone in terms of resources, infrastructure, and capabilities required. There is a strong interplay with other technologies, disciplines, and eco-systems developed around the areas of practice.

The typical technologies include but are not limited to:

Exponential Technologies	Capabilities	Ecosystems/Infrastructure
Computing	Domain Knowledge	Cloud/Fog/Edge Facilities
Storage	Information Technologies	Mobility/Nomadic Technologies
Connectivity	Data Science and Engineering	Power and Energy
Sensors	System Design	Manufacturing Facilities
Actuators	Integration	Public Infrastructure
Human Interfaces	Deployment and Implementation	Education and Training
Software	Operational Technologies	Research and Development

Artificial Intelligence – From Development to Operations

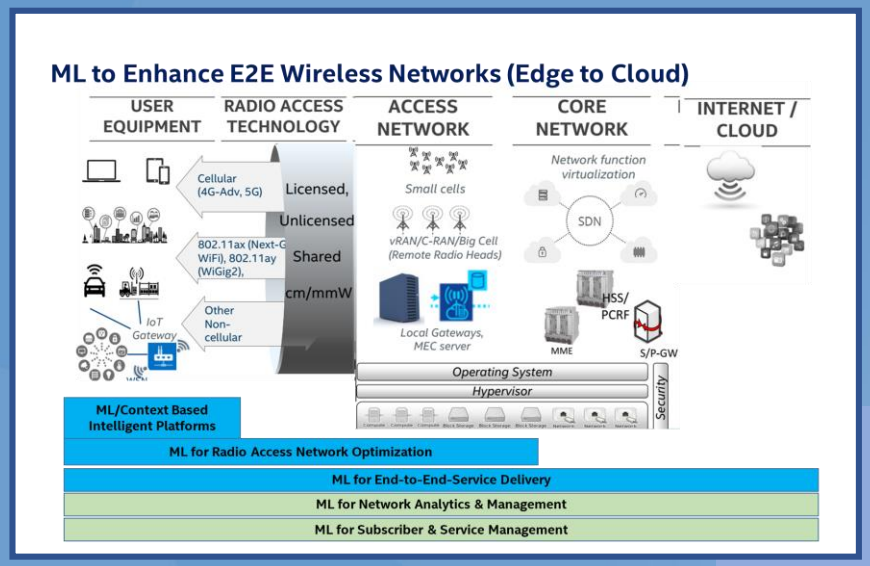
AI-based methods and techniques are likely to be important for almost every Vertical in the US Economy and affect:

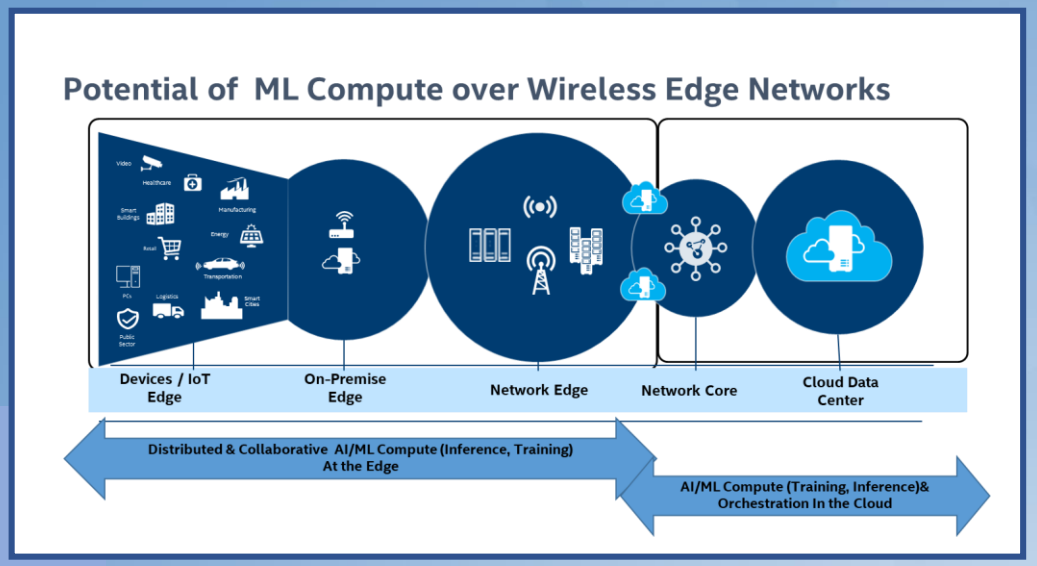
- Manufacturing
- Goods/Products
- Services
- Processes within organization (business to business, and customer facing)

The influence and impacts include Industry, the Public Sector, Small and Medium Sized Enterprises, and Consumers

There are already many AI based products and services well established in the marketplace!

Applications of AI and ML techniques in Wireless Networks

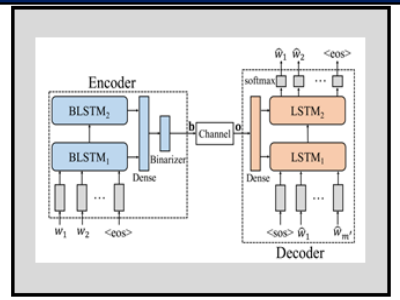




Traditional Applications

Source:
Nageen Himayat
Intel

ML for Communicating E2E Semantics



"Deep Learning for Joint Source and Channel Coding of Text."
(N. Farsad, M. Rao, A. Goldsmith, 2018)

ML for Wireless Sensing

https://atap.google.com/soli/

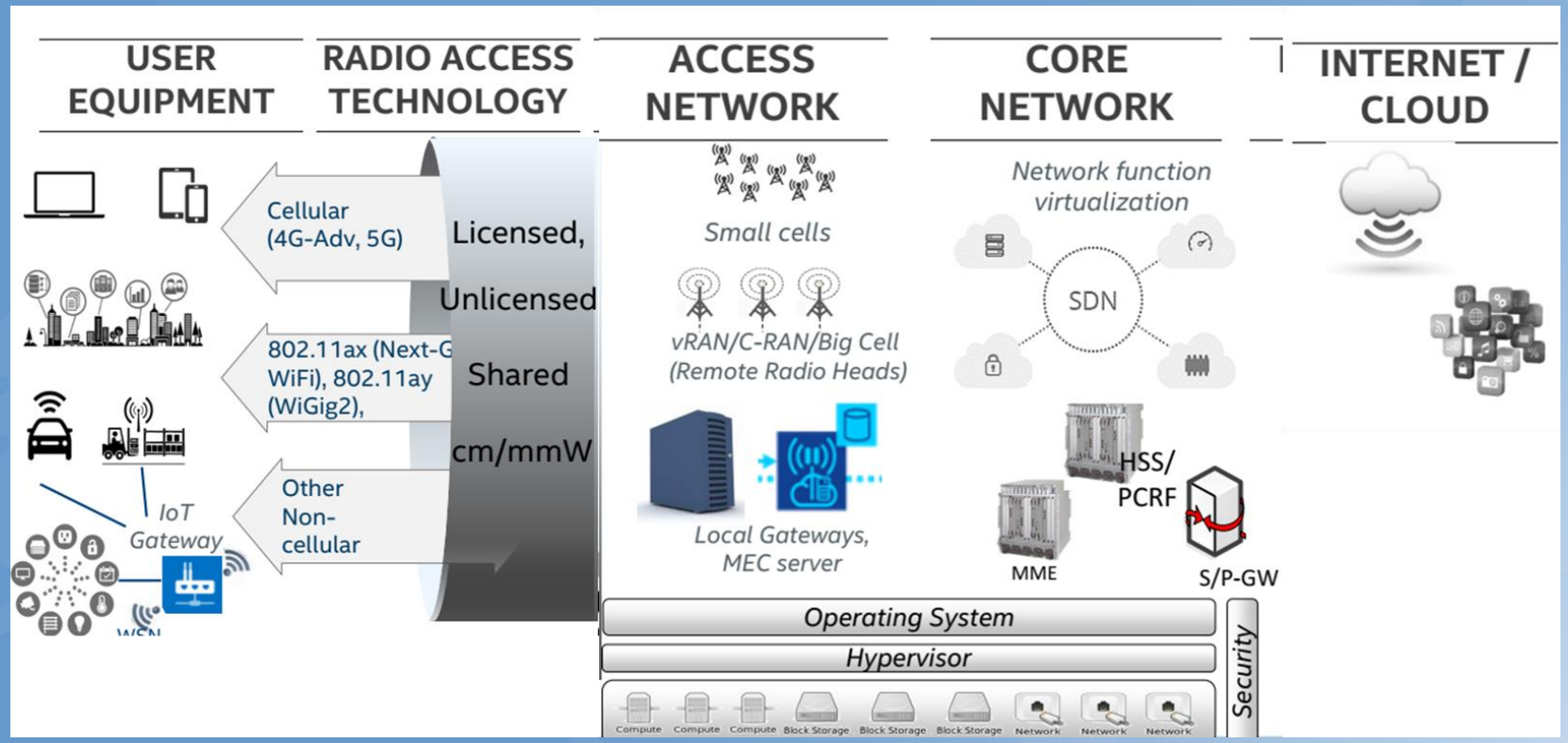
Google Project Soli uses radar for gesture recognition

https://www.aerial.ai/

Aerial uses ML with WiFi sensing for motion detection

New Applications

Applications of AI and ML techniques in Wireless Networks



AI as a fundamental tool for:

- Performance
- Optimization
- Efficiency

And Innovation In what the Network can do

Source:
Nageen Himayat
Intel

Dealing with Heterogeneity, Complexity, Traffic, and Diversity of Services

Applications of AI and ML techniques in Wireless Networks

Semantics	Optimizing for semantics (text, video), semantic aware source channel coding.	Multi-disciplinary AI/ML techniques
Application	Optimizing service delivery, co-design control and wireless, predicting user behavior, application quality, QoE optimization.	Context Aware processing, Predictive Methods, (Deep) Reinforcement learning, Recurrent Neural Networks, Generative Networks, Actor Critic Models
Network Layer	Routing/Forwarding, Traffic Classification Congestion Control, Mobility Management, Anomaly Detection.	(Stochastic) Optimization, Deep Learning, Deep Reinforcement Learning, Graphical Models
Medium Access	Random access , Radio Resource Management, Scheduling, Cell Association, Interference Control, Cell deployments, Handovers	(Stochastic) Optimization, Reinforcement Learning, Graph Neural Networks, Multi-agent learning, Bayesian Learning
Physical Layer	RF front-end, waveform design, channel estimation, modulation schemes, Multi-antenna, channel coding, air-interface design.	Detection, Estimation, Bayesian Learning, Deep Learning, Generative Networks, Auto-encoders
Spectrum	Spectrum sensing, monitoring, analysis, channel characterization, co-existence, dynamic sharing	(Stochastic) Optimization, Expert Systems, Deep Learning, Recurrent Networks, Reinforcement Learning, Multi-agent Learning

Source:
Nageen Himayat
Intel

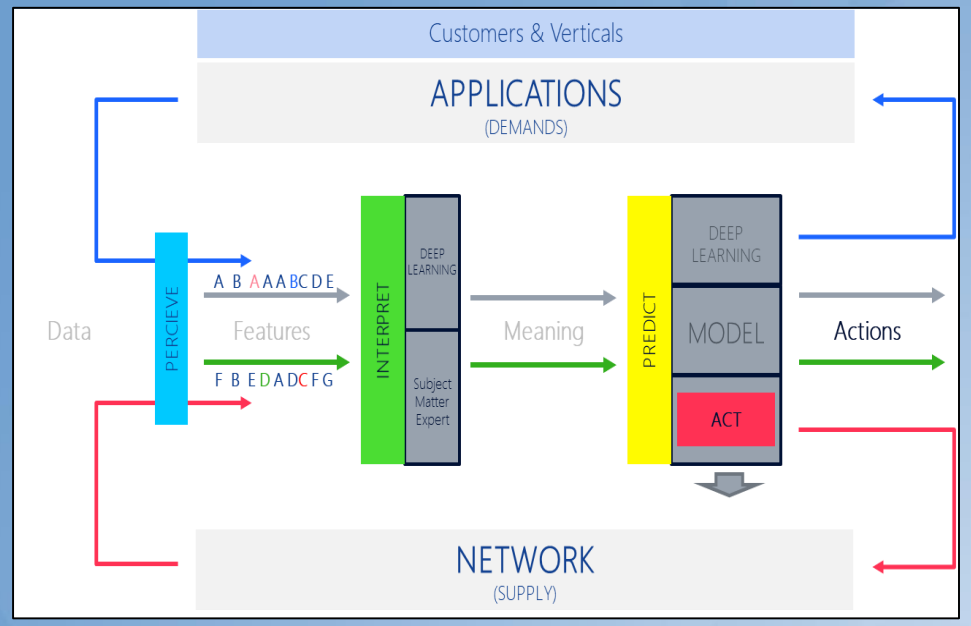
Applications of AI and ML techniques in Wireless Networks

Machine Learning Methods and Techniques applied to Network Architecture, Design, and Operation

Source: J. Wang, C. Jiang, H. Zhang, Y. Ren, K.-C. Chen and L. Hanzo, "Thirty years of machine learning: The road to Pareto-optimal next-generation wireless networks," *preprint arXiv:1902.01946*, 2019.

Applications of AI and ML techniques in Wireless and Broadband Networks

- Network as an AI Consumer
  - Channel modulation
  - Smart routing
  - Predictive maintenance
  - Latency management
- Network as a provider of AI as a Service
  - AI Platform
    - Network improves outcomes in the Perceive-Interpret-Predict-Act cycle
  - Phishing detection (“fake” news and emails)
  - Decision making assistant
  - Big data compaction

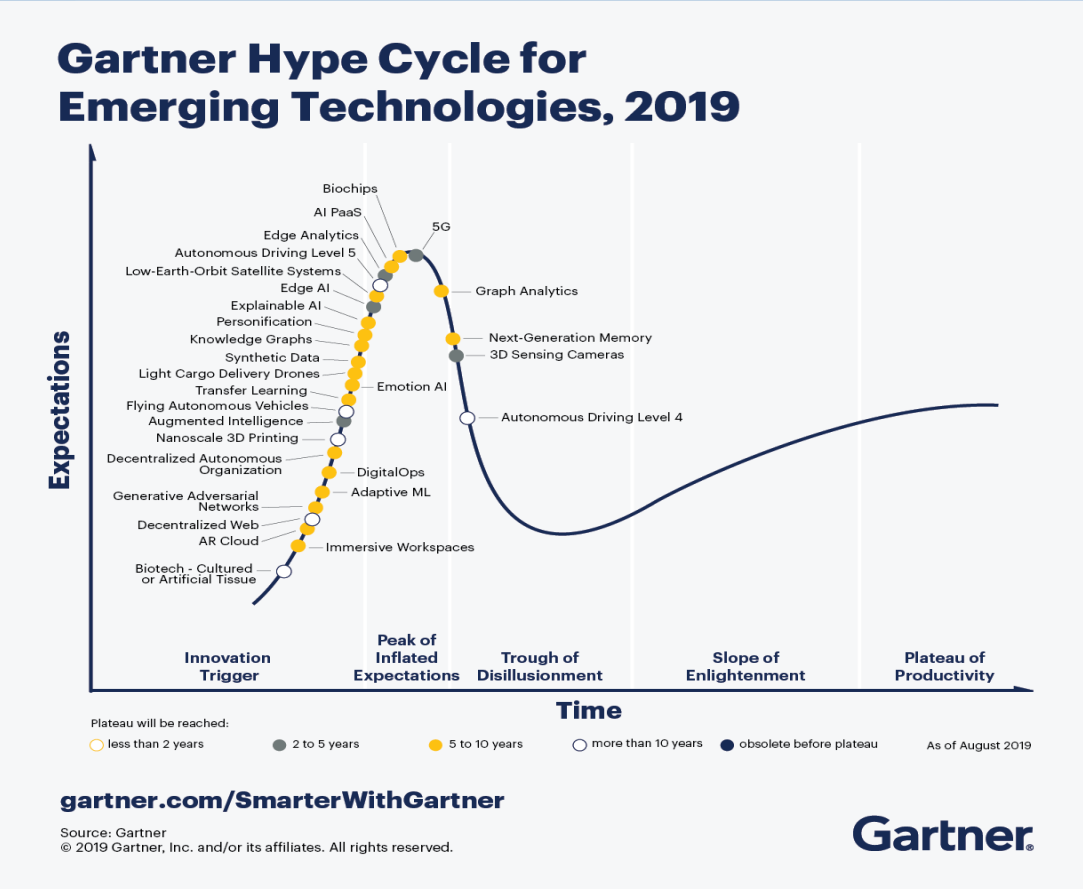


AI is important for enabling the next wave of Network Functions, Network Automation, and Optimization of Network Resources.

Intelligence and resources in the Network create a new and growing opportunity for providing AI services as an important aspect of Service and Edge Provider Businesses

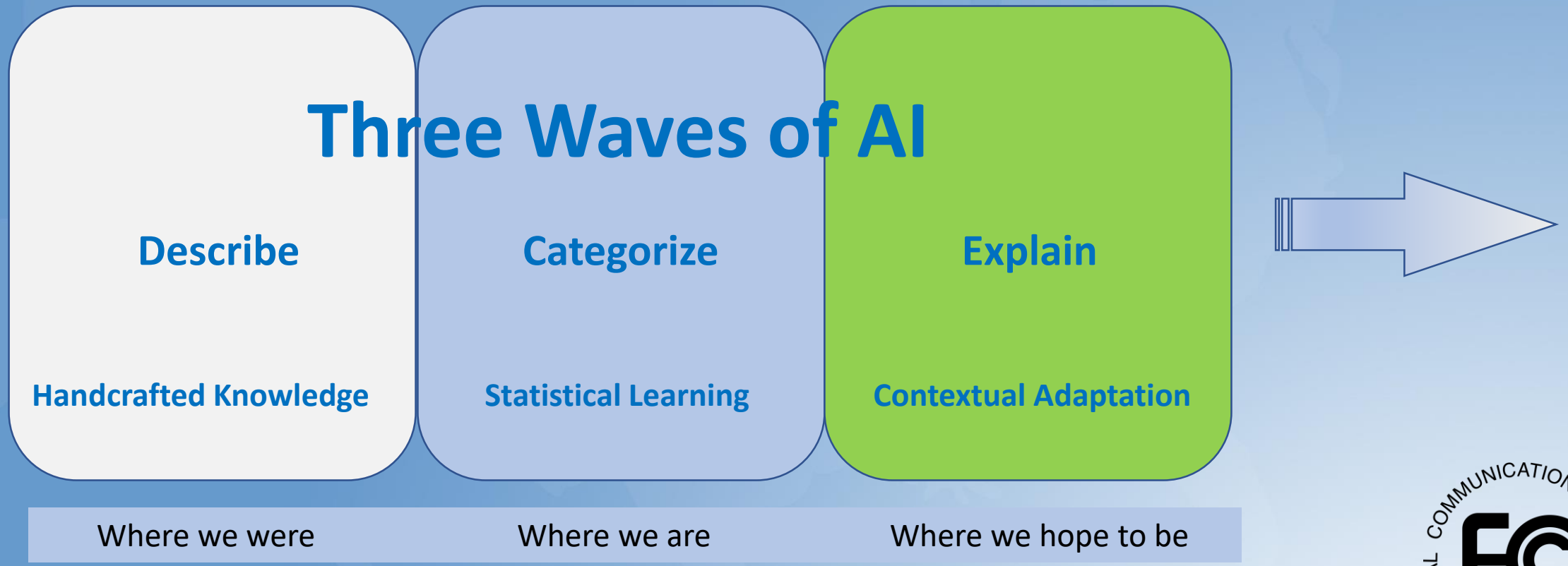
** Chris Smith, "Artificial Intelligence", Presentation to the FCC TAC, August 13, 2018

Market and National Trends in Artificial Intelligence



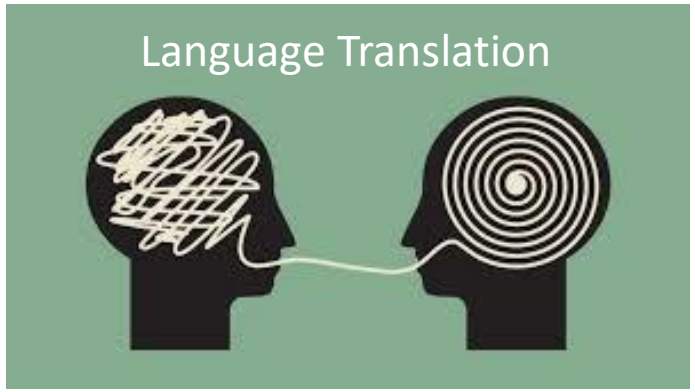
- Many Useful Applications where AI Technologies bring value now and where the underlying Technologies are mature
  Examples
  - Speech Recognition
  - Translation
  - Biometrics
  - Optical Character Recognition
- Strong Divergence between public perception and where AI is as a field when it comes to general intelligence and cognition!

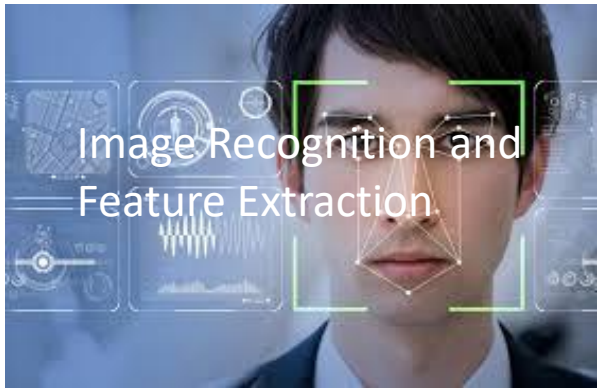
Market and National Trends in Artificial Intelligence

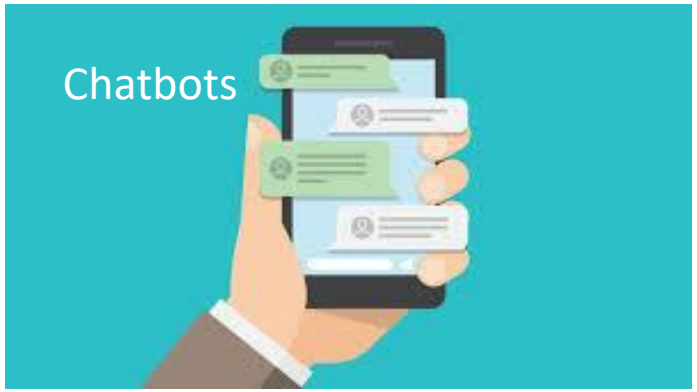


Source: John Launchbury DARPA - https://www.darpa.mil/about-us/darpa-perspective-on-ai

Market and National Trends in Artificial Intelligence







Many AI Products already in the Market Place!

National Trends in Artificial Intelligence

- The US has a National Plan on Artificial Intelligence

  - ”The National Artificial Intelligence Research and Development Strategic Plan”, NITRD October 2016
  - ”The National Artificial Intelligence Research and Development Strategic Plan”, Update 2019, NITRD June 2019
  - “The Networking & Information Technology Research and Development Program”, (Supplement to the President’s FY2019 Budget), National Science and Technology Council,

  - Executive Order on Maintaining American Leadership in Artificial Intelligence, The Whitehouse, February 2019.

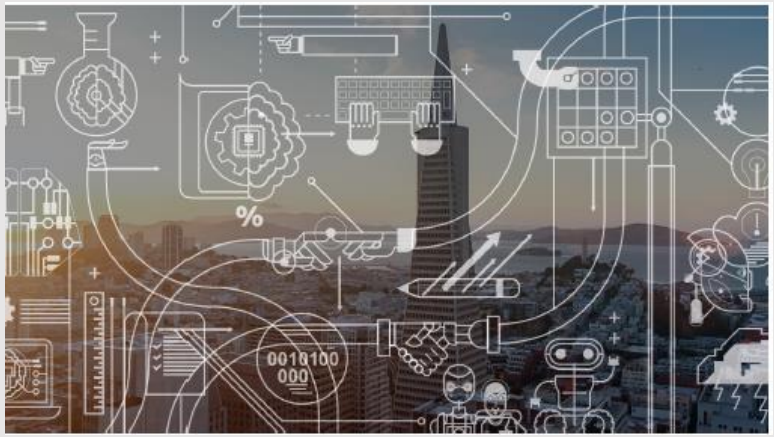
  ** An extensive list of references on plans by Federal Departments and Agencies is included in the Appendix

National Trends in Artificial Intelligence

From stakeholders and experts on Artificial Intelligence:

”Artificial Intelligence and Life in 2030: One Hundred Year Study on Artificial Intelligence”, Stanford University, September 2016

- The One Hundred Year Study on Artificial Intelligence, launched in the fall of 2014, is a long-term investigation of the field of Artificial Intelligence (AI) and its influences on people, their communities, and society. It considers the science, engineering, and deployment of AI-enabled computing systems.



National Trends in Artificial Intelligence

From the Research Community

"A 20-Year Community Roadmap for Artificial Intelligence in the United States", CCC, AAAI, and NSF, August 2019.

- Identifies three areas of concentration as long term goals and six areas of societal impact!

 Integrated intelligence, including developing foundational principles for combining modular AI capabilities and skills, approaches for contextualizing general capabilities to suit specific uses, creation of open shared repositories of machine-understandable world knowledge, and understanding human intelligence both to inspire novel AI approaches and to develop models of human cognition.

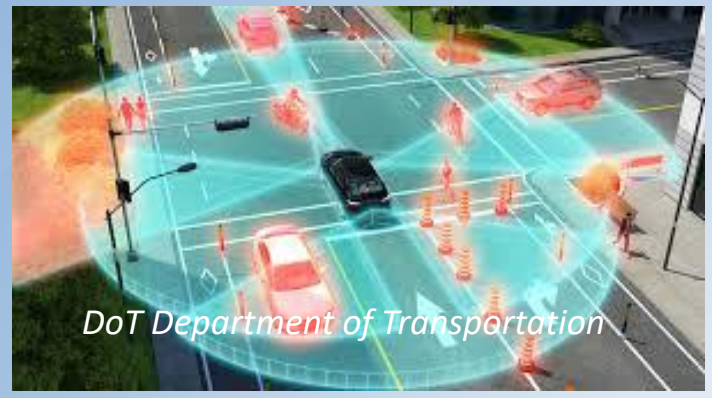
 Meaningful interaction, comprising techniques for productive collaboration in mixed teams of humans and machines, combining diverse communication modalities (verbal, visual, emotional) while respecting privacy, responsible and trustworthy behaviors that can be corrected directly by users, and fruitful online and real-world interaction among humans and AI systems.

 Self-aware learning, developing robust and trustworthy learning, quantifying uncertainty and durability, learning from small amounts of data and through instruction, incorporating prior knowledge into learning, developing causal and steerable models from numerical data and observations, and learning real-time behaviors for intentional sensing and acting.

Figure 2. Identifying Societal Drivers.

National Trends in Artificial Intelligence

Significant Research Investments by the US Government Agencies and Departments in AI Research and Early Development: over $1B for non-DoD agencies and ~ $1.5B for DoD and the Intelligence Community for this fiscal year. Over an order of magnitude more for Deployment Programs.



National Trends in Artificial Intelligence

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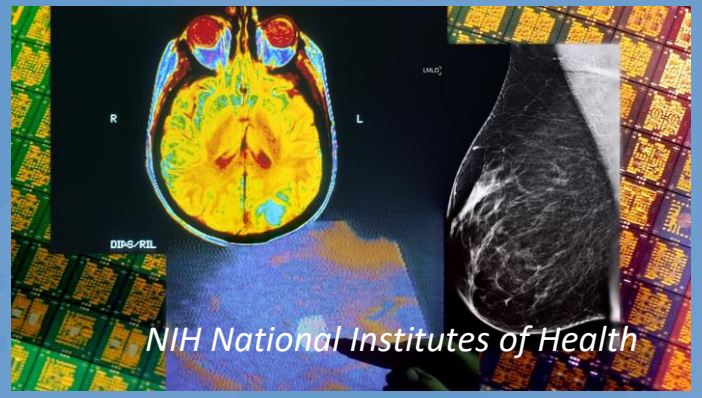
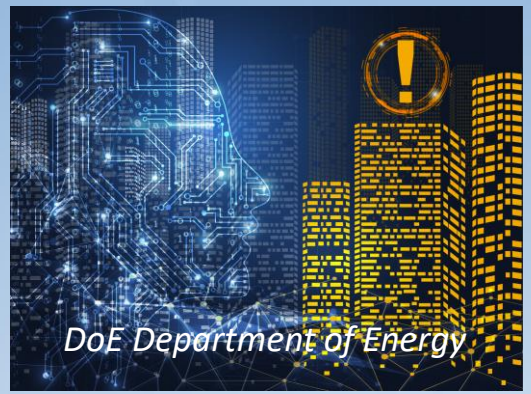


NIH National Institutes of Health


DARPA Defense Advanced Projects Agency


DoE Department of Energy

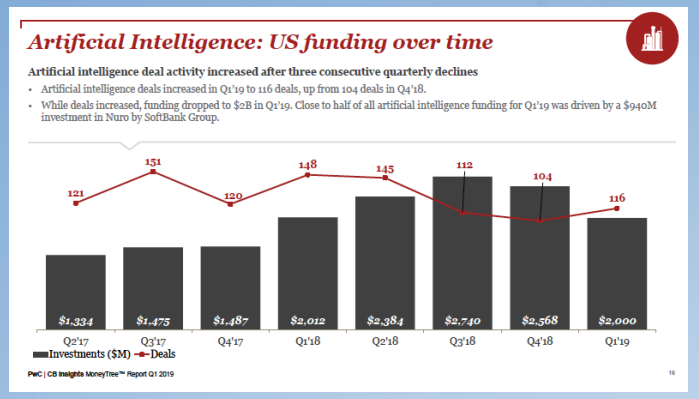

NASA National Aeronautics and Space Administration

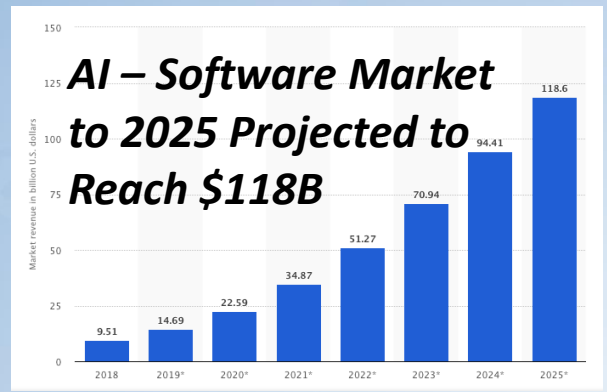

NSF National Science Foundation


DoD Department of Defense

Market and International Trends in Artificial Intelligence

Worldwide AI Investments and Projections of AI Market Size



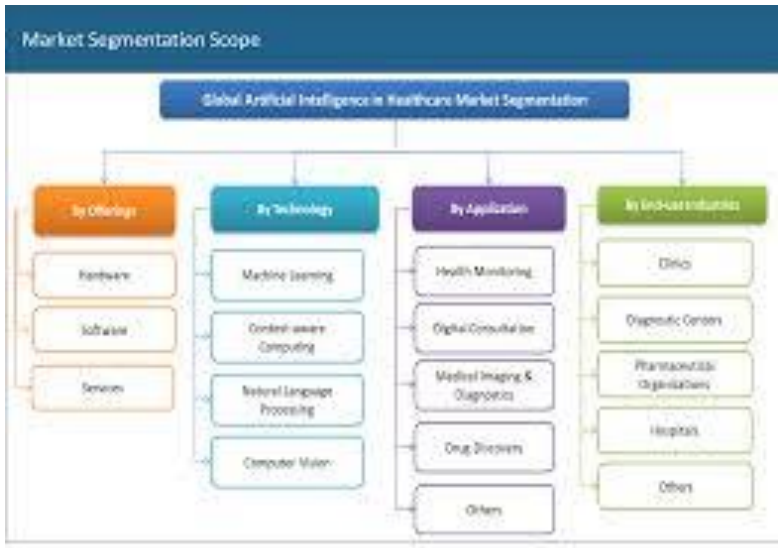


Sources: IDC, MarketWatch, PWC Insights, CNBC, Statista

Market and International Trends in Artificial Intelligence

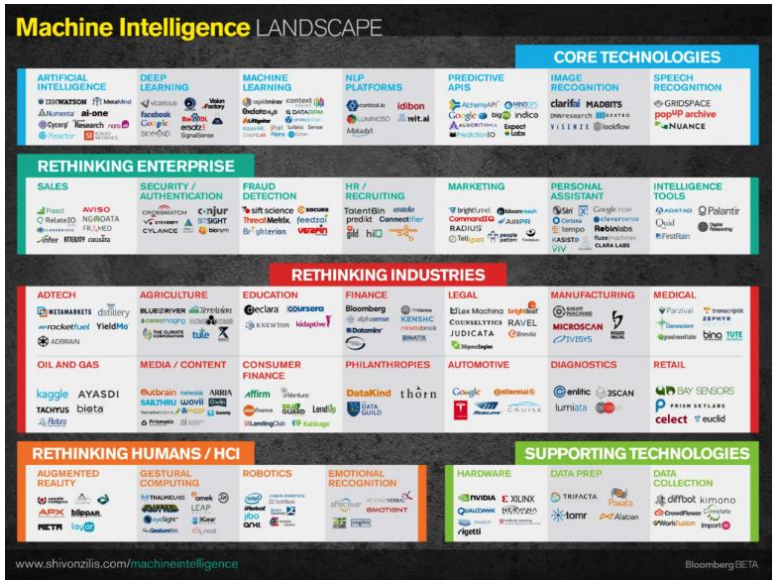
AI – Products, Services, and Processes already have significant penetration in the marketplace.

Healthcare Market Segmentation



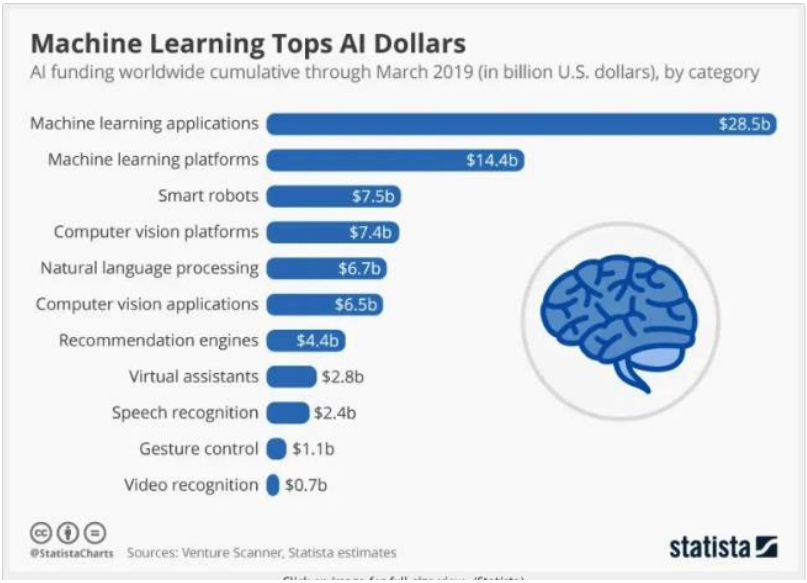
Source: https://www.alltheresearch.com/report/97/artificial-intelligence-in-healthcare-market

ML Market Framework



Source: https://emerj.com/ai-sector-overviews/artificial-intelligence-industry-an-overview-by-segment/

Market Applications



Source: https://sciencebusiness.technewslit.com/?p=36620

The FCC TAC WG on AI and Computing – Areas Considered During the Year

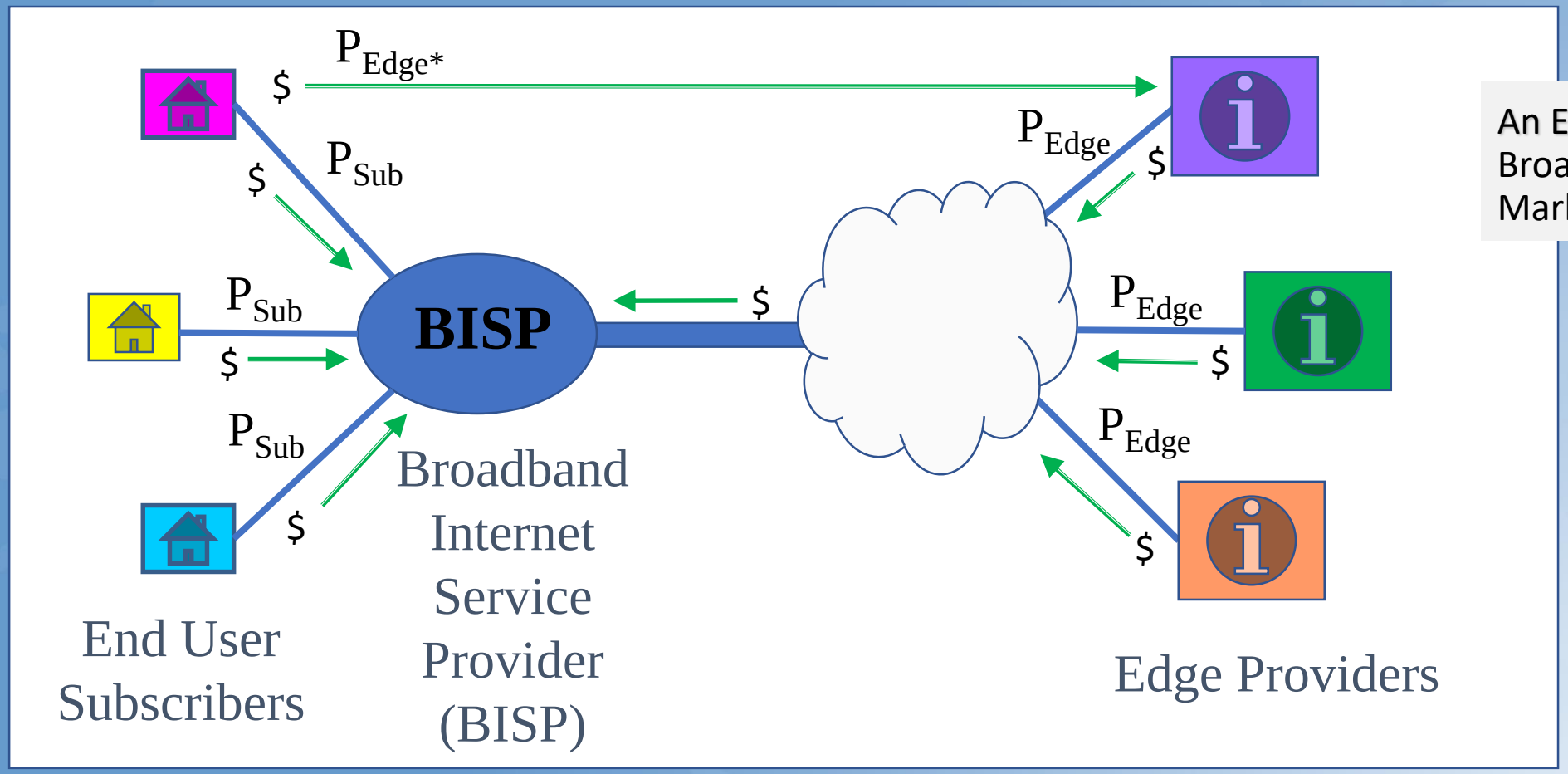
- AI Technologies for use by the FCC
- AI Technologies for Network use by Operators and Service Providers
- AI Technologies for Economic, Critical, and Societally Important Applications
- AI Technologies – The Dark side of AI, the use of AI to cause detriment or harm.

Working Group Results for CY2019 Opportunities – Two Sided Markets

(An Example AI Technologies for Economic Use)

- **Background:**
  - Changes in rules governing how broadband service providers manage their network now allow them to charge "edge providers" a price for interacting with their subscribers. One proposed way of charging edge providers a price involves constructing a "two-sided" market. Under that market organization the service provider sets two prices, one for subscribers, and one for edge providers. All things being equal, economic efficiency would be enhanced if the broadband provider could better estimate the demand each side of the market will place on its network at any moment in time.
- **Opportunity:**
  - By assisting in the estimation of demand, AI can assist a broadband service provider in building a "two-sided market" that more efficiently allocates the provider's costs across users.

Working Group Results for CY2019 - Opportunities



An Example: Local Broadband: A Two-sided Market

Source:
Mark Bykowsky
FCC

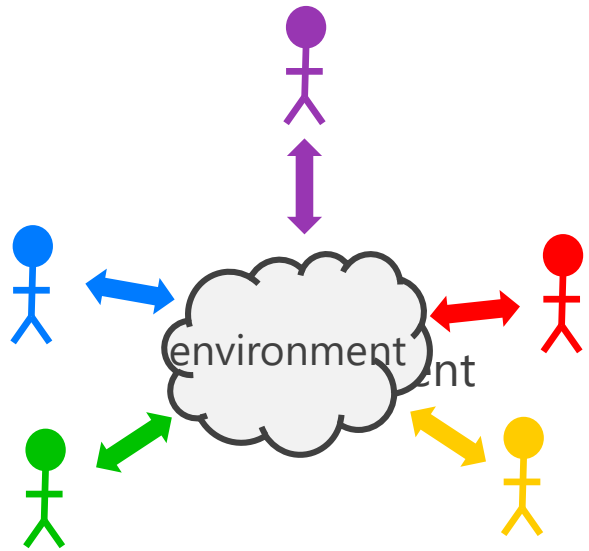
Working Group Results for CY2019 – Opportunities - Spectrum Sharing

(An Example of AI Technologies for Network Use)

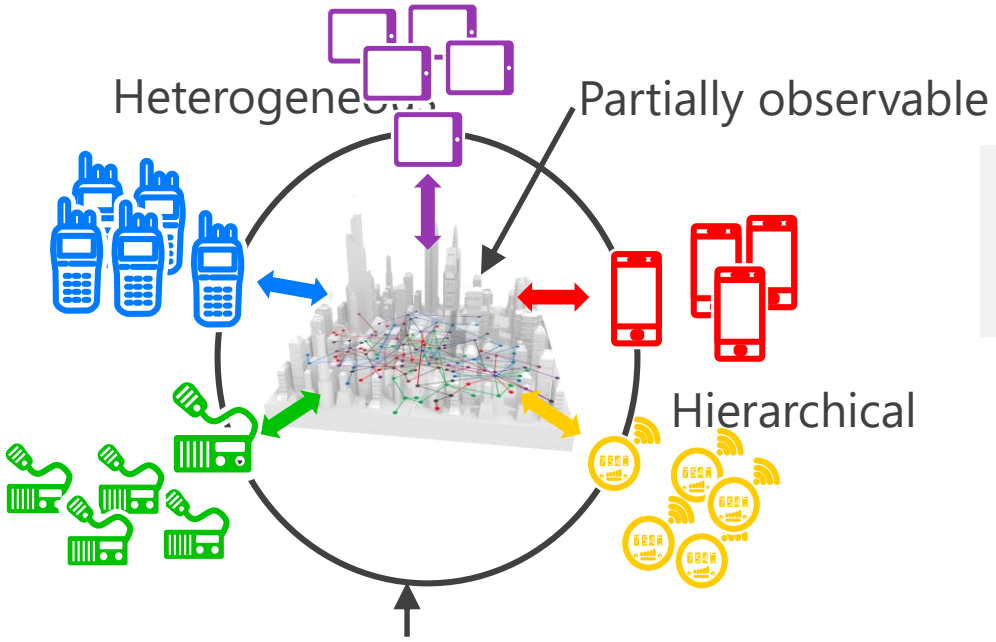
- **Background:**
  - Promising Research presented by DARPA addressed two issues. The first of those was the application of AI to spectrum sharing regimes – with the intent of optimizing spectrum utilization and the ability of multiple spectrum users to optimize the Network performance for a set of highly dis-similar applications. The second was the use of AI Techniques to characterize spectrum emissions and to automatically identify and fingerprint the nature of those emissions.
- **Opportunities:**
  - To develop new regimes for efficient spectrum utilization and sharing by incorporating economic considerations into the AI approaches used by DARPA and making it possible to develop new business models and policies that better serve national needs.
  - To utilize the tantalizing early results for identification of sources of interference and improper use of transmissions to aid and automate enforcement.

Working Group Results for CY2019 – Opportunities (An Example)

Multi-agent problem



SC2 hierarchical multi-agent problem



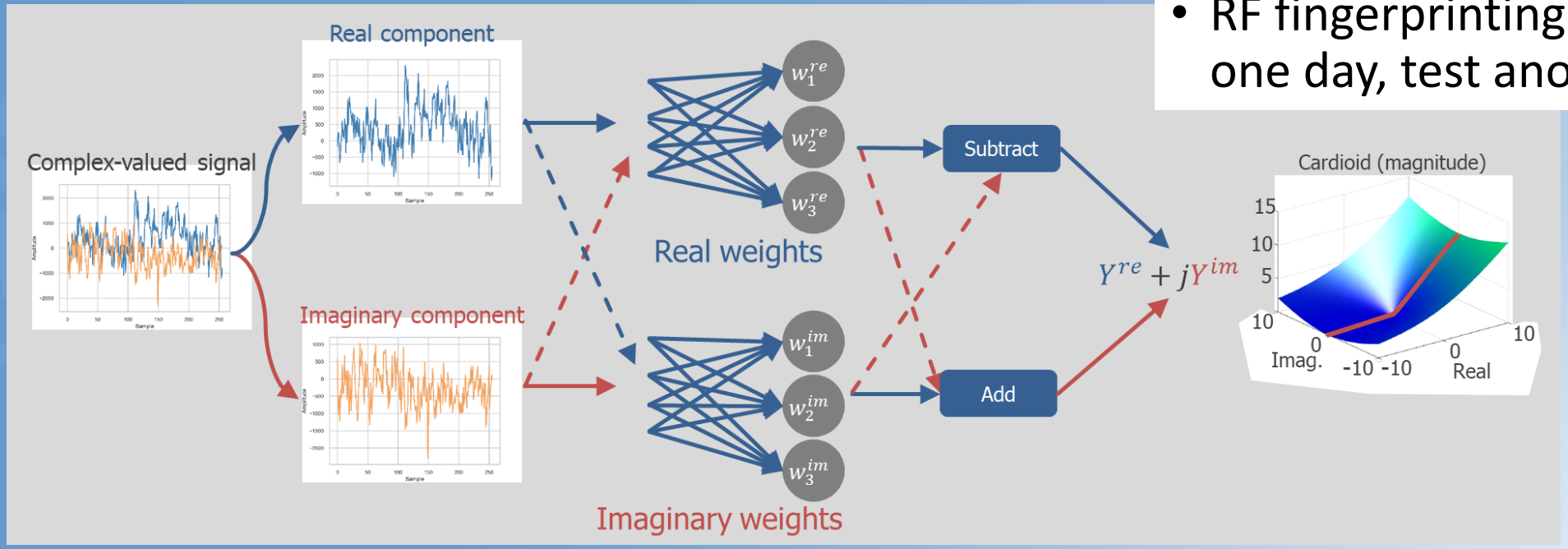
An Example: AI for Spectrum Sharing and Collaboration

Working Group Results for CY2019 – Opportunities (An Example)

Complex fully-connected layer with complex activation function

Real-valued	4%
Complex-valued	**78%**

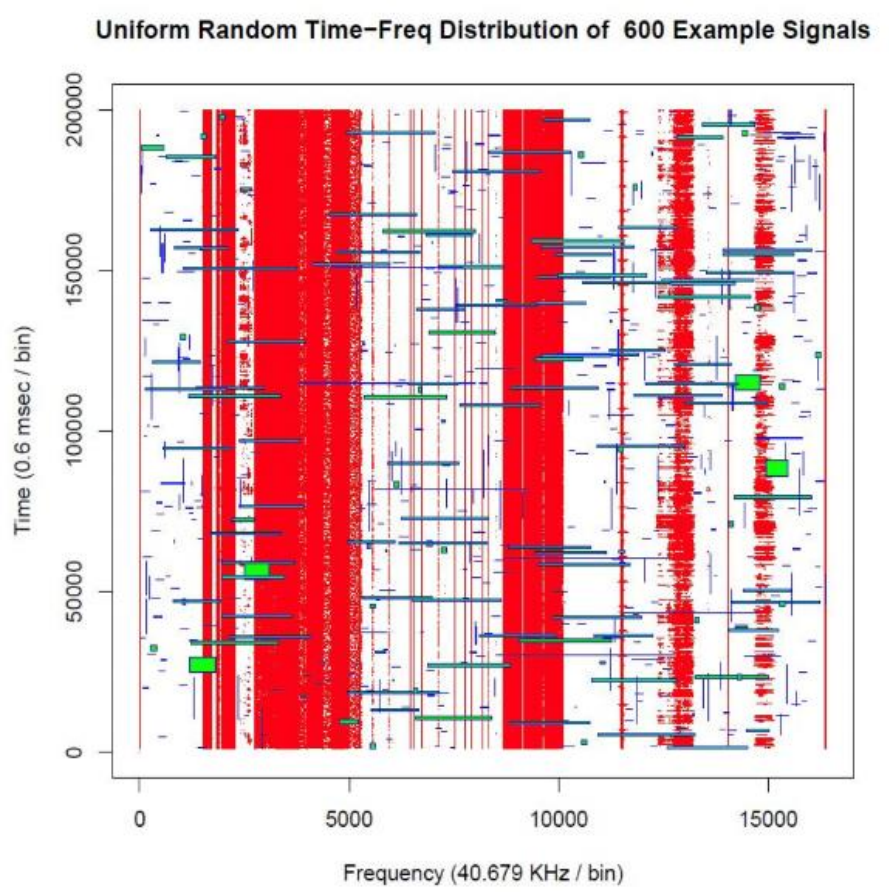
- Real RF fingerprints vary with emitter location and propagation channel conditions
- RF fingerprinting challenge: train one day, test another day



An Example: AI Fingerprinting of RF Emissions

Add two more examples

Working Group Results for CY2019 – Opportunities (An Example)



Providing Answers to:

Which signals are “background”?

Which signals are known and expected?

Which signals have been modified in some way?

Which signals are anomalous and unexpected?

An Example: AI Fingerprinting of RF Emissions

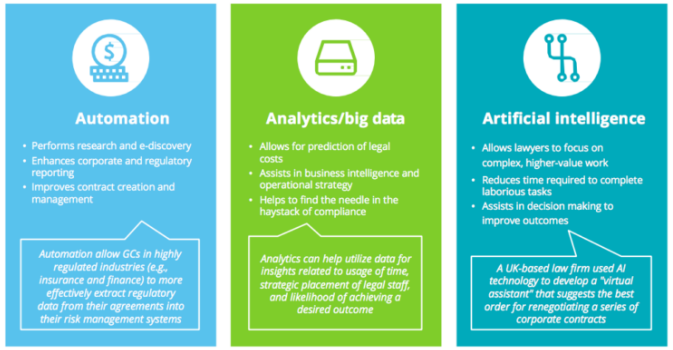
Working Group Results for CY2019 – Opportunities - Intelligent Text Analysis, Informatics, and Search *(An Example of AI for Internal FCC and Public Use)*

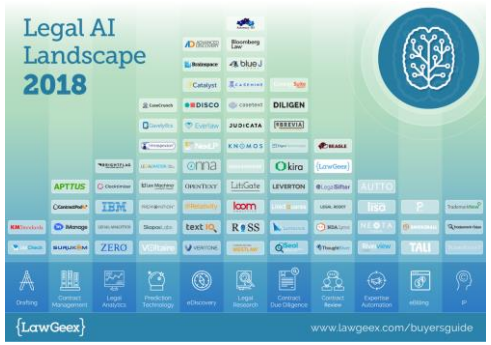
- **Background:**
  - One aspect of AI technologies that has had considerable success and shows promise of further advances is Text Understanding and Intelligent Text Processing. The mandates that the FCC has depend on a complex body of Legislation, the Federal Code, Rules and Regulation, Public Notices and Hearings, Enforcement Actions, and Public Comments. If is further influenced by State, and Local Laws, Ordinances, and Regulatory regimes, and finally by proceedings in Federal, State, and Local Courts. When an issue arises either for the FCC or for the public it is often tedious and difficult to determine what aspects of existing rules and procedures apply (search) and how consistent they may be with rules and precedent (analysis), usage trends, impacts, and public sentiment (informatics).

- **Opportunity:**
  - Over time to collect all documents applicable to the FCC's mandate, structure and annotate the collected works, and automate the collection of relevant new information thus enabling AI tools to perform timely analysis on the gathered corpus. This would aid the FCC in its internal work and better serve the public needs through powerful modern tools for search, analytics, and informatics.

Working Group Results for CY2019 – Opportunities - Text Content Analysis, Informatics, and Search *(An Example of AI for Internal FCC and Public Use)*

AI Uses in Text Content Analysis





Text Analytics Use Cases

Manufacturers
- Identify root causes of product issues quicker
- Identify trends in market segments
- Understand competitors' products

Government
- Identify fraud
- Understand public sentiments about unmet needs
- Find emerging concerns that can shape policy

Financial Institutions
- Use contact center transcriptions understand customers
- Identify money laundering or other fraudulent situations

Retail
- Identify profitable customers and understand the reasons for their loyalty
- Manage the brand on social media

Legal
- Identify topics and keywords in discovery documents
- Find patterns in defendant's communications

Healthcare
- Find similar patterns in doctor's reports
- Use social media to detect disease outbreaks earlier
- Identify patterns in patient claims data

Telecommunications
- Prevent customer churn
- Suggest up-sell/cross-sell opportunities by understanding customer comments

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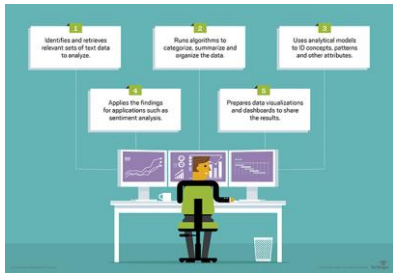
Life Sciences
- Identify adverse events in medicines or vaccines
- Recommend appropriate research materials

Insurance
- Identify fraudulent claims
- Track competitive intelligence
- Manage the brand on social media



Sources: Deloitte, LawGeex, LexisNexis, GAO, IBM

EMERJ: Artificial Intelligence in Regulatory Technology (RegTech) – 5 Current Applications
https://emerj.com/ai-sector-overviews/artificial-intelligence-in-regulatory-technology-regtech/

WG on AI and Computing Plan for CY2020

We suggest that the AI and Computing WG concentrate on no more than four areas in the coming Calendar Year. We have identified the following options as possibilities:

1. Application of AI to Heterogenous Networks.
   - ❖ Efficiency, Optimization, and Operation of Wireless Networks
     - Spectrum Sharing
     - Capacity Planning, Network Architectures and Design, and Asset Placement
     - Wireless Traffic Offloading
     - Design of Radio Network Components (Antennas, Filters, Adaptive Signal Processing, …..)
   - ❖ Network Management, Network Automation and Autonomy
   - ❖ Broadband mapping and Better Collection of National Network Data and Information
   - ❖ Ability to leverage satellite and other transport means to address the challenges posed by geography, population density, and economic considerations.
   - ❖ Enablement of new AI driven services, business processes, and new business and market models for operators, edge providers and other emerging players.

WG on AI and Computing Plan for CY2020

2. Application of AI to mitigating threats to the network from practices in ongoing operations and from nefarious actors:
   - ❖ Anticipating and reacting to conditions likely to cause Network Outages
     - ➢ Root cause identification of failures and outages
     - ➢ Preventive Network Maintenance
     - ➢ Improving time to recovery from natural events
     - ➢ Planning and prepositioning of recovery resources
   - ❖ Mitigating Interference on the Network
     - ➢ Improving approaches to Spectrum Sharing
     - ➢ Identification and location of Spurious Signals and Sources of Interference
     - ➢ Automating control of Network settings to minimize interference
   - ❖ Dealing with Bad Actors
     - ➢ Robocalling
     - ➢ Hacking
     - ➢ Spoofing
     - ➢ Jamming
     - ➢ …….

WG on AI and Computing Plan for CY2020

3. AI based mechanisms and techniques to provide trusted information, Trusted AI for Network Operations, and AI for Network provided Trusted AI Services.

- Establishing Trust
  - Basic mechanisms, metrics and rating systems for AI software and algorithms
  - Identity of AI solution components, provenance, and chain of custody
  - Reliability and Availability
  - Vetting of data and information, and reputation scoring
  - Tamper proof techniques
- AI for operating the Network
  - Architectural implications
  - Reliability and Completeness
  - Security and Cyber-security
  - Testing and certification
- The Network as a source of AI Services
  - Acceptability
  - Safety
  - Public Perception
  - Legal Framework

WG on AI and Computing Plan for CY2020 - Continued

4. AI and the customer (Consumers, the Public Sector, Industry, and Small and Medium Enterprises)
   - Customer experience - quality of experience and quality of service
   - How AI is used in networks for important applications to deliver effective functionality, differentiated performance metrics and attributes, enable new business models and innovation.

     ❖ Consumer - Connected Healthcare, Education, Social and Work-related Networking, and Smart Home
     ❖ Industry – Manufacturing, Transportation, Logistics, Enterprise Services, Retailing, Finance, Agriculture, ….
     ❖ Public Sector – Infrastructure, Public Safety (Law-enforcement, Firefighting, Emergency Services)
     ❖ Small and Medium Enterprises – Access to markets, Supply Chains, Management, Business to Business services, Consumer Services, Delivery

Anything for the Customer in settings that requires **both AI and communications** with consideration for geographic diversity, population density, economic and societal impact.

WG on AI and Computing Plan for CY2020 - Continued

Our suggestion is to create a sub working group on no more than four topics. The goal is to produce meaty actionable recommendations during 2020 and to create a mini-roadmap that prepares the FCC for anticipating and planning the steps to play a significant role for:

- Adoption of useful AI Technologies,
- For eliminating barriers where appropriate,
- Assuring that the Nation has the Networks that are needed for the positive impacts of AI Technologies.

As part of that we intend to:

- Gather experts specific to each of these topics to understand impacts and issues at depth
- Understand where AI technologies are helpful for specific Network capabilities and consequent National impact, flag where they are not ready for prime time, and project a time frame when they may mature(where possible).
- Identify how relevant the AI technologies and areas of concern are to the FCC during 2020 and recommend FCC actions for creating future value.

Recommendations from CY2019

1. Improve the FCC's practical understanding of how to exploit AI technologies and establish a concrete strategic AI plan for doing so (For internal processes, for how AI will be used by Operators, and for how it will influence the Networks the Nation needs to take full advantage of the promise of AI). A specific early and important step is to execute a limited number of focused AI pilot projects in partnership with AI expert agencies/institutions to deliver short term tangible results to gain experience and develop internal capacity.

Suggested pilot areas:

- Speed Testing – Use of AI techniques to develop predictive models surpassing the accuracy of current mapping results.
- Market forces – Improve efficiency and transparency for two-sided markets involving Operators and Edge Providers.
- Enforcement – Exploit promising results on fingerprinting of RF emissions that may interfere with networks and help identify source location and characteristics automatically.
- Intelligent Text Processing – Conduct a focused demonstration on a chosen aspect important to the FCC's ongoing work (Such as a subset of legal issue, analysis of public comments, etc.)

Recommendations from CY2019

2. We encourage the FCC to continue its activities to understand how the Operators that it “oversees” will use AI technologies, and how AI capabilities can be exploited by the FCC in carrying out its mandates.

In addition it may be important for the FCC to take additional steps to foster a dialog that reflect the viewpoints of a larger set of stakeholders around AI technologies who will be affected by Network capabilities and operations as businesses or end-users. The purpose of setting such forums in place is to anticipate and guide the interaction with external interfaces to the AI community to be constructive, and cooperative for the greater good, contributing to national competitiveness, economic wellbeing, and in achieving important societal goals.

3. Renew AI and Computing WG for next year with an agreed upon charter

Thank You!

Appendix

-References

-Speakers

References, Documents, and Resources on Artificial Intelligence

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Speakers

- Mark Bykowsky – FCC
  - "Information and the Economically Efficient Sharing of Spectrum"
- Mike Nawrocki and Tom Anderson – ATIS
  - "The AI-Enabled Network"
- Michael Griffiths – ASAPP
  - "AI on the Network and for use in customer service"
- Bart Selman, Dept of CS, Cornell
  - "Machind Reasoning, progress in AI and Applications"
- Yolanda Gil, Knowledge Technologies Group
  - "Recently released NSF/CRA 20-year AI Research Roadmap"

Speakers

- Larry Carin – Infinia ML/Duke University
  - “From Cutting-Edge AI Research to Business Impact “
- Monisha Ghosh – University of Chicago
  - “LTE-U and WiFi Coexistence: Can Machine Learning Help?”
- Nageen Himayat – Intel
  - “Implications of Machine Learning for Wireless Networks”
- Sam Abuelsamid - Navigant Research and Forbes
  - “Role AI and Connectivity for Autonomous and Connected Vehicles”
- Paul Tilghman - DARPA
  - “The AI Spectrum Challenge and AI for Classification and Fingerprinting of Spectral Emissions”

July 10, 2019 " Information and the Economically Efficient Sharing of Spectrum"

Mark Bykowsky
Senior Economist
FCC

Dr. Mark Bykowsky is a Senior Economist at the FCC. He advises the FCC on economic aspects involving net neutrality, spectrum policy, and media concentration. His latest economic analysis examines the conditions for how "interference limits" could improve receiver quality. He has recently examined the possibility of creating a market in which spectrum licensees can assign interference rights to competing owners. Dr. Bykowsky is a four-time recipient of the FCC's prestigious Excellence in Economic Analysis Award.

Previously, Dr. Bykowsky was Senior Partner at EonXchange, the first electronic market for the trading of emissions credits. He was also instrumental in developing the technology for the creation of a NASDAQ-like market for the trading of non-digital media. Before that he was at the National Telecommunications and Information Administration (NTIA) as an economist. There he (and Dr. Robert Cull and colleagues at Caltech) demonstrated the feasibility of conducting a purely electronic auction for spectrum. In addition to demonstrating the importance of a simultaneous auction, he and his colleagues demonstrated the desirability of allowing for package bidding for spectrum licenses. As Senior Economist at the National Cable Television Association, he provided the economic basis for the FCC's decision in 1985 to deregulate basic cable television prices. Dr. Bykowsky received his Ph.D. in Economics from the University of Colorado.

July 17, 2019 “Evolution to an AI-Enabled Network”

Michael Nawrocki,

VP Technology and Solutions

ATIS

As Vice President of Technology and Solutions, Mike Nawrocki focuses on strategic initiatives to advance ATIS members’ business and technology priorities.

Bringing extensive telecommunications strategy experience and a service provider perspective, Mike provides ATIS direction on emerging technology trends as well as next generation technologies and networks. Before ATIS, he served as Director – Standards for Verizon Technology, and previously, as principal technologist in Verizon’s CTO organization. His extensive career with major service providers includes working in network planning and engineering positions at Verizon and AT&T Bell Labs. Mike has previously served on the MoCA Board of Directors and participated on FCC working groups, including the Technological Advisory Council, CSRIC and Network Reliability Council. At ATIS, he serves as a key policy interface with the FCC and other agencies.

Mike holds a master’s degree in Electrical Engineering – Communications from the George Washington University School of Engineering & Applied Science. He earned a bachelor’s degree in Electrical Engineering from Johns Hopkins University.

July 17, 2019 “Evolution to an AI-Enabled Network”

Thomas W. Anderson,
Principal Technologist
ATIS

Tom Anderson is a Principal Technologist specializing in standards, architecture and evolution of service provider networks. In the past, he has worked for major industry vendors including Cisco, Juniper, Alcatel-Lucent, and Bell Labs where he managed network technology evolution, strategy, standards and architecture. As a 30+ year veteran of the telecommunications industry, Tom has been active in telecommunications standards activities and has held numerous positions in the areas of architecture, product development, systems engineering, and product management. His more recent work has focused on AI, 5G and Cyber-Security, chairing ATIS working groups in these areas.

July 31, 2019 “Artificial Intelligence (AI) on the Network”

Michael Griffiths
Data Scientist
ASAPP

Michael Griffiths is a data scientist at ASAPP, a company with offices in New York City and San Francisco that leverages artificial intelligence to deliver products that automate and simplify complex problems. Before working with ASAPP, Michael spent time in advertising and consulting.

Michael earned his BA in Epistemology of the Social Sciences from Skidmore College. He is a member of Alpha Kappa Delta, Phi Beta Kappa, and the Periclean Honors Society.

August 21, 2019 “Opportunities and Challenges for Artificial Intelligence (AI)”

Prof. Bart Selman, Dept of Computer Science, Director of the Intelligent Information Systems Institute, Cornell University

Bart Selman is a Professor of Computer Science at Cornell University. He previously was at AT&T Bell Laboratories. His research interests include efficient reasoning procedures, planning, knowledge representation, and connections between computer science and statistical physics. He has (co-)authored over 100 publications, including six best paper awards. His papers have appeared in venues spanning Nature, Science, Proc. Natl. Acad. of Sci., and a variety of conferences and journals in AI and Computer Science. He has received the Cornell Stephen Miles Excellence in Teaching Award, the Cornell Outstanding Educator Award, an NSF Career Award, and an Alfred P. Sloan Research Fellowship. He is a Fellow of the American Association for Artificial Intelligence and a Fellow of the American Association for the Advancement of Science. Web-Stat hit counters

August 28, 2019 “Developing a 20-Year Research Roadmap for the US”

Yolanda Gil, Research Professor of Computer Science and Spatial Sciences, and Principal Scientist Information Sciences Institute at USC

Dr. Yolanda Gil is Director of Knowledge Technologies and Associate Division Director at the Information Sciences Institute of the University of Southern California, and Research Professor in Computer Science and in Spatial Sciences. She is also Associate Director of Interdisciplinary Programs in Informatics. She received her M.S. and Ph. D. degrees in Computer Science from Carnegie Mellon University, with a focus on artificial intelligence. Dr. Gil has served in the Advisory Committee of the Computer Science and Engineering Directorate of the National Science Foundation. She initiated and chaired the W3C Provenance Group that led to a community standard in this area. Dr. Gil is a Fellow of the Association for Computing Machinery (ACM), and Past Chair of its Special Interest Group in Artificial Intelligence. She is also Fellow of the Association for the Advancement of Artificial Intelligence (AAAI) and was elected as its 24th President in 2016.

September 4, 2019 “From Cutting-Edge AI Research to Business Impact ”

Lawrence Carin, Professor, Department of Electrical and Computer Engineering, Duke University and Chief Scientist InfiniaML,

Lawrence Carin earned the BS, MS, and PhD degrees in electrical engineering at the University of Maryland, College Park, in 1985, 1986, and 1989, respectively. In 1989 he joined the Electrical Engineering Department at Polytechnic University (Brooklyn). In September 1995 he joined the Electrical Engineering Department at Duke University, and is now a Professor, and Vice Provost for Research. From 2003-2014 he held the William H. Younger Distinguished Professorship, and he was ECE Department Chair from 2011-2014. Over the last 15 years his research has been in applied statistics and machine learning (ML). He has recently served on the Program Committees for the following ML conferences: International Conf. on Machine Learning (ICML), Neural and Information Processing Systems (NIPS), Artificial Intelligence and Statistics (AISTATS), and Uncertainty in Artificial Intelligence (UAI). He is currently an Associate Editor for the J. of Machine Learning Research and an IEEE Fellow.

September 25, 2019 “LTE-U and WiFi Co-existence: Can Machine Le

Monisha Ghosh
Research Professor, IME, Department of Computer Science, University of Chicago

Monisha is currently a Research Professor at IME, and an Associate Member of the Computer Science Department at the University of Chicago. Dr. Ghosh received her Ph.D. in Electrical Engineering in 1991 from USC and her B.Tech in Electronics and Electrical Communications Engineering from IIT, Kharagpur, in 1986.

She joined Philips Research in 1991 and was a member of the team that developed the first digital broadcast HDTV system working on the physical layer that led to the first VSB IC implementing a blind decision feedback equalizer. Between 1998-1999 she was at Bell Labs working on OFDMA for cellular systems. She returned to Philips in 1999 as a Principal Member of Research Staff as a key contributor to 802.22, the first cognitive radio standard for the TV White Spaces. In 2012, Dr. Ghosh joined Interdigital where she continued to work on standardization for 802.11.

Dr. Ghosh has over 50 scientific papers and 40 patents. She received the Distinguished Engineer Award in Philips in 2008 and is a Fellow of the IEEE.

October 9, 2019 “Voice User Interfaces (UI) and Artificial Intelligence (AI)”

Sayon Deb,
Senior Analyst,
Consumer
Technology
Association

Sayon Deb is Senior Analyst, Market Research at the Consumer Technology Association (CTA)™ the U.S. trade association representing more than 2,200 consumer technology companies and which owns and produces CES® – The Global Stage for Innovation.
Sayon joined CTA in June 2018 with a decade of experience as a quantitative researcher.

As part of CTA’s research group, Sayon regularly authors reports, delivers presentations, and engages member companies in briefings on a variety of topics pertaining to the consumer tech market, including applications of Artificial Intelligence (AI) and AR/VR.
Prior to joining CTA, Sayon held research positions at 451 Research, International Food Policy Research Institute (IFPRI), Harvard Kennedy School of Government, and Harvard’s Department of Economics. He has an M.A. in Economics from Boston University and B.A. in Biomedical Engineering from Syracuse University.

October 16, 2019 “Implications of Machine Learning (ML) for Wireless Networks”

Nageen Himayat, Principal Engineer and Director Intelligent and Distributed Networks Laboratory, Intel

Nageen Himayat is a Principal Engineer, and Director of Intelligent Distributed Edge Networks Labs, at Intel, where she conducts research on distributed learning and data centric protocols over 5G/5G+wireless networks. Her research contributions span areas such as machine learning for wireless, millimeter wave and multi-radio heterogeneous networks, cross layer radio resource management, and non-linear signal processing techniques.

Prior to Intel, Dr. Himayat was with Lucent Technologies and General Instrument Corp, where she developed standards and systems for both wireless and wire-line broadband access networks. Dr. Himayat obtained her B.S.E.E degree from Rice University, and her Ph.D. degree from the University of Pennsylvania. She also holds an MBA degree from the Haas School of Business at University of California, Berkeley.

October 23, 2019 “Artificial Intelligence and Mobility”

Sam Abuelsamid, Principal Research Analyst, Navigant and Senior Contributor at Forbes

Sam Abuelsamid is a principal research analyst leading Navigant Research’s Mobility research service as part of the Urban Innovations program. With a focus on automated driving, mobility services, telematics, connectivity, cybersecurity, and advanced propulsion systems, Abuelsamid works with clients to help them understand emerging technology trends and shape strategies.

Trained as a mechanical engineer, Abuelsamid has more than two decades of experience as a product development engineer in the automotive industry, working on advanced electronic control systems and embedded software and architecture. Prior to joining Navigant Research, he worked as an automotive journalist and worked in product and technology communications at Ford and General Motors. Abuelsamid regularly contributes to multiple publications, including Forbes, Automotive Engineering, and others. He holds a BSc in mechanical engineering from Kettering University.

October 30, 2019 “DARPA AI Applications in Wireless”

Paul Tilghman, Program Manager, Microsystems Technology Office, DARPA

Mr. Paul Tilghman joined DARPA in December 2014 as a program manager in the Microsystems Technology Office. His research interests include intelligent and adaptive RF systems, digital signal processing, machine learning, wireless communications and electronic warfare. Prior to joining DARPA, Mr. Tilghman was a senior research engineer at Lockheed Martin’s Advanced Technology Laboratories where he led programs in adaptive electronic warfare, signals intelligence and non-cooperative geolocation.

While at Lockheed Martin, Tilghman led the development of a real-time cognitive electronic warfare system, which used machine learning techniques to characterize and counter previously unknown radio emitters on the battlefield. He is a recipient of Lockheed Martin’s highest award, the NOVA award, and was also previously honored as the company’s Engineer of the Year. Mr. Tilghman received a Bachelor of Science degree in computer engineering from the Rochester Institute of Technology and a Master of Science in electrical engineering from Drexel University.

November 13, 2019 “”

Patricia Florissi, VP and Global CTO for Sales, Information Technology and Services, DellEMC

Patricia Florissi is vice president and global chief technology officer for sales at EMC Corporation. As global CTO for sales, Florissi helps define mid and long-term technology strategy, representing the needs of the broader EMC ecosystem in EMC strategic initiatives. Before joining EMC, she was the vice president of advanced solutions at Smarts in White Plains, New York. Florissi holds multiple patents and has published extensively in periodicals including Computer Networks and IEEE Proceedings.

She is a member of the Columbia School of Engineering Board of Visitors and is on the advisory board at Worcester Polytechnic Institute. Additionally, she serves as a mentor for several groups both inside and outside of EMC. She sits as mentor and judge for the Boston based Mass Challenge group, as well as the Boston Club for advancing women’s leaders. Florissi holds the honorary title of EMC Distinguished Engineer, having been nominated in October 2007. She also earned a Ph.D. in computer science from Columbia University in New York, graduated valedictorian with an M.B.A. at the Stern Business School in New York University, and has a master’s and a bachelor’s degree in computer science from the Universidade Federal de Pernambuco, in Brazil.

Backup

1. AI Technologies for use by the FCC

	Use Case	Description and Impact
1.	Identification of Infractions	Improving Enforcement Processes via Automated use of sensors and information to detect, and identify. AI with geolocation can better detect the sources of interference and nefarious acts.
2.	Detecting “jammers”	Leverage AI to web crawl and detect jammer offerings.
3.	Robocalling prevention	Augment current “stir/shaken” as needed with AI. Provide policies to help operators work together efficiently, with AI as a possible tool.
4a.	Analyze various databases	Monitoring FCC databases and the users that are served to better utilize information that’s generated. Making items more accessible to the population and to 3rd party companies for the betterment of the network.
4b.	Improve the DIRS Tracking Process	Seek paths to improve the tracking of high impact outages and their restoration via AI.

1. AI Technologies for use by the FCC (cont.)

	Use Case	Description and Impact
5.	Spectrum Management	Need for the demand of tighter limits and more efficiency which will drive the use of AI to make the network better and faster.
6.	Complex rules and regulations	Ensure rules and regulations co-exist, do not conflict, and are as simply defined as possible.
7.	Leveraging information from FCC Call Center Data including Direct Interference complaint lines	Using AI/ML to determine trends of interference from the complaint calls. A database exists to document tower locations. The agency collects interference complaints and publishes information that can be analyzed by third parties to identify trends. Example – this can help carriers understand the best locations for new base sites.

2. AI Technologies for the Network use by Operators and Service and Providers

	Use Case	Description and Impact
1.	Support for Granular "Slicing"	Balancing virtual resources applied to each slide. This is very complicated for humans to do.
2.	Network and Service Management, security and privacy	Security and user experience. Anomaly detection. Secure the control plane and the user plane. Identification and mitigation of Jamming and Spoofing. Maximizing throughput by E2E optimization of the service with best use of spectrum. Ability to meet requirements for the applications to ensure SLAs (jitter, loss, latency)
3.	Two-sided Markets	Gathering, analyzing, and disseminating information for matching investment options for infrastructure and content providers, net neutrality is an example. Broadband service is a two-sided market - the provider's resources are demanded by 1)subscribers and 1)edge providers. FCC decision to allow broadband SPs to charge edge providers a fee for accessing their subscribers can enhance the efficiency of the broadband SP resources. ML can assist in promoting more efficient use of resources.

2. AI Technologies for the Network use by Operators and Service and Providers (cont.)

	Use Case	Description and Impact
4.	Interference Mitigation	Use of AI and automated use of sensors to reduce Spectrum interference
5.	Improved Customer Experience	Understanding the UE and location information in order to maximize their experience, such as beam forming, and maximize the throughput of the network.

3. AI Technologies for Important and Critical Applications

	Use Case	Description and Impact
1.	Autonomous and Connected Vehicles	Consumer level, and services available from intelligent transportation systems such as “Lyft” and “Uber”
2.	Healthcare	Utilizing high resolution video is important. Machine vision. These are likeliest to have the biggest impact on the network by volume.
3.	Education	Machine intelligence itself can drive up the use of the network.
4.	Law Enforcement and Emergency Response	AI machine vision, correlation, video, geolocation, safety and criticality.
5.	Consumer services and retail	Artificial Intelligence (AI) has become a key element in the digitalization of in-store retail by personalizing the customer experience and creating a more engaged business-to-consumer interaction. For retail companies, AI creates an opportunity to bridge the gap between virtual and physical sales channels
6.	Industrial Asset Management	High resolution inspection of facilities, inventory control and optimization

4. AI Technologies – The Dark side of AI, the use of AI for harm

	Use Case	Description and Impact
1.	Compromise security or privacy	Replay attacks. DDoS, Jamming, spoofing, unlawful eavesdropping, etc
2.	Use of spoofing in many ways	In Autonomous driving, someone could intentionally place an incorrect speed limit sign and “fool” the car.
3.	Facial recognition and bias	May introduce discrimination against certain groups depending on the algorithm
4.	Robocalling	Monitor and select numbers of significants
5.	Spearfishing	Monitoring what is there to understand how to optimally provide malware for a specific individual
6.	“Deepfakes”	
7.	DDOS attacks	AI creates smarter and even brand new attack vectors that have not existed in the past. Autonomation of the best way to find user vulnerabilities at large scale.
8.	Eavesdropping	Advanced ways to extrapolate data to do even more prediction and intelligence

2019 Execution Plan for Artificial Intelligence -WG

- Identify High impact applications for AI relative to FCC mission
- Learn from the experts
  - General Artificial Intelligence (AI)
    - Invite experts to describe an overall view of AI in the industry, including impact to the industries themselves
  - Network Automation and Architecture
    - Include a deeper dive including Cloud/DC, edge processing, remote workers and the network impact
  - FCC Application
    - Understand how the FCC can optimize workflow and execution
- Desired Outcomes
  - Provide education
    - Understand the impact of AI on fundamental network architecture and the FCC mission
  - Define continuance of mission for WG into 2020
  - Develop Actionable Recommendations (examples below)
    - How to use AI within the process of the FCC to make regulations more accessible
    - Identify where the current regulatory structure is called into question because of AI

Additional inputs for CY2020 plan

- Concrete and fleshed out proposals for how the FCC can apply AI to better provide data on the broadband fabric. Estimates are all over the map. What is in the RDOF NPRM for Phase II is completely out of synch with what is suggested by Cost Quest. Phase II of RDOF depends on an accurate mapping of the broadband fabric and it seems to me that there are better ways to collect data with an AI approach than are currently being considered.
- Hybrid networks and the role of AI in increasing the heterogeneity of commercially available networks and network services. More specifically, what can the FCC do to enable hybrid networks to make coverage accessible everywhere – not just all locations associated with a US mail address, but really everywhere there could be a user with needs.
- FCC should undertake a small project to apply AI and build internal experience and expertise. Potential areas include: customer service (chatbot or complaint handling, but I don't know the volume of consumer input they get), processing of high-volume filings like the network neutrality proceeding (perhaps already done?), or something more experimental in OET's realm, similar to DARPA's spectrum sharing project.
- Possible PN or NOI to collect information from industry on where AI is being applied and will be applied in communication networks. It would serve as an extension of our work and a broader call to industry so the FCC can build a record for future action if any is needed. We would want to be clear that no regulation is anticipated, which perhaps means a PN is preferred.
- More of an assignment for us, but similar to the PN, we could develop a white paper that compiles active and likely near-term applications of AI in networks. That white paper could assess the application areas for known AI limitations like bias, brittleness, adversarial attacks, lack of transparency, to rank risk. For example, network management that is infused with AI might be low risk for problems associated with bias but might be high risk if not designed with adversarial attacks in mind.