SPECTRUM COLLABORATION CHALLENGE

The world's first collaborative machine-intelligence competition to overcome spectrum scarcity.

Spectrum sharing through collaborative autonomy

Paul Tilghman
Program Manager, DARPA/MTO

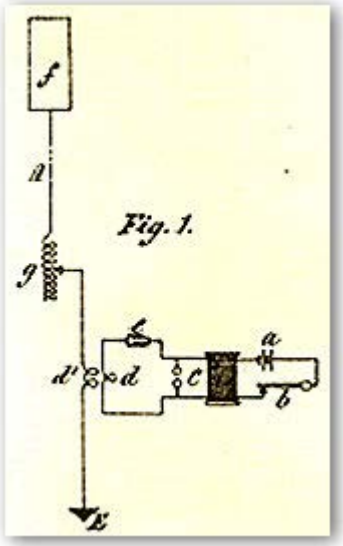
November 15th, 2017

DARPA

An abridged history of spectrum sharing

What is harmful interference?

1899
Marconi



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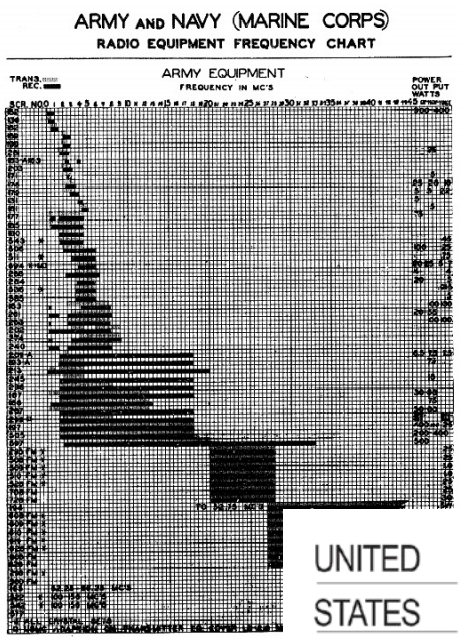

1899 Marconi

1934 FCC Founded

1926
Federal Radio Commission

1934
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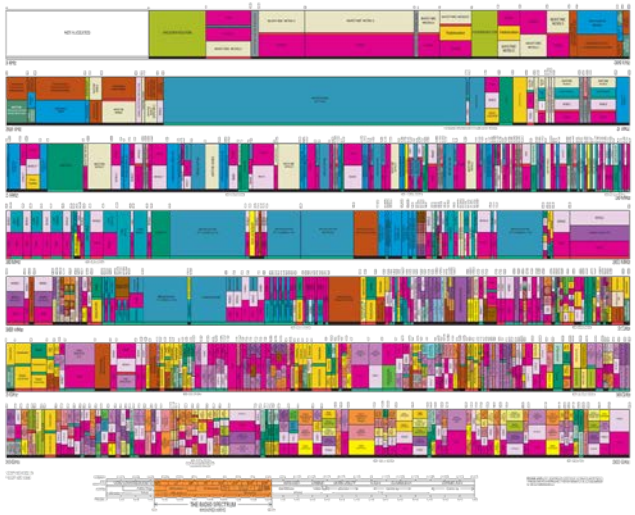

https://www.ibiblio.org/hyperwar/USMC/ref/Amphibious/img/Amphibious-5-9.jpg
https://upload.wikimedia.org/wikipedia/commons/4/45/United_States_Frequency_Allocations_Chart_2003_-_The_Radio_Spectrum.jpg

An abridged history of spectrum sharing

What is harmful interference?

Broadcast Era *Person-To-Person Era*

1899 Marconi

1934 FCC Founded

1973 First Mobile Cell Phone

How much spectrum do we need?

$$\frac{\#\text{ of Stations} \times \text{Voice Bandwidth}}{\text{Spatial Reuse}}$$

$$\frac{\frac{\textbf{\#\ of People} \times \text{Voice Bandwidth}}{\text{Spatial Reuse}}}{2}$$

$$\frac{\textbf{323 Million} \times 12.5\ \text{kHz}}{\frac{300\ \text{area codes} \times 10\ \text{cell towers}}{2}} = 700\ \text{MHz}$$

https://cdn.newsday.com/polopoly_fs/1.7585942.1396473650!/httpImage/image.jpg_gen/derivatives/display_1004/image.jpg

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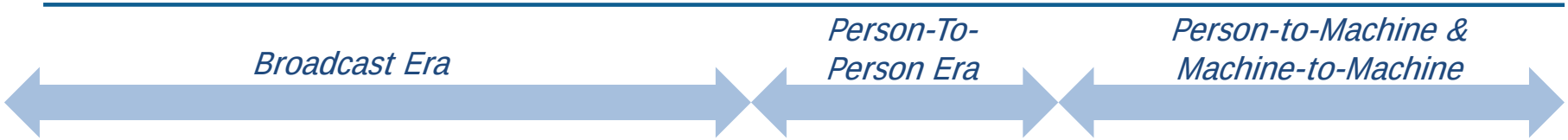

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1999 Birth of WiFi

1985
FCC approves the unlicensed ISM bands for communications use

1997
First version of 802.11 protocol

1999
802.11b released commercially

https://upload.wikimedia.org/wikipedia/commons/thumb/a/ae/WiFi_Logo.svg/2000px-WiFi_Logo.svg.png

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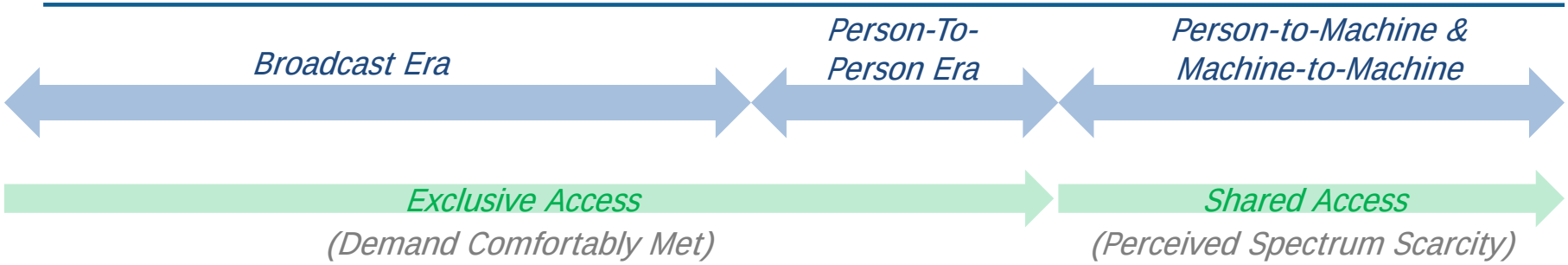
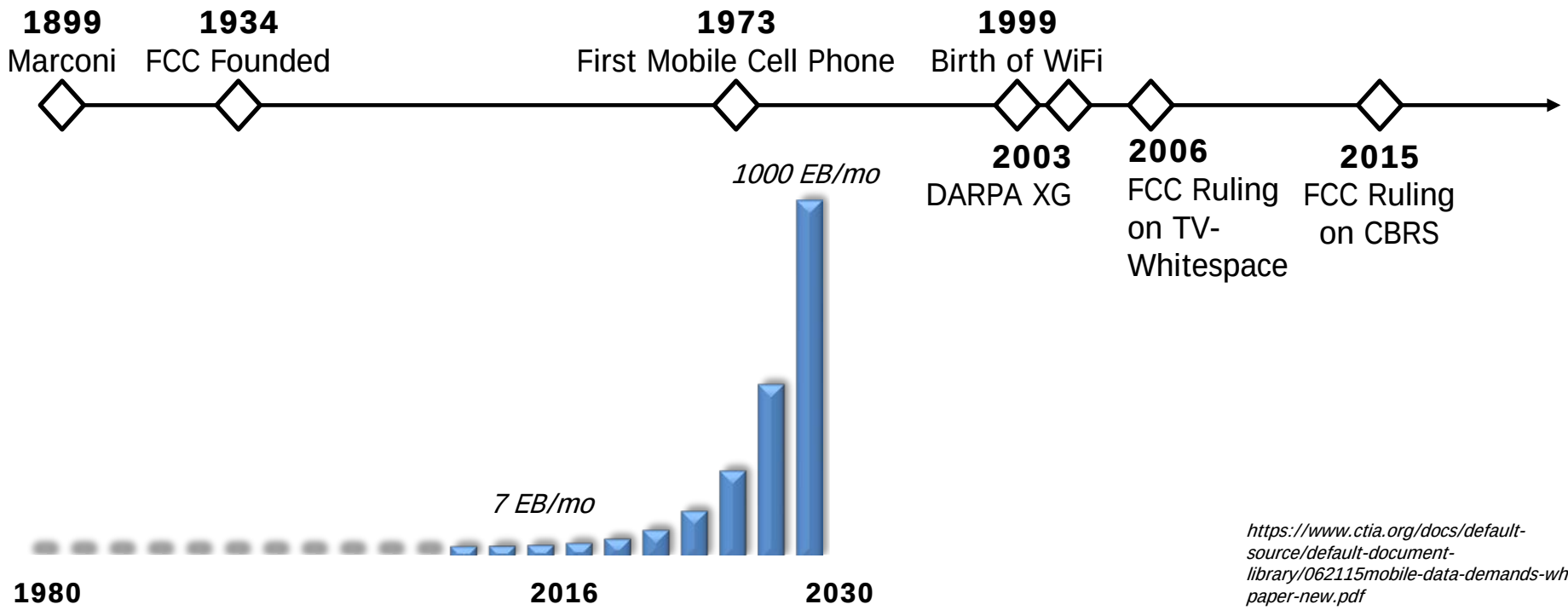
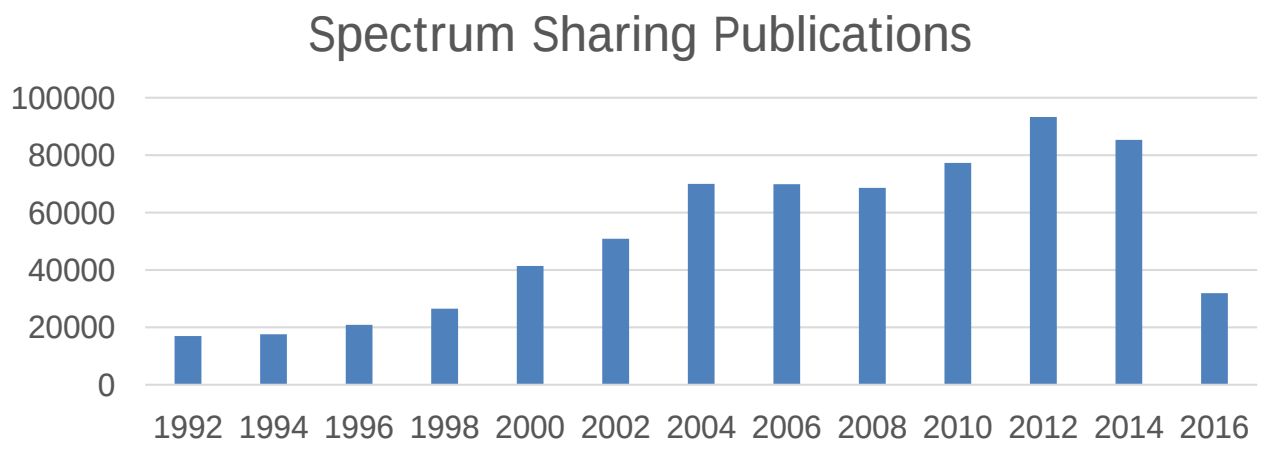


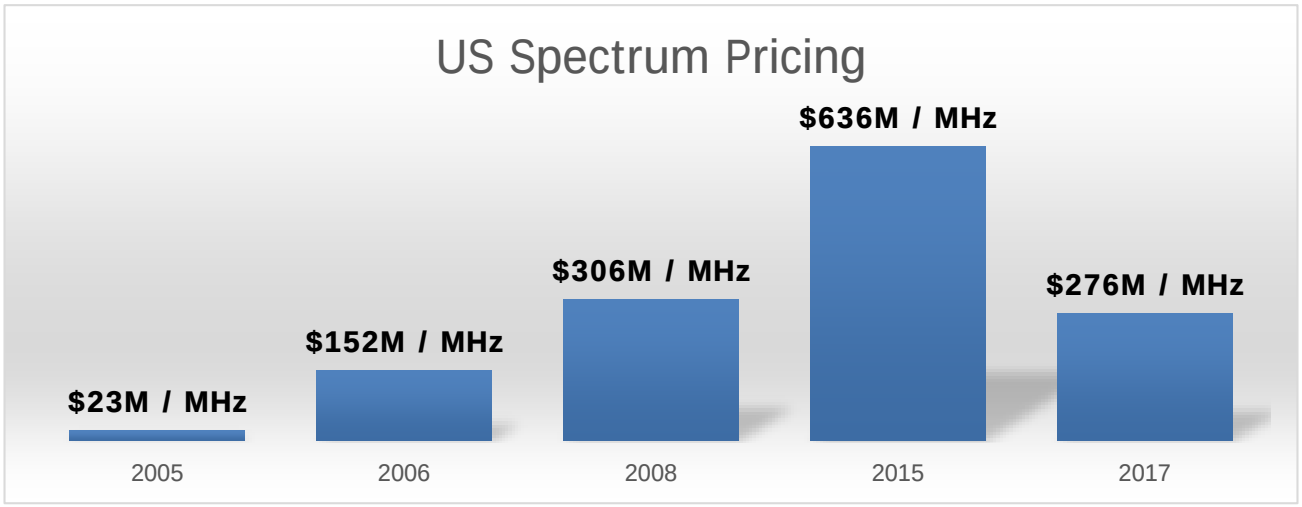


https://www.ctia.org/docs/default-source/default-document-library/062115mobile-data-demands-white-paper-new.pdf

Spectrum sharing struggle to take hold



scholar.google.com



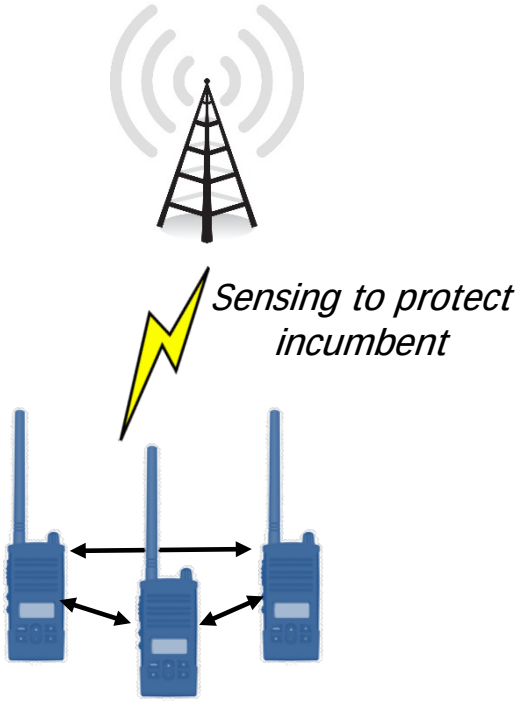
http://wireless.fcc.gov/auctions/default.htm?job=auctions_all

Technical challenges in wide-scale adoption of spectrum sharing

- A single unified definition of harmful interference?
  - *Between what set of devices?*
  - *In what environment?*
- "Outcome-based" sharing impossible in previous spectrum sharing generations
- Difficult to scale beyond one system sharing with one incumbent
- Database approaches limit the granularity of spectrum sharing

A new approach to spectrum sharing...

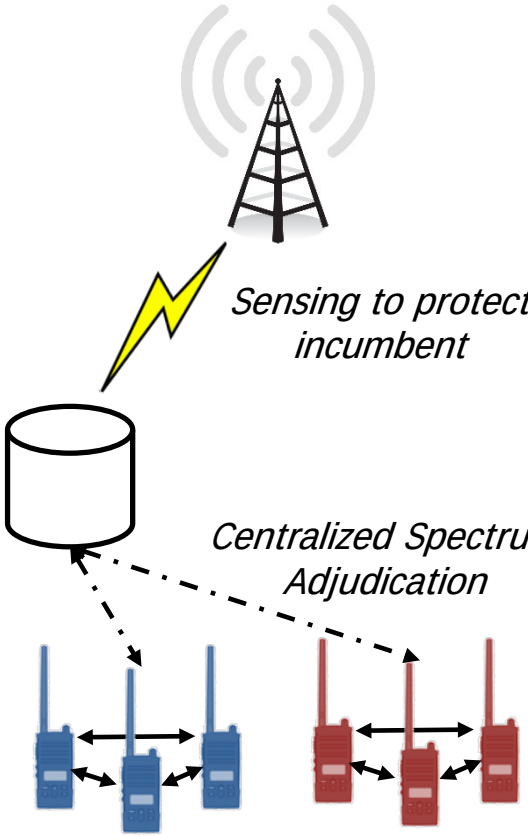
"XG" Approach



Milliseconds

Vertical Sharing

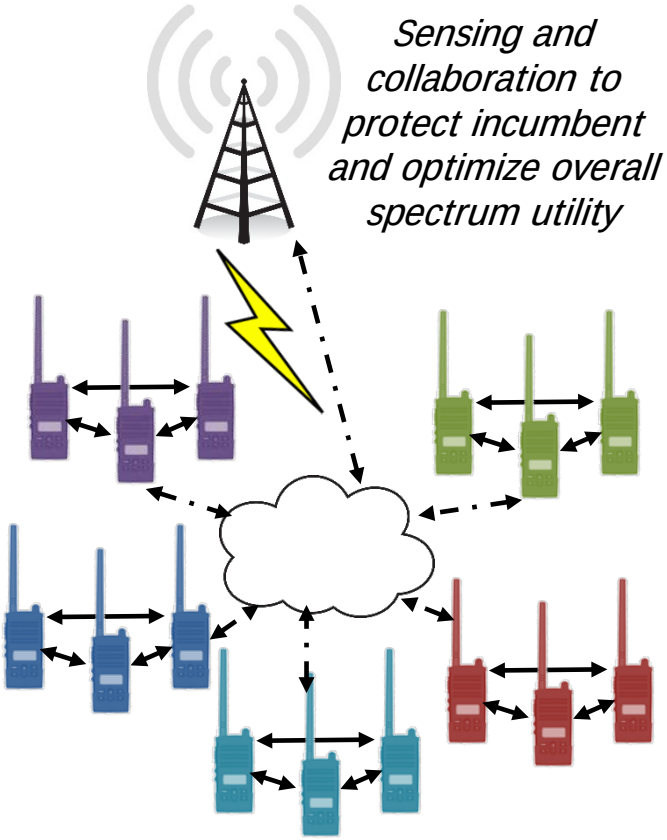
Database Approach



~ Minute

Vertical Sharing

Collaborative Sharing

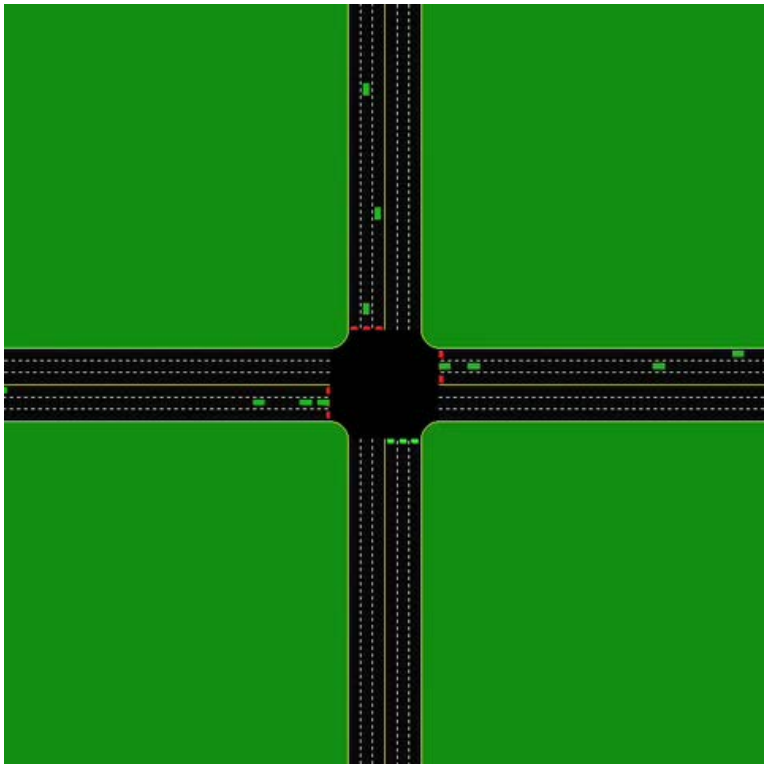


Seconds

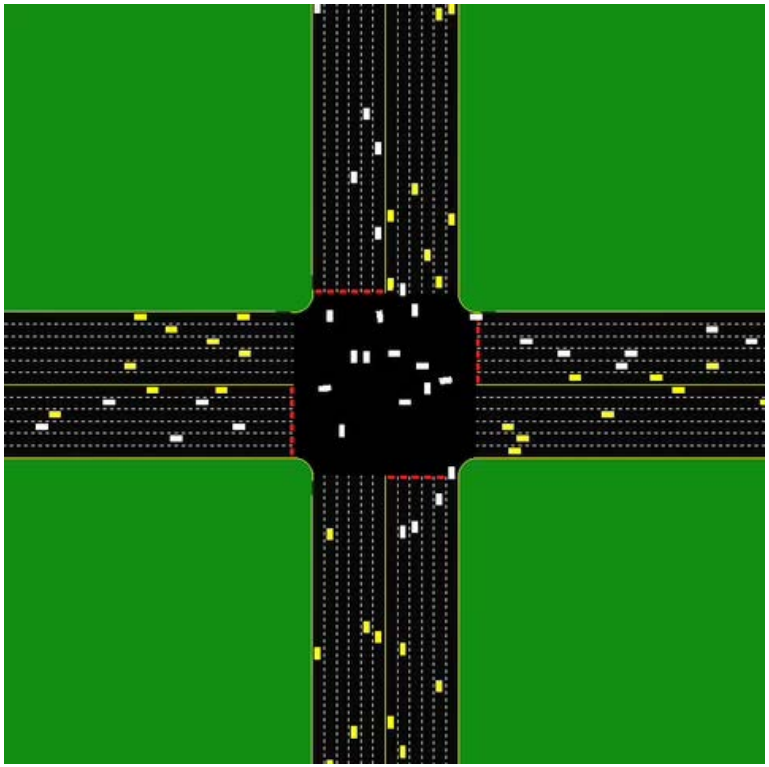
Vertical & Horizontal Sharing

Why is collaboration so important?

Open loop autonomy (requires rules)
OK for light traffic…doesn't scale with congestion/demand



Collaboration and autonomy
Scaling to meet congestion/demand

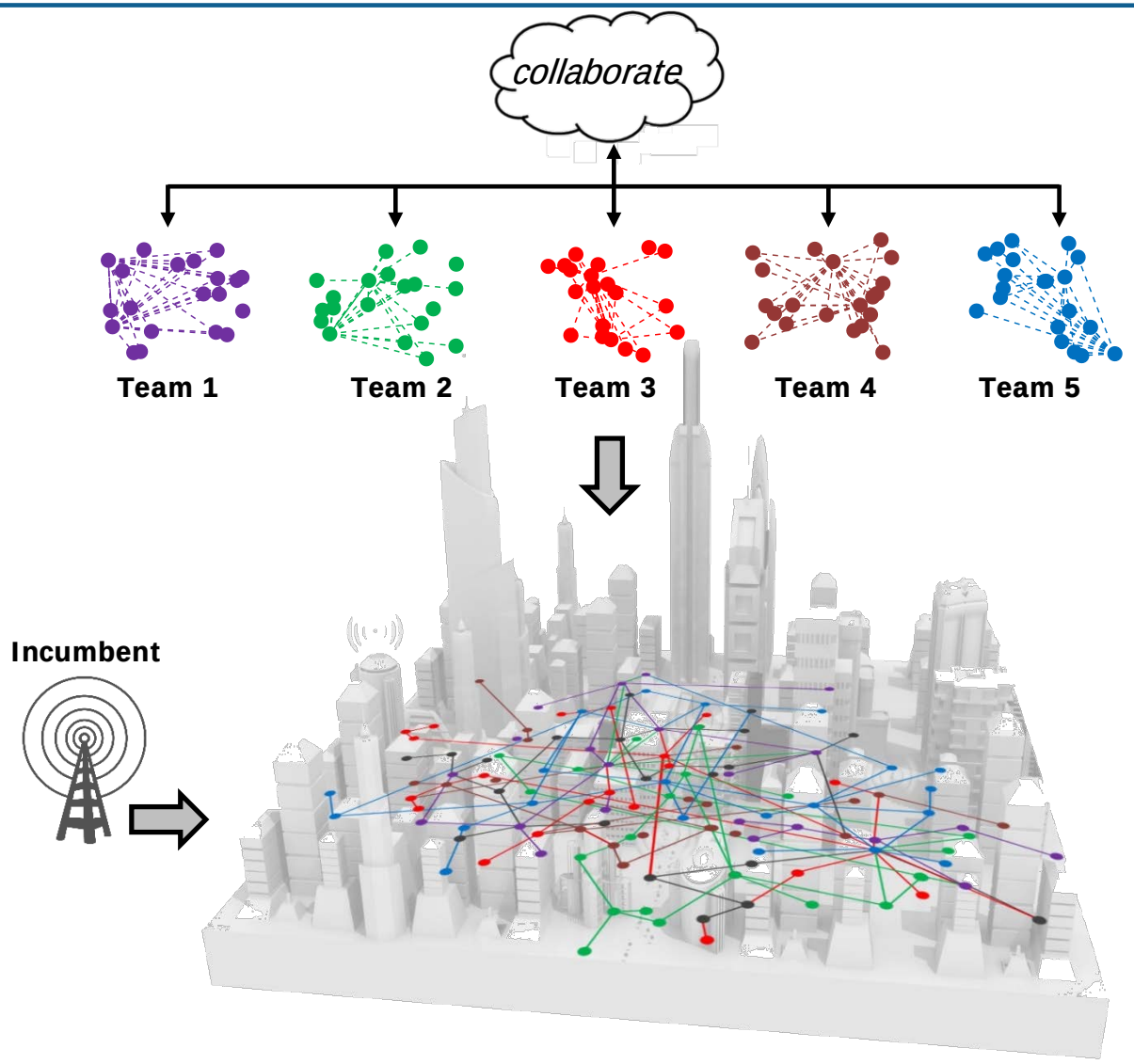


UT Austin AI Laboratory:
http://www.cs.utexas.edu/~aim/

SC2 Collaborative Competition

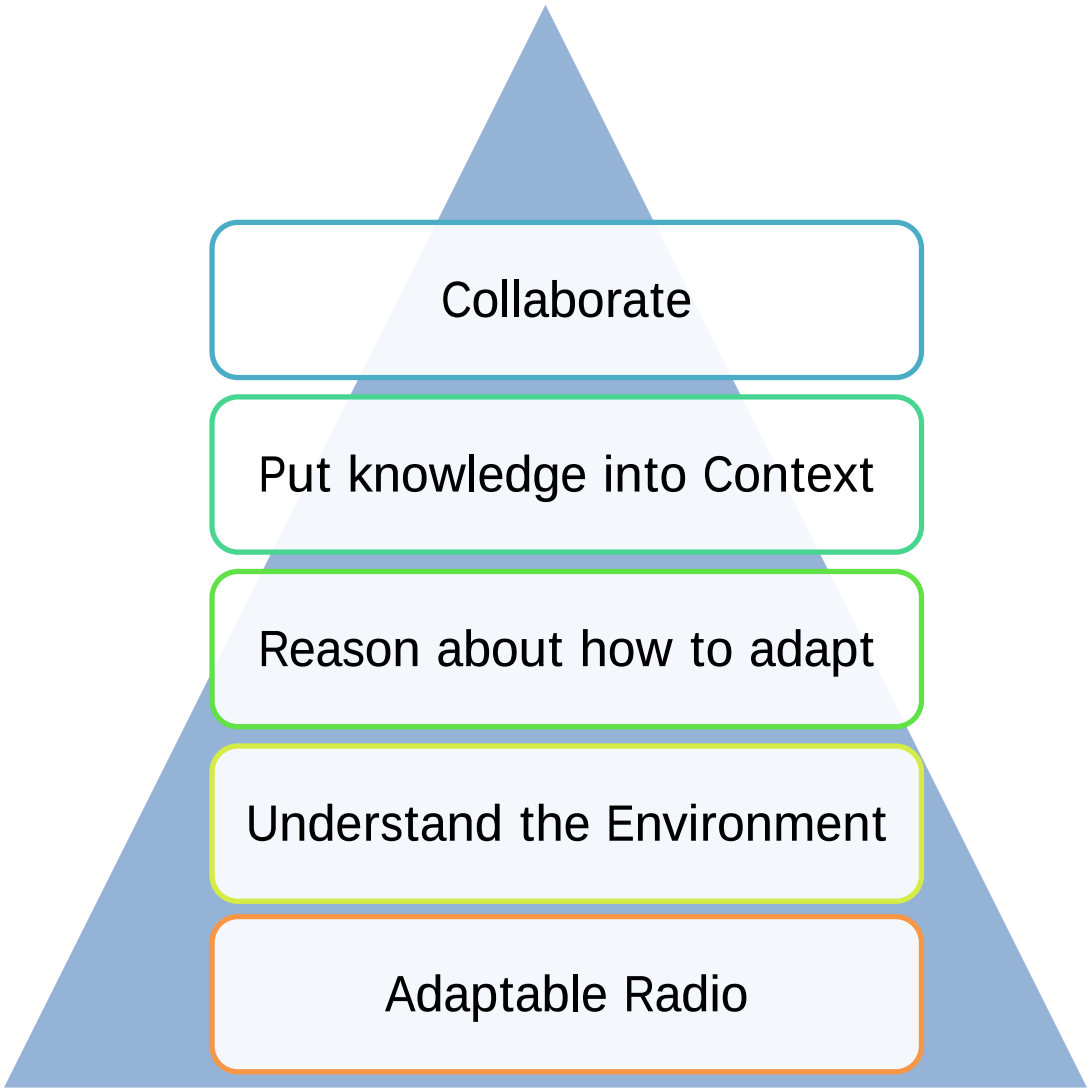
THE GAME:

- Five teams need to move data through a spectrum obstacle course.
- The obstacle course can change over time.
- The teams themselves are obstacles.
- A team earns points by successfully navigating the course.
- A team earns more points by describing obstacles accurately so other teams can avoid them.
- The team that navigates the course and helps the most teams wins.



SPECTRUM COLLABORATION CHALLENGE

5 Elements of a Collaborative Intelligent Radio Network



Collaborate with previously unknown radio systems, discover the value of information and optimize the overall joint utility

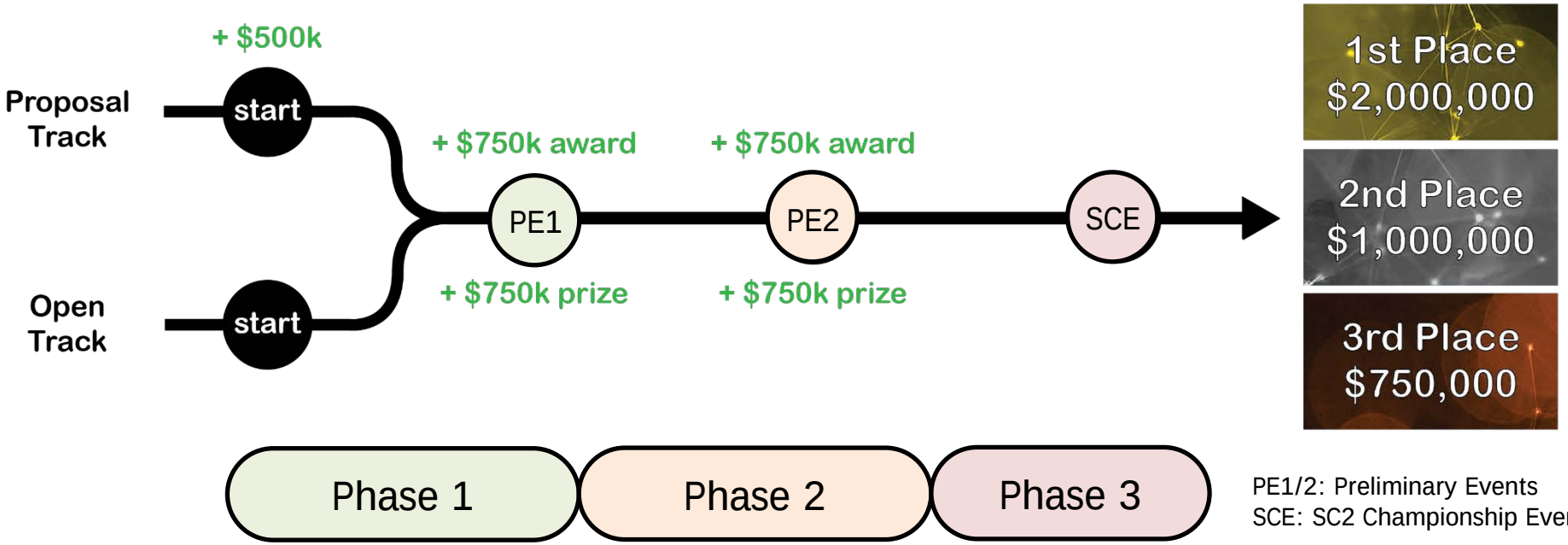
Contextualize existing knowledge to rapidly overcome changes and new challenges

Reason about how to take actions to result in successful communication, taking into account the effect the action may have on others

Understand and characterize signals to infer the conditions of the local RF environment through noisy observations

Adaptability in time, frequency, space, code, waveform, MAC scheme, network, etc.

Overall Schedule of Prizes

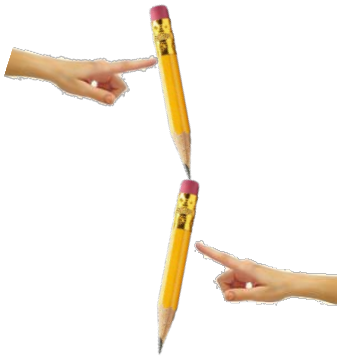


PE1/2: Preliminary Events
SCE: SC2 Championship Event

Registration now open for Phase 2 teams!
SpectrumCollaborationChallenge.com/join/

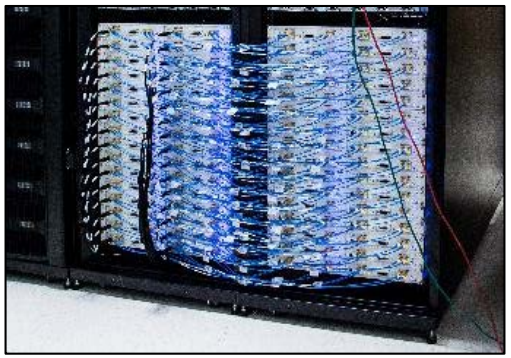
Spectrum Collaboration Challenge – Challenges

Collaborate Without Co-Design



Create radio networks that work with others without knowing how they "think"

Engineer Emergent Effects



Discover and solve issues that only arise in large-scale realistic settings

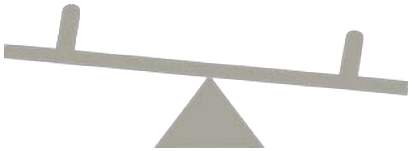
Communicate Without Constraints

too specific

frame 15, slot 7

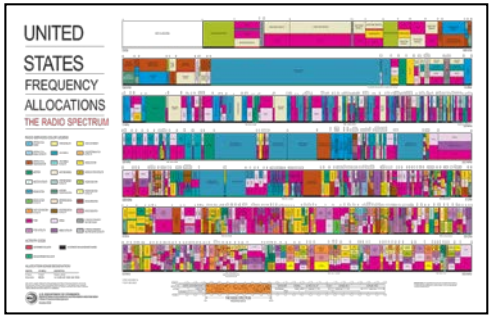
too general

A B C → D



Create a protocol that supports evolving new forms of collaboration

Evolve The Ecosystem



Change radio design, applications, and spectrum management to enable and leverage collaboration.

Thumbs-up image source: http://sr.photos3.fotosearch.com/bthumb/CSP/CSP880/k8803233.jpg
Pencil image source: http://www.pngall.com/wp-content/uploads/2016/03/Pencil-PNG.png

Spectrum Collaboration Challenge

SpectrumCollaborationChallenge.com

DARPA

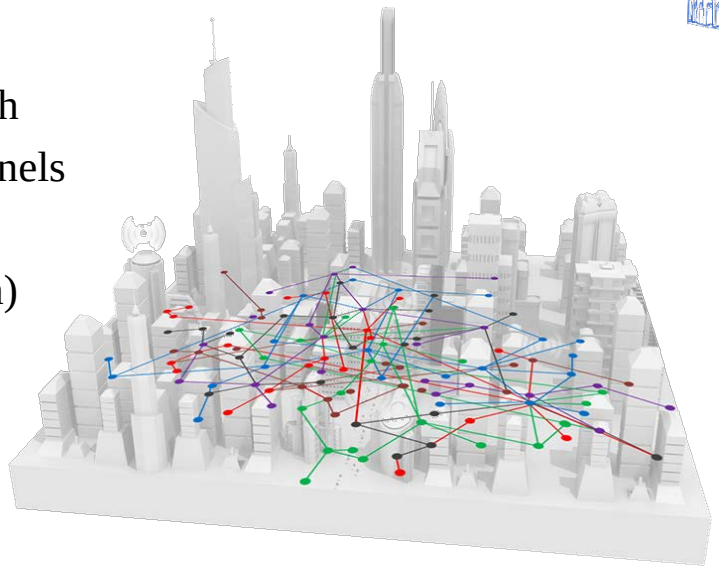
Colosseum: The world's largest RF emulator..

The environment for ensemble spectrum AI

1 Quadrant
(64 ports)

It's Really Big

- 25.6 GHz total instantaneous bandwidth
- 100MHz per channel x 256 x 256 channels
- 420 Tb/s of digital RF data
- 1.88 TB of scenario model data (30min)



Comprised of

- 128 USRP X310
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Specifications

- 128 2x2 MIMO Tx/Rx Ports
- Phase Coherent
- Bandwidth : 80 MHz BW
- Tunable: 10 MHz to 6GHz
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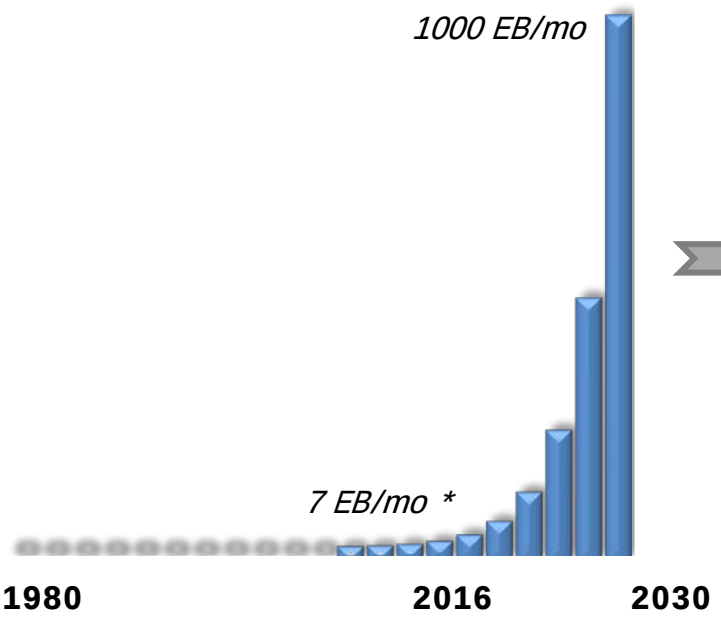
Spectrum Collaboration Challenge Overview

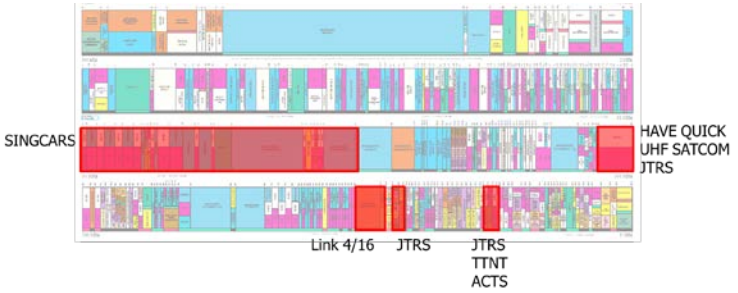
Surging Spectrum Demand



Challenges to Military Spectrum Operations

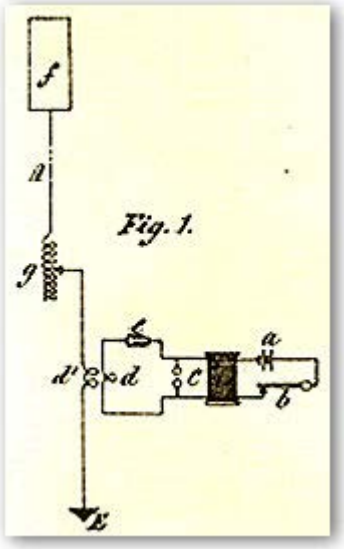
Manual & inefficient spectrum planning tools can't keep up with demand / pace

Converging military and commercial spectrum needs



Limited and predictable spectrum "mobility"

Origins of the spectrum Grand Challenge… Coexistence



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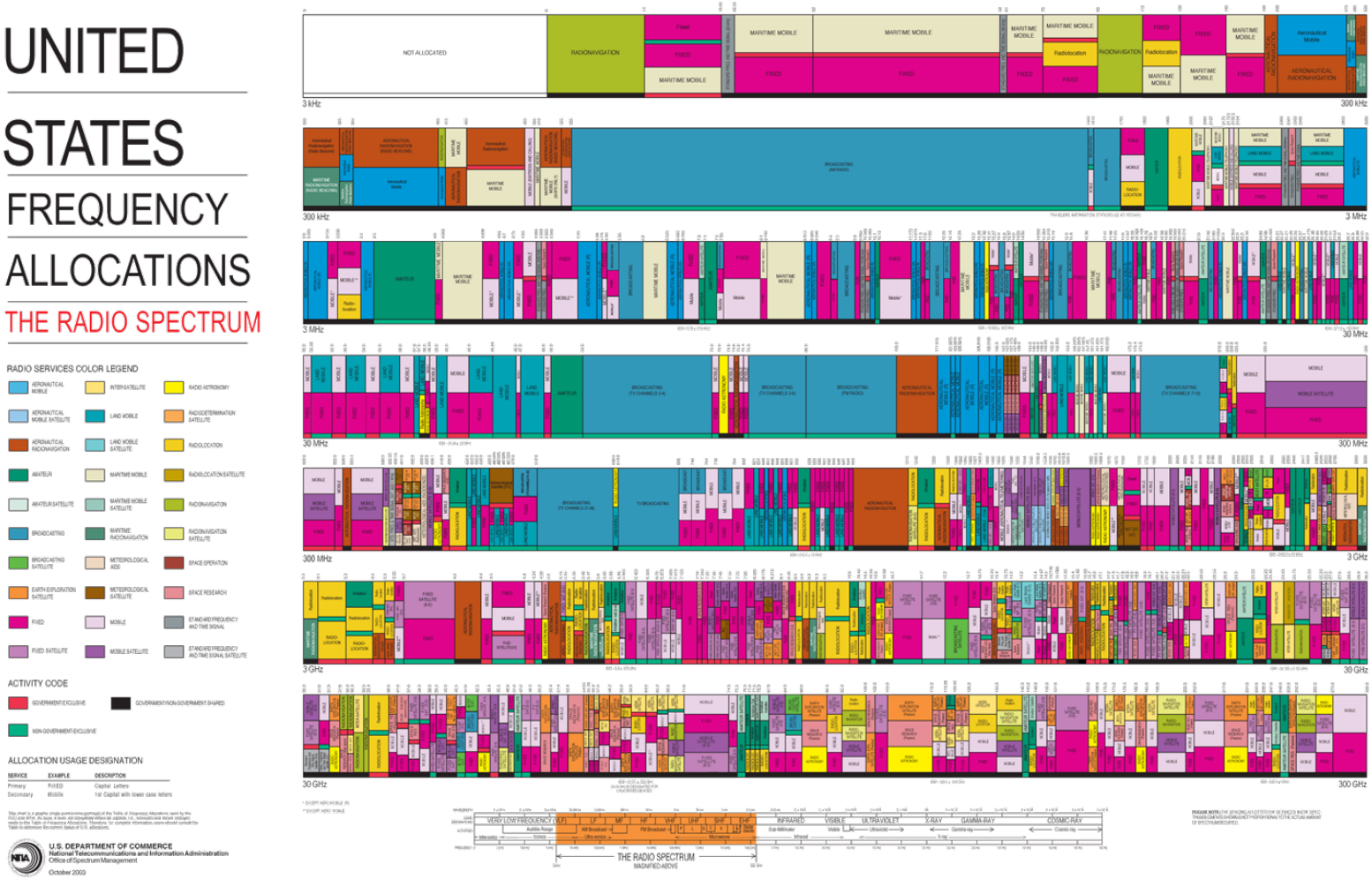
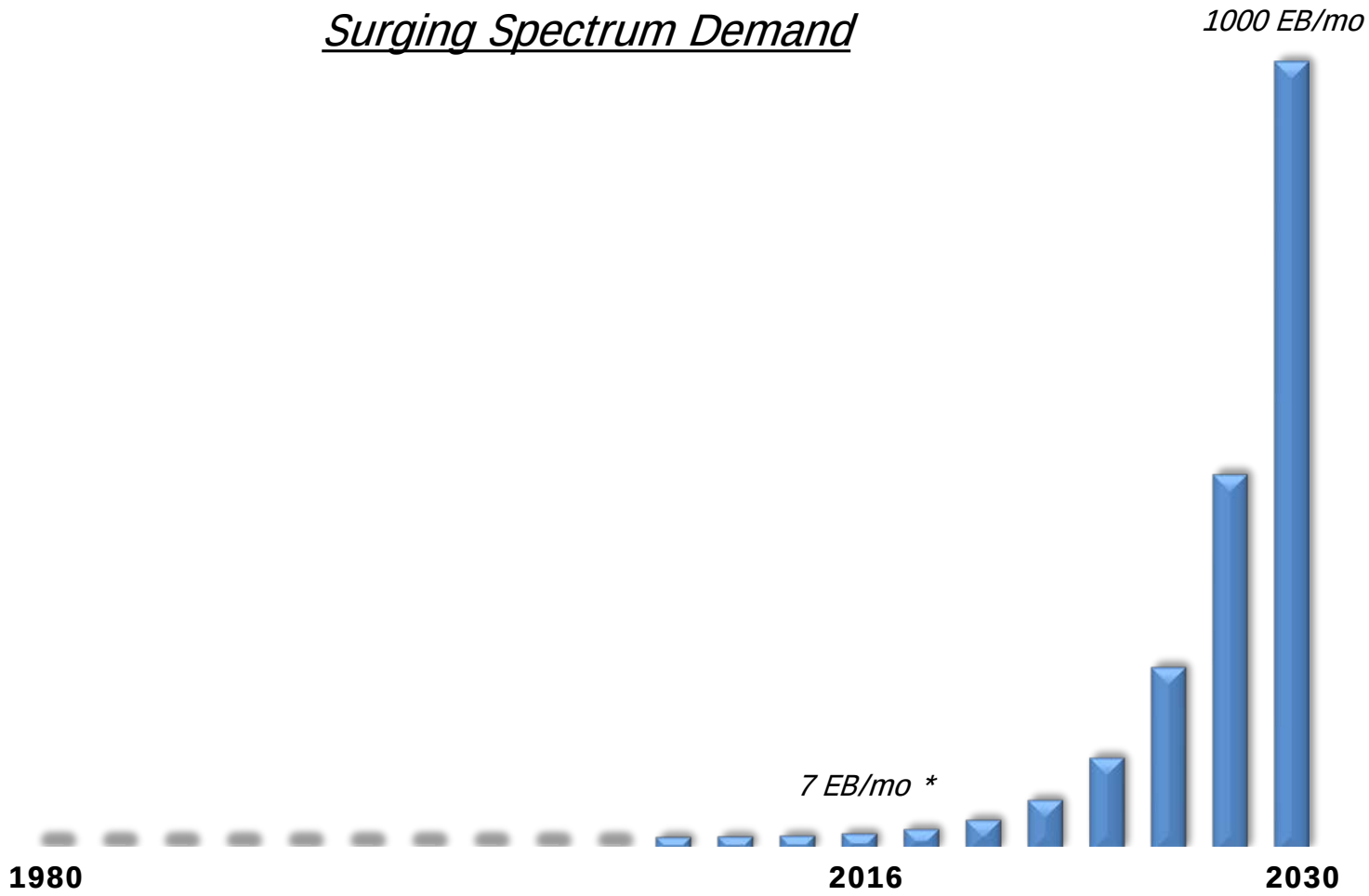
Coexistence is the original, and enduring, Spectrum Grand Challenge

The Wireless World Today



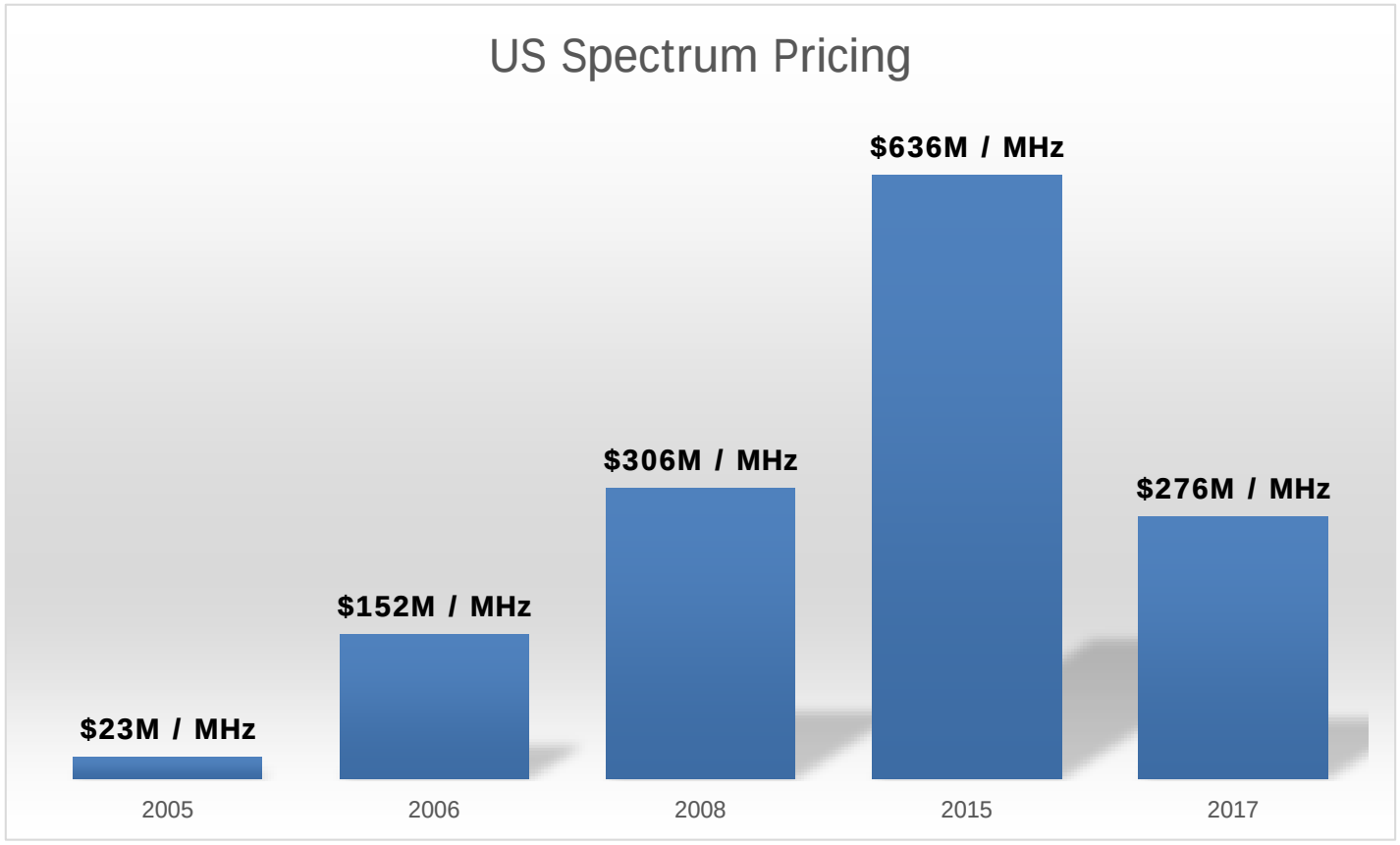
100 years of spectrum management practice increasingly challenged



Meeting spectrum demand requires spectrum sharing through autonomy

** Cisco Visual Network Index*

High Cost of Maintaining the Status Quo



http://wireless.fcc.gov/auctions/default.htm?job=auctions_all

History of DARPA's Grand Challenges

*Collaborative **autonomous** spectrum sharing and optimization*

*A tournament for fully **automated** network defense*

*Developing **autonomous** ground robots*

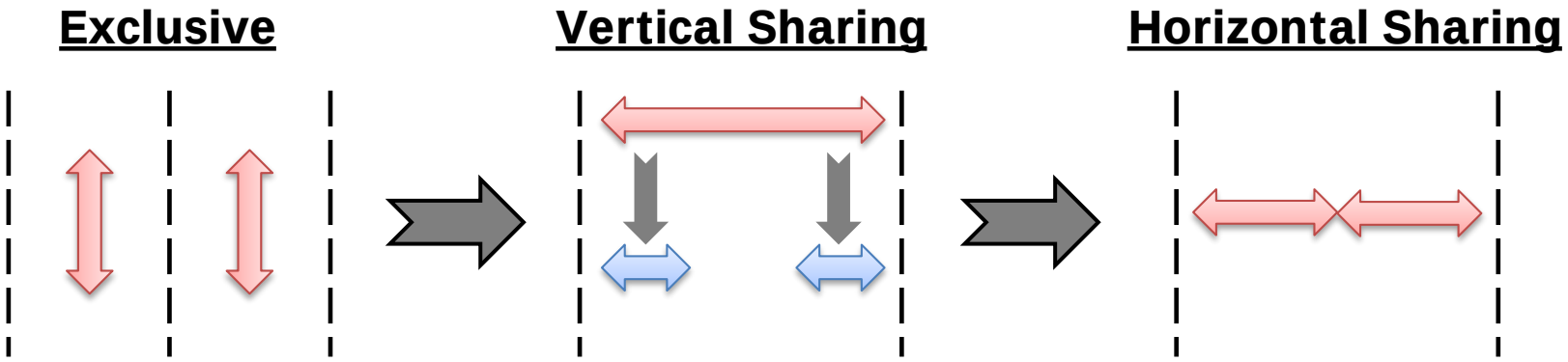
*A push to develop **autonomous** vehicle capabilities*

2000 2010 2020

Grand challenges are not the end-state, but the beginning of a new paradigm

Considerations for spectrum autonomy in sharing

- Technology heterogeneity
  - There is no one-sized fits-all, “protocol” to rule them all
  - Multi protocol sharing must handle the combinatorial explosion of different spectrum technologies
- Handle real-world, not worst case conditions
  - There is no single interference level that makes sense in all circumstances
  - Tailor sharing parameters given the current conditions
- Sharing with locality and speed
  - Sharing on order of milliseconds and meters…
  - NOT: minutes/hours/days/months/year(s), 10+ kilometer



Progression of Spectrum Sharing

Solution Space

Coexistence level →

Packet

Waveform

Spatial
(in prop range)

Temporal

Spectral

Centralized 3rd-party decisions
Slow-time adaptation

"Get what you get"

Too rigid, too slow
Human time not machine time

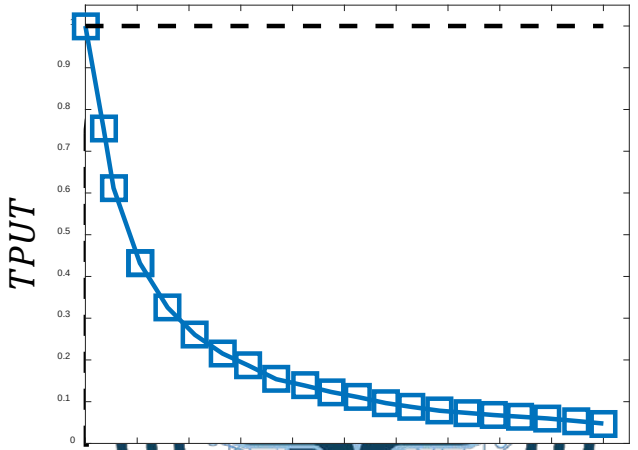
ISM
(400/900
MHz)

Lte
2G
3G

cbrs

Wi Fi

DSA
DYNAMIC SPECTRUM ALLIANCE



Open loop, impact assumed
Exponential penalty for sensing

Non-adaptive (blissfully ignorant)

Semi-adaptive (lumbering)

Reflexive (skittish)

Predictive (artful dodger)

Collaborative (social)

Coexistence type →

**image citations in notes

SC2 Collaborative Competition

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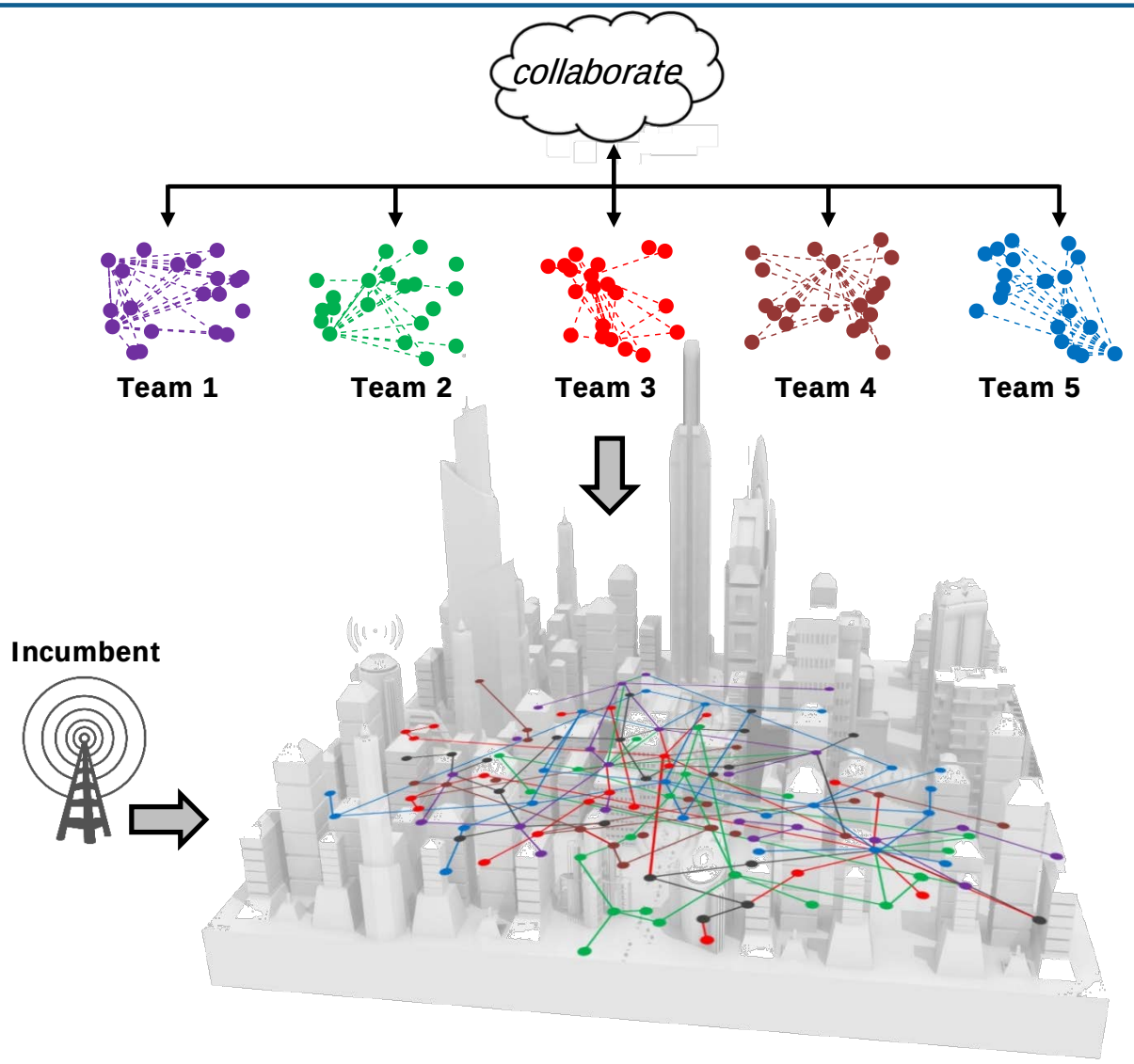

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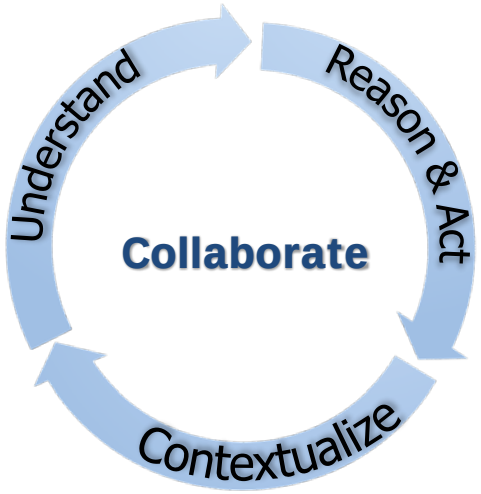
Reconfigurable radio

- Adaptability along dimensions of time, frequency, space, code, waveform, MAC scheme, network, etc.

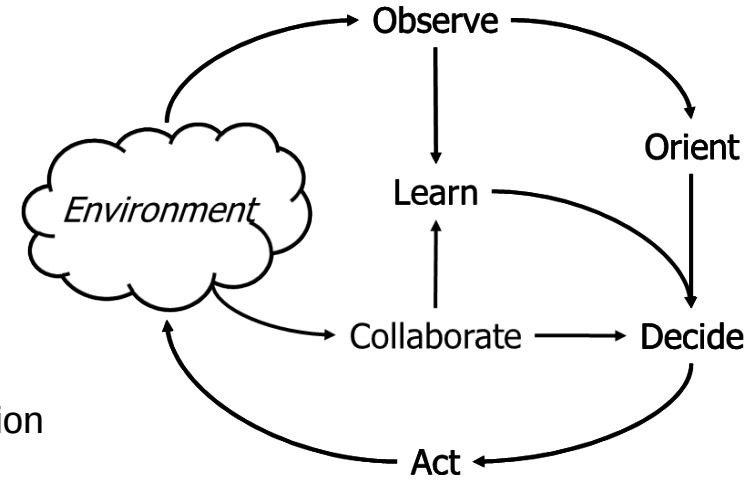


Intelligent radio characteristics

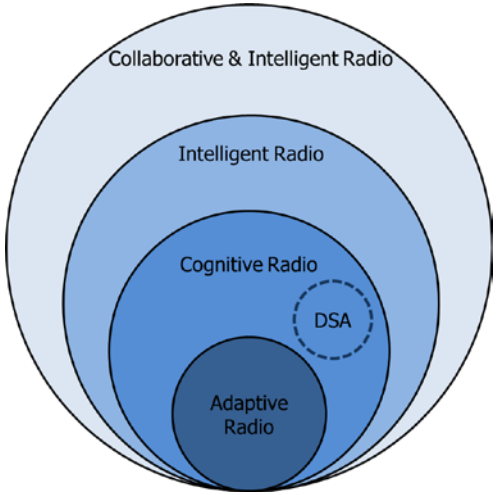
- Understanding: Understand and characterize signals to infer the conditions of the local RF environment through noisy observations
- Reasoning: Reason about how to take sequential actions to result in successful communication, taking into account the effect the action may have on others using the same spectrum
- Contextualization: Contextualize what the system has already learned to be able to rapidly overcome changes and new challenges by leveraging and transferring previous knowledge to these new problems
- Collaboration: Learn how to collaborate with previously unknown radio systems by discovering what information is valuable to them to optimize the overall joint outcome while minimizing the cost of collaboration

“Cognitive” radio?

- Collaborative *Intelligent* Radio Networks, not *cognitive*
- “Cognitive” parlance in the radio community owes its heritage to Mitola, 1998
  - Grand vision for what a cognitive radio should be
  - Formalizes the OODA loop as the *cognition cycle*



- OODA loop definition leaves “cognitive” open to interpretation
- DSA (c. 2004) gives an interpretation
  - Observe = FFT, Orient = Threshold, Decide = Best Channel, Act = Retune
- This interpretation is a limited subset of cognitive radio



- SC2 strives for a more ***intelligent*** radio, that can learn, predict, and be social
- Attributes of “intelligence”:
  - Ability to acquire, store, and apply knowledge over long timeframe
  - Self awareness within the environment (e.g., understand your impact upon and how you fit within the environment)

http://www.wirelessinnovation.org/Defining_CR_and_DSA

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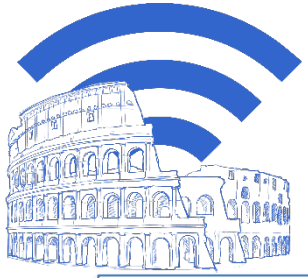

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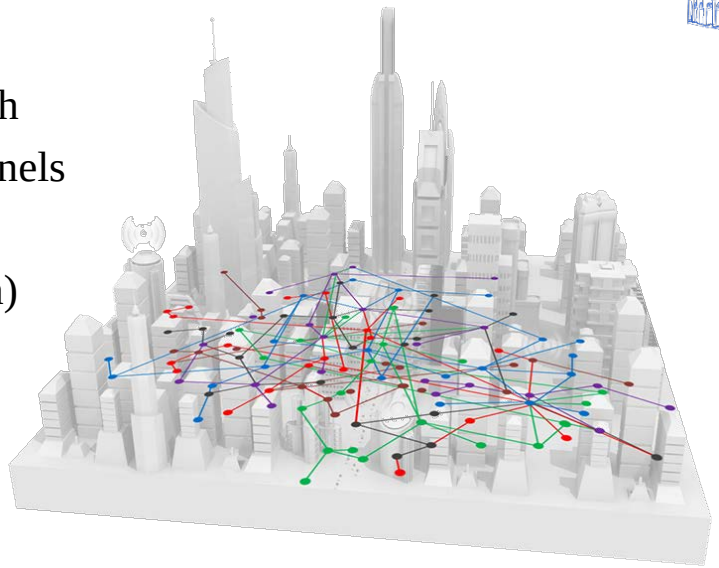

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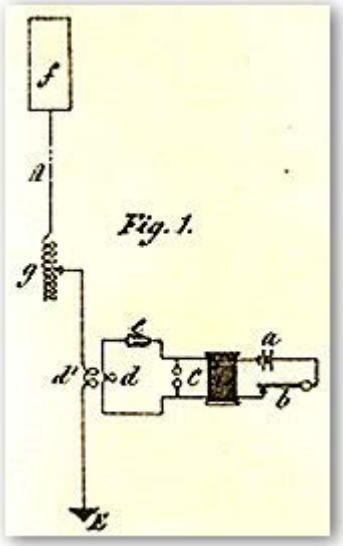
Marconi



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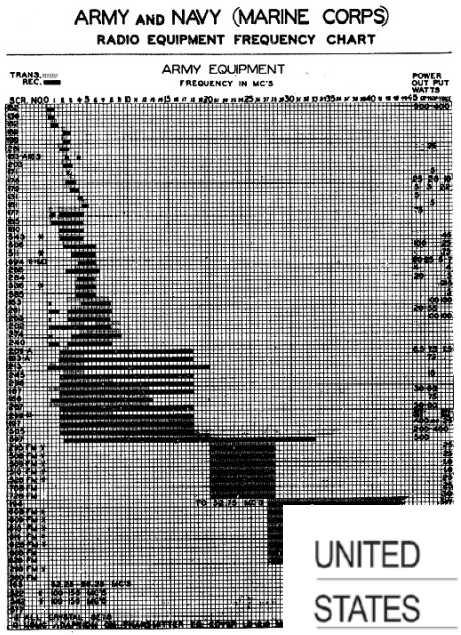

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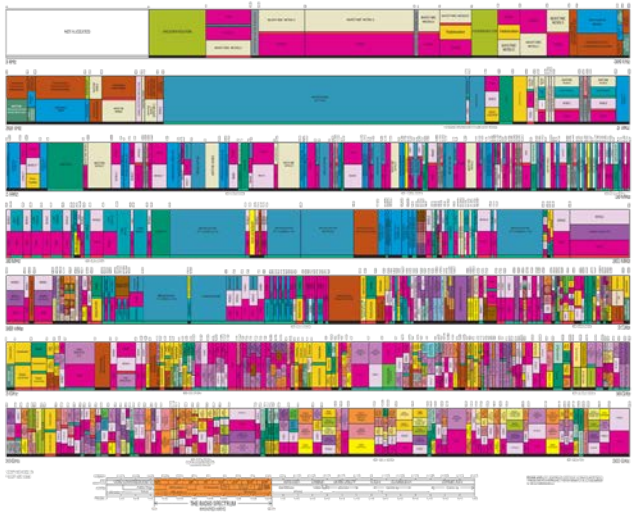
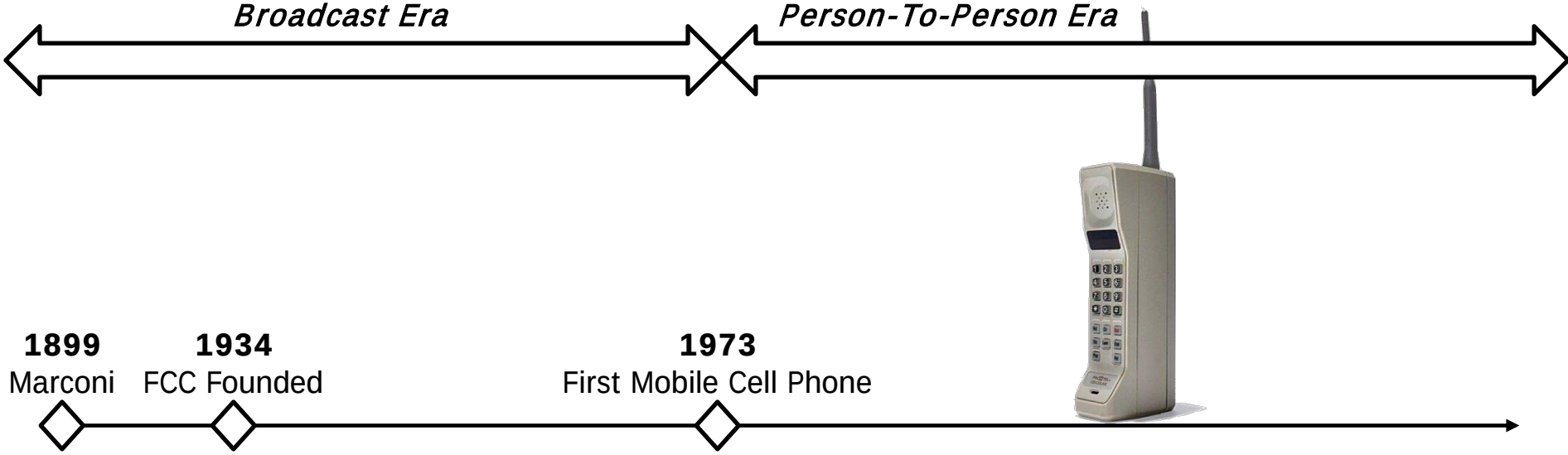


https://www.ibiblio.org/hyperwar/USMC/ref/Amphibious/img/Amphibious-5-9.jpg
https://upload.wikimedia.org/wikipedia/commons/4/45/United_States_Frequency_Allocations_Chart_2003_-_The_Radio_Spectrum.jpg

An abridged history of spectrum sharing

What is harmful interference?



$$\frac{\#\text{ of Stations} \times \text{Voice Bandwidth}}{\text{Spatial Reuse}}$$

$$\frac{\frac{\textbf{\# of People} \times \text{Voice Bandwidth}}{\text{Spatial Reuse}}}{2}$$

$$\frac{\frac{\textbf{323 Million} \times 12.5\text{ kHz}}{300\text{ area codes} \times 10\text{ cell towers}}}{2} = 700\text{ MHz}$$

https://cdn.newsday.com/polopoly_fs/1.7585942.1396473650!/httpImage/image.jpg_gen/derivatives/display_1004/image.jpg

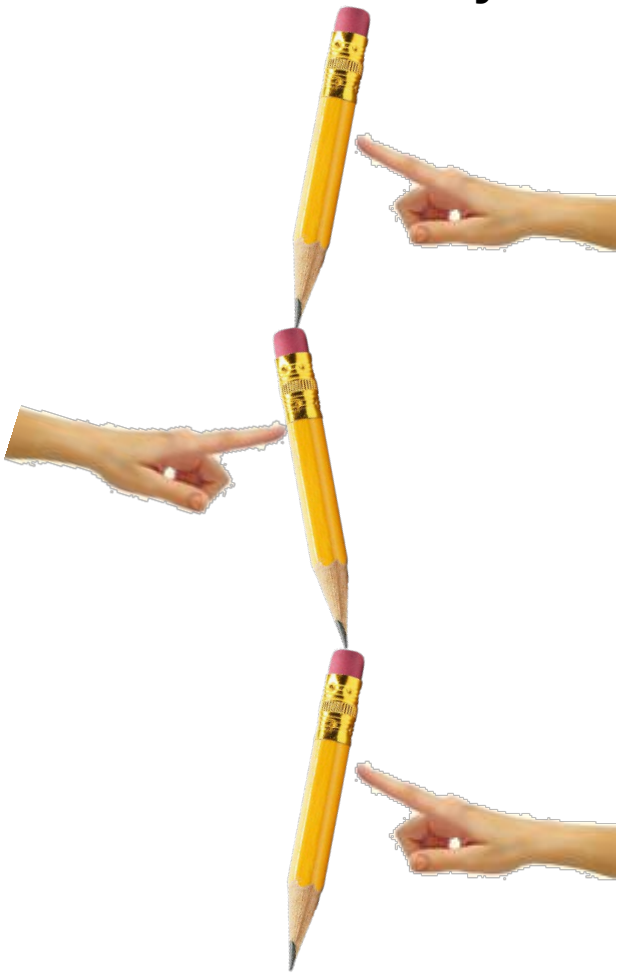
What is harmful interference?
Complications

- Heterogeneous systems
- Managing aggregate effects
- What's important?
- When is frequency reuse OK? When is it not?

- *There is no "one-size fits all" answer.*
- *"It depends" emphasizes importance of the outcome*

What's so hard about collaborative spectrum use?

Challenge #1: How do you work with others without knowing how they "think" and act?

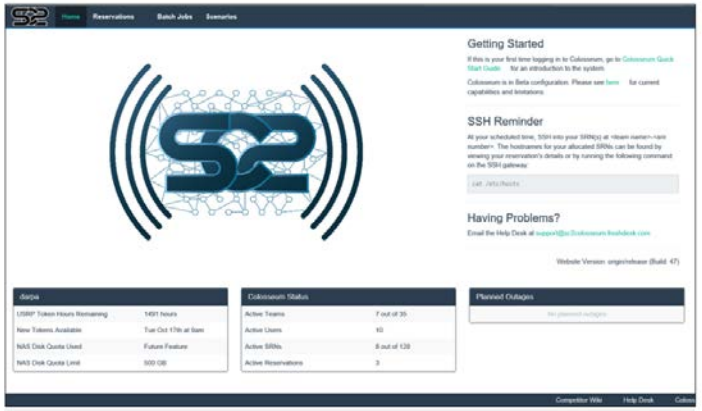


http://sr.photos3.fotosearch.com/bthumb/CSP/CSP880/k8803233.jpg

http://www.pngall.com/wp-content/uploads/2016/03/Pencil-PNG.png

What's so hard about collaborative spectrum use?

Challenge #2: How can we build radio technology which can only be evaluated at large-scale?



sc2colosseum.com

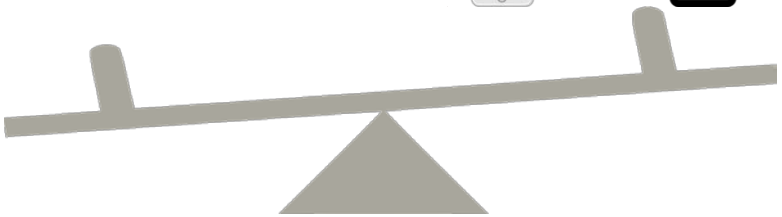
What's so hard about collaborative spectrum use?

Challenge #3: How do you enable collaboration?

too specific
frame 15, slot 7

too general

A *B* *C* → *D*

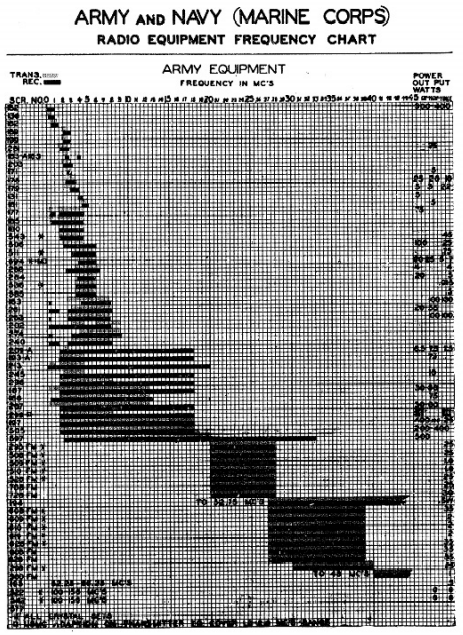


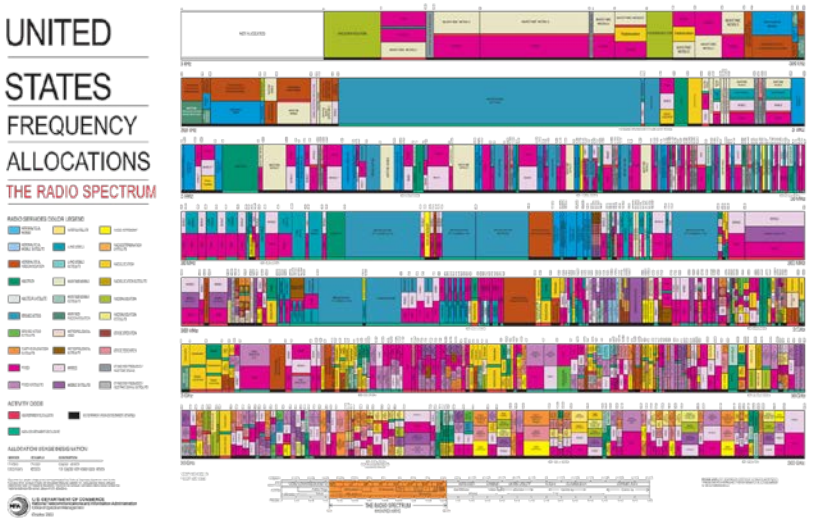
What's so hard about collaborative spectrum use?

Challenge #4: How do we change 100+ years of spectrum management practice?

What applications would benefit?

How does the radio need to change to support them?





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https://upload.wikimedia.org/wikipedia/commons/4/45/United_States_Frequency_Allocations_Chart_2003_-_The_Radio_Spectrum.jpg