This material is based upon work supported by the National Science Foundation under Grant No. 1932418. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

# Do We Still Need Wi-Fi in the Era of 5G (and 6G)?

Henning Schulzrinne

Columbia University

# Classical ecological niches

mesh
low energy

pairing
profiles

Bluetooth

peripherals

zigbee

lowest-end
devices

Wi Fi


laptops
Wi-Fi offload

speed
authentication

Lte

5G

smartphones
international roaming
voice
IoT WAN

voice
mobility
international roaming

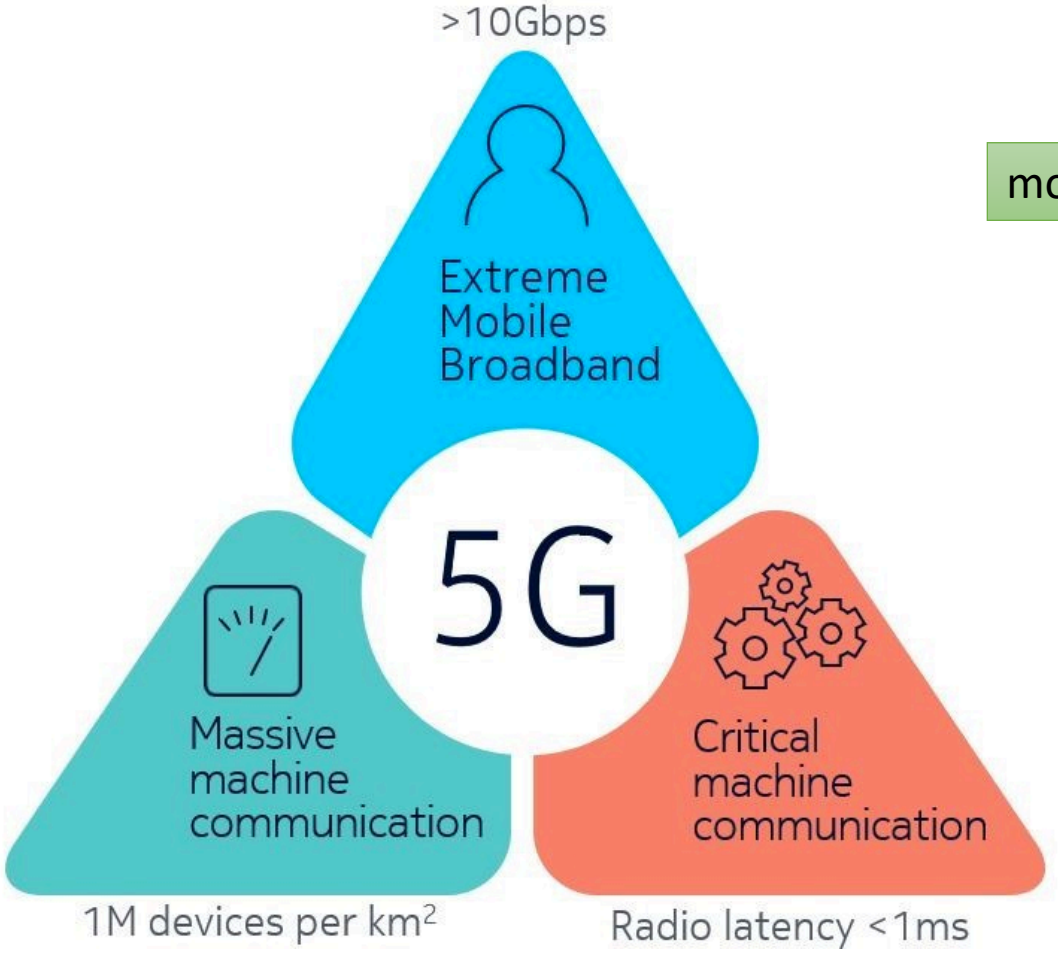
# But now there’s 5G – the grand unified network

# Generational surprises

| Generation | Expectation | Surprise | Cost per GB |
|---|---|---|---|
| **0G** (landline) | voice | fax & modem | |
| 1G | corporate limousine | eavesdropping | |
| **2G** | better voice quality (“digital!”) | SMS | $1000 |
| 3G | WAP | web | $100 |
| **4G** | IMS | YouTube, WhatsApp, notifications | $10 |
| 5G | IoT (low latency) | ? | $1? |

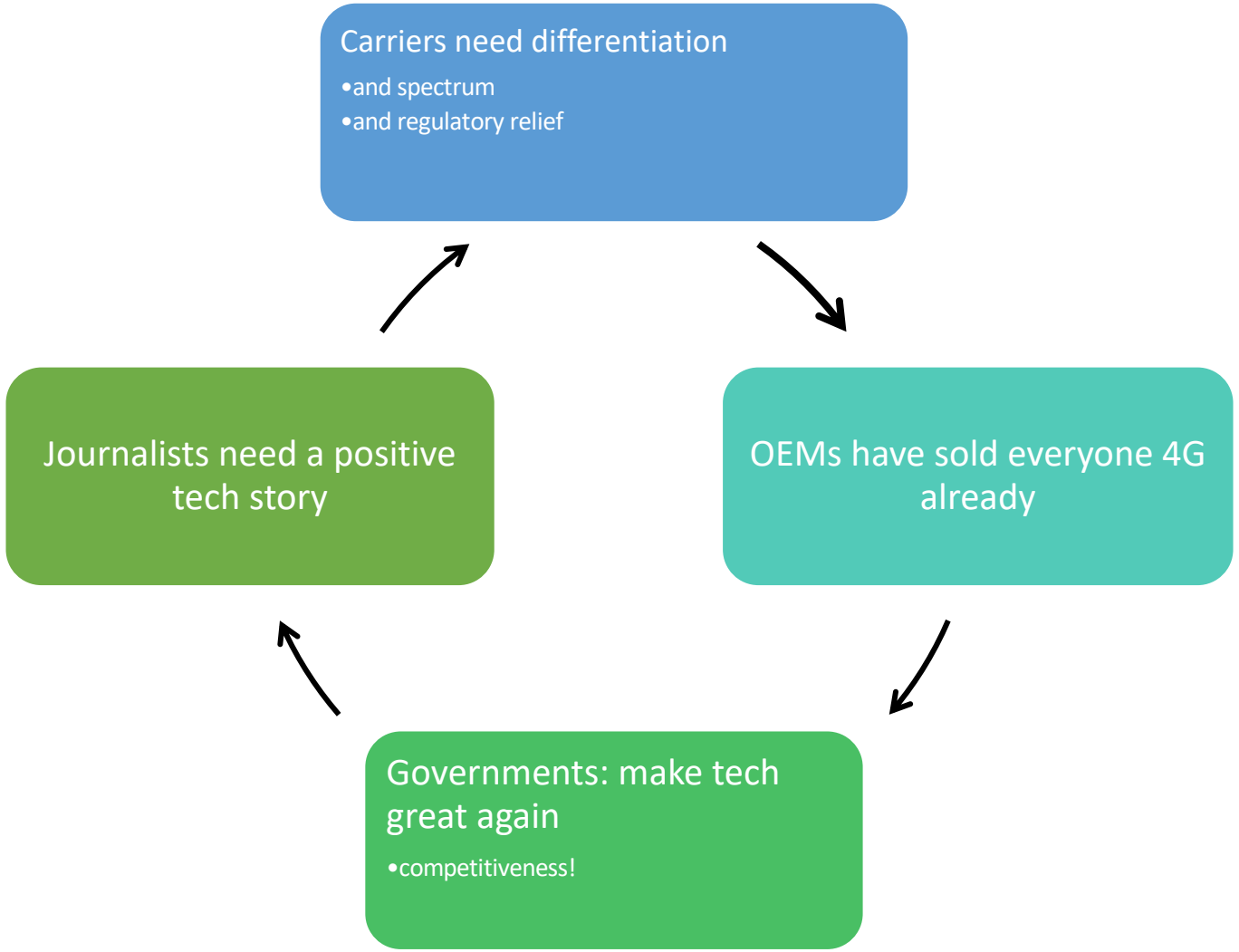
- underestimated cost and fixed-equivalence as drivers
- are the even generations the successful ones?

# Classical (5G) requirements pyramid



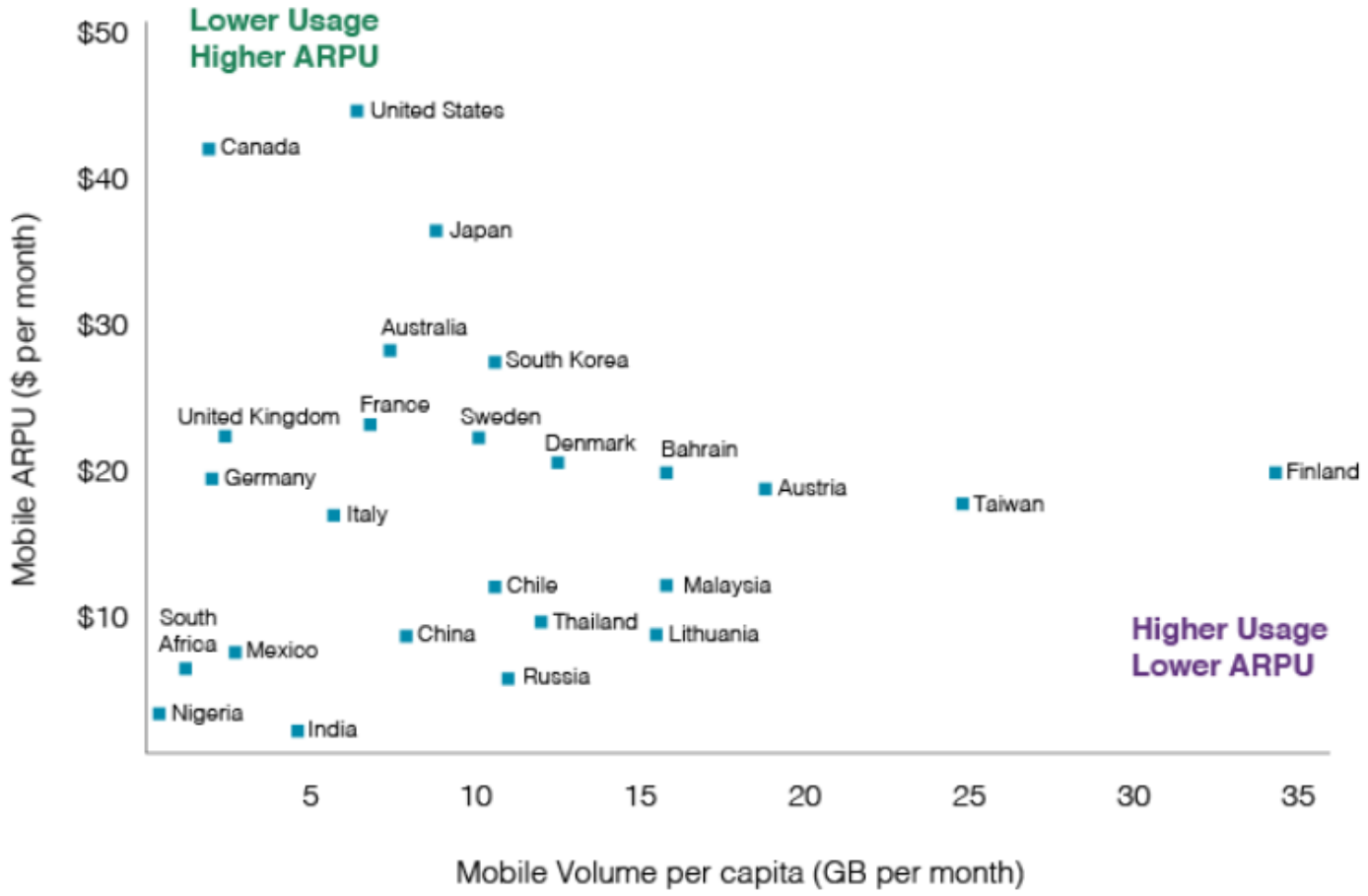

mostly PHY requirements!

# Everybody needs 5G




… and researchers need another QoS motivator (slices! URLCC!)

# What's the economic case for 5G?



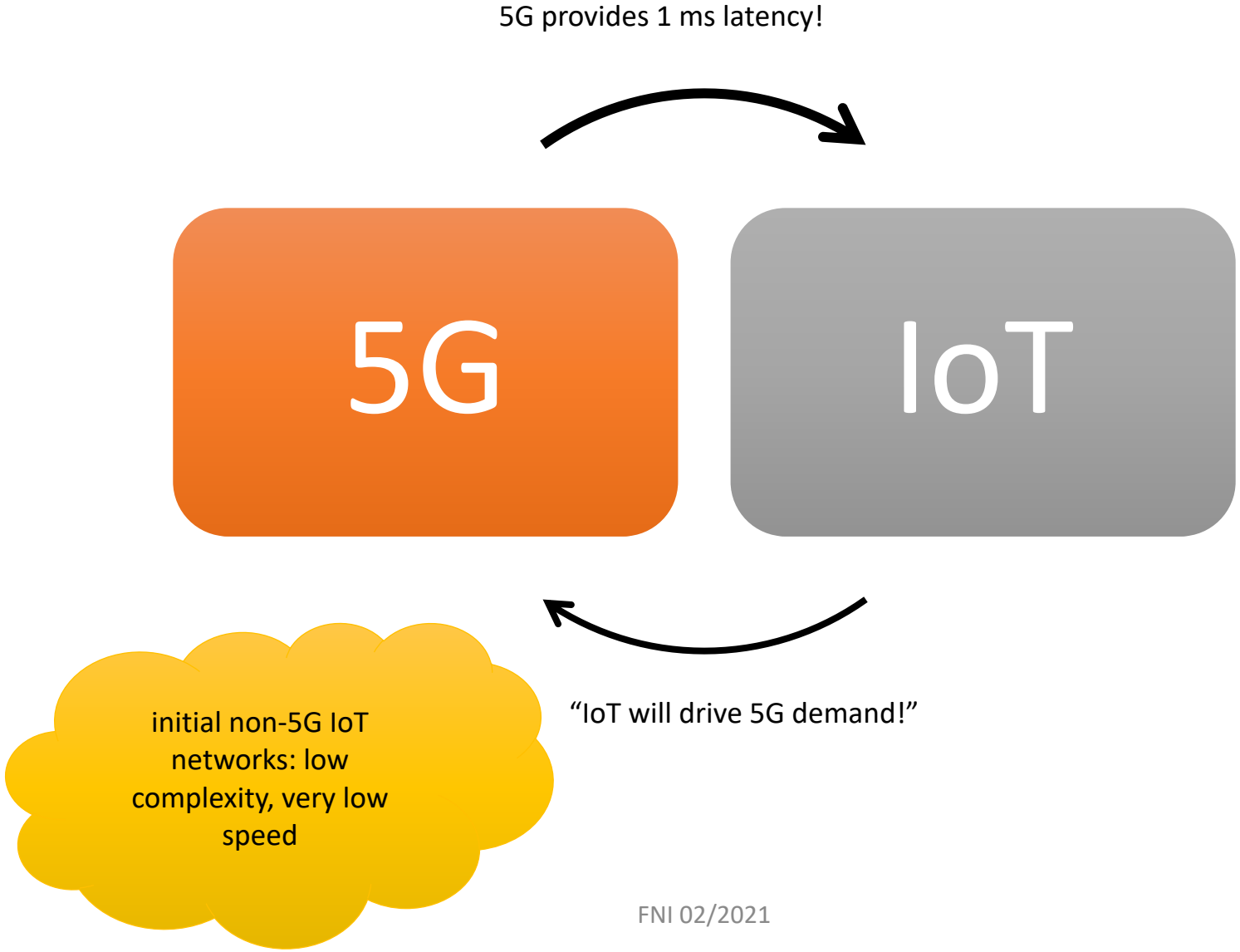

avg. about 5.1 GB/month
T-Mobile: 10 GB tethering

March 2020

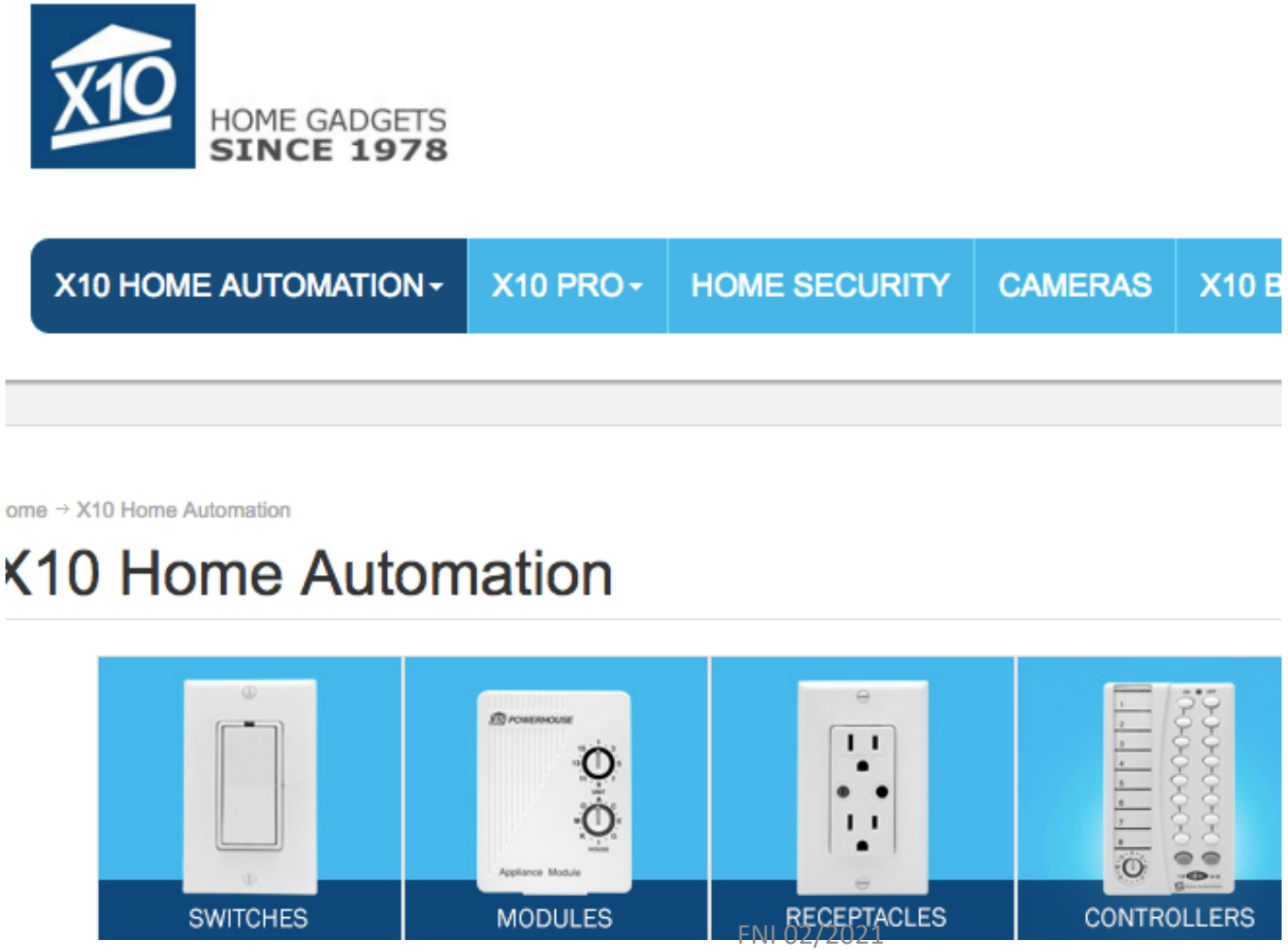


TeleGeography

# Hype feedback loop



# IoT is not exactly new (1978)



# IoT – an idea older than the web (1985)

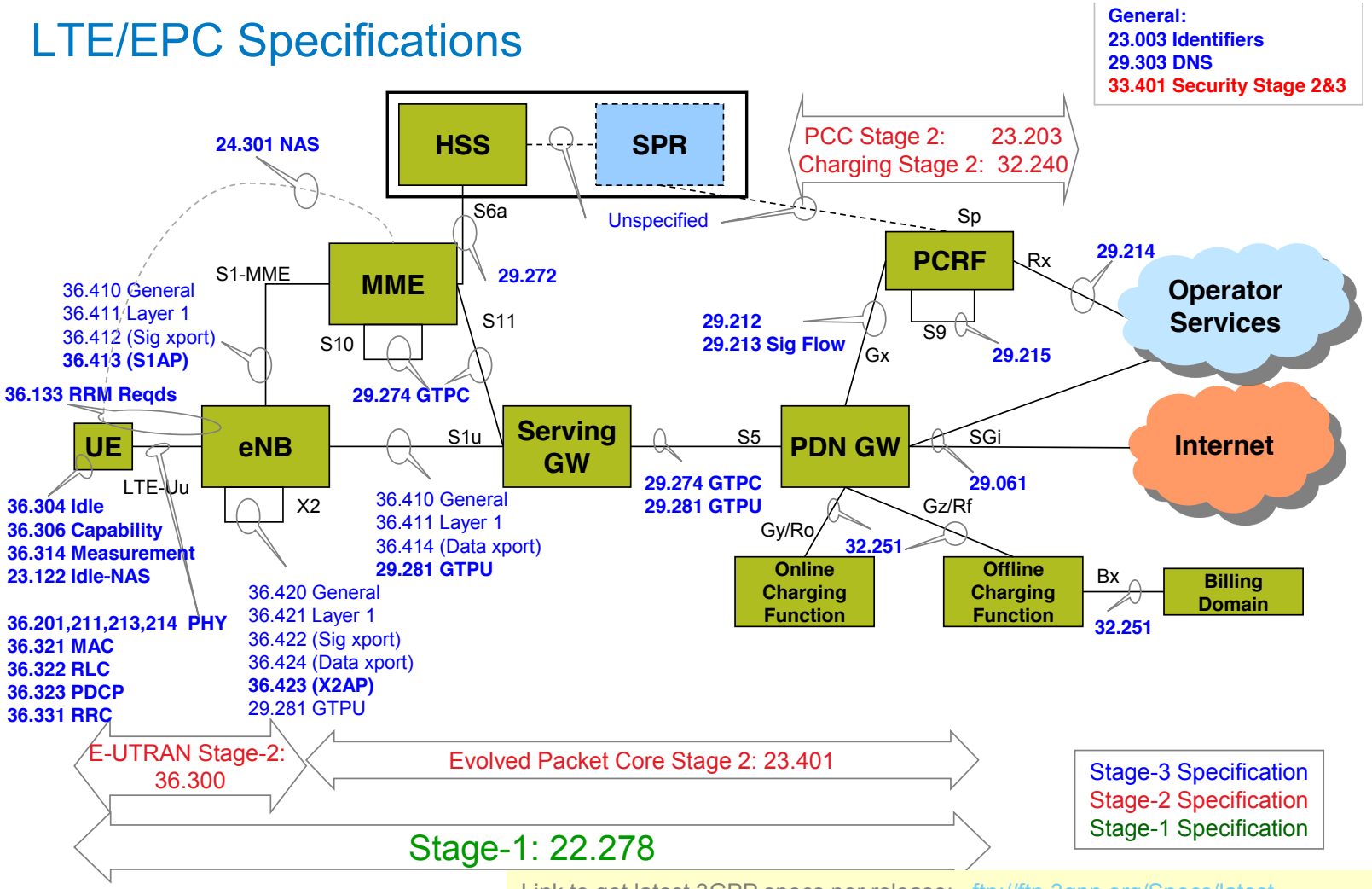
Peter Lewis (panel discussion 1985)

*By connecting devices such as traffic signal control boxes, underground gas station tanks and home refrigerators to supervisory control systems, modems, auto-dialers and cellular phones, we can transmit status of these devices to cell sites, then pipe that data through the Internet and address it to people near and far that need that information. I predict that not only humans, but machines and other things will interactively communicate via the Internet.* ***The Internet of Things, or IoT, is the integration of people, processes and technology with connectable devices and sensors to enable remote monitoring, status, manipulation and evaluation of trends of such devices****. When all these technologies and voluminous amounts of Things are interfaced together -- namely, devices/machines, supervisory controllers, cellular and the Internet, there is nothing we cannot connect to and communicate with. What I am calling the Internet of Things will be far reaching.*

From Chetan Sharma Consulting 2016

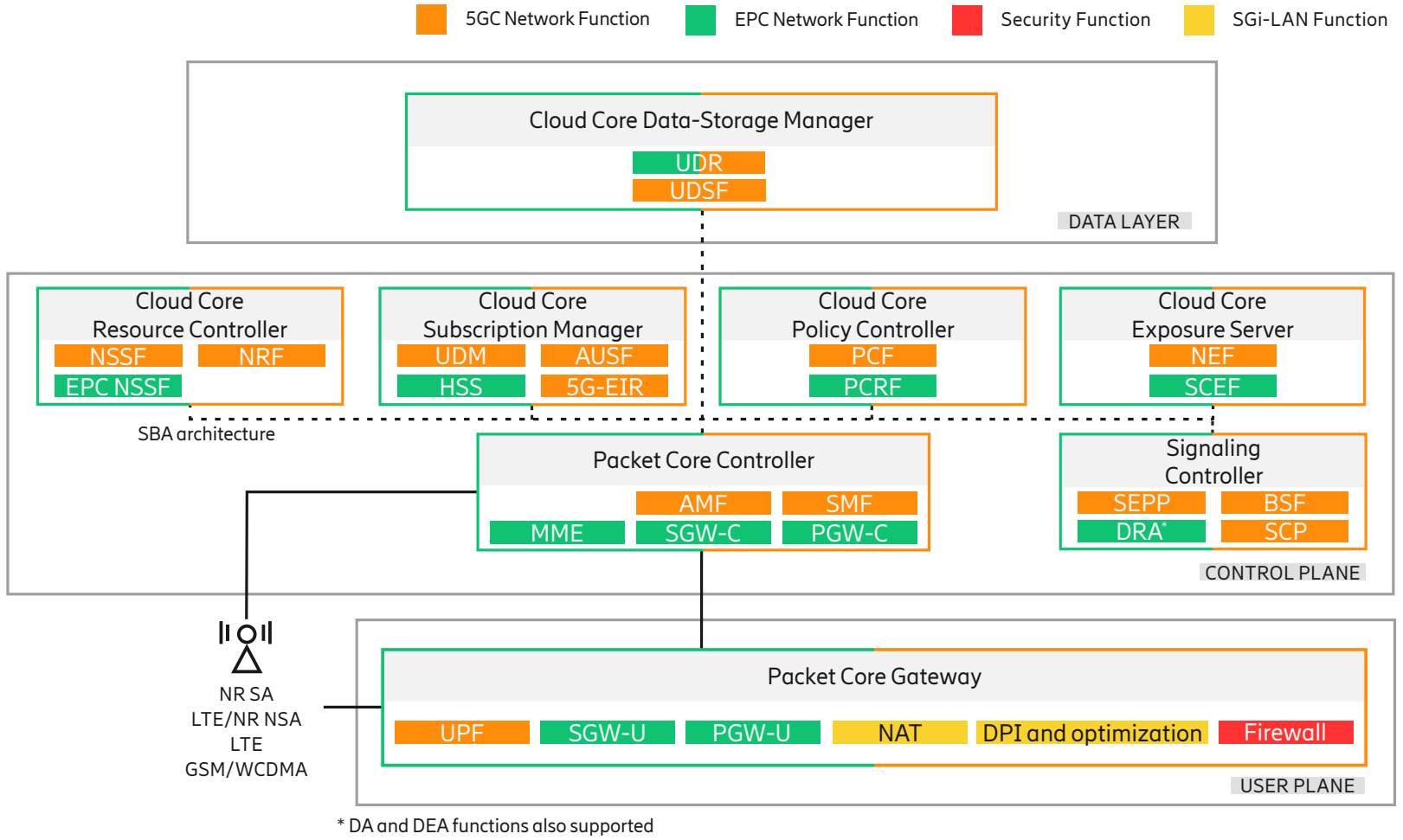
# LTE EPC

## LTE/EPC Specifications



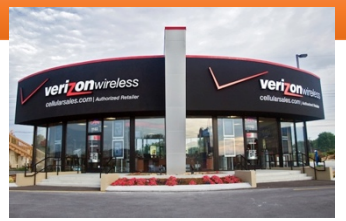

Link to get latest 3GPP specs per release: ftp://ftp.3gpp.org/Specs/latest
Link to find out what a spec covers: http://www.3gpp.org/Specification-Numbering

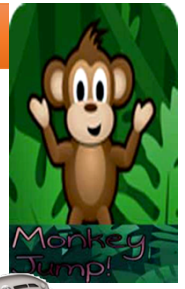
# 5G & 4G EPC

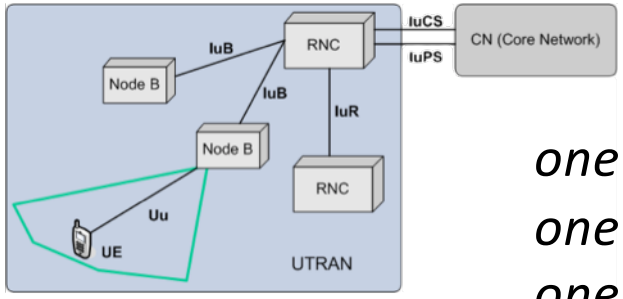

5GC Network Function
EPC Network Function
Security Function
SGi-LAN Function
Cloud Core Data-Storage Manager
UDR
UDSF
DATA LAYER
Cloud Core
Resource Controller
NSSF
NRF
EPC NSSF
Cloud Core
Subscription Manager
UDM
AUSF
HSS
5G-EIR
Cloud Core
Policy Controller
PCF
PCRF
Cloud Core
Exposure Server
NEF
SCEF
SBA architecture
Packet Core Controller
AMF
SMF
MME
SGW-C
PGW-C
Signaling
Controller
SEPP
BSF
DRA*
SCP
CONTROL PLANE
NR SA
LTE/NR NSA
LTE
GSM/WCDMA
Packet Core Gateway
UPF
SGW-U
PGW-U
NAT
DPI and optimization
Firewall
USER PLANE
* DA and DEA functions also supported

# Networks 1G through 4Gish

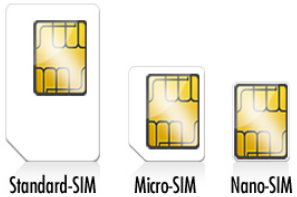
national carrier




*one subscriber,*
*one phone,*
*one provider*



# What exactly is a carrier?

AMERICAN TOWER®
*40k towers each (US)*

CROWN CASTLE

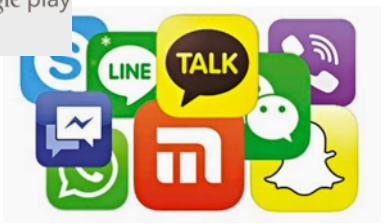
FiberLight

lightower

zayo

Spectrum DB

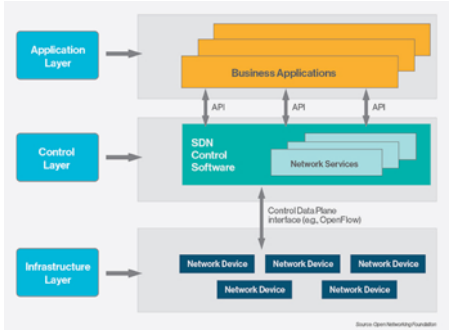
Google play




Level3
Cogent

comcast

LTE-U
802.11n
LTE

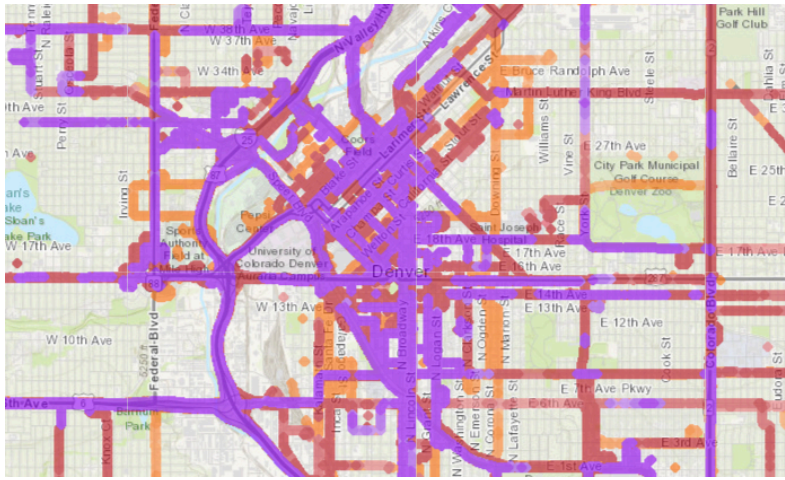



ERICSSON

**Verizon shrinks 5G Home install time to under an hour**

# Why 5G for non-carrier networks?

- Home networks —FWA (instead of cable/DSL)
  - largely downtown urban
- Venue networks (airports, stadiums, convention centers)
  - largely mobile users
  - integrated with MNO or eSIM (longer term)
- Factory networks
  - but complexity of EPC → likely only for large enterprises or maybe cloud 5G SA core?
  - advantage: access to 3.5 GHz “clean” CBRS spectrum (PAL)
  - carriers may want to operate, but in-house or system integrators seem more likely

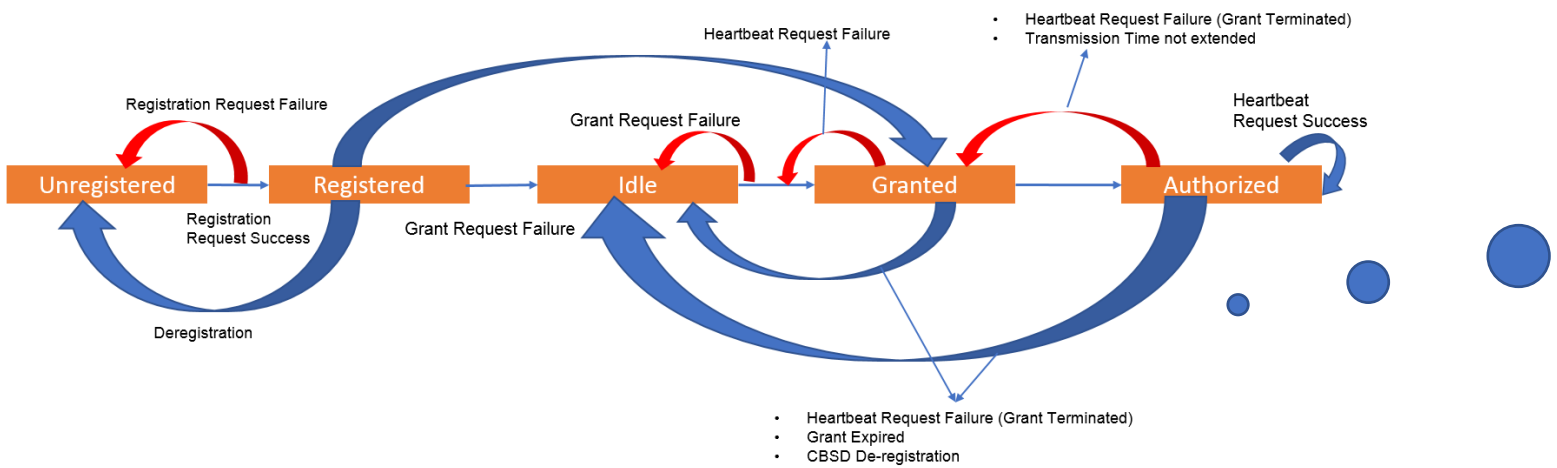



incentives:
carriers → get back into enterprise
Nokia & Ericsson → new markets

# CBRS as new spectrum opportunity for LAN model

| | | 3550 | 3600 | 3650 | 3700 | MHz |
|---|---|---|---|---|---|---|
| **Tier 1** | Incumbents | *Naval Radar* | | | | Incubents have first right to access the spectrum and are protected from PAL and GAA interference |
| | | | *FSS Earth Stations* | | | |
| | | | | *WISPs* | | |
| **Tier 2** | Priority Access License (PAL) | *PAL* | | | | Up to 7 licenses avalable per county by auction of 10 MHz channels with priority over GAA |
| **Tier 3** | General Authorized Access (GAA) | *GAA* | | | | Can utilize any spectrum not in use by Incumbents and PAL |


CBRS range: 2-6 miles on 200-250 ft tower, 20-30 ft customer antenna




so far, only LTE (band 48)

# Parallel timelines

*realistic top speeds*

< 0.1 Mb/s | 0.1-1.5 Mb/s | 5-50 Mb/s | 150-200 Mb/s

1G | 2G | 3G | 4G | 5G

1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020

2.4 GHz ISM


802.11 ~2 Mb/s

802.11a ~20 Mb/s

802.11b ~6 Mb/s

802.11g ~20 Mb/s

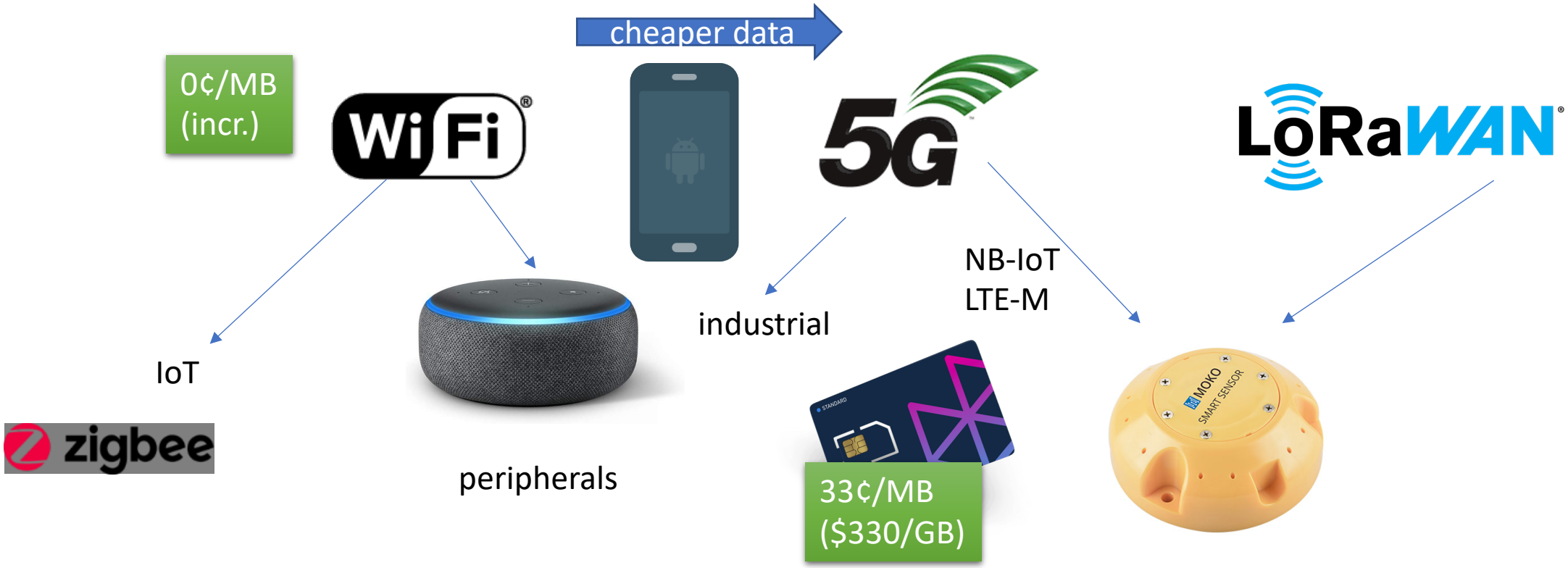
802.11n ~100 Mb/s

802.11ac ~200 Mb/s

802.11ax ~1 Gb/s

approximate standardization or first deployment

# But it’s looking like a Wi-Fi vs. 4G/5G (+ LoRA?) fight

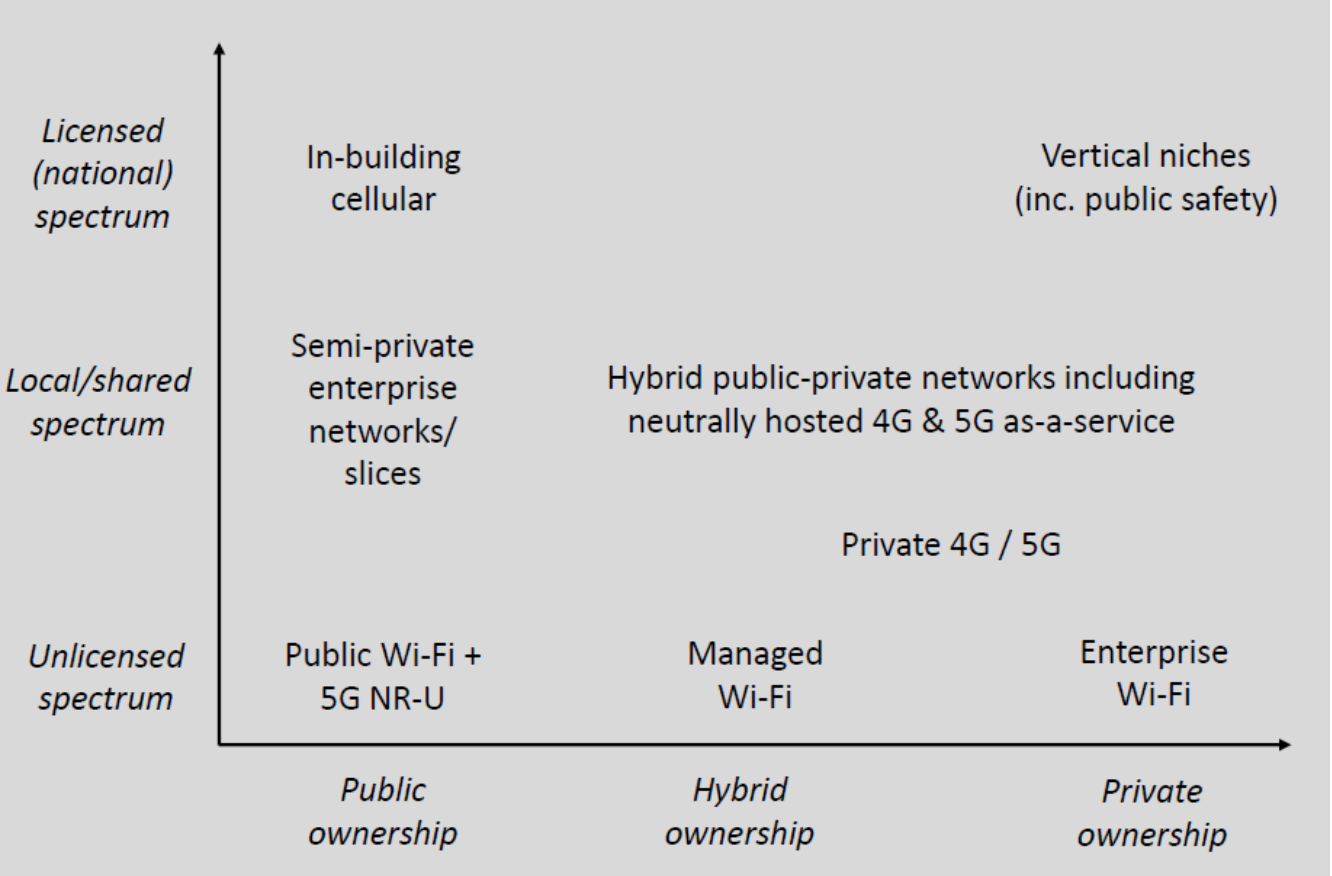



*Similar PHY: OFDM, OFDMA, QAM, MIMO, etc.*

# Wi-Fi & 5G technology likely similar

| Category | Variable | 5G | Wi-Fi 6 / Wi-Fi 6E |
|---|---|---|---|
| **Technical** | **Peak data rate** | 2 Gbps (DL), 1Gbps (UL) | 10 Gbps 8x8 (DL), 5 Gbps (UL) |
| **Technical** | **MU-MIMO** | 128x128 | 8x8 |
| **Technical** | **Coverage range** | 100-300 meters for small cells, up to tens of km for macro cells | <50 meters indoor, up to 300 meters outdoor |
| **Technical** | **Carrier aggregation** | Yes | Yes, 40, 80, 160 (or 80+80) |
| **Technical** | **Inter-cell interference** | Controlled | Mainly uncontrolled |
| **Technical** | **Channel Access Scheme** | OFDMA | OFDMA |
| **Spectrum** | **License type** | Mostly licensed | Unlicensed |
| **Spectrum** | **General bands** | Low, mid and high | Low and mid |
| **Spectrum** | **Specific frequencies** | 700 MHz, 3.5 GHz, 26 GHz, 60 GHz | 2.4 GHz, 5 GHz, 6 GHz |
| **Spectrum** | **Channel Bandwidth** | 20, 40, 80, 100 MHz | 20, 40, 80, 160 MHz |
| **Business model and cost** | **Revenue model** | Pre- or post-pay billing for data services | None ('Piggybacks' on fixed broadband connections) |
| **Business model and cost** | **User equipment price** | High (>=$300) | Low (>=$100) |
| **Business model and cost** | **Public versus private** | Traditionally publicly provided by an MNO | Traditionally privately provided |
| **Business model and cost** | **Chip/modem cost** | High ($10-50) | Low ($1-5) |
| **Business model and cost** | **Data cost** | Monthly subscription ($5-20) | Free ('piggybacks' on fixed broadband) |
| **Installation and skills** | **Deployment approach** | Controlled and managed | Uncontrolled and unmanaged |
| **Installation and skills** | **Installation skill level** | High | Low |
| **Installation and skills** | **Development skill level** | High | Low |

# Spectrum & management > technology




Revisiting Wireless Internet Connectivity: 5G vs Wi-Fi 6

# What kind of communication networks today?

| Dominant challenge | Example | solution |
|---|---|---|
| Fixed-function peripherals | earphones, mouse, keyboard | Bluetooth |
| Low monthly bandwidth cost | Residential | Wi-Fi |
| High bandwidth outdoors | Stadium (spectators, cameras) | 5G mmWave |
| High bandwidth indoors | University lecture hall | Wi-Fi |
| Outdoor, but regional or urban | Public transit, metering, traffic signage | NB-IoT, LoRAWAN |
| Outdoor, on major roads | Connected vehicles | DSRC + LTE? |
| Outdoor (land-based)<br>100% coverage, small antenna | Agriculture sensors | Iridium NEXT? |
| Outdoor (including oceans)<br>100% coverage, antenna size not limited | Agriculture machinery, construction, pipelines, shipping, logistics | LEO satellites? |

# Network value is (much) more than PHY

| Property | Requirements? | Example |
|---|---|---|
| Universality | Can I operate my system (almost) anywhere in the world? | Adaptive frequency use by region<br>(device knows location) |
| Incremental system cost | How much does it cost to add the functionality to the system? | < $5 for IoT devices |
| Data cost | Can I build “free” data systems, even if restricted? Can I leverage cheap landline BW? | < $0.10/GB for in-home use |
| Network architecture | Can I build my own network? | peer-to-peer → mesh → access point → cellular → long-range |
| User management | Can I design my own user management? | database + credential<br>device-based model<br>coupled to other systems (e.g., combined with other services) |
| System management | Can the system largely manage itself? | Frequencies & power, but also users and traffic restrictions |

# Scaling down is harder than scaling up

no PhD (or carrier training) needed!


firewall
DNS
edge computing



mesh backhaul

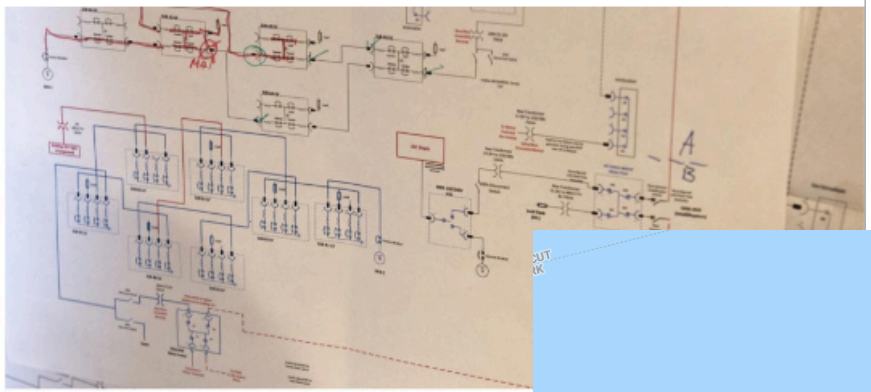
large enterprise
management

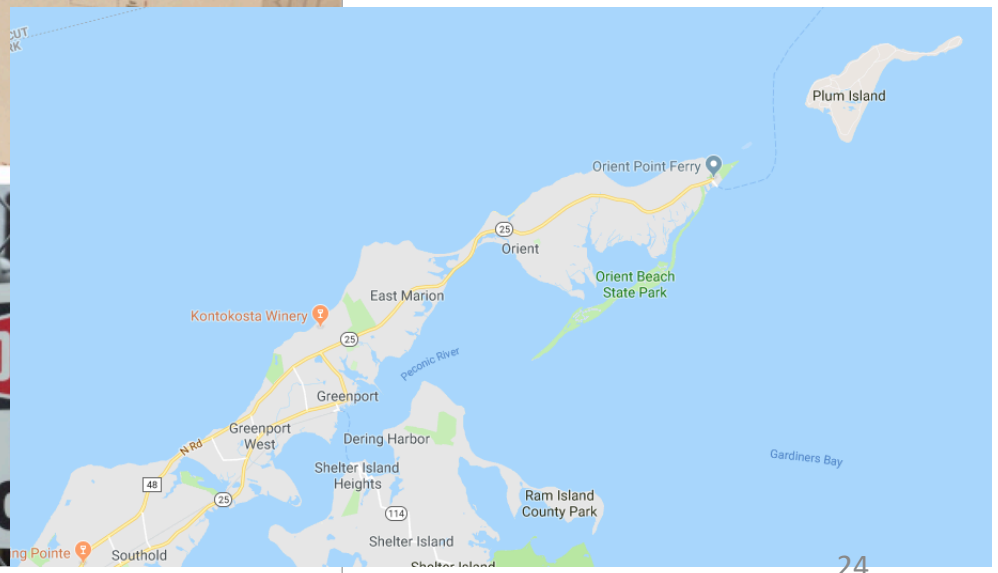
identity management and trust still deficient

# DARPA RADICS

GOVERNMENT

## Mock grid, real threats: DARPA borrows an island for a cyberattack drill



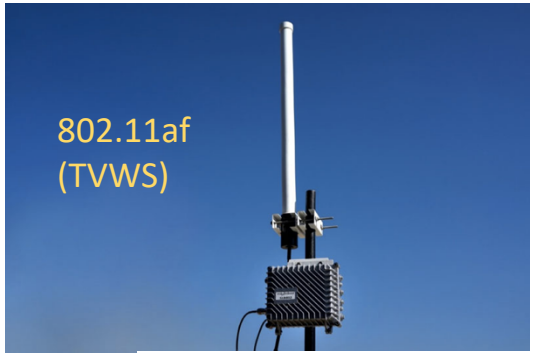



Scenes from DARPA's electrical-grid cyberattack drill on Plum Island, New York, in November. (DARPA photos)

# Example: DARPA PHOENIX nodes

DARPA RADICS: support blackstart for electric utilities

mesh



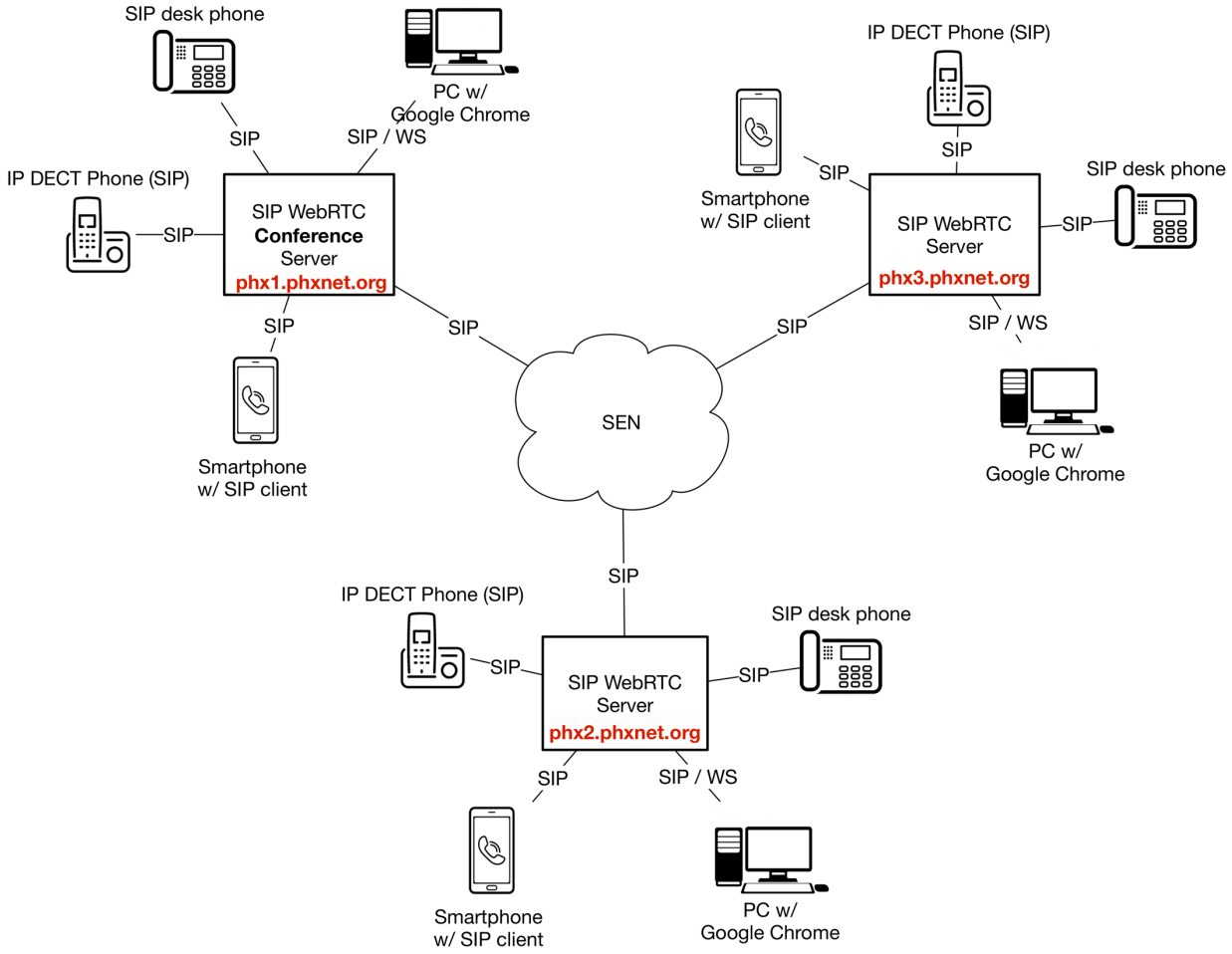

high-bandwidth
VHF



SDR: P.25
over VHF + Codec2 + data

- mesh network (OLSR) with multiple VLANs (VoIP, SCADA, …)
- goal: self-configuring – just turn on
- network-technology agnostic (not just 4G)
- local services (VoIP, messaging, edge cloud)
- with diagnostics and traffic isolation

# Example: distributed VoIP implementation




Every node can function by itself
Local capability, “global” dial plan

# What made Wi-Fi successful?

- Scalable complexity – 802.11b/g/n to 802.11ax
- Architectural flexibility
  - peer-to-peer, access point, mesh, long haul Pt2MP & Pt2Pt
  - re-use cheap local wired network and shared (managed & firewalled) access
- Multiple authentication models
  - from open access to federated 802.1x RADIUS
- Minimal viable network functionality
  - Ethernet frames + IP
  - local multicast
- International usability
  - universal “bootstrap” band (2.4 GHz)
  - locally-discoverable spectrum availability

# What didn’t work so well?

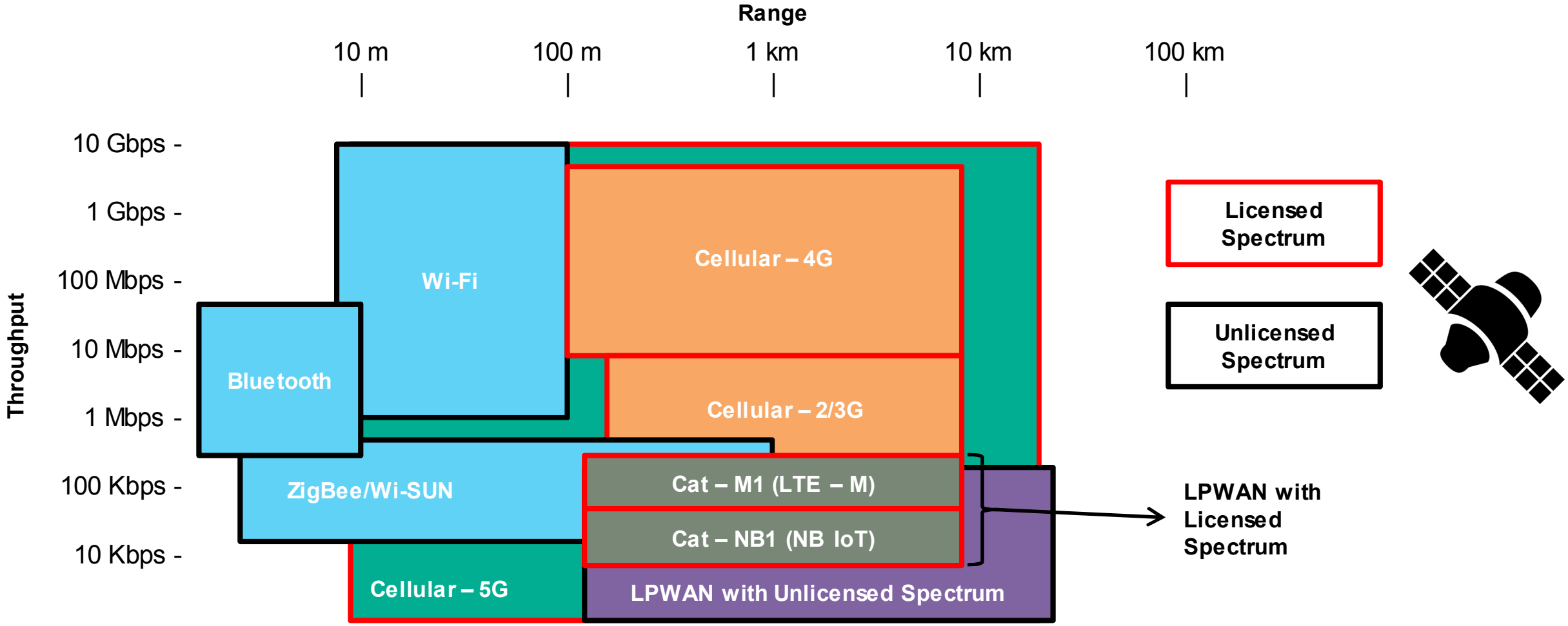
- Authentication has had repeated security problems
- More complex authentication (802.1x) seems rarely used
  - separate L2 confidentiality from access authorization
- Captive portal model cumbersome and doesn’t work for IoT devices
- Unlicensed-only model decreases reliability
  - interference & insufficient capacity in dense urban areas
- QoS degradation is still hard to diagnose

# Why have Zigbee and Bluetooth remained niche?


- Most home IoT devices are probably Wi-Fi, not Zigbee
- Need for gateway to home network
- Smart home speakers


- Mostly relegated to headphones, car audio systems, keyboards, mice and fitness watches
  - good functional interoperability
- Never quite got IP or IoT
- Pairing remains awkward and error-prone

# 5G can, theoretically, replace Wi-Fi




Source: HP Enterprise and Bernstein analysis.

# What's bad about having both Wi-Fi and (nG) cellular?

- System hardware complexity (e.g., for IoT devices)
- No seamless roaming
- Maintain multiple user identities
- Difficult to do consistent traffic restriction
  - cellular bypasses corporate firewall
- Inconsistent network behavior
  - e.g., IPv6 support
- More limited competition

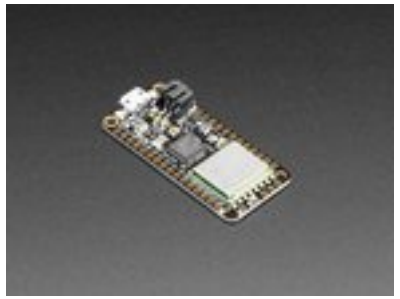
# Wi-Fi (and BT & LoRa) ”won” by integration

$6.95

ESP8266

Arduino Uno WiFi R2
$45

Arduino MKR1000
$36



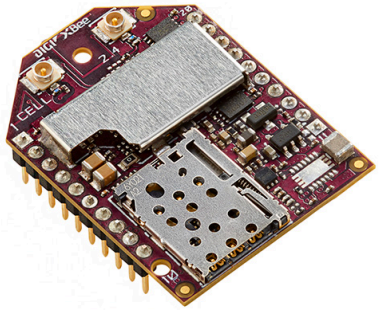
Wi-Fi + computer

Wi-Fi 802.11b/g/n
$7.84


Adafruit Feather M0 with RFM95 LoRa Radio - 900MHz – RadioFruit $35

Japanese operator NTT Docomo announced it will shut down its NB-IoT network today (31 March), less than a year after launching the service, as it looks to prioritise resources and turn its focus to LTE-M.

# Currently, 3G/4G is ~10-15x expensive – why?



Bluetooth, Cellular 4G LTE CAT-M1 (AT&T/Verizon) Transceiver Module
$69

Cellular LTE Transceiver Module 700MHz, 850MHz, 1.7GHz, 1.9GHz
$104


Cellular 3G (AT&T) Transceiver Module 850MHz, 900MHz, 1.8GHz, 1.9GHz, 2.1GHz
$69

AT&T: >72¢ /MB

# Current authentication models

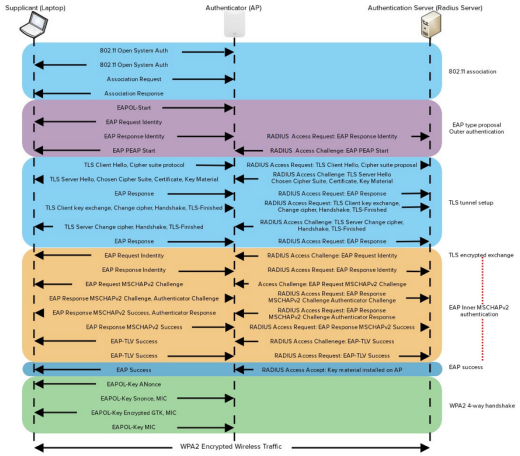
picket fence security

802.1x

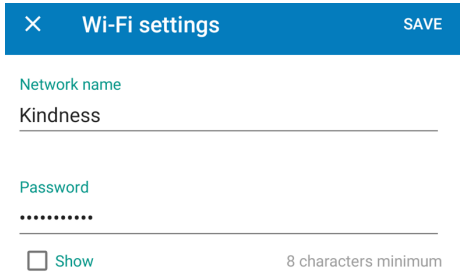
international roaming

hard to scale to IoT


SCAN ME



federated (RADIUS, DIAMETER)

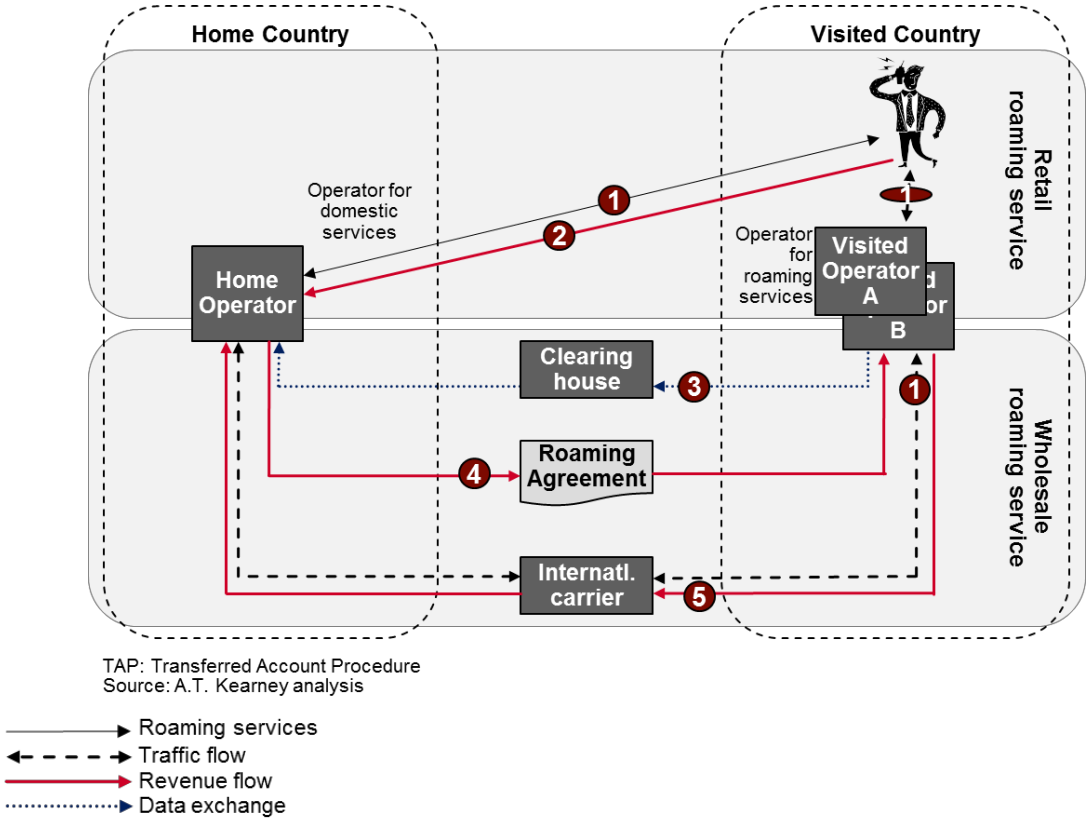



*WPA2-Personal*

eduroam

Global WiFi Roaming For Academia

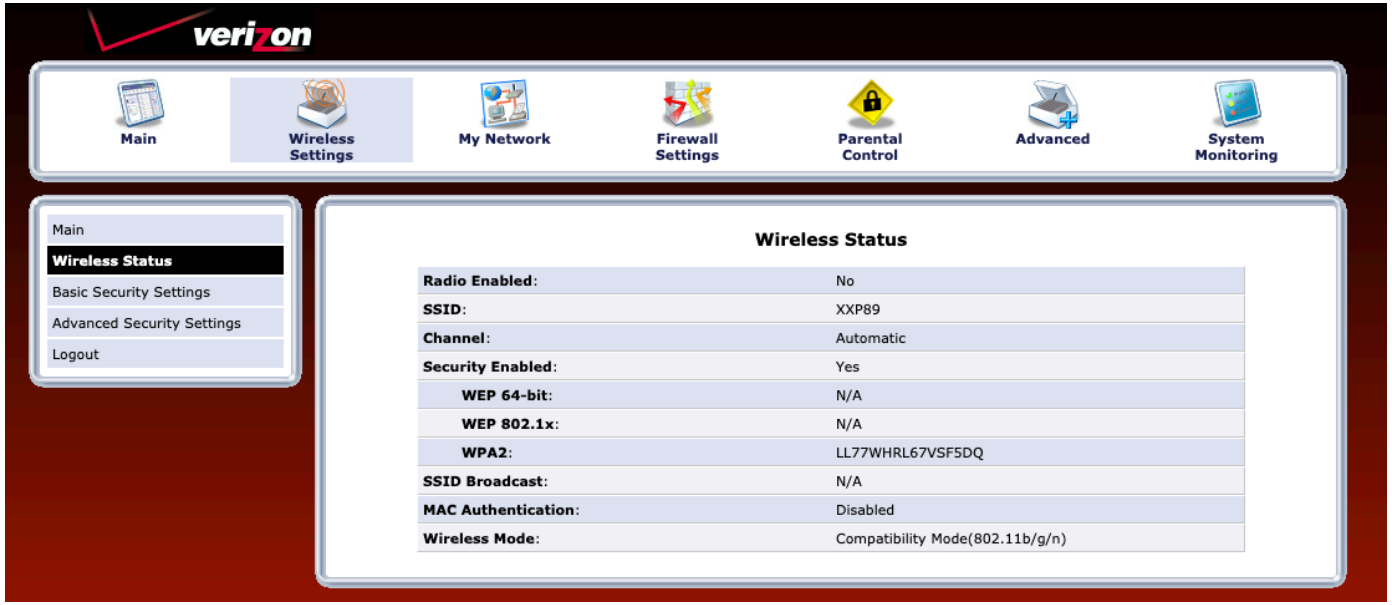
an Internet2 NET+ service

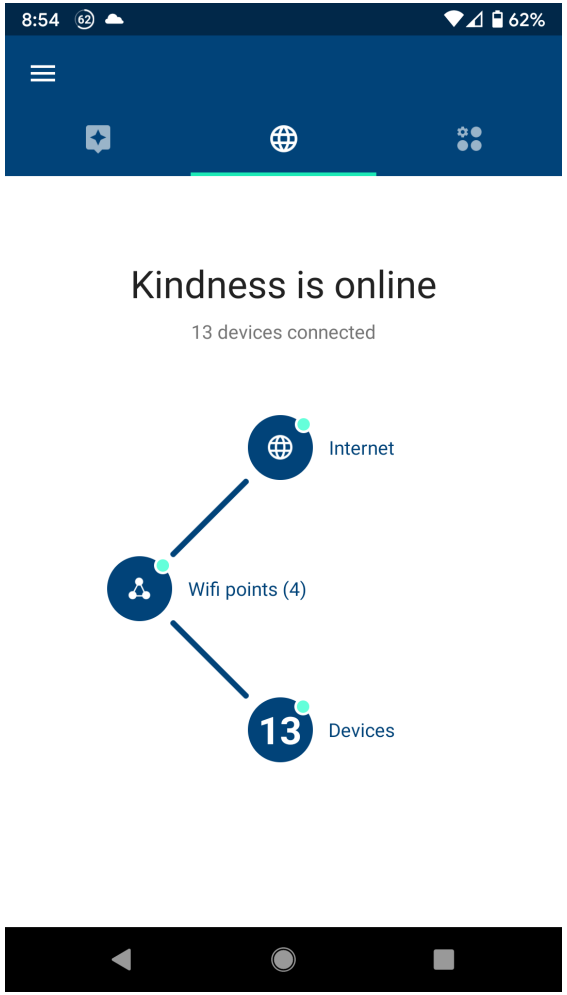



TAP: Transferred Account Procedure
Source: A.T. Kearney analysis

Roaming services
Traffic flow
Revenue flow
Data exchange

# From web login to apps



# Anybody use WPS?

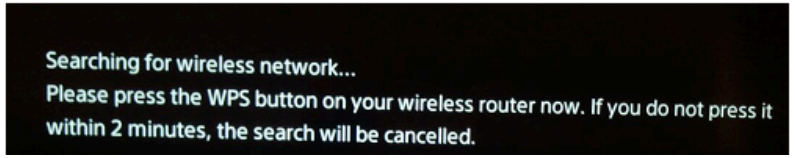
1. Look on your modem or router to see if it has a WPS button:




2. Go into the Network menu of your Internet capable device to see if the WPS option is availa

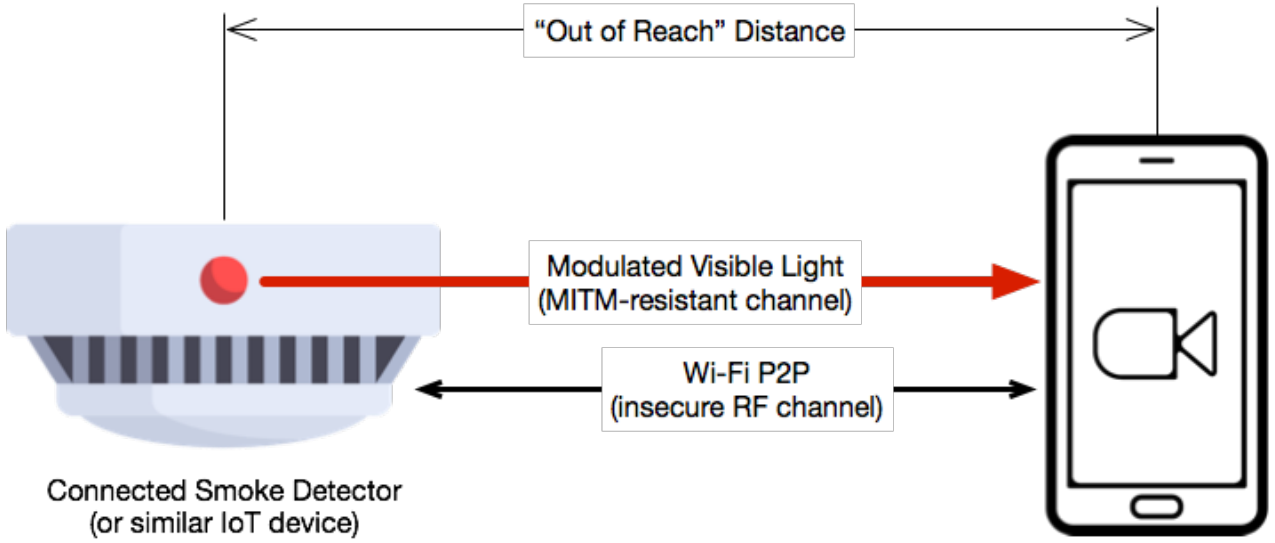

ollow these steps to set up a WPS (Push Button) connection:

1. Using the supplied remote, press the HOME button.
2. Select Settings.
3. Select Network.
4. Select Network Set up or Setup Network Connections.
5. Select Wireless, Wireless LAN or Wi-Fi.
6. Select WPS (Push Button).
7. Select Start so that the TV searches for the WPS connection.



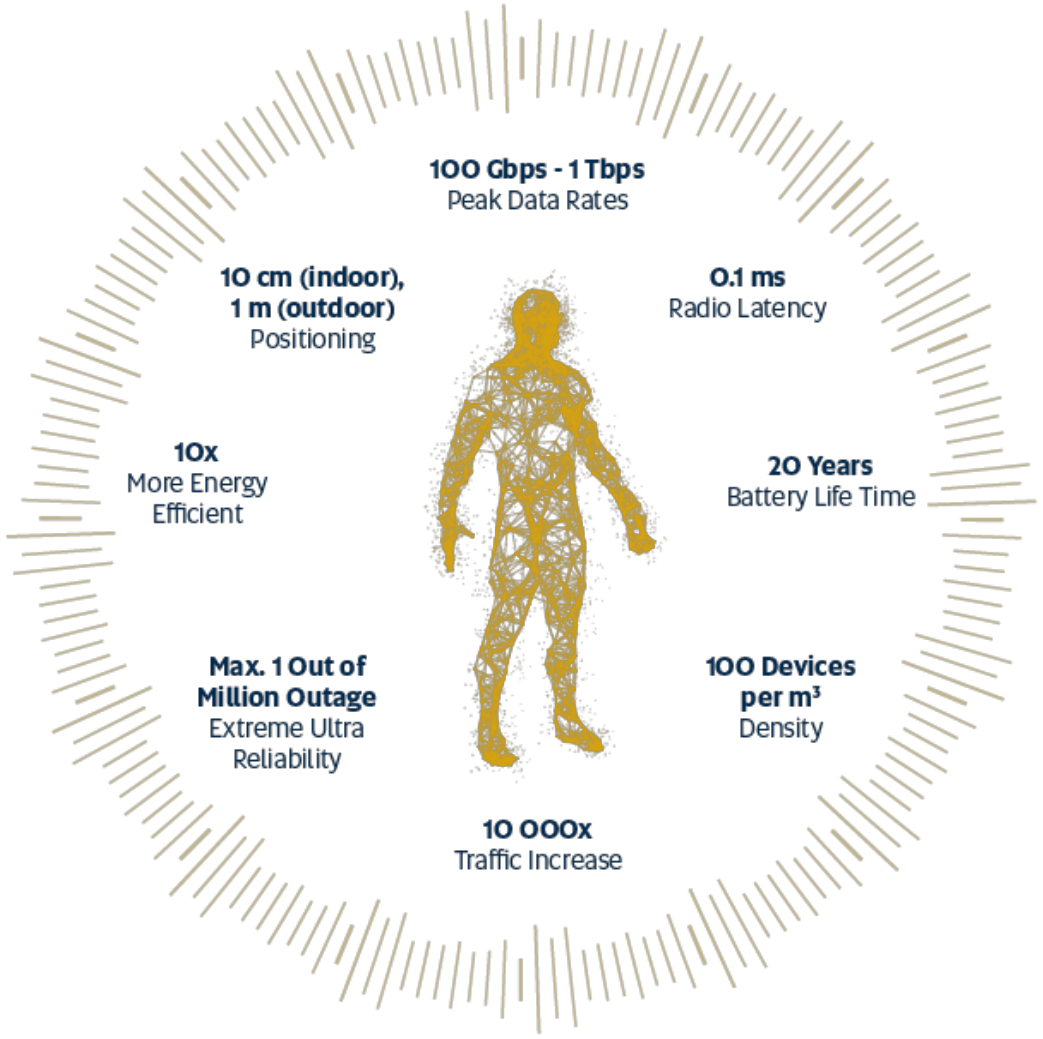
# New (additional) authentication model

- Old model assumed human-at-machine (laptop, printer, …)
- Or opaque 802.1x certificate model
- Add hardware admission model
  - “Should I admit the Smart Teapot blinking red and blue?”
  - “Here’s a list of device manifests – add them to the network”
  - “Admit the device I just touched”
  - ”Admit the blinking device I’m pointing the camera at”
  - “Admit the device playing a melody”

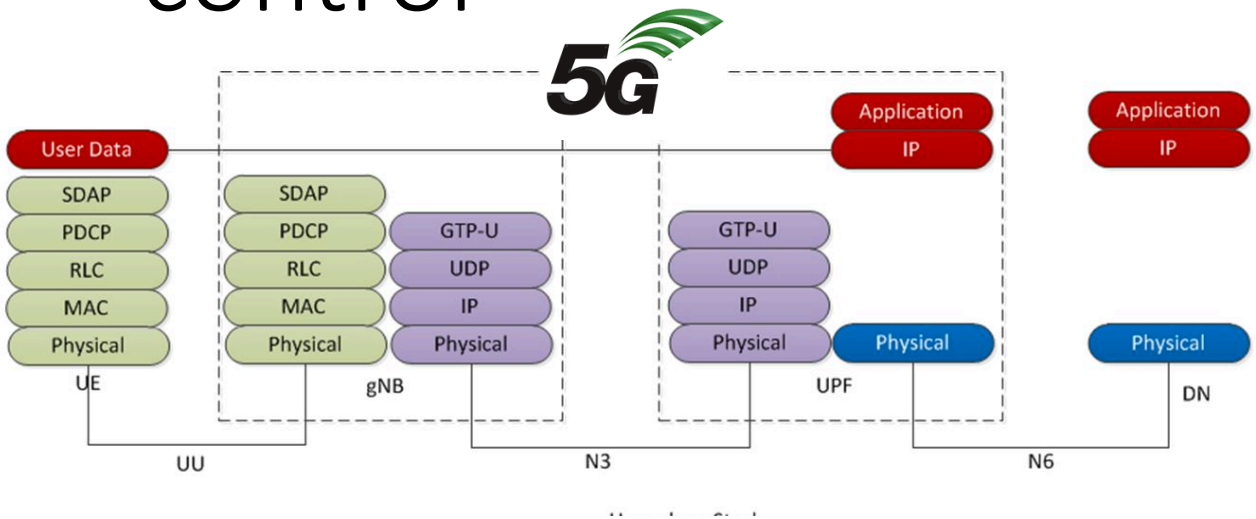


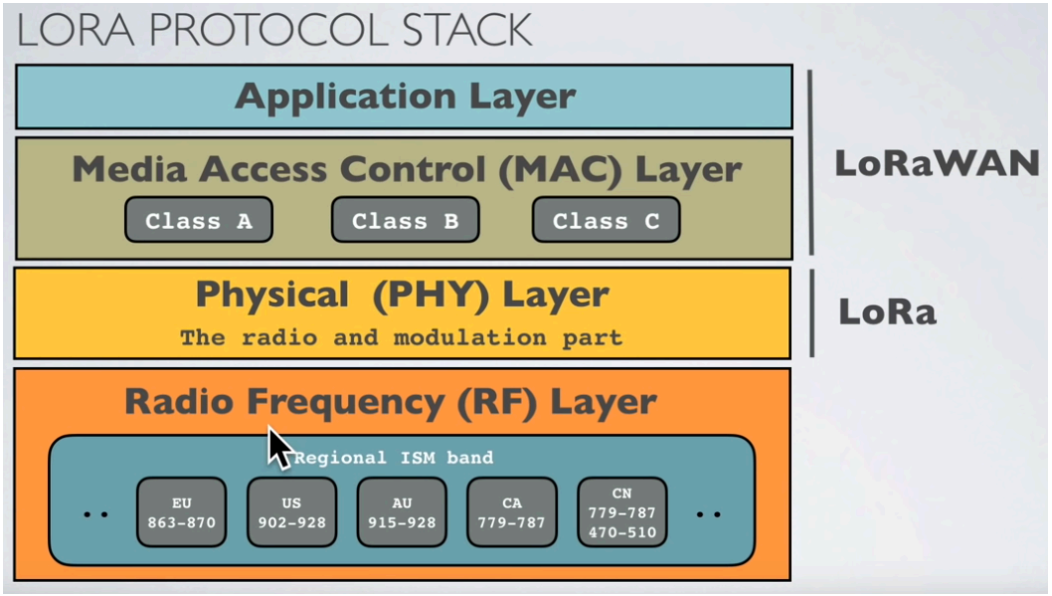
# Next-generation networks (6G!)

# 6G vision – multiply or divide by 10



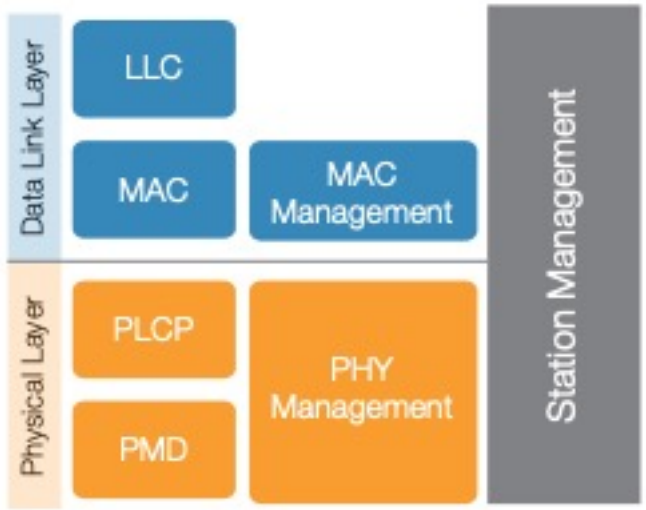
# Stacks always focus on data – complexity is in control




LoRaWAN®

Wi Fi®



# Two evolutionary paths for 6G

mostly not a PHY problem




lowest bandwidth cost

like 4G & 5G, just more
highest mobility


# Protocols matter, but programmability matters more

- Nobody wants to program raw protocols
- Most significant network application creation advances:
  - 1983: socket API → abstract data stream or datagram
  - 1998: Java network API → mostly names, HTTP, threads
  - 1998: PHP → network input as script variables
  - 2005: Ruby on Rails → simplify common patterns
- Many fine protocols and frameworks failed the programmer hate test
  - e.g., JAIN for VoIP, SOAP for RPC
- Most IoT programmers and factory automation specialists will not be computer scientists (and won't have a telecom background)
- Nobody learns ONAP in their CS BS

# Requirements for simple networks

- Separate link layer from network architecture
  - Why can’t 5G (or 6G) NR operate on a home router, without a carrier?
  - Assume flexible spectrum access (geo database)
- Every interface must be testable and self-testing
- *Interface neutrality* = every control needs to be accessible to network consumer, not just operator (bounded by slice or authorization)
- Clean interfaces particularly at layer 2 and 3
- No configuration files, ever
- No hard-coded addresses (e.g., gateways), ever

# Conclusion

- 6G needs an architecture re-think, not (only) better PHY
- Cleaner separation between media/complexity-dependent layers, common data transport and control planes
- Design scalable, IP-based control plane for everything from peer-to-peer mode to managed national cellular network
- Cleanly separate access from backbone
  - since likely continue to be both locally (enterprise) and third-party managed
- Opportunity to bridge the Wi-Fi - cellular chasm