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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

WiFi



laptops
Wi-Fi offload

speed
authentication





smartphones
international roaming
voice
IoT WAN



voice
mobility
international roaming

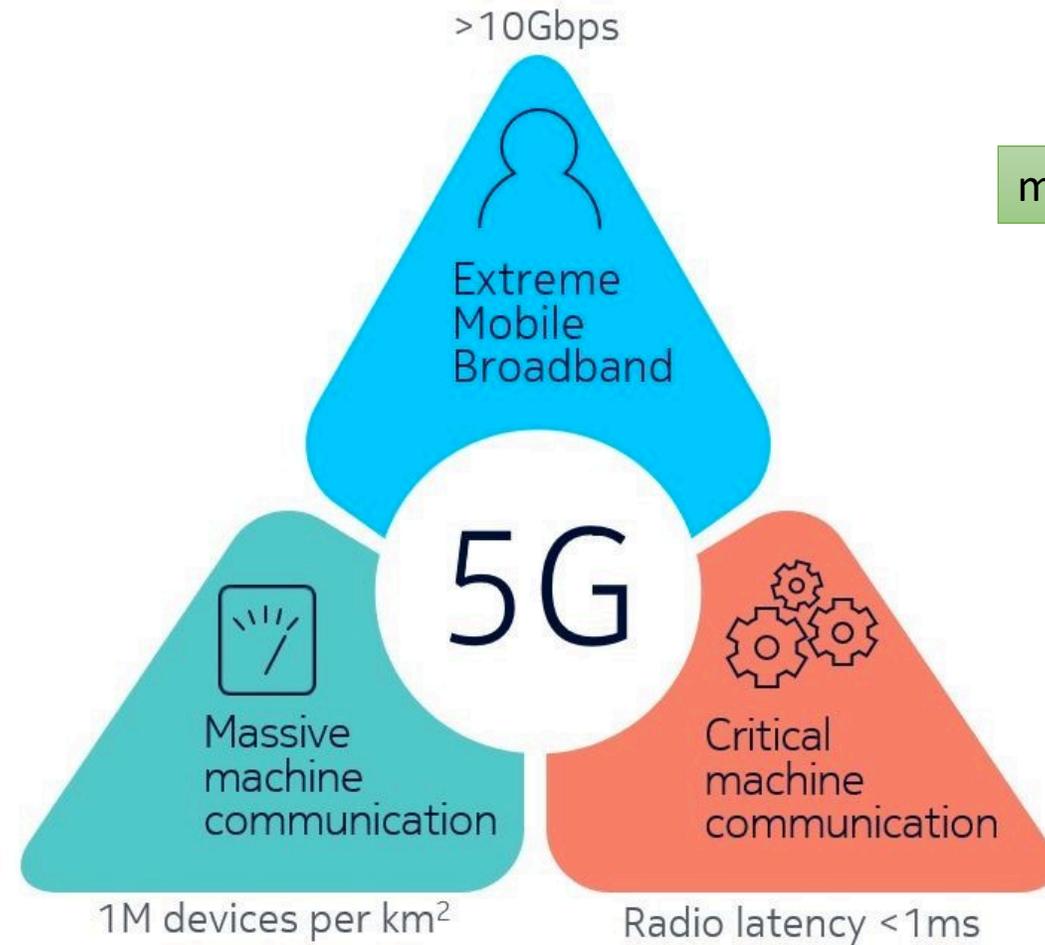
But now there's 5G – the grand unified network

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? |

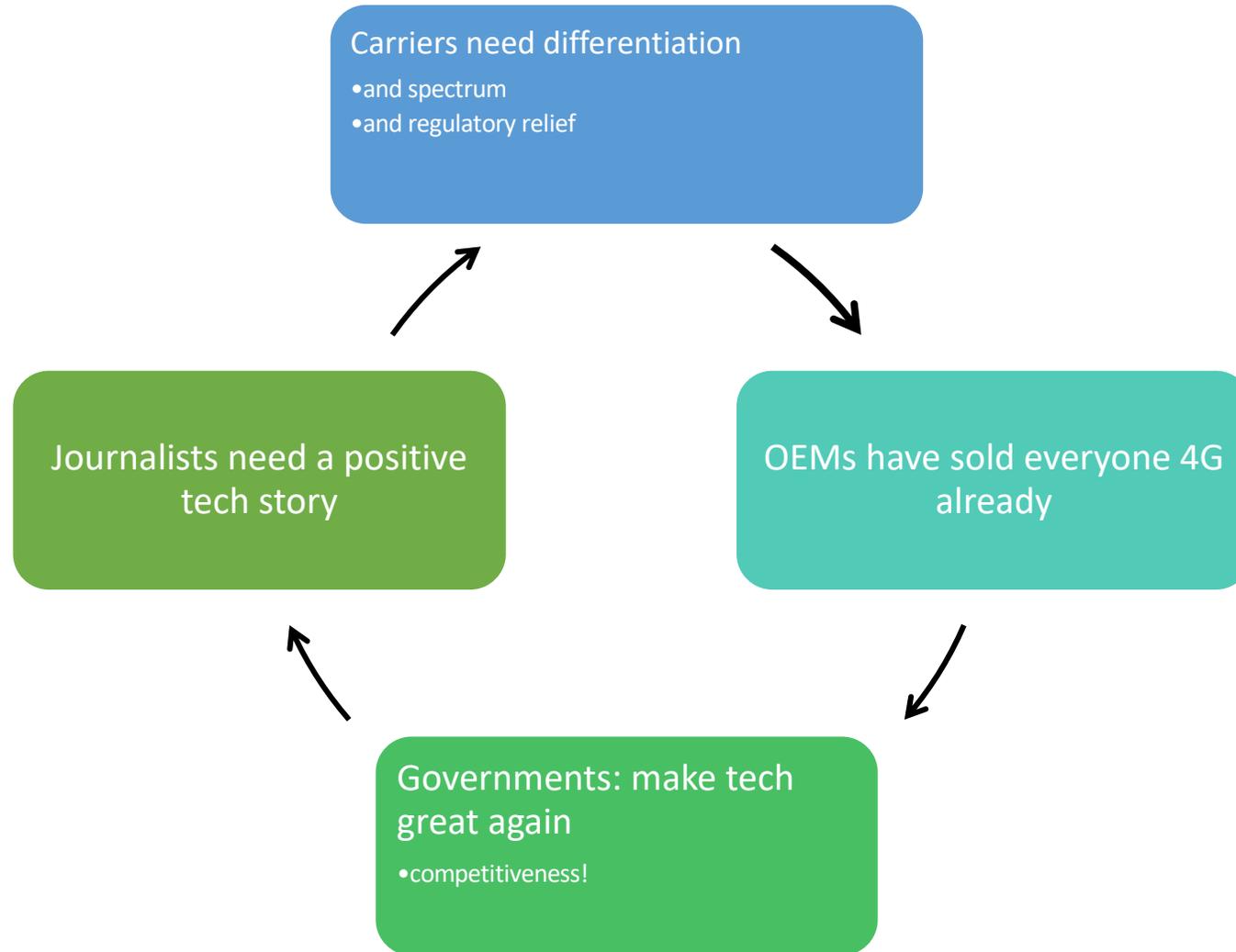
- underestimated cost and fixed-equivalence as drivers
- are the even generations the successful ones?

Classical (5G) requirements pyramid



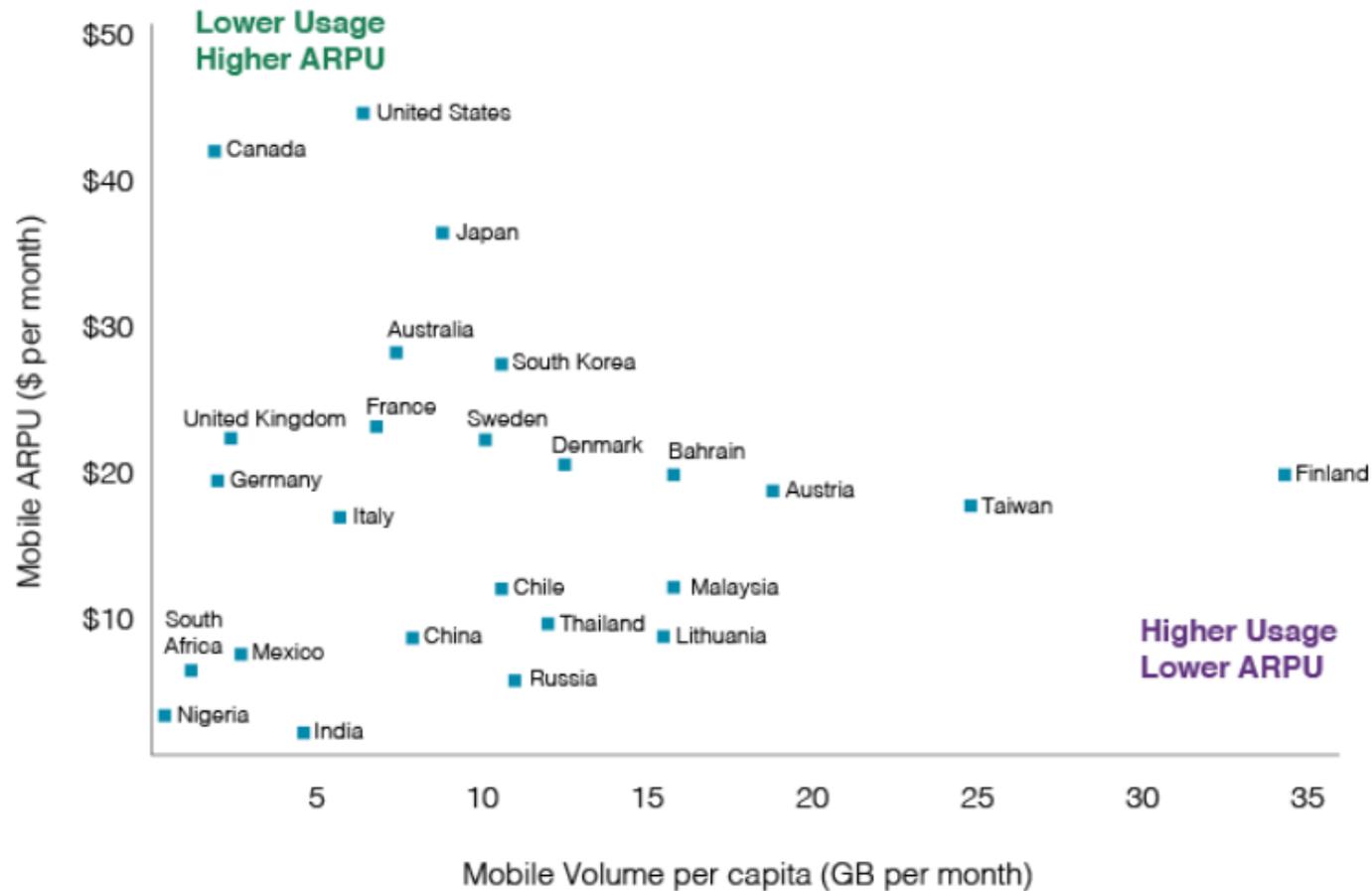
mostly PHY requirements!

Everybody needs 5G



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

What's the economic case for 5G?

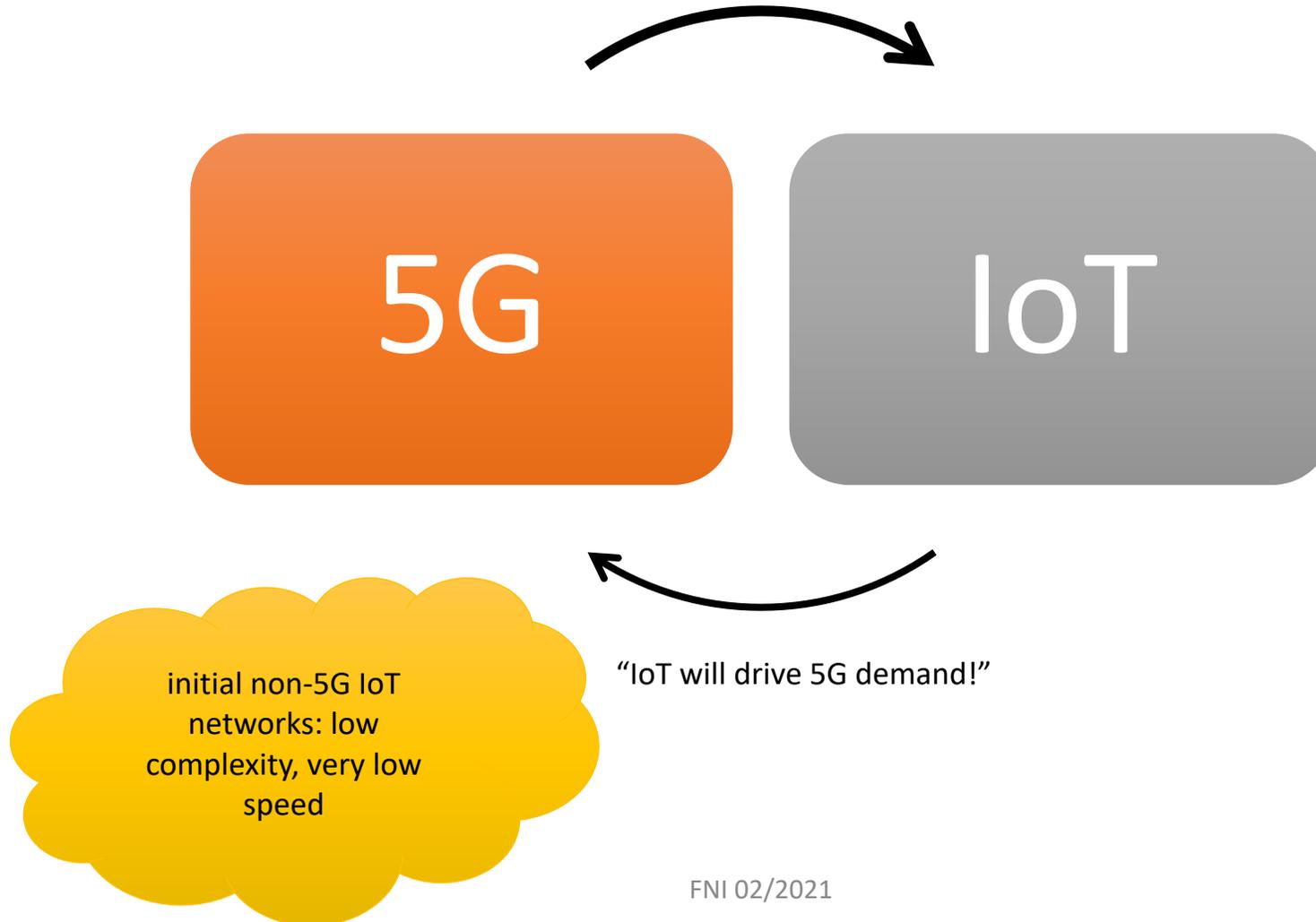


avg. about 5.1 GB/month
T-Mobile: 10 GB tethering

March 2020

Hype feedback loop

5G provides 1 ms latency!



IoT is not exactly new (1978)



X10 HOME AUTOMATION ▾

X10 PRO ▾

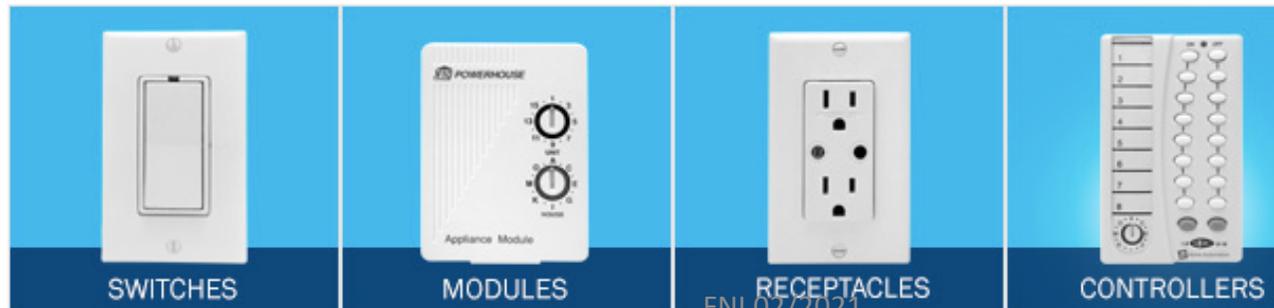
HOME SECURITY

CAMERAS

X10 B

ome → X10 Home Automation

X10 Home Automation



IoT – an idea older than the web (1985)

Peter Lewis (panel discussion 1985)

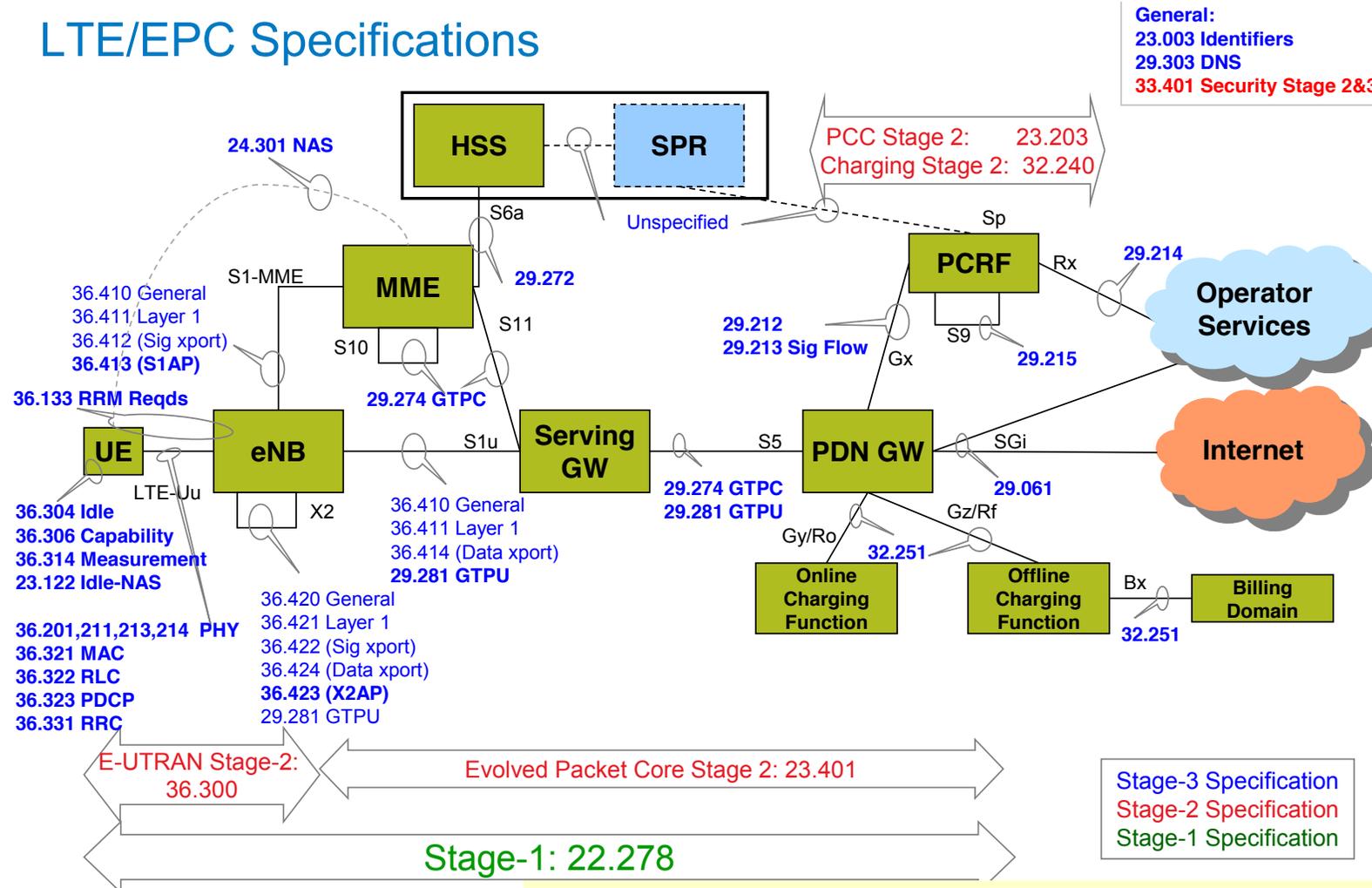
*By connecting devices such as traffic signal control boxes, underground gas station tanks and home refrigerators to supervisory control systems, modems, auto-dialers and cellular phones, we can transmit status of these devices to cell sites, then pipe that data through the Internet and address it to 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

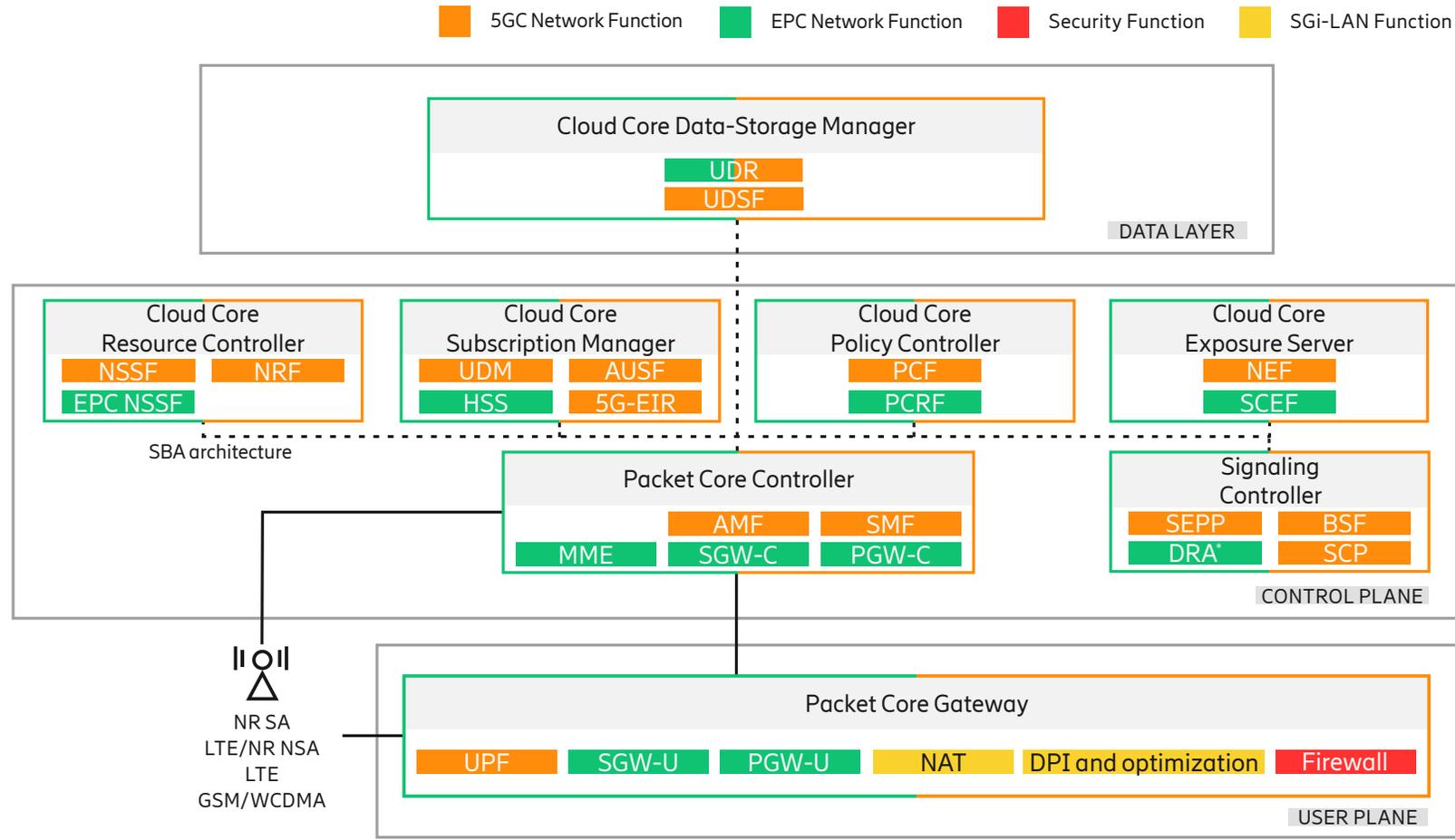
LTE EPC

LTE/EPC Specifications



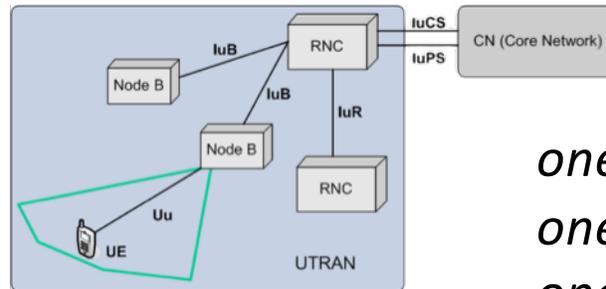
Link to get latest 3GPP specs per release: <ftp://ftp.3gpp.org/Specs/latest>
 Link to find out what a spec covers: <http://www.3gpp.org/Specification-Numbering>

5G & 4G EPC



Networks 1G through 4Gish

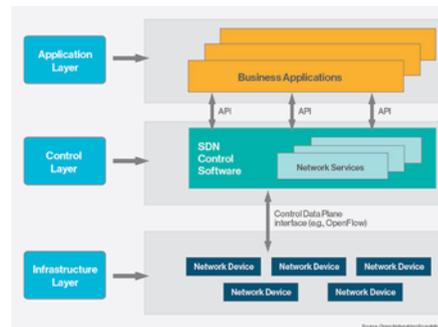
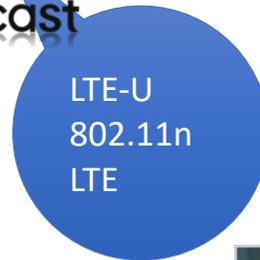
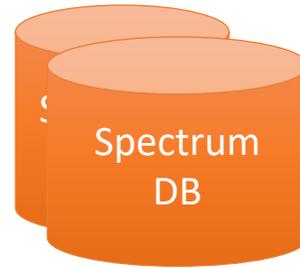
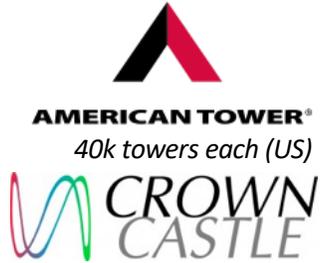
national carrier



*one subscriber,
one phone,
one provider*

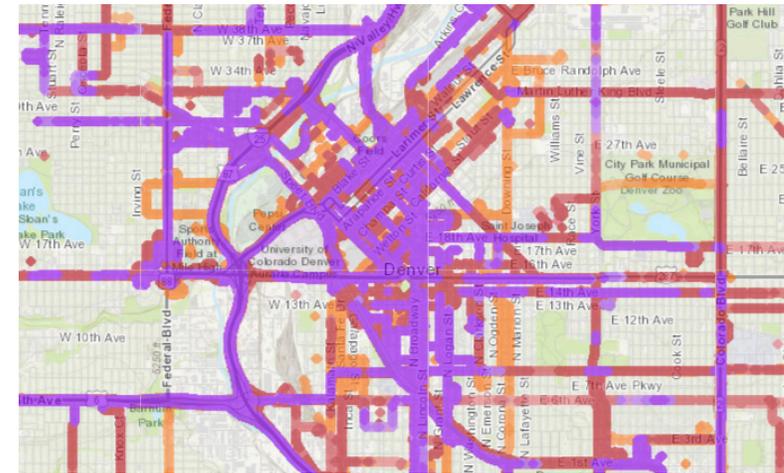


What exactly is a carrier?



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:

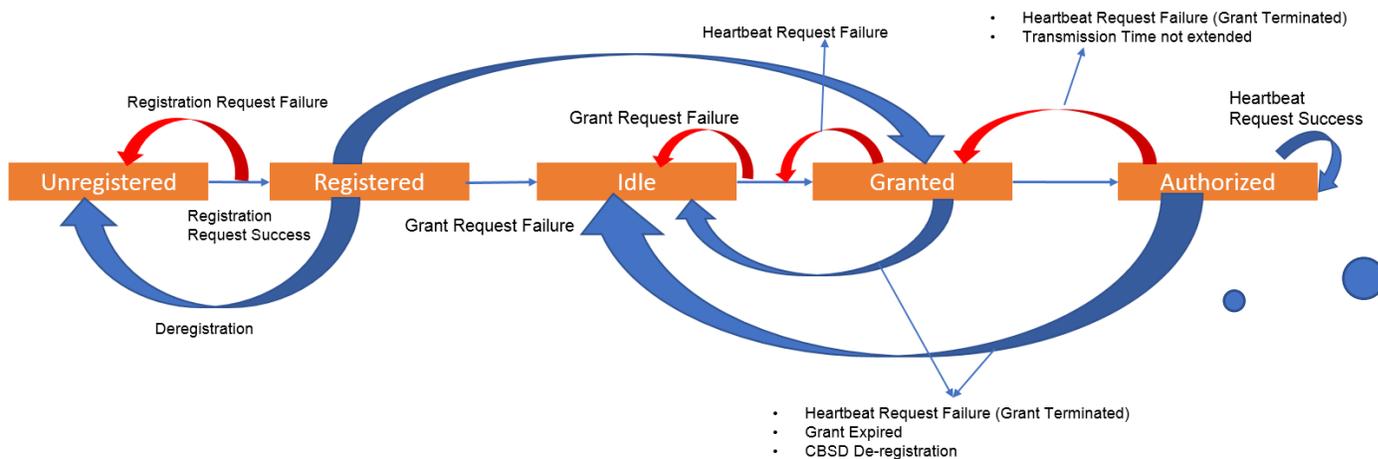
carriers → get back into enterprise
Nokia & Ericsson → new markets

CBRS as new spectrum opportunity for LAN model

| | | 3550 | 3600 | 3650 | 3700 | MHz |
|---------------|---------------------------------|------|------|------|--|--|
| Tier 1 | Incumbents | | | | | Incumbents have first right to access the spectrum and are protected from PAL and GAA interference |
| Tier 2 | Priority Access License (PAL) | | | | Up to 7 licenses available per county by auction of 10 MHz channels with priority over GAA | |
| Tier 3 | General Authorized Access (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



2.4 GHz ISM



802.11
~2 Mb/s

802.11a
~20 Mb/s

802.11b
~6 Mb/s

802.11g
~20 Mb/s

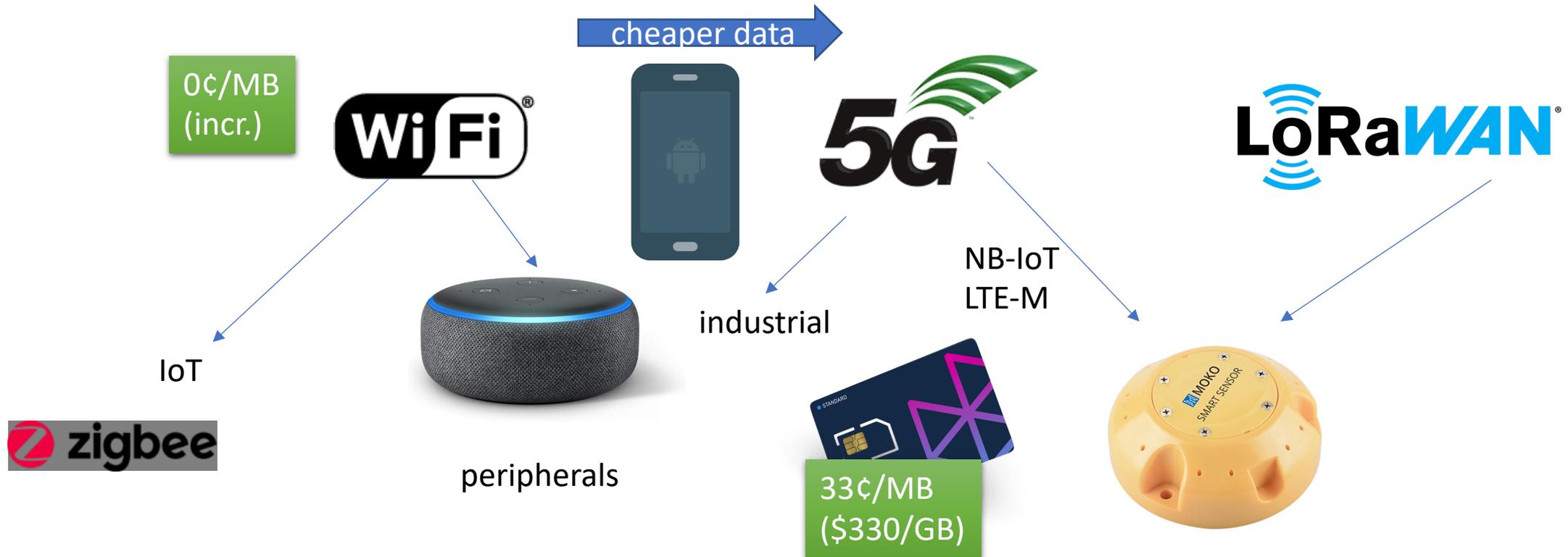
802.11n
~100 Mb/s

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

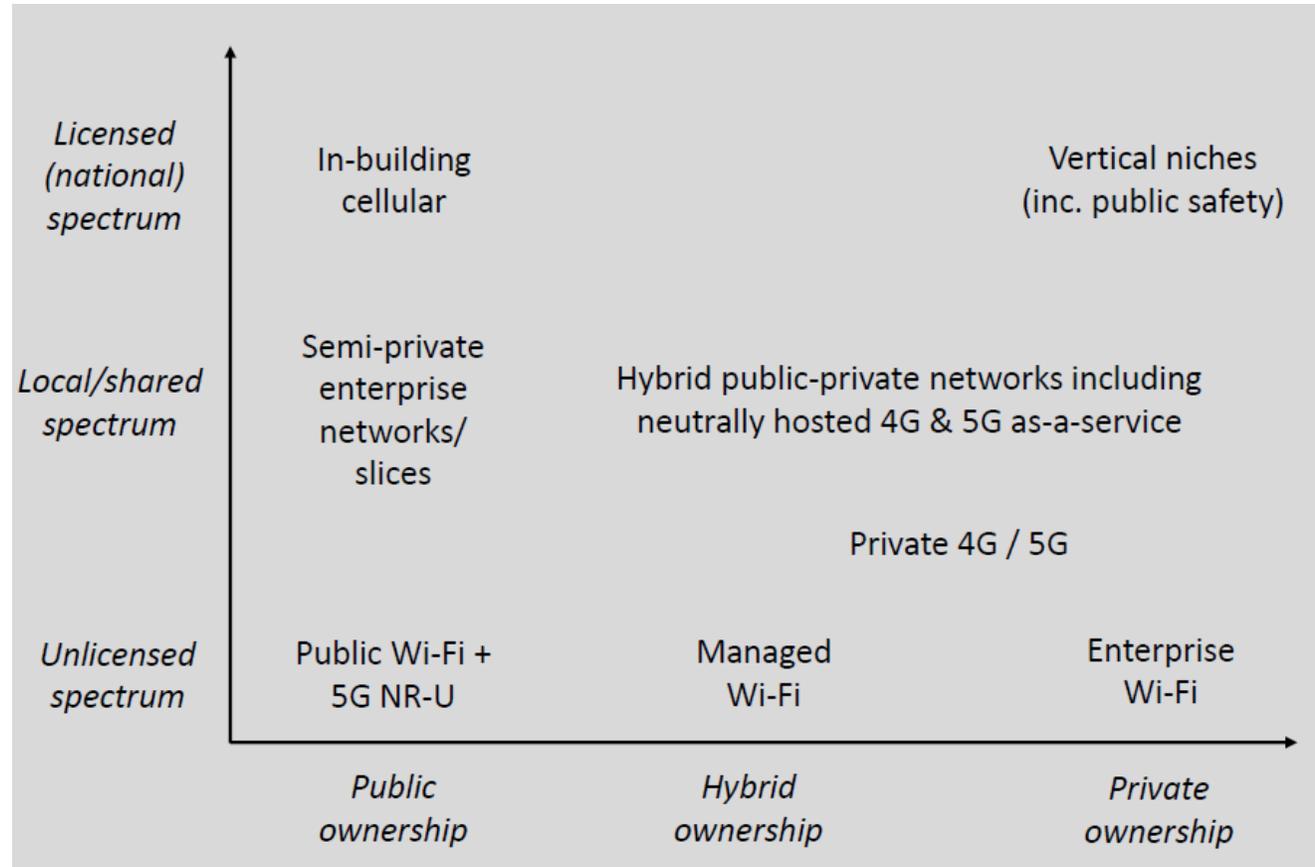


Similar PHY: OFDM, OFDMA, QAM, MIMO, etc.

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) 100% coverage, small antenna | Agriculture sensors | Iridium NEXT? |
| Outdoor (including oceans) 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 (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 device-based model 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

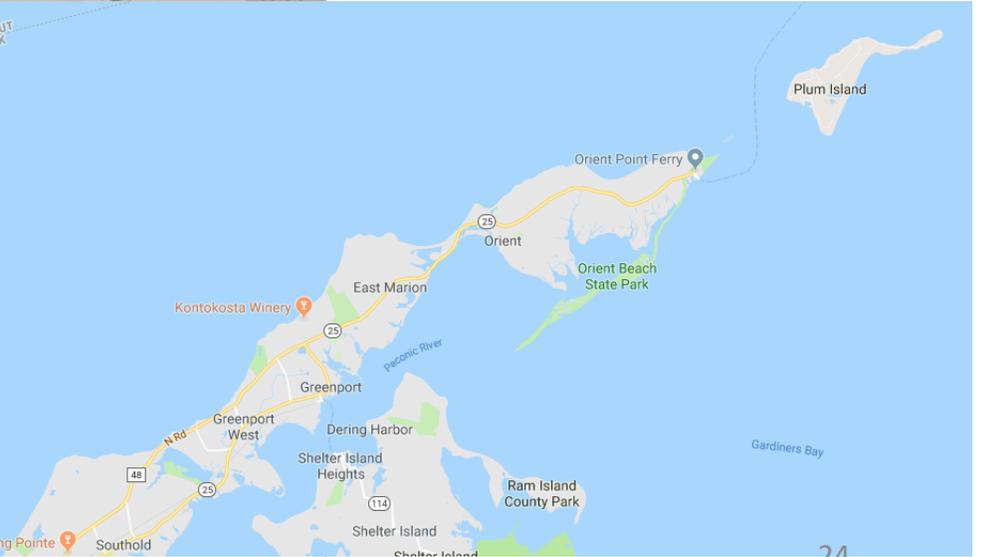
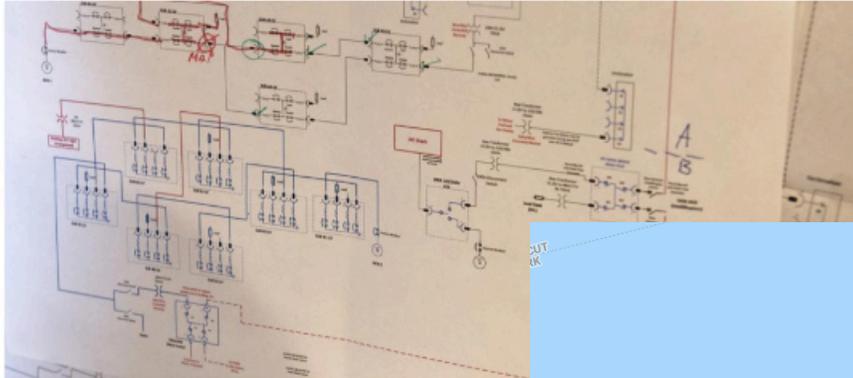
identity management and trust still deficient

DARPA RADICS

GOVERNMENT

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

- Twitter icon
- Facebook icon
- LinkedIn icon
- Reddit icon
- Email icon



2/3/21

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



802.11af
(TVWS)

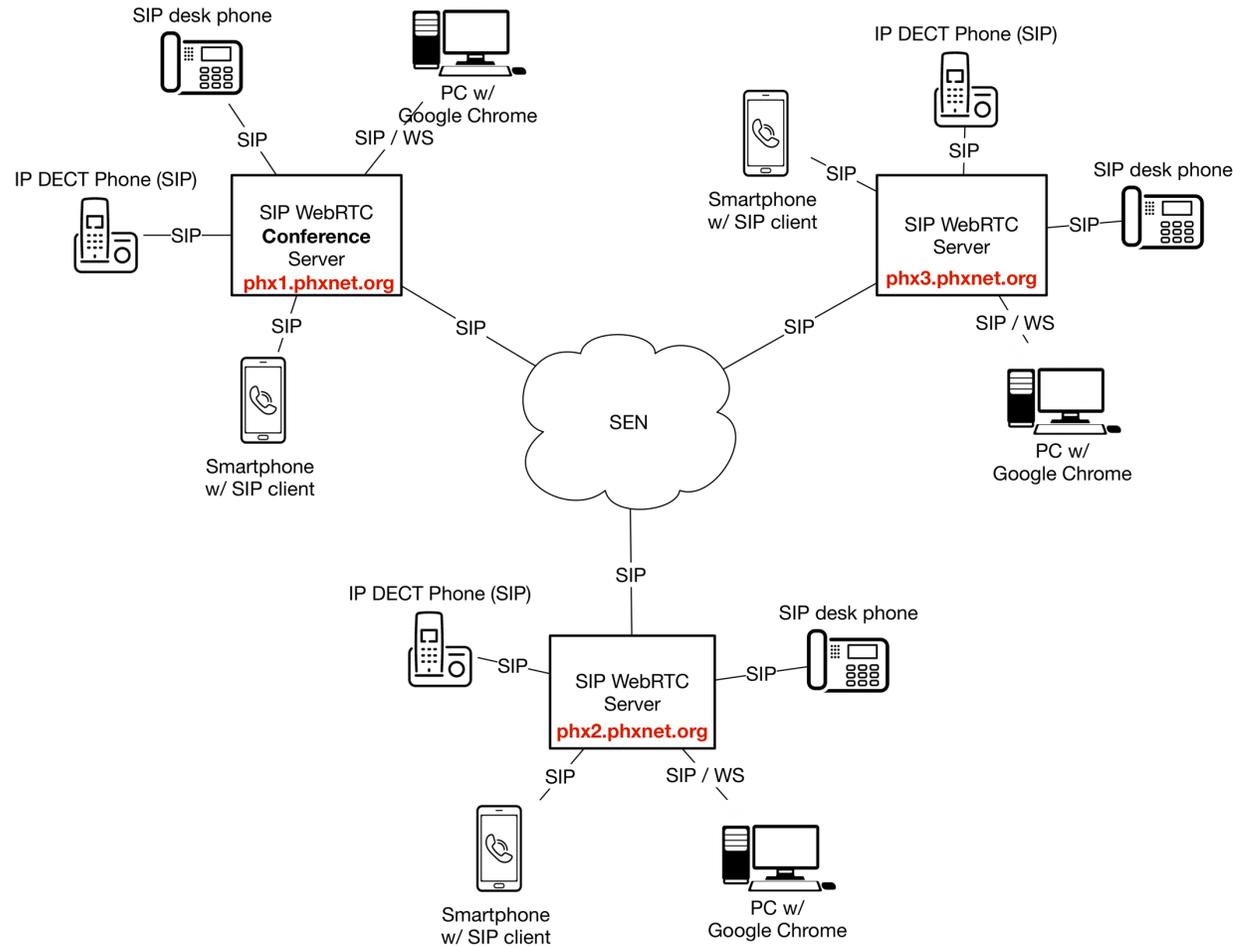
high-bandwidth
VHF



- 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

SDR: P.25
over VHF + Codec2 + data

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



The image shows a captive portal interface for a hotspot. At the top, there is a red antenna icon with signal waves, followed by the text "Raymond.cc Hotspot". Below this is a blue header with the text "User account registration". The main content area is white with a blue background for the text. It says "You can log in using your username and password:" next to a small user icon. There are two input fields: "Username:" with the text "raymond" and "Password:" with five black dots. Below the password field is a small eye icon. There are two buttons: a white "Login" button and a black "Options" button. At the bottom, there is a small text line: "By logging on you are accepting our [Terms of Use](#)".

Why have Zigbee and Bluetooth remained niche?

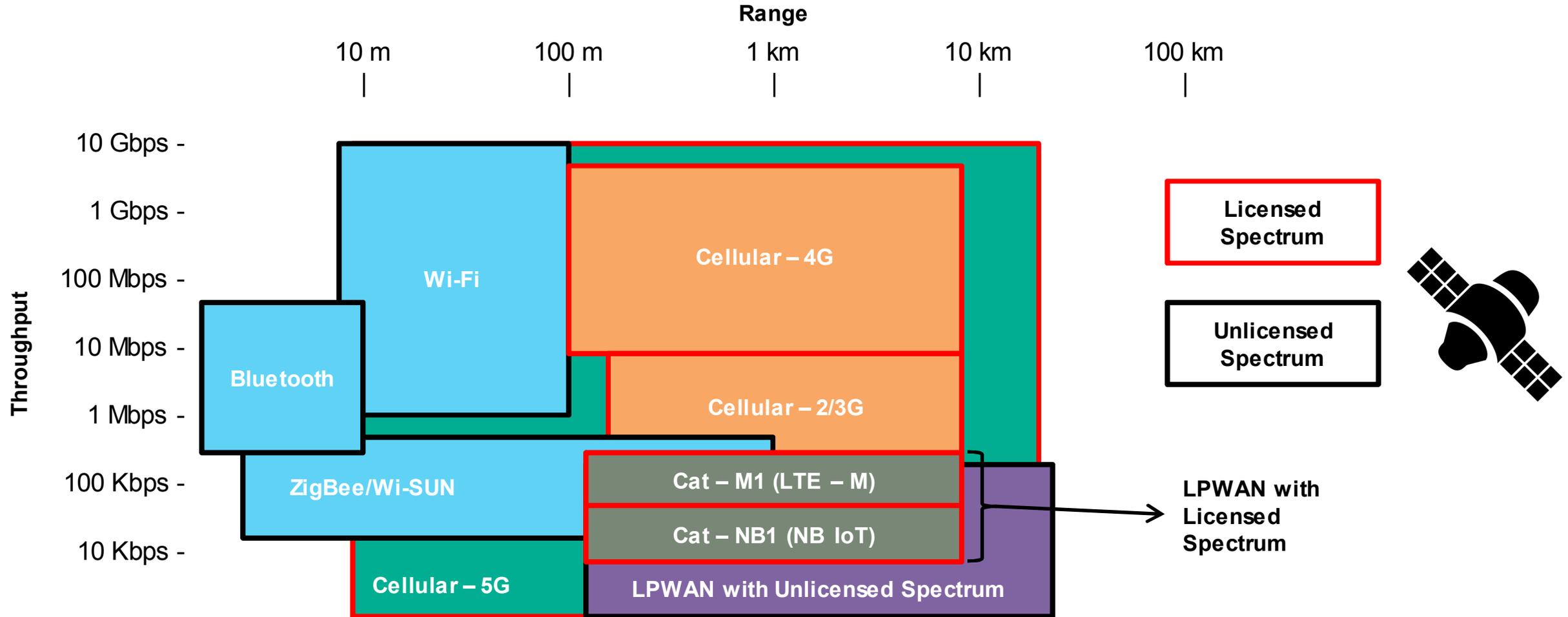


- Most home IoT devices are probably Wi-Fi, not Zigbee
- Need for gateway to home network
- Smart home speakers



- 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



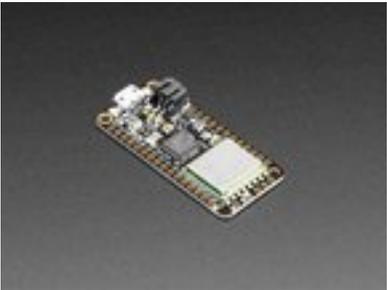
Arduino Uno WiFi R2

\$45



Arduino MKR1000

\$36



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

Wi-Fi + computer

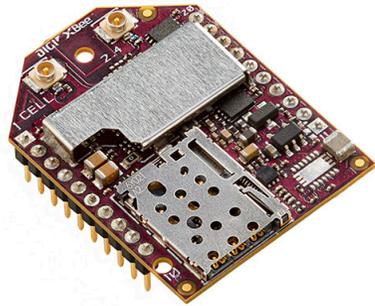
Wi-Fi 802.11b/g/n

\$7.84



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

AT&T: >72¢ /MB



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

Current authentication models

picket fence security

hard to scale to IoT



Wi-Fi settings SAVE

Network name _____

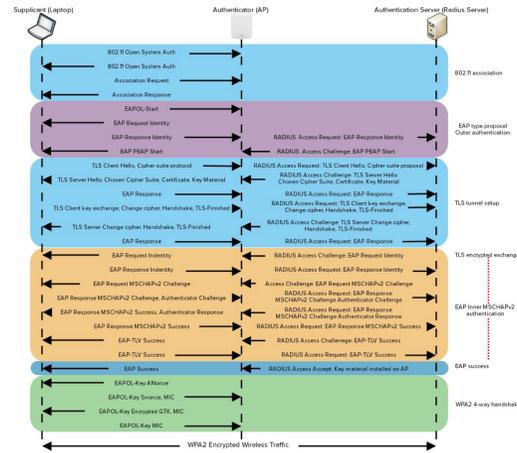
Kindness _____

Password _____

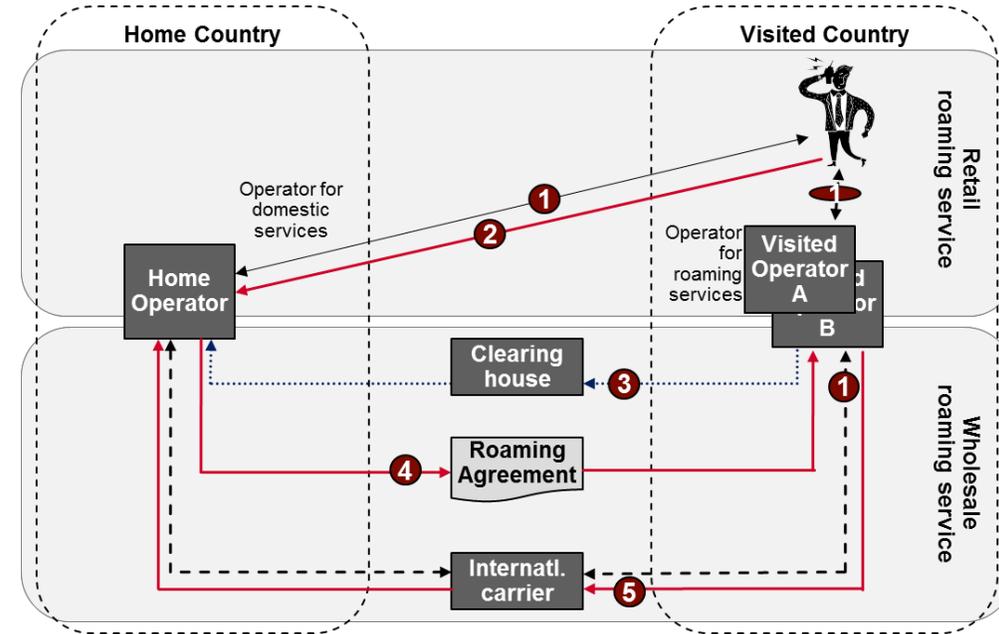
Show 8 characters minimum

WPA2-Personal

802.1x



international roaming



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

- Roaming services
- ← Traffic flow
- Revenue flow
- ⋯ Data exchange

federated (RADIUS, DIAMETER)



From web login to apps



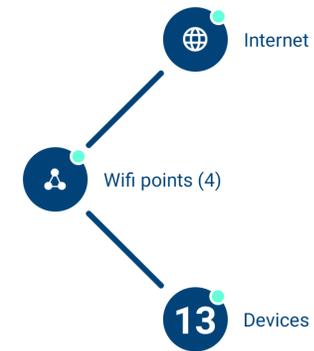
The screenshot shows the Verizon wireless settings web interface. At the top, there is a navigation bar with icons for Main, Wireless Settings, My Network, Firewall Settings, Parental Control, Advanced, and System Monitoring. Below this, a sidebar on the left contains a menu with 'Main', 'Wireless Status' (highlighted), 'Basic Security Settings', 'Advanced Security Settings', and 'Logout'. The main content area displays the 'Wireless Status' page with the following information:

| | |
|----------------------------|---------------------------------|
| Radio Enabled: | No |
| SSID: | XXP89 |
| Channel: | Automatic |
| Security Enabled: | Yes |
| WEP 64-bit: | N/A |
| WEP 802.1x: | N/A |
| WPA2: | LL77WHRL67VSF5DQ |
| SSID Broadcast: | N/A |
| MAC Authentication: | Disabled |
| Wireless Mode: | Compatibility Mode(802.11b/g/n) |



Kindness is online

13 devices connected



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 available



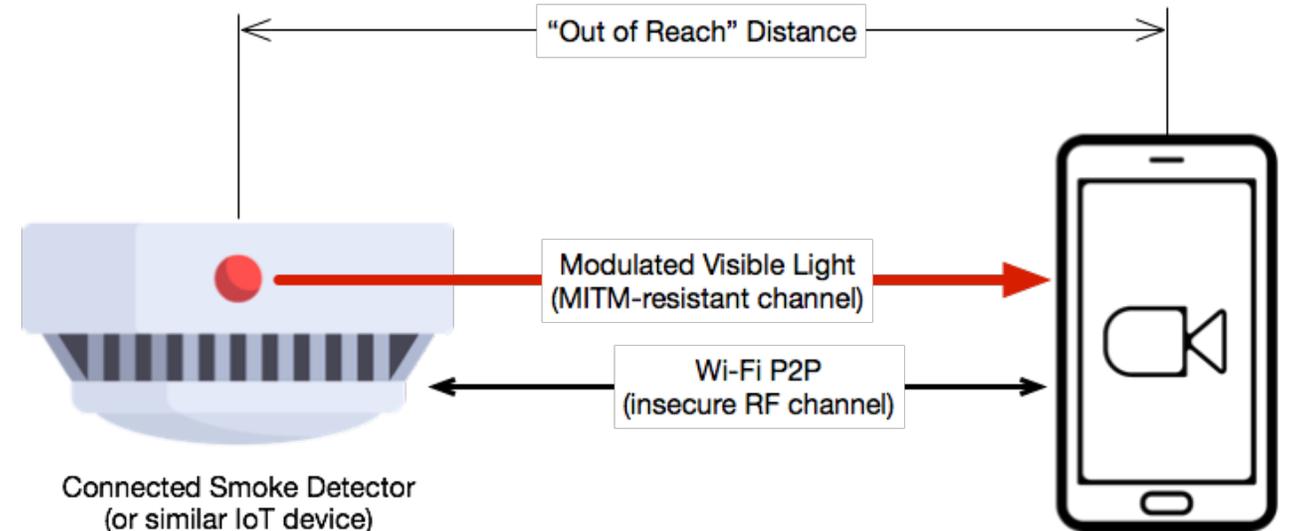
Follow these steps to set up a WPS (Push Button) connection:

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.

Searching for wireless network...
Please press the WPS button on your wireless router now. If you do not press it within 2 minutes, the search will be cancelled.

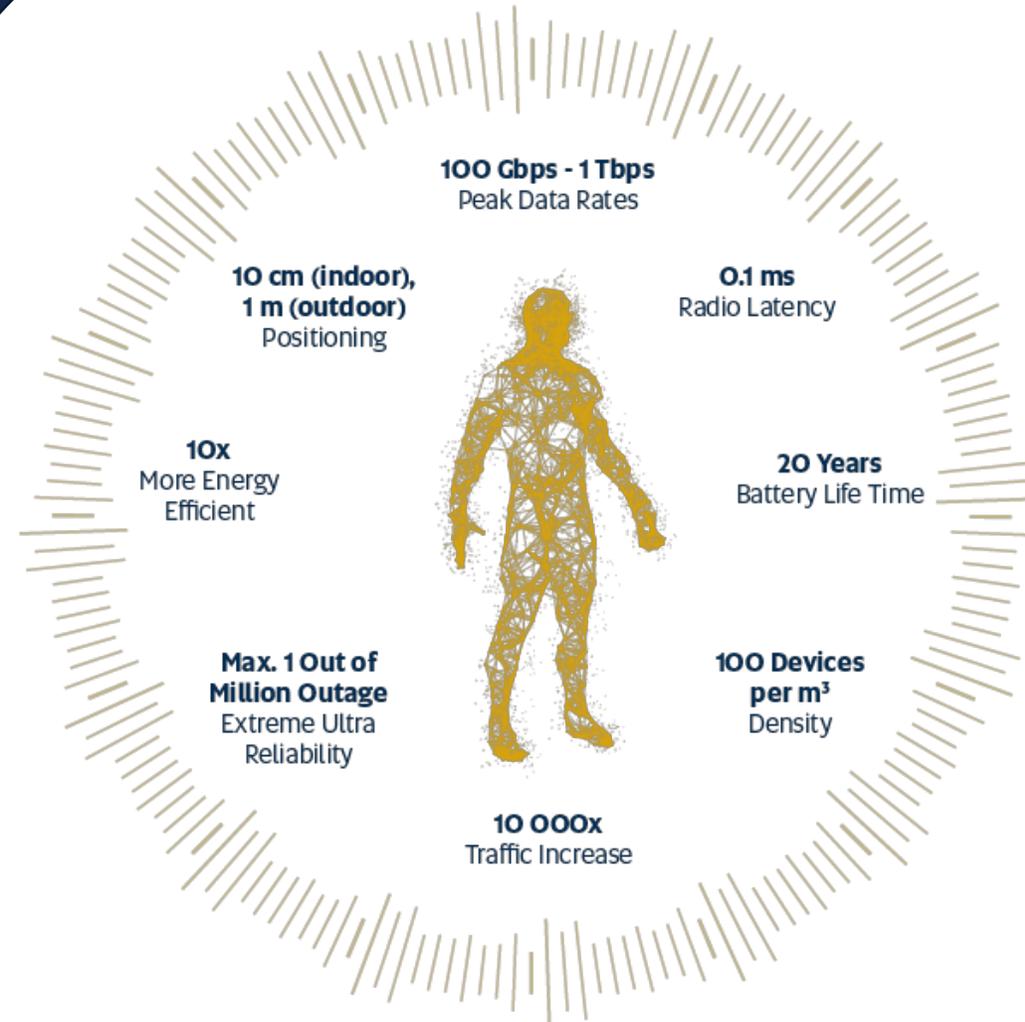
New (additional) authentication model

- 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”

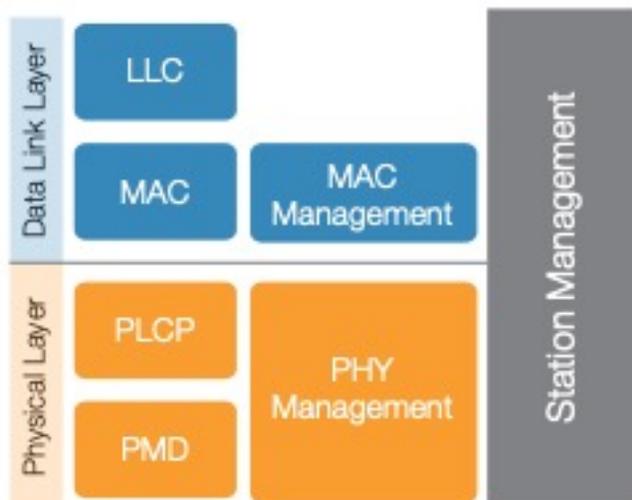
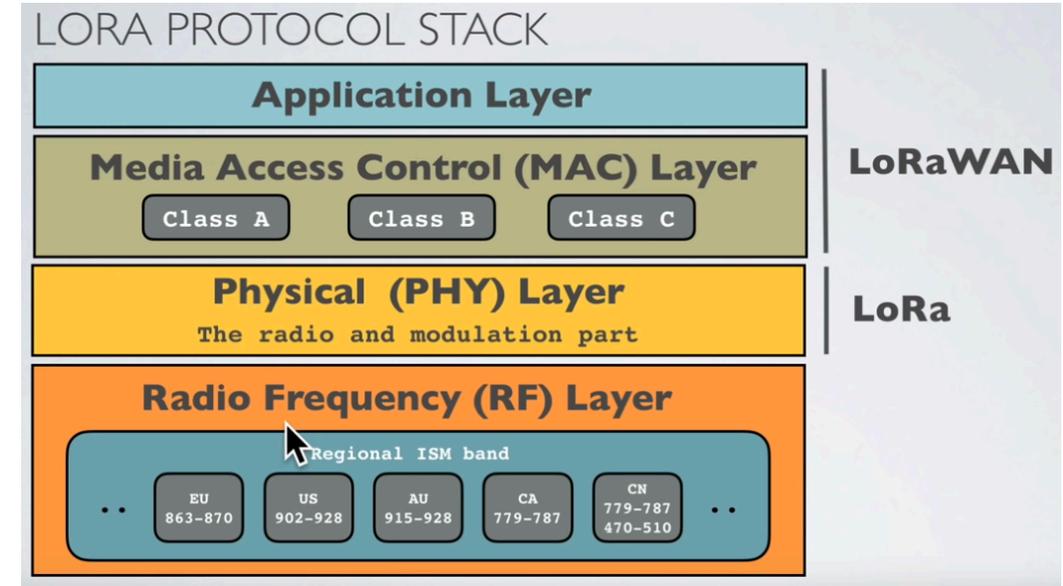
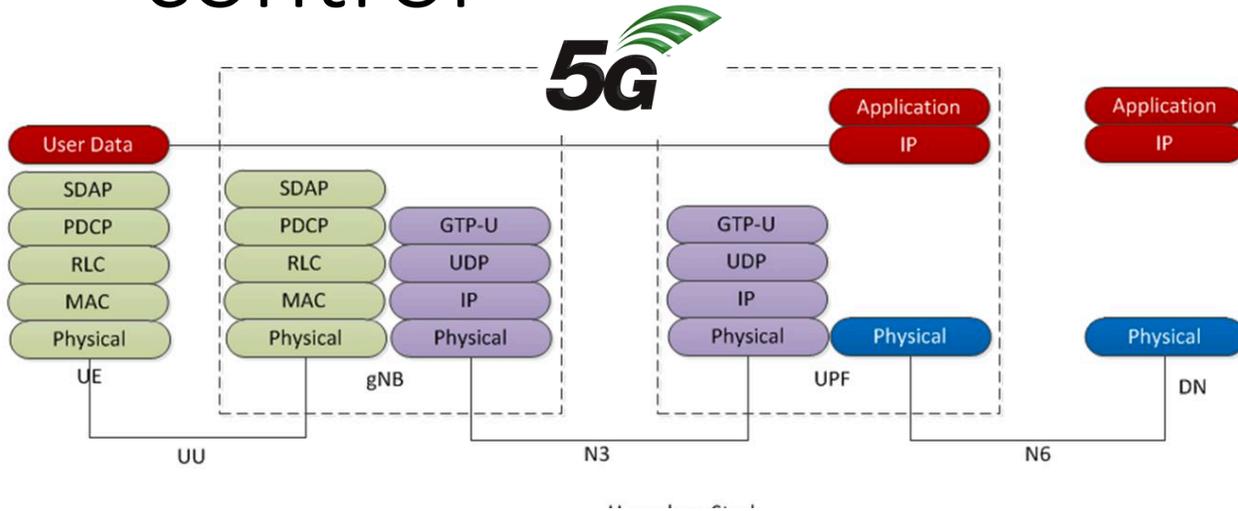


Next-generation networks (6G!)

6G vision – multiply or divide by 10



Stacks always focus on data – complexity is in control



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