5G and IoT - Separating Hype from Promise

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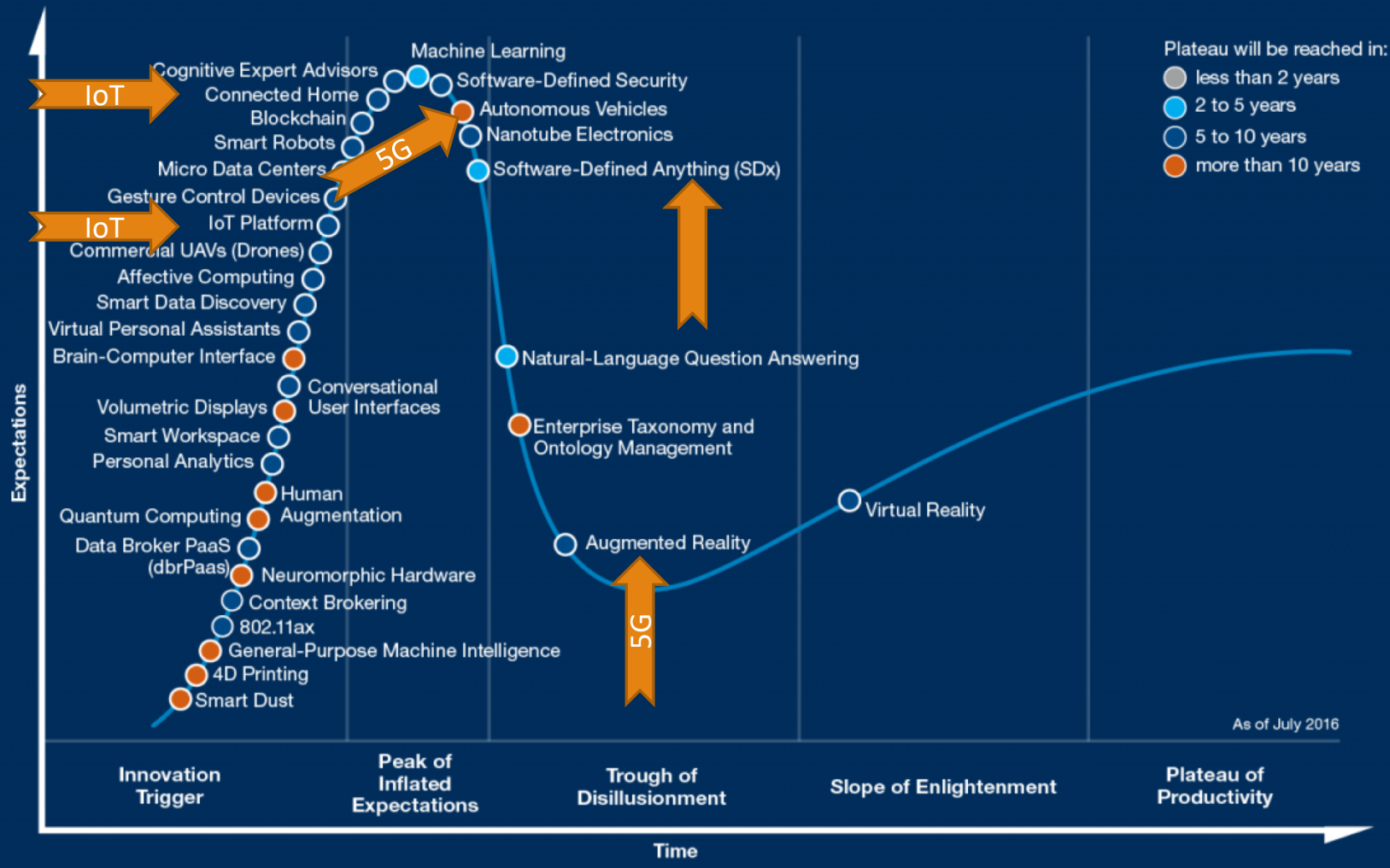
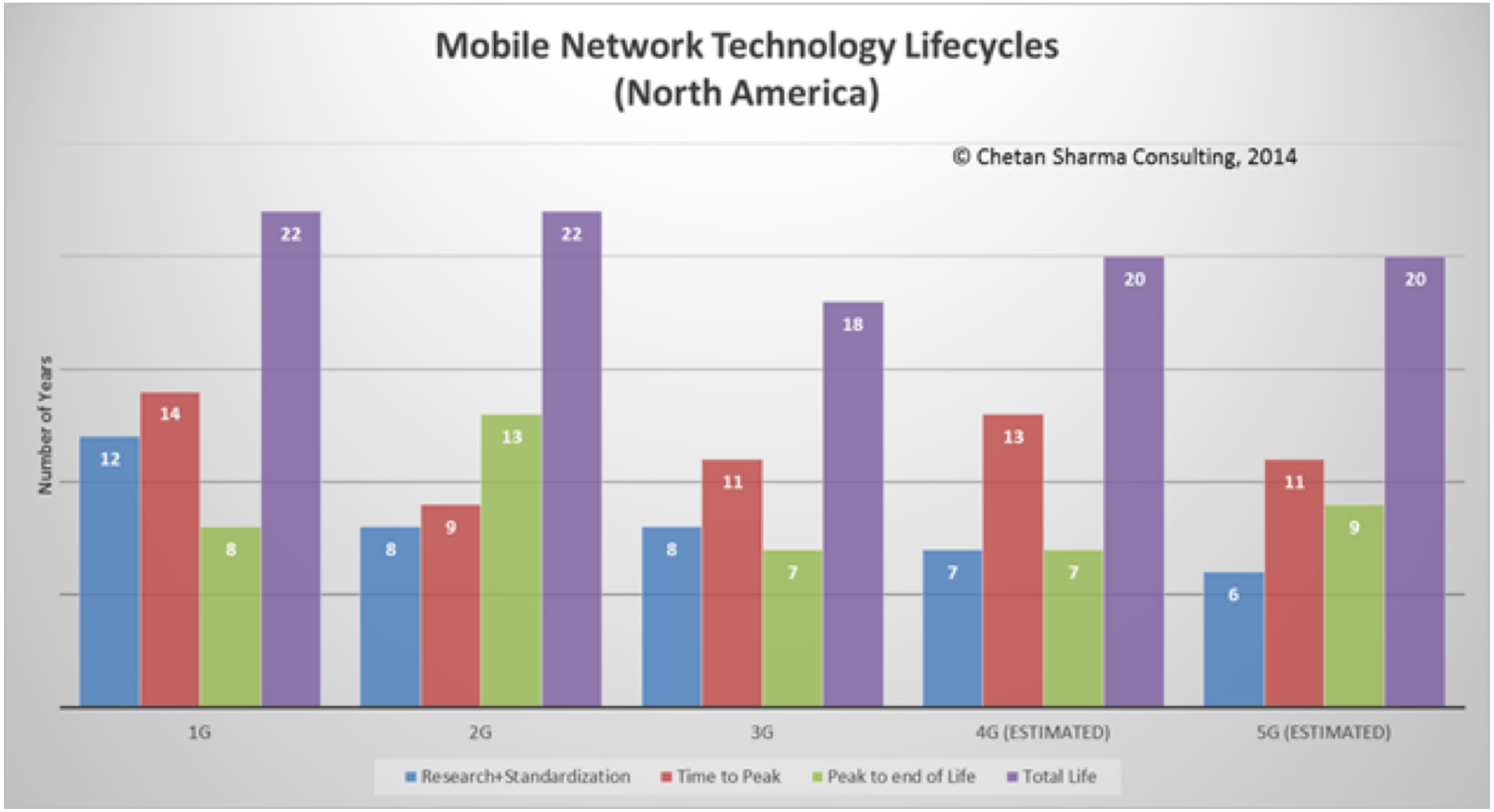
Gartner Hype Cycle for Emerging Technologies, 2016



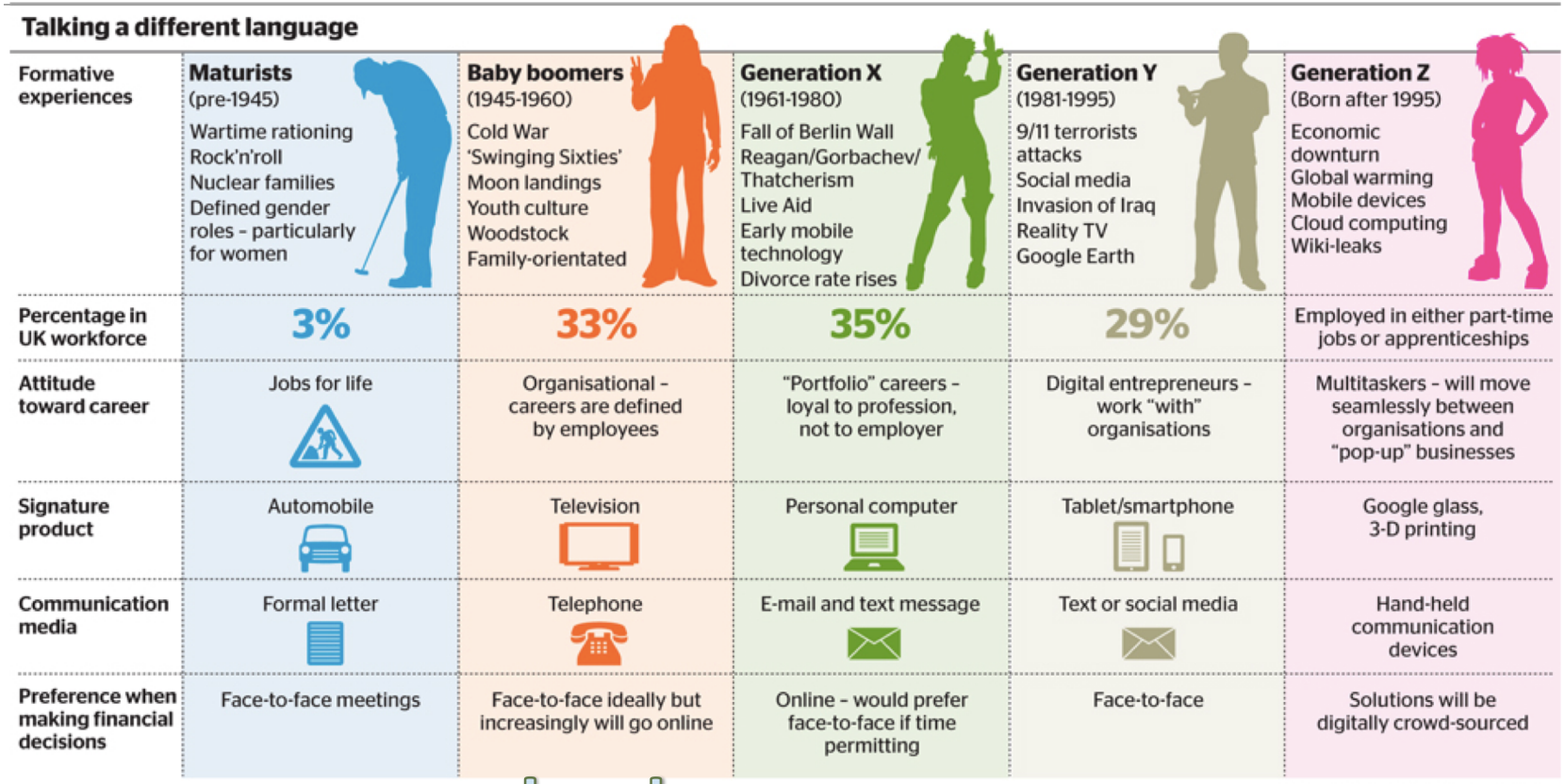
Source: Gartner

Gartner

Design for 20 years



Generations are distinct



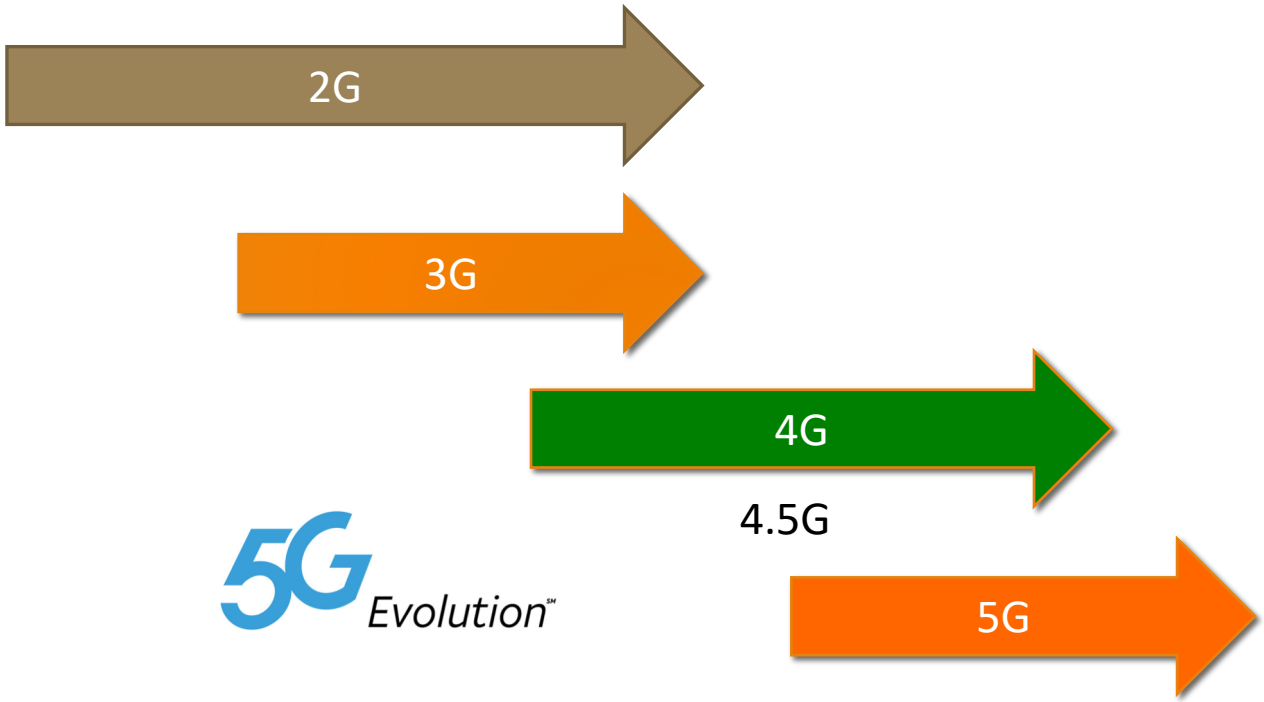
land line

2G

3G

4G

Generations overlap



Generational surprises

Generation	Expectation	Surprise
2G	better voice quality (“digital!”)	SMS
3G	WAP	web
4G	IMS	YouTube, WhatsApp, notifications
5G	IoT (low latency)	?

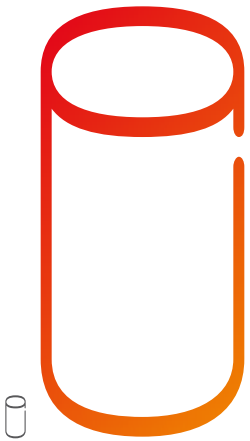
underestimated cost and fixed-equivalence as drivers

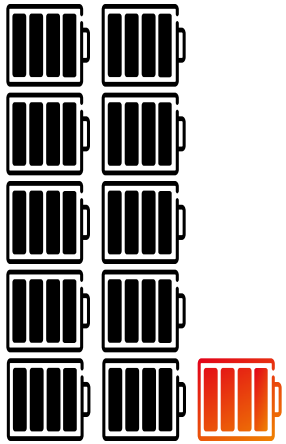
Lessons, in brief

Experience	Lessons
VoLTE, IMS	avoid complexity avoid entanglement plan intercarrier interfaces
Wi-Fi	don't trust the RAN/AP
disaggregation of functions	clear & simple interfaces don't assume trust between elements
app stores	keep it application-neutral
FTTH, backhaul cost	re-use backhaul where you can find it

METIS Technical Objectives

1000x data volume	50/500 B devices	Up to 10Gbps	Few ms E2E	10 years





1000x	10-100x	10-100x	5x	10x
higher mobile data volumes	higher number of connected devices	typical end-user data rates	lower latency	longer battery life for low-power devices

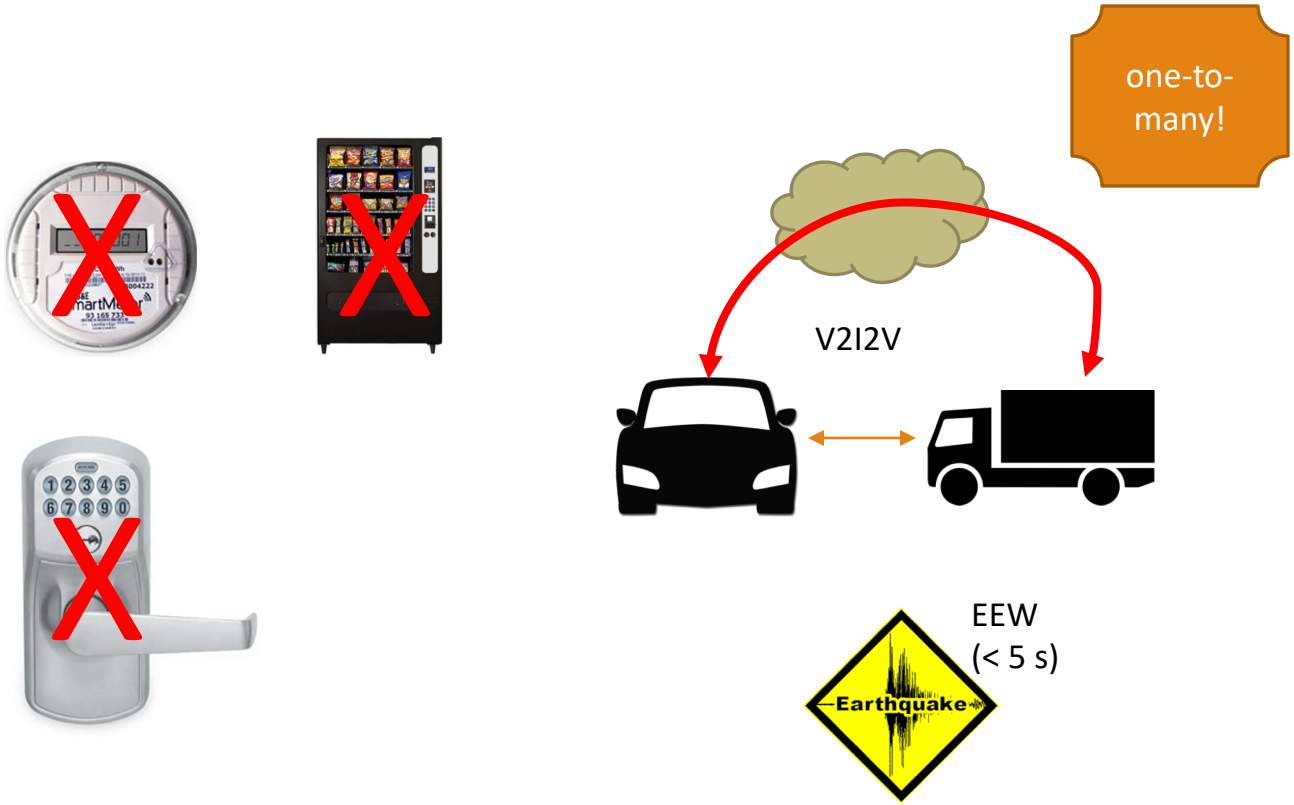
METIS, "Toward a 5G Mobile & Wireless System Concept"

2G → 3G → 4G → 5G ➔ increasing number of technology components

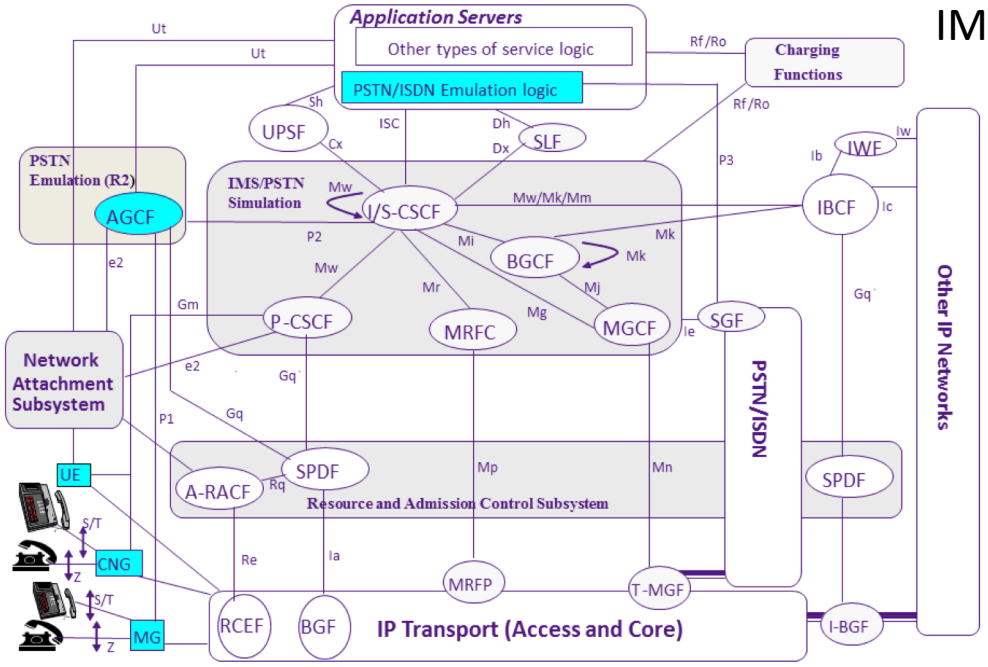
5G is a systems standard

Technology component	Proposed application	Less exciting, but likely
mmWave	10 Gb/s user rates	capacity in stadiums fixed wireless?
edge computing	IoT	video caching
M2M	billions & billions of devices! autonomous vehicles!	electric meters
1 ms latency	autonomous vehicles!	keep it application-neutral
slicing	QoS	test networks, VPNs

5G low latency



Complexity kills



Long-range networks

FEATURE	LTE Rel 13	Combined Narrow Band (NB) and Spread Spectrum (SS) (Semtech)	Cooperative Ultra Narrow Band (Sigfox)	Narrow Band M2M Clean Slate (Huawei/ Neul)
Bandwidth	1.4 MHz	400 Hz to 12.8 KHz NB and 200 KHz SS UL / 3.2 KHz to 12.8 KHz DL	160 Hz UL / 600 Hz DL	2 or 3.75 KHz UL / 15 KHz DL per channel
UL Data Rate	TBD	122 bps – 7.8 Kbps	160 bps / 600 bps	200 bps to 45 Kbps
Range / MCL	155.7 dB (24 dBm Tx Pwr)	164 dB (20 dBm TX Pwr)	164 dB (24 dBm Tx Pwr)	162 dB (24 dBm Tx Pwr)
Broadcast/Multicast	Yes	Yes	No	No?
Duplex	Full/Half Duplex (FDD)	Full-Duplex	Full Duplex	Full-duplex
Synchronization	Yes	Yes	No	Yes

IoT requirements

Application	Range	Mo-bility	Device characteristics	Service characteristics	Suitable networks
• Connected car • Fleet management • Remote health monitoring	~1000m	Yes	Rechargeable battery	Managed service, highly secure	• Cellular • Satellite
• Smart metering • Parking meter	~1000m	No	Low rate, low power, low cost	Managed service	• Cellular • Dedicated network
• Hospital asset tracking • Warehouse logistics	~100m	Yes	Low rate, low power, low cost	Enterprise-deployed	• WiFi • RFID
• Industrial automation • Home automation	~10m	No	Low rate, low power, low cost	Subscription-free	• Zwave • Zigbee • Wifi • Powerline
• Personal activity • Local object tracking • Point of sale	~1m	No	Low rate, low power, low cost	Subscription-free	• Bluetooth • NFC

Niche networks persist

short range

ZigBee®

low energy; mesh

tries to usurp niche

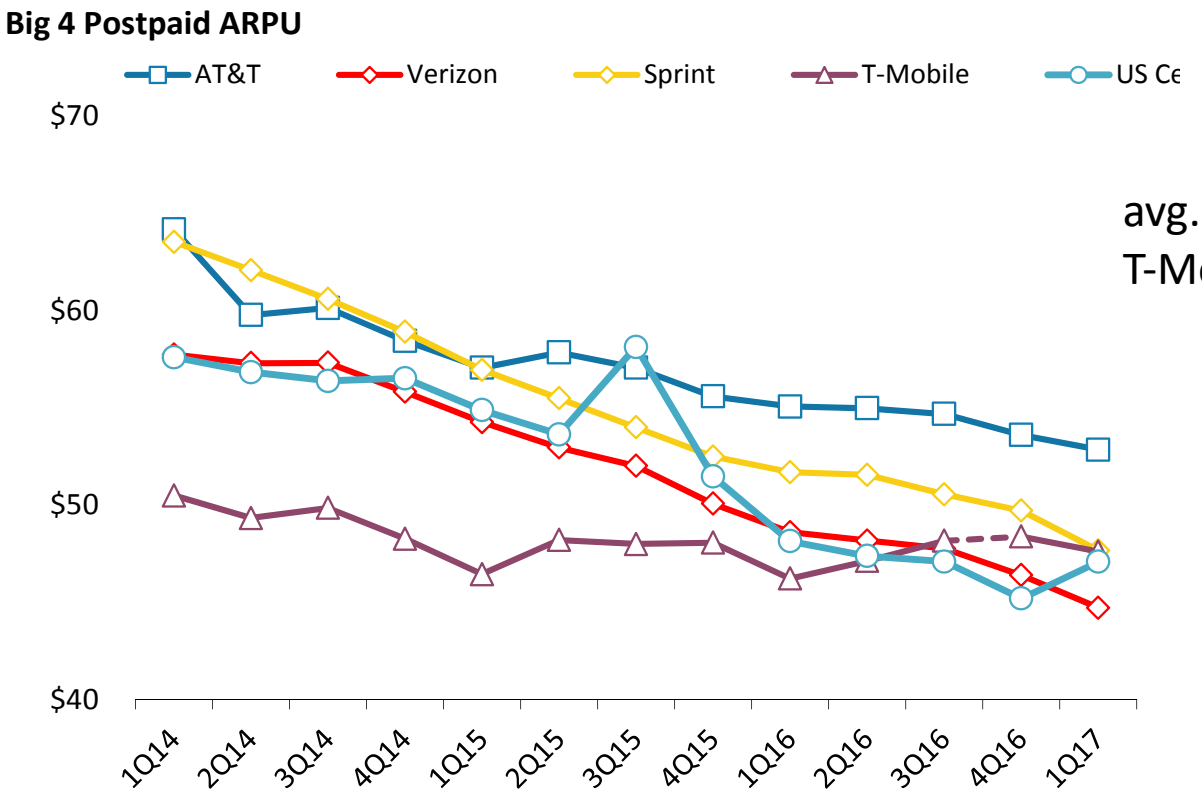
Bluetooth®

ubiquity; low cost

Wi Fi™

speed; public APs

What's the economic case for 5G?

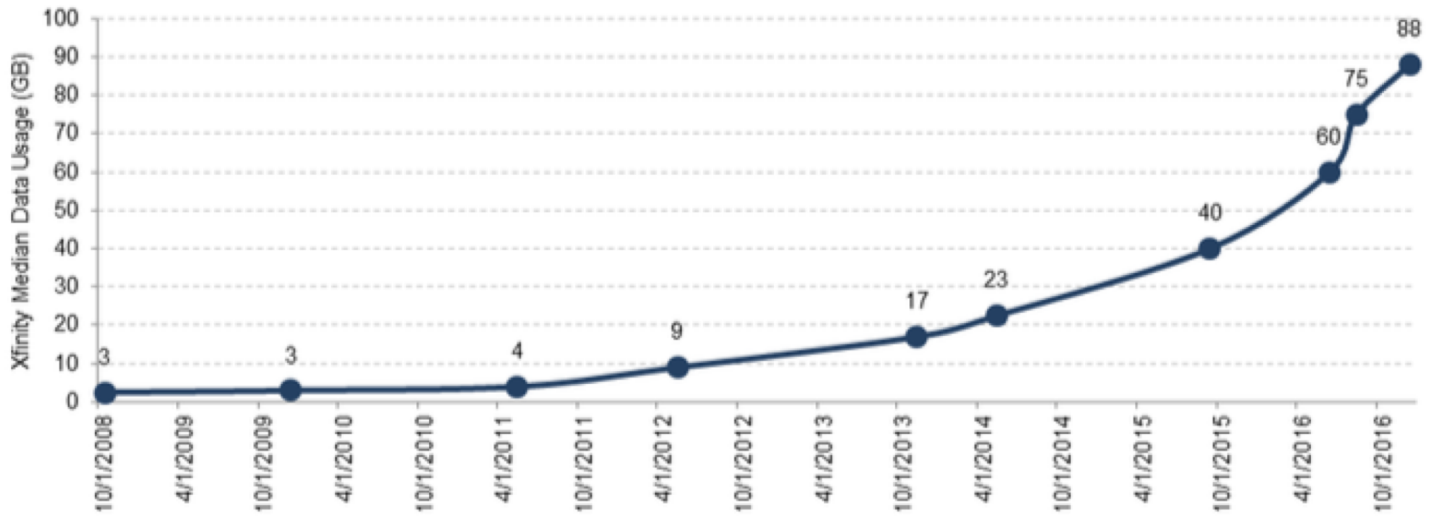


avg. about 2.1 GB/month
T-Mobile: 10 GB tethering

Cord-cutting for broadband?

Exhibit 13

Comcast: Median Bandwidth Usage per Household per Month, 2008 to 2016



Source: Comcast's website, MoffettNathanson estimates and analysis

How can 5G be cheaper by GB?

Backhaul is major cost factor

- "Backhaul costs represent almost 6% … of a wireless carrier total operating expenses (OPEX) and 30% of total network costs."

Re-use existing fiber to residential users

- Requires cooperation of cable/FTTH provider

Reduce license cost for spectrum → unlicensed, mmWave

- first step: LTE-U

Table 5. Wireless Network Cost Breakdown (OPEX and Headcount CAPEX)

Subcomponents	Carrier A	Carrier B	Carrier C	Carrier D	Average of All Carriers
Strategy and Support	13	8	10	19	14%
Network infrastructure rent	36	45	33	37	39%
Transmission	6	5	13	8	7%
Core Network	10	9	13	3	8%
Radio ops & maintenance	11	15	18	14	14 %
Radio deployment	13	8	8	10	10 %
Radio design	10	9	5	8	8 %

Source: Wireless Carriers Benchmarking Study

Spectrum for 5G

Changing spectrum environment

Except at highest frequencies, all new spectrum likely to be shared

- e.g., 3.5 GHz
- in time & space

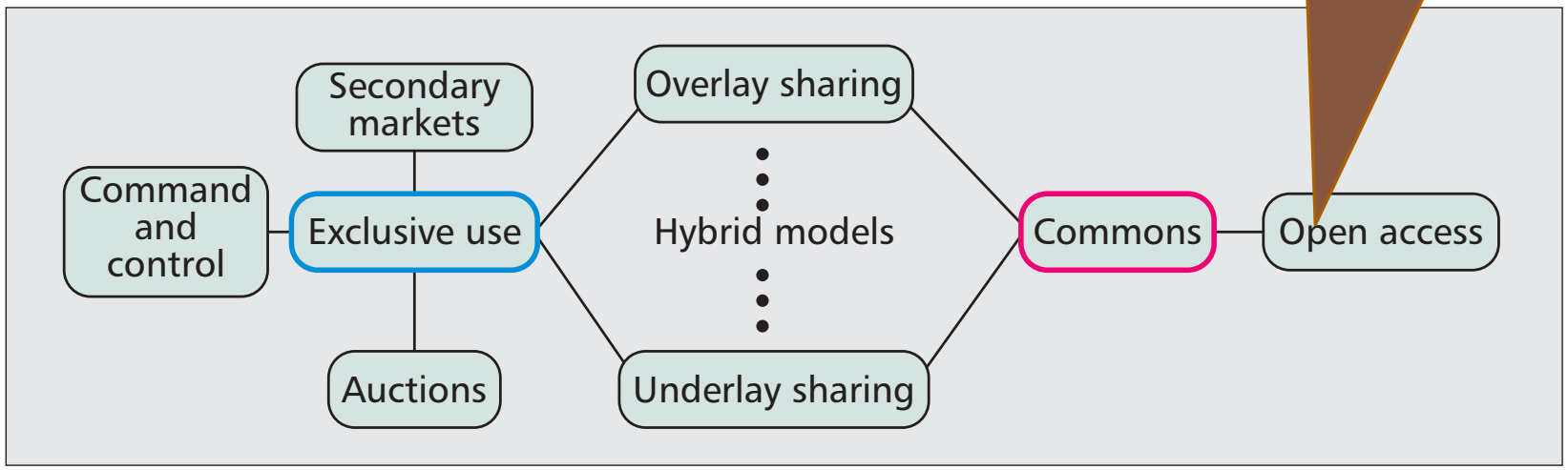
→ need frequency-agile systems that can shift capacity to different bands, quickly

→ few common bands for consulting spectrum database

- **now**: scan, pray & wait
- **5G**: shared band → database

Spectrum sharing

How much politeness & fairness is required?
→ LTE-U & LTE-LAA (license-assisted, listen-before-talk)



Ideal spectrum

Unused or cheap

Av ilable globally (rtant for consum ize)
- rably und sing condi

No r

Propag

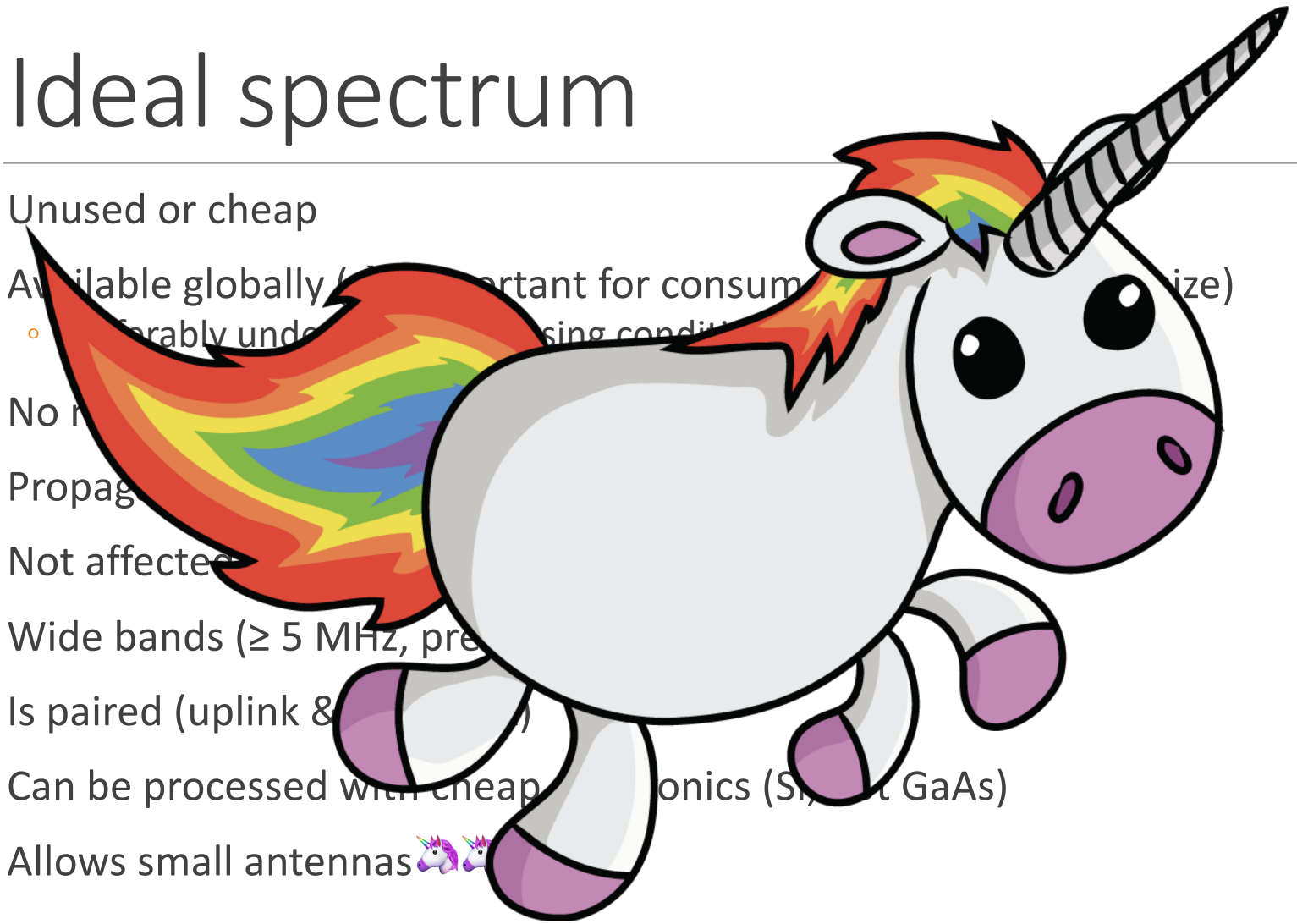
Not affecte

Wide bands (≥ 5 MHz, pre

Is paired (uplink &

Can be processed with cheap onics (Si t GaAs)

Allows small antennas



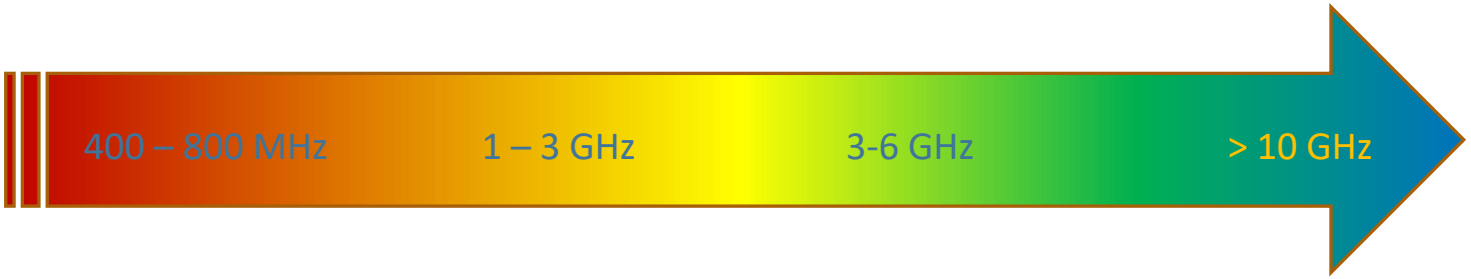
Spectrum co-existence

"high tower, high power"
(TV, cellular downlink, radar transmitter)

vs.

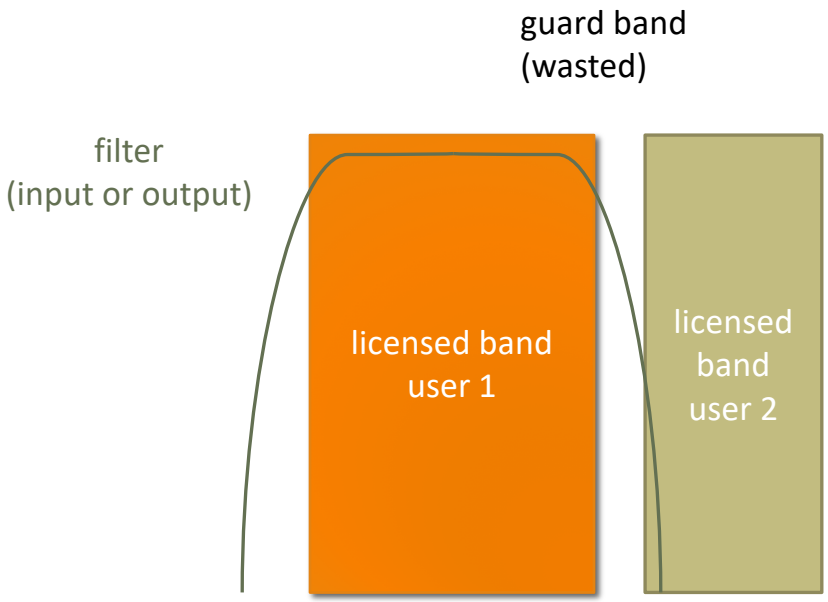
- cellular uplink
- radar receiver
- GPS receiver

Spectrum roles



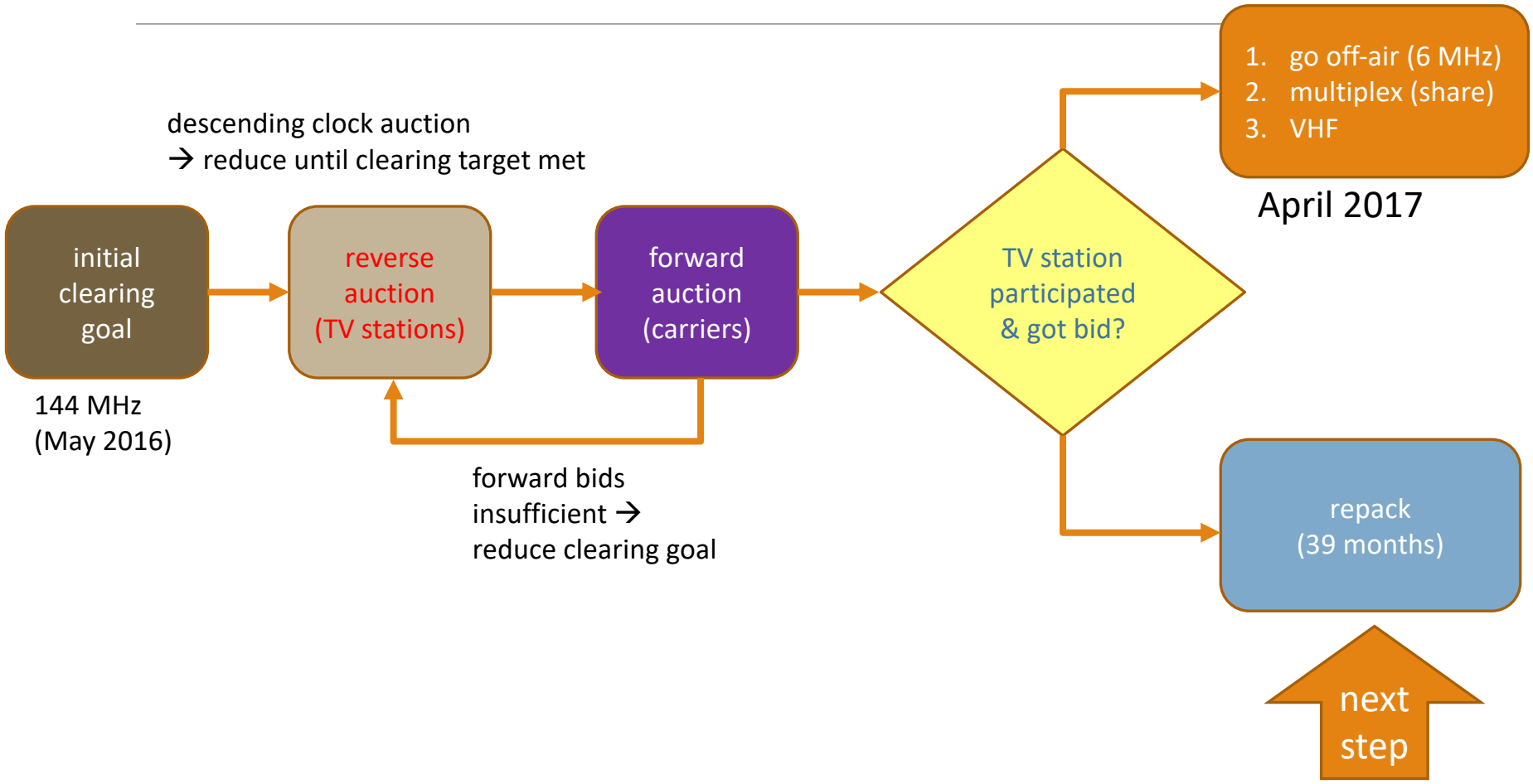
base-level coverage (particularly rural)	urban capacity	indoor & capacity	directional capacity
Digital dividend TV incentive auction	AWS-3	3.5 GHz	mmWave R&O

The filter problem



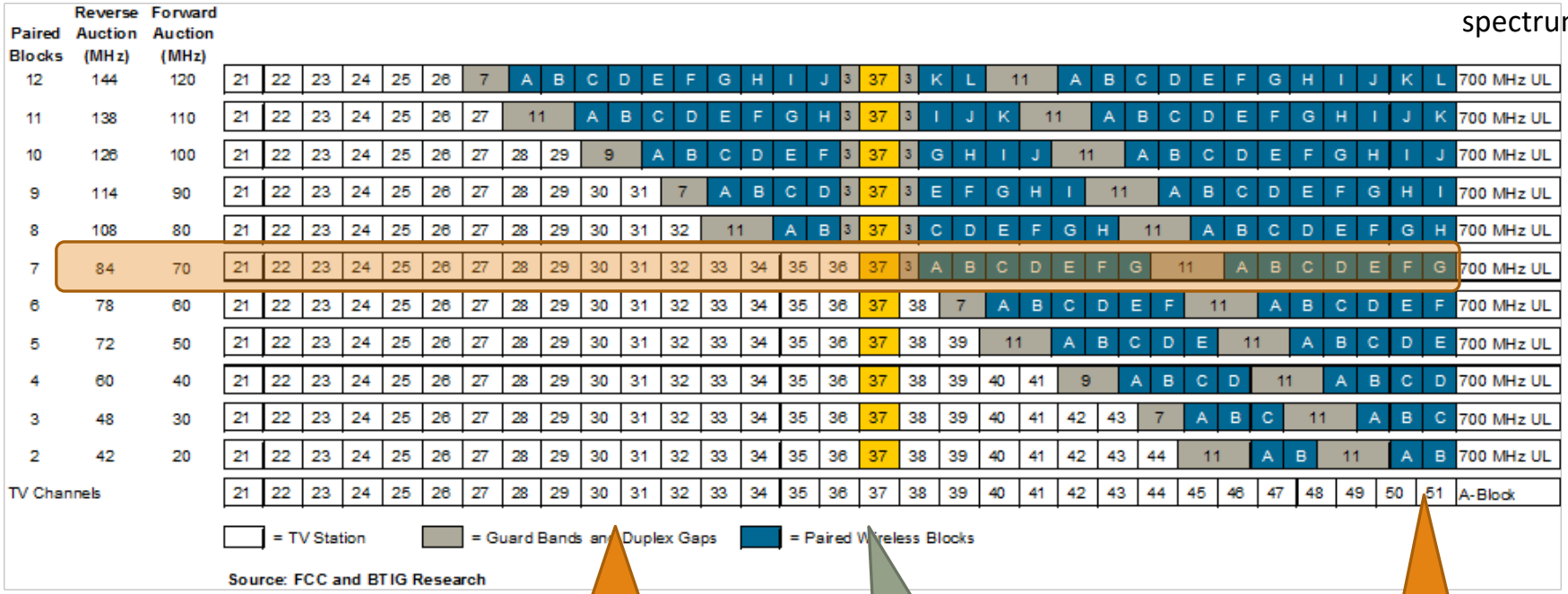
Power imbalance:
- cell downlink: 100 W ERP
- cell uplink: 0.05 – 2 W

TV incentive auction



600 MHz incentive auction

FirstNet spectrum



5 MHz downlink blocks

radio astronomy, medical monitoring

5 MHz uplink blocks

Incentive auction facts

Forward Auction

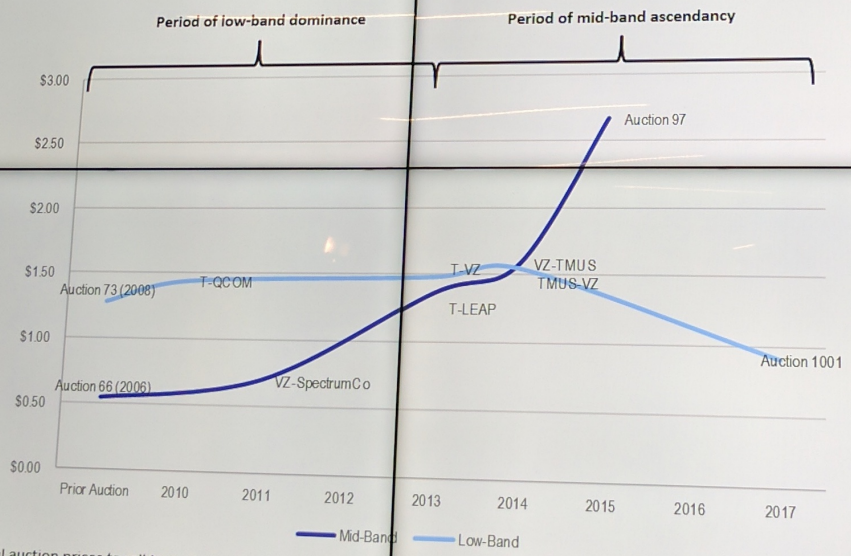
$19.8 billion	Gross revenues (2nd largest in FCC auction history)
$19.3 billion	Revenues net of requested bidding credits
$7.3 billion	Auction proceeds for federal deficit reduction
70 MHz	Largest amount of licensed low-band spectrum ever made available at auction
14 MHz	Spectrum available for wireless mics and unlicensed use
2,776	License blocks sold (out of total of 2,912 offered)
$1.31	Average price/MHz-pop *sold* in Top 40 PEAs
$.93	Average price/MHz-pop *sold* nationwide

Spectrum Needs And Values Are Changing

Prior to 2013, low-band routinely fetched 2x the amount of mid-band. The perceived value of mid-band vs low-band started to shift after VZ deployed LTE on 700MHz. By the AWS-3 auction in 2015, mid-band sold for more than 2x the last significant low-band transaction. The incentive auction was conceived in an era when low-band was the most valuable spectrum, and executed in an era when focus had shifted to higher bands.

Mid-Band Vs. Low-Band Values - Selected Transactions [1]

$ / MHz-POP



1) Indexes reported values to national auction prices for all transactions, save VZ-SpectrumCo and auctions themselves.
Source: Company data, FCC, New Street Research estimates

new|street RESEARCH

Jonathan Chaplin | 212 921 9876 | jonathan.chaplin@newstreetresearch.com

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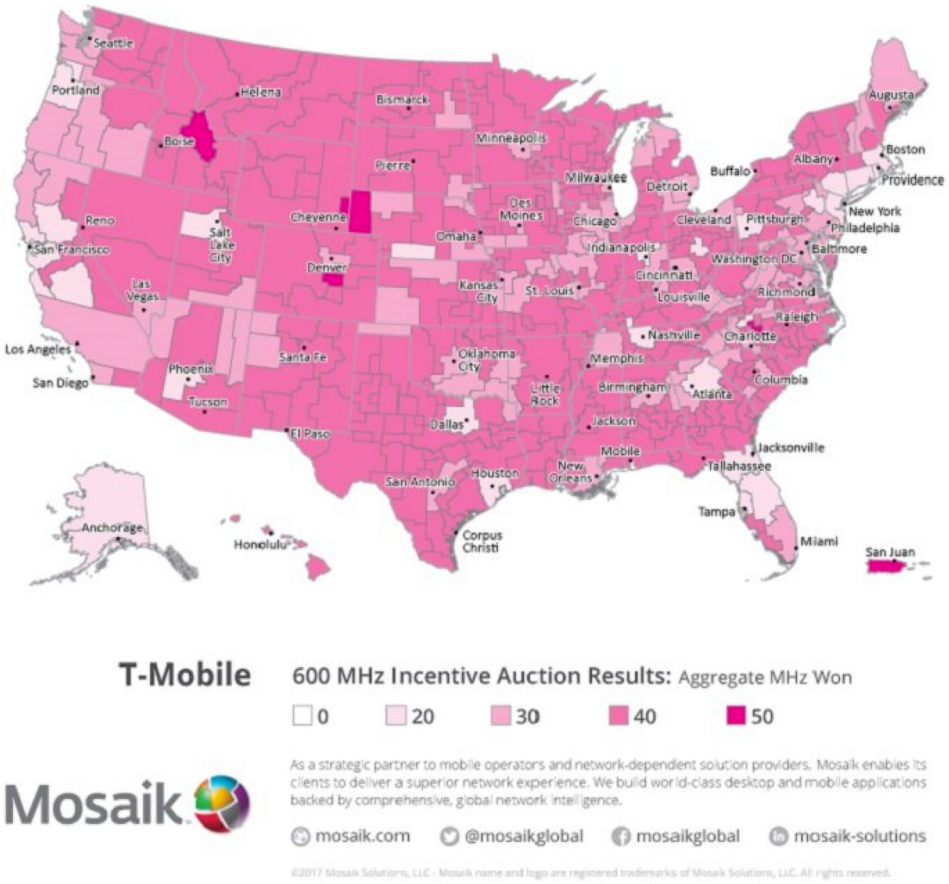
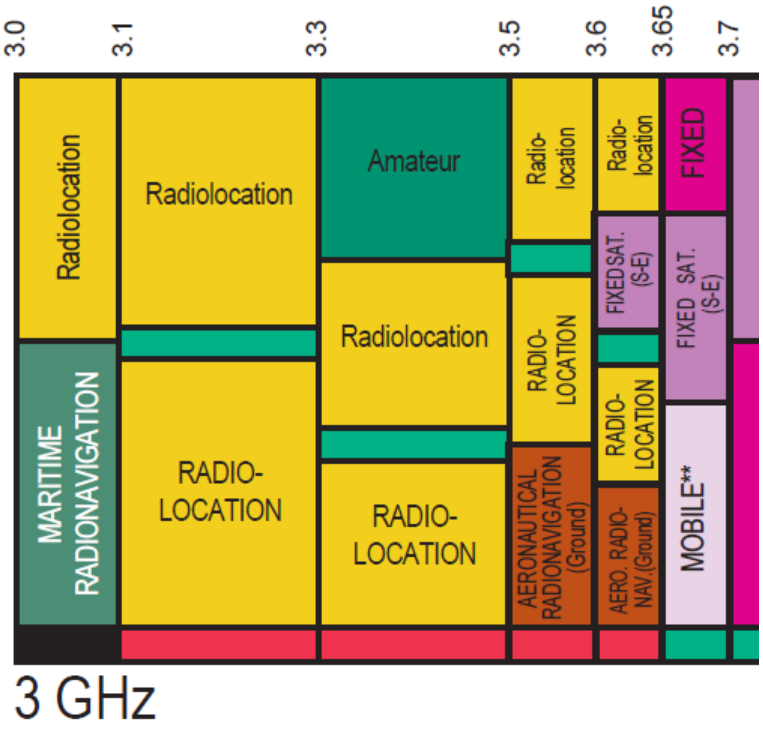
https://law.duke.edu/innovationpolicy/spectrum-incentive-auction/

Forward auction: T-Mobile



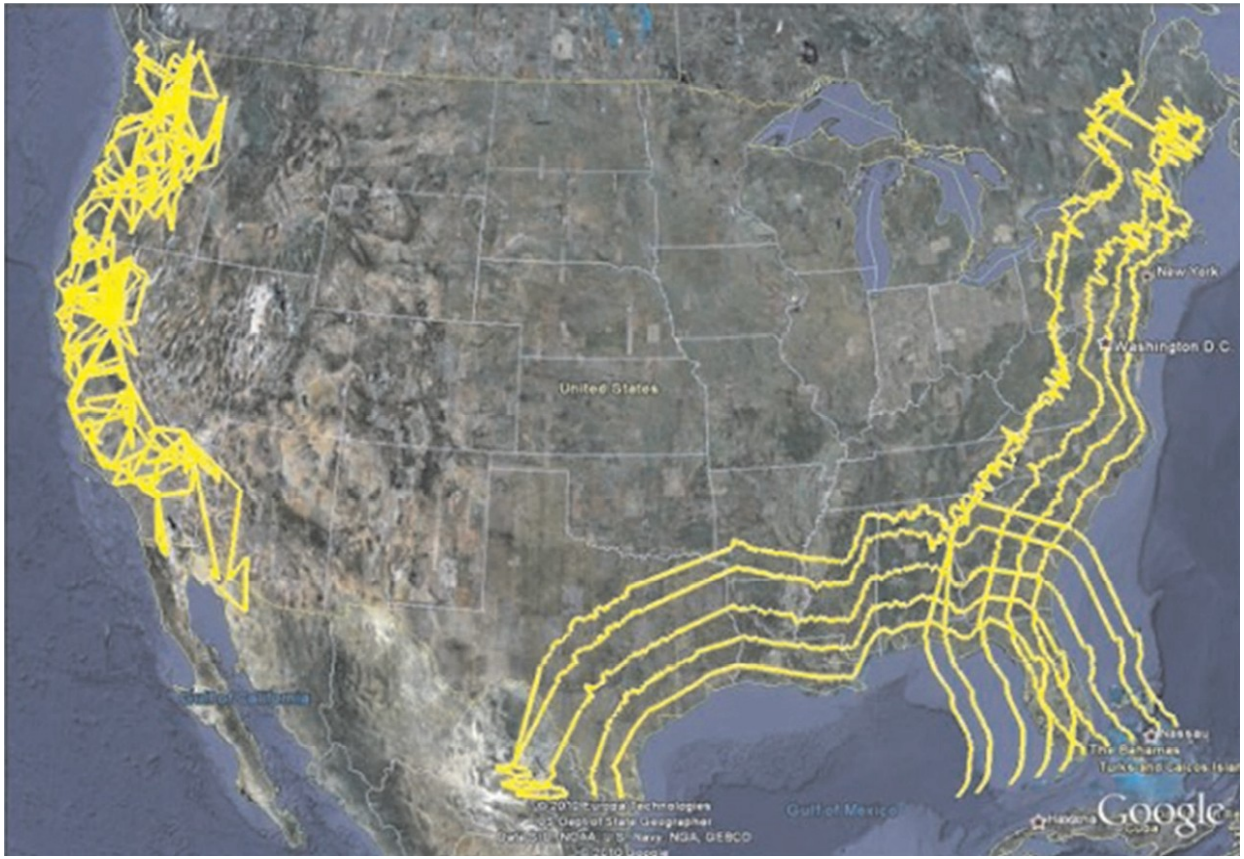
$8B

3.5 GHz band

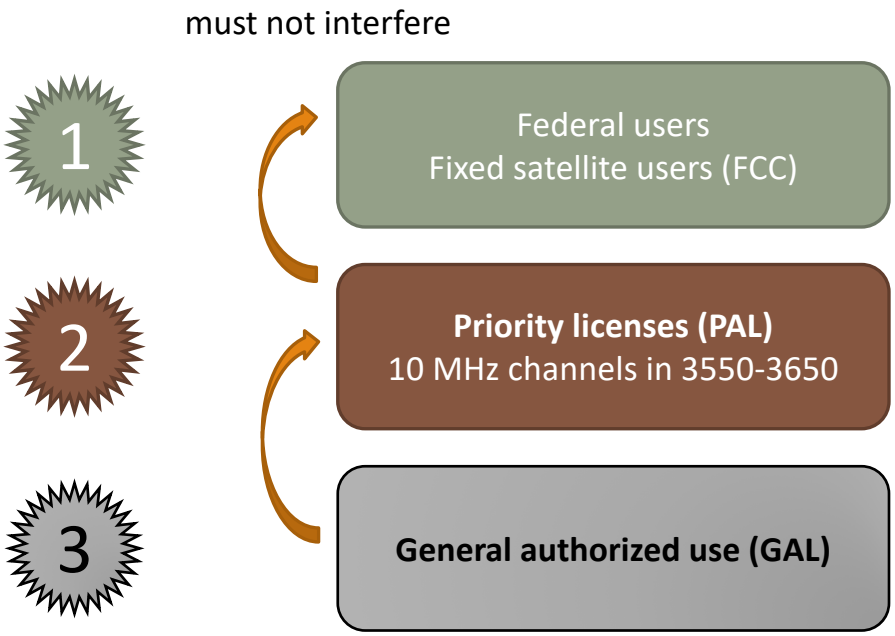


FSS: C Band (3.625–4.200)

Federal Exclusion Zones



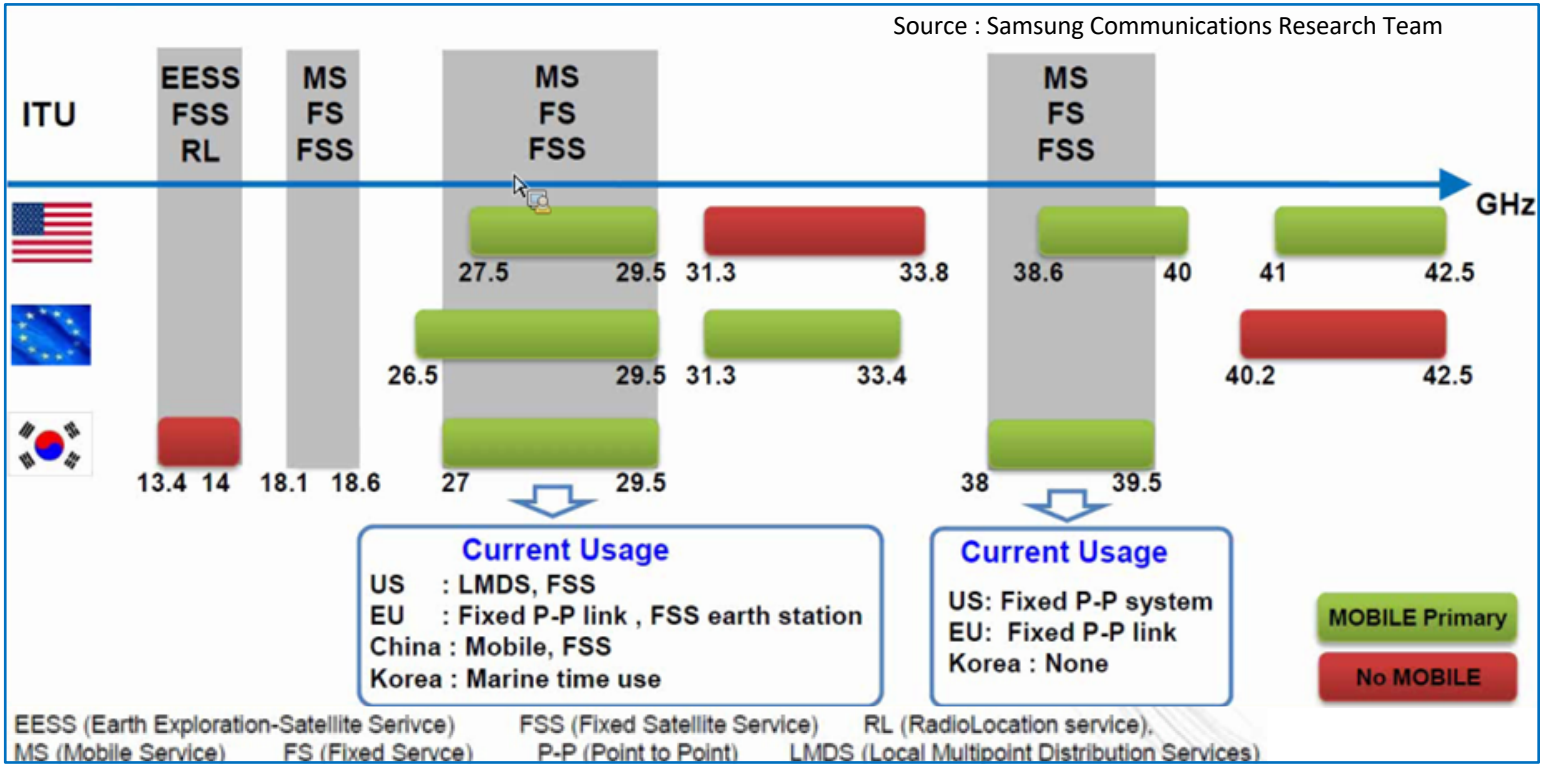
3.5 GHz user classes



census tract
≤ 70 MHz
3-year licenses
assigned via SAS

ESC (environmental sensing capability) allows commercial use in coastal and Great Lakes region

30-40 GHz mmW overview



- Note: The Commission's Fixed Microwave (Part 101) and Satellite Communications (Part 25) service rules govern most of US mobile allocations shown above

MMW: Spectrum Frontiers R&O

Core Principles

- Identify substantial spectrum in MMW bands for new services
- Protect incumbent services against interference
- Flexible use: enable market to determine highest valued use
- Overlay auctions where no existing assignments
- Provide spectrum for both licensed and unlicensed use

R&O – 10.85 GHz added for mobile service (July 2016)

- Licensed bands (3.85 GHz): 27.5-28.35 GHz; 37-38.6 GHz; 38.6-40 GHz
- Unlicensed bands (7 GHz): 64-71 GHz

FNPRM – seeks comment on another 18 GHz & above 95 GHz

- 24.25-24.45 GHz; 24.75-25.25 GHz; 31.8-33.4 GHz; 42-42.5 GHz; 47.2-50.2 GHz; 50.4-52.6 GHz; 71-76 GHz; 81-86 GHz; bands above 95 GHz

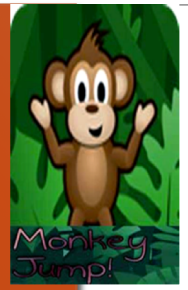
Licensing, operating and regulatory rules

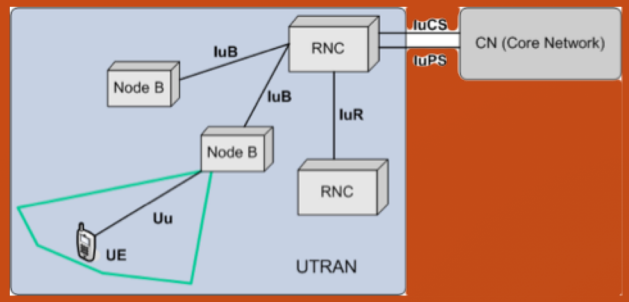
- Part 30: Upper Microwave Flexible Use Service (UMFUS)
- Geographic area licensing, area size, band plan, license term

Network architecture

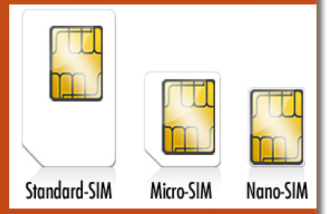
Networks 1G through 4Gish

national carrier

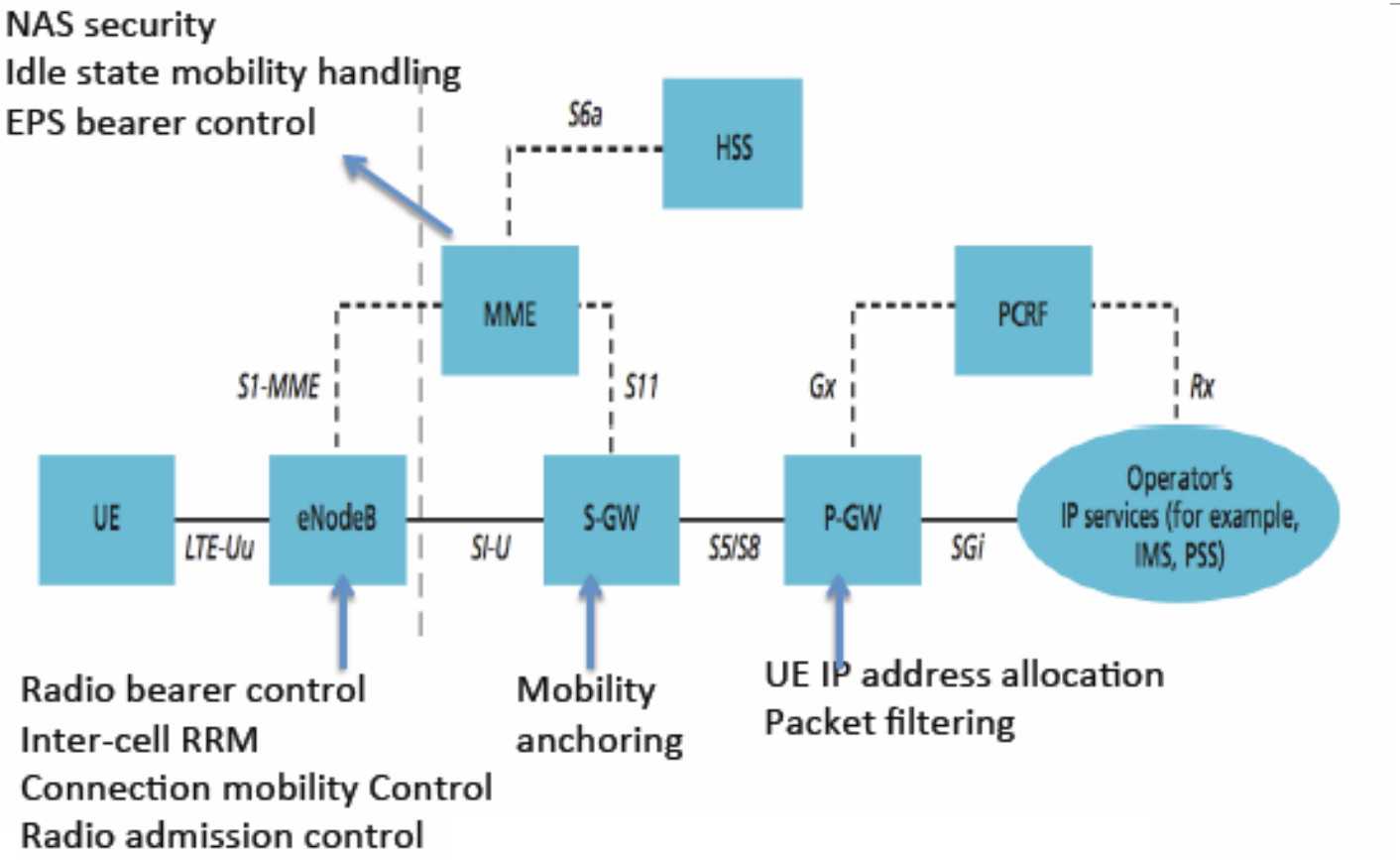




one subscriber,
one phone,
one provider



LTE – one carrier, plus roaming



5G – what exactly is a carrier?

AMERICAN TOWER®
40k towers each (US)

CROWN CASTLE

Spectrum DB

Google play

Level3
Cogent

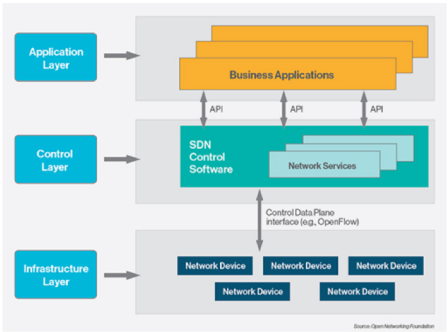
comcast

LTE-U
802.11n
LTE

FiberLight

lightower

zayo

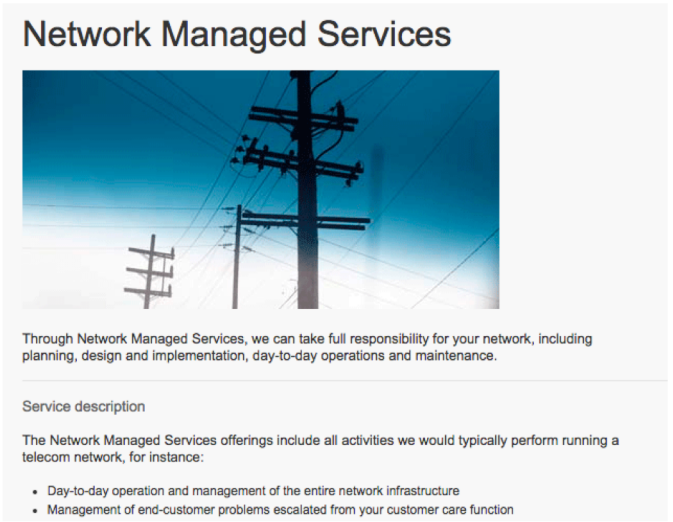


ERICSSON

5G: Carriers as consumer brand

Outside

Inside



What are carriers good at?

Research?

Software development?

- Who is going to develop those 5G SDN applications?

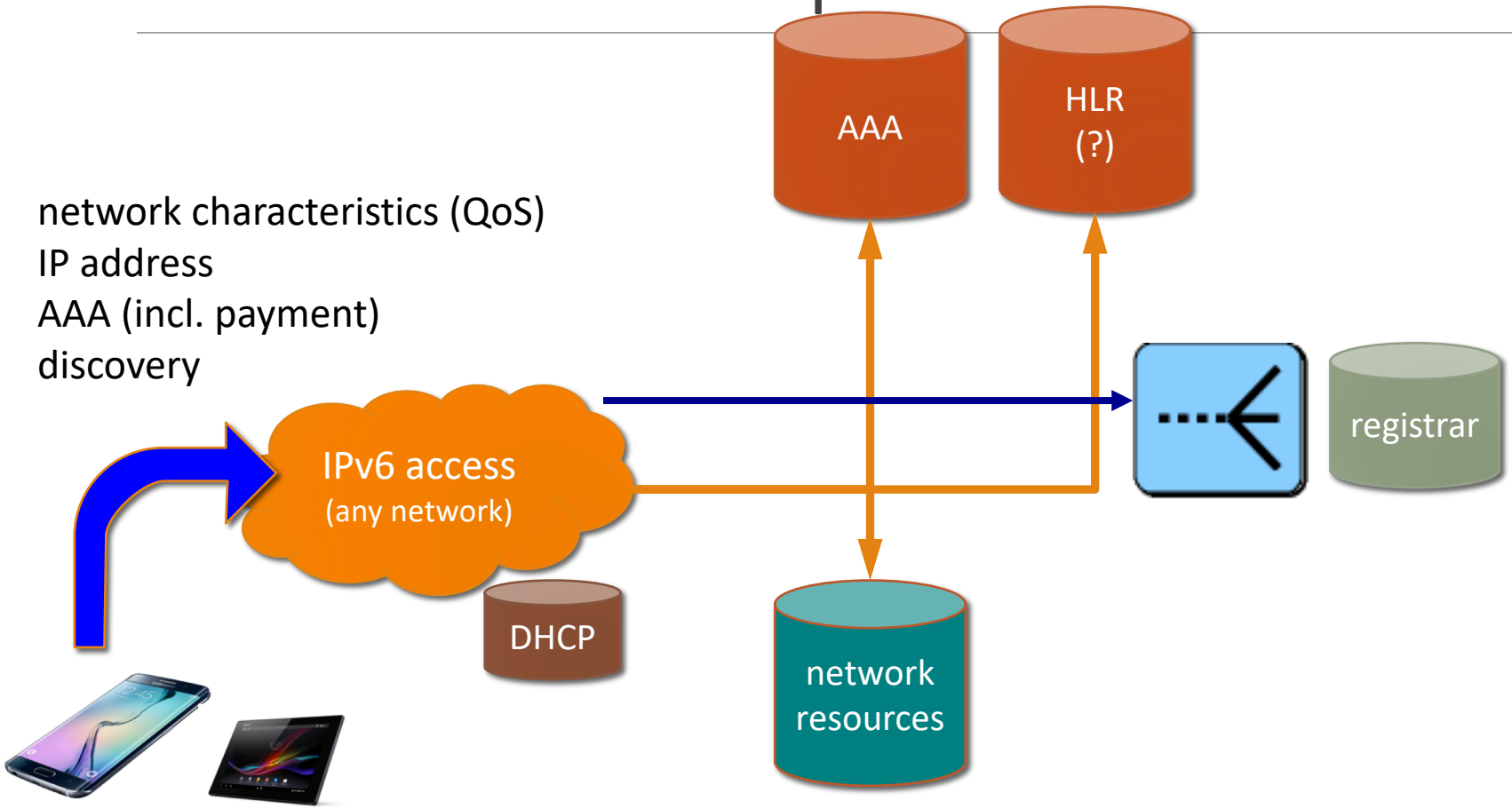
OTT applications?

API-based services?

- Why did Twilio and Tropo offer voice service APIs and not the ILECs?

What's the simplest network?

network characteristics (QoS)
IP address
AAA (incl. payment)
discovery



one subscriber, multiple devices, multiple providers

Where do we need mobility?

likely to have access provider diversity
- what is expected lifetime of IP address?

PMIP and MIP complex
- need to re-create application-layer security at L3

not really needed for HTTP video
- use mTCP?
- or HTTP restart?

maybe not even for real-time media
- registrar for new-call reachability
- application layer (SIP) mobility for mid-call hand-off?

or tunnels, tunnels everywhere?

The law of new networks

"Any new network technology will be justified on (finally) providing QoS"

To succeed, they have to provide good-enough QoS for best effort

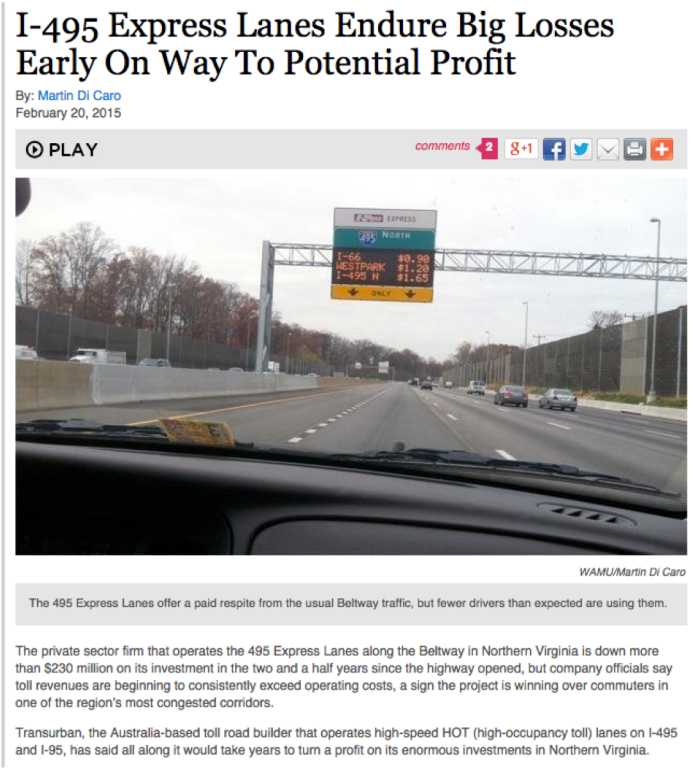
- at least with competition

The business model for QoS is difficult

- see bypass toll roads

QoS is usually not accessible to applications

- or not end-to-end



I-495 Express Lanes Endure Big Losses Early On Way To Potential Profit

By: Martin Di Caro
February 20, 2015

PLAY

comments 2

WAMU/Martin Di Caro

The 495 Express Lanes offer a paid respite from the usual Beltway traffic, but fewer drivers than expected are using them.

The private sector firm that operates the 495 Express Lanes along the Beltway in Northern Virginia is down more than $230 million on its investment in the two and a half years since the highway opened, but company officials say toll revenues are beginning to consistently exceed operating costs, a sign the project is winning over commuters in one of the region's most congested corridors.

Transurban, the Australia-based toll road builder that operates high-speed HOT (high-occupancy toll) lanes on I-495 and I-95, has said all along it would take years to turn a profit on its enormous investments in Northern Virginia.

Providing a network API

Currently, applications can detect Wi-Fi vs. cellular

What is the correct API for discovering network properties?

- available options (“BE”, “LBE”, “low latency”)

public int getType () Added in API level 1

Reports the type of network to which the info in this `NetworkInfo` pertains.

Returns

one of `TYPE_MOBILE`, `TYPE_WIFI`, `TYPE_WIMAX`, `TYPE_ETHERNET`, `TYPE_BLUETOOTH`, or other types defined by `ConnectivityManager`

NetworkInfo.DetailedState	AUTHENTICATING	Network link established, performing authentication.
NetworkInfo.DetailedState	BLOCKED	Access to this network is blocked.
NetworkInfo.DetailedState	CAPTIVE_PORTAL_CHECK	Checking if network is a captive portal
NetworkInfo.DetailedState	CONNECTED	IP traffic should be available.
NetworkInfo.DetailedState	CONNECTING	Currently setting up data connection.
NetworkInfo.DetailedState	DISCONNECTED	IP traffic not available.
NetworkInfo.DetailedState	DISCONNECTING	Currently tearing down data connection.
NetworkInfo.DetailedState	FAILED	Attempt to connect failed.
NetworkInfo.DetailedState	IDLE	Ready to start data connection setup.
NetworkInfo.DetailedState	OBTAINING_IPADDR	Awaiting response from DHCP server in order to assign IP address information.
NetworkInfo.DetailedState	SCANNING	Searching for an available access point.
NetworkInfo.DetailedState	SUSPENDED	IP traffic is suspended
NetworkInfo.DetailedState	VERIFYING_POOR_LINK	Link has poor connectivity.

cost?
($ or count for bucket?)

predicted performance?

IMS /VoLTE

IMS = It Mostly Speaks
VoLTE = Voice-Only Later than Expected

VoLTE: Taking Carriers Beyond Voice

Mon, 06/06/2011 - 12:43pm

by Maisie Ramsay

Get today's wireless headlines and news - Sign up now!

Project yourself into the future – let's say mid-2012. It's been about a year and a half since Verizon Wireless first launched its LTE network in December 2010, and after a long wait, the company has finally come out with the first smartphone running voice over LTE (VoLTE) technology.

You go out and buy the device, turning it on the second you have it out of the box. One of the first things you notice: The phone's native voice application isn't limited to just voice. It has an option for video calls, and there's also an option to send multimedia messages, along with presence indicators that show when people on your contact list can participate in a video call.

AT&T, Verizon Target VoLTE Interop in 2015, RCS Later

By Doug Mohney / November 04, 2014

AT&T and Verizon have officially declared they are working on Voice over LTE (VoLTE) connections between their respective networks and customers. VoLTE calls between Verizon and AT&T customers "is expected" in 2015, according to a statement from the companies. And, there's also some Rich Communications Services (RCS) news buried in the text.

The announcement comes as three out of four major U.S. carriers promote LTE networks and a number of countries plan to turn up LTE and VoLTE in the next 15 months. "Interoperability among VoLTE service providers in the United States and around the world will create a better and richer mobile experience for customers," declares Verizon's press release.

Vodafone Germany announces VoLTE rollout

17 Mar 2015

Germany

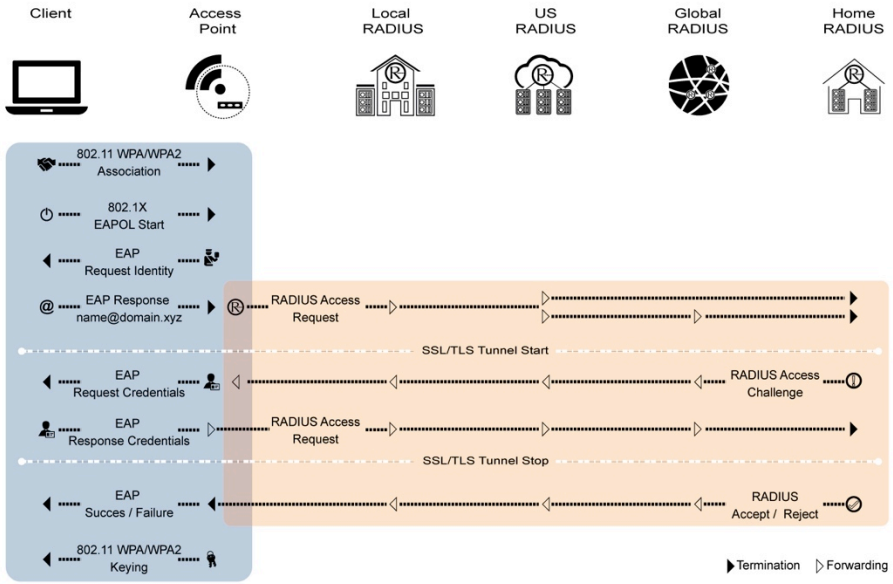
Vodafone Germany claims it has become the first German operator to initiate the rollout of voice-over-LTE (VoLTE), having demonstrated the first live VoLTE call on its network at the CeBIT 2015 technology fair in Hanover. The UK-owned operator says that the technology offers customers an 'unprecedented voice service and telephony experience', ensuring 'crystal clear voice quality, super-fast call set-up and encrypted phone calls' across its LTE network, which currently covers 70% of Germany. Vodafone revealed that it will soon be launching new LTE smartphones for VoLTE, including handsets from manufacturers such as Samsung, Sony and HTC. The announcement follows reports last week that Vodafone plans to introduce both Wi-Fi calling and VoLTE in the UK this summer, following trials of the technologies in laboratory conditions.

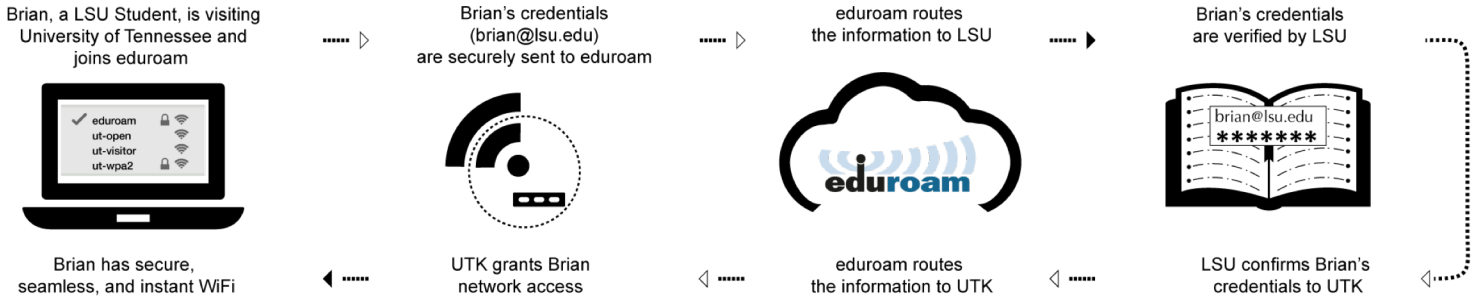
5G prototype: Eduroam

eduroam

Global WiFi Roaming For Academia

an Internet2 NET+ service





Growing-up lessons

Applications surprise

Low cost may beat QoS

Complexity kills

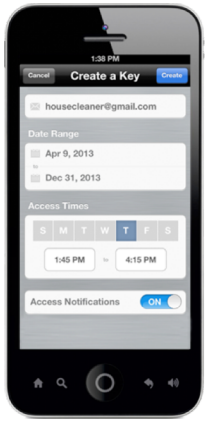
Spectrum is for sharing

5G: 4G++ or opportunity for re-thinking design assumptions

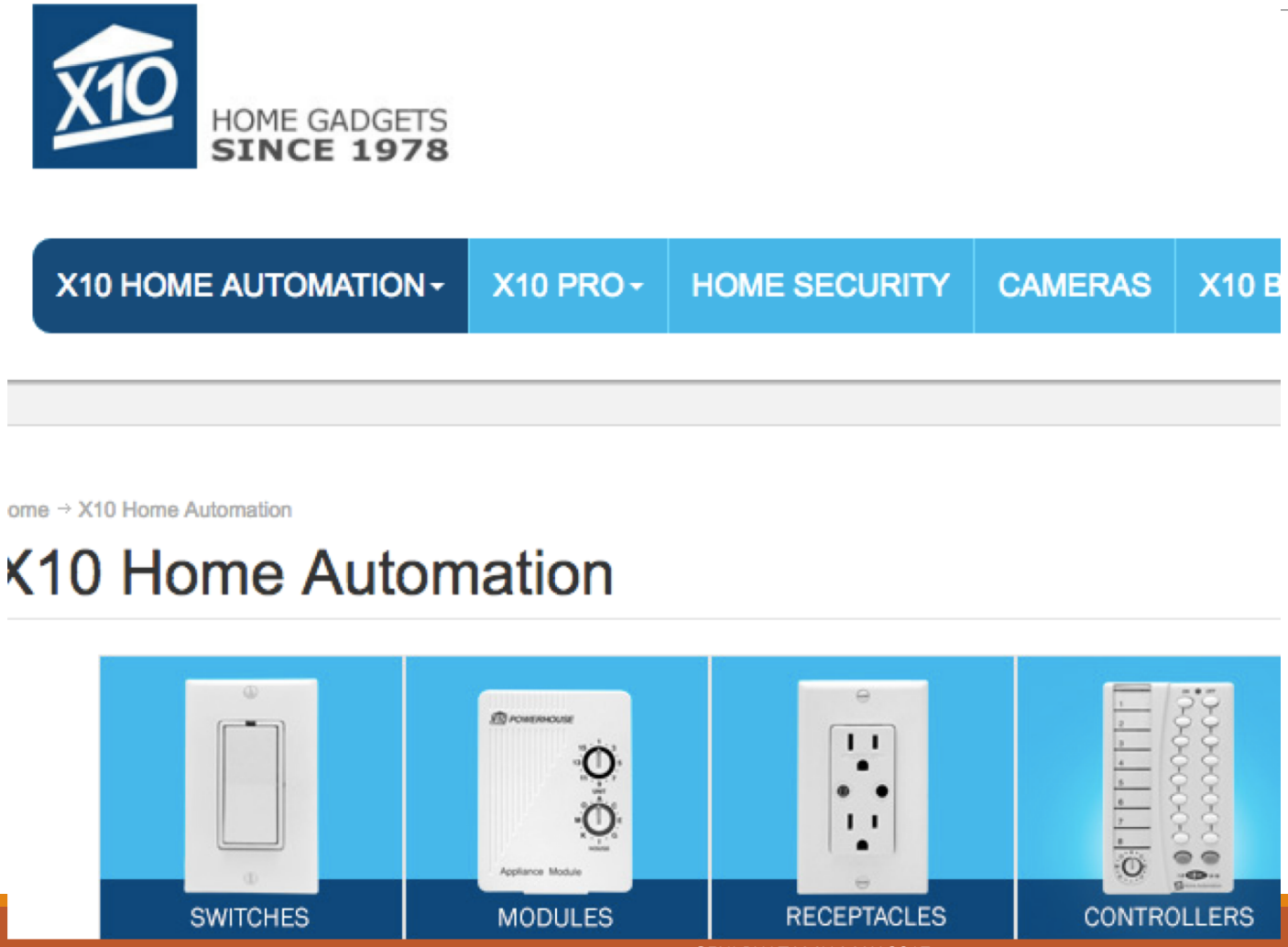
- complexity vs. modularity

IoT

Natural evolution



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


HUGGIES
Tweet Pee
The first diaper that tells mommy when it's time to change.
Solution
Idea
Design
Results

Towel dispensers

Power over ethernet powered paper towel dispensers

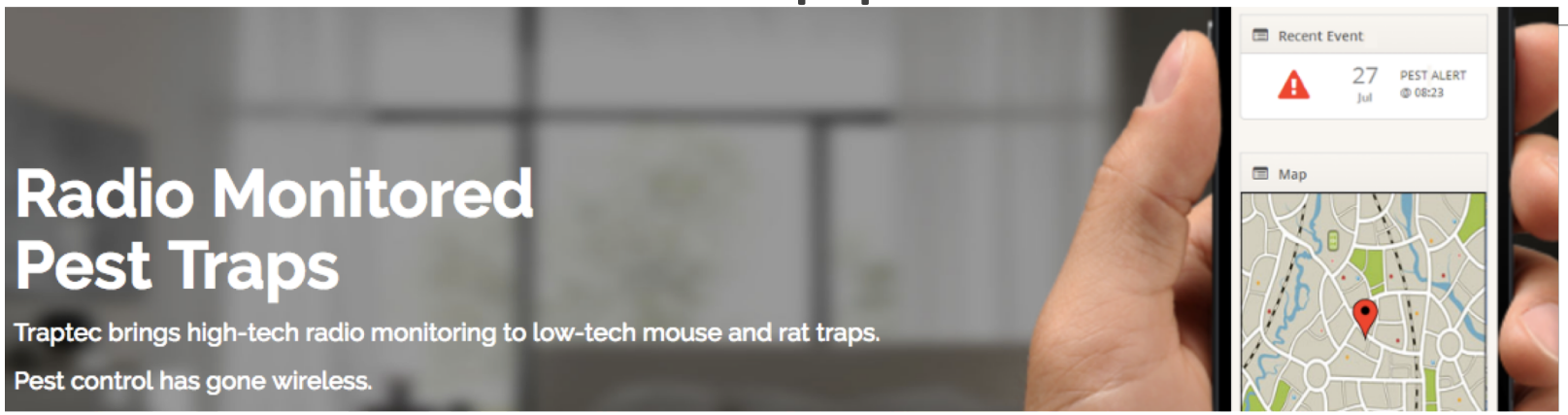
WO 2014028808 A1

ABSTRACT

A system for providing power to a plurality of paper towel dispensers (10) through a power over ethernet (PoE) network (14) and for sensing various operational parameters of the dispensers (10) and communicating those parameters through the network to a central computing device (16). The system includes a Data/Power controller (12) associated with each of the dispensers (10) for providing power (26) to the dispensers (10) and for sending and receiving data (24) between one or more sensors in the dispensers (10) and a central computer device (16).

The IoT has already been used for a range of use cases in facilities management. For example, Coor has worked with a paper towel manufacturer in Sweden to implement automated monitoring of dispensers. Sensors fitted to each dispenser monitor its fill level, and send an alert to the building manager, who can make sure it is refilled before it becomes empty.

The IoT killer app



http://www.traptec.eu/

link.nyc & smart trash cans

GPRS or CDMA
GPS location service

But controlling light switches is still not the best use

Want to turn on the bedroom light? Sure, just pick up your smartphone, enter the unlock code, hit your home screen, find the Hue app, and flick the virtual switch. Suddenly, the smart home has turned a one-push task into a five-click endeavor, leaving Philips in the amusing position of launching a new product, Tap, to effectively replicate the wall switches we always had.

https://techcrunch.com/2014/12/04/the-problem-with-the-internet-of-things/

Where does IoT make sense?

Probably

- home security
- residential & commercial locks
- home medical (recording)
- housekeeping (restroom supplies)
- outdoor lighting
- parking meters
- vending machines

Not so much

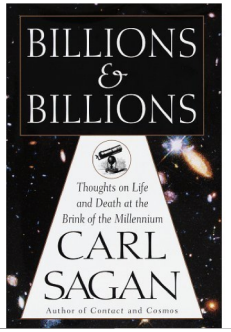
- light switches
- most household appliances
- clothing
- smoke detectors?

not cost-effective, not just useless

Two kinds of IoT devices

< $20	> $50
BlueTooth, ZigBee, proprietary L2	Wi-Fi, LTE-M, LoRa, SIGFOX
connected only via gateway	direct connection to Internet possible
fixed-function: sense or activate	SOC + network module
single chip transceiver + MPU	run (small) Linux stack
only use L2 security	programmable
similar to peripherals	TLS and kin easy

Billions & billions



Ericsson (2010): 50 billion connections in 2020

IBM (2012): 1 trillion by 2015

Gartner (2015): 6.4 billion (2016)

Stringify (2016): 30 billion (2020)

IHS Markit (2016): 30.7 billion (2020)

IDC (2016): 28.1 billion (2020)

3 billion Internet users

Uninteresting – most of these devices are just BlueTooth and Zigbee nodes talking to a gateway

About as useful as counting web pages

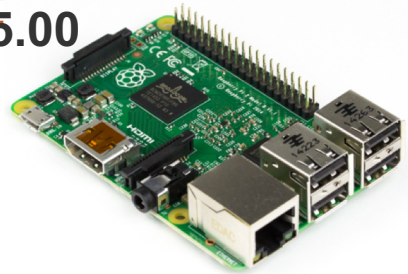
Sensor networks may be (tiny) niche

- Most IoT systems will be near power since they'll interact with energy-based systems (lights, motors, vehicles)
- Most IoT systems will **not** be running TinyOS (or similar)
- Protocol processing overhead is unlikely to matter
- Low message volume → cryptography overhead is unlikely to matter
  - exceptions: light switches & 1-function I/O devices → BT/Zigbee
  - Treat like USB devices

In particular, a Pi 2 is **sixteen**

bout **seven** times as fast as a baseline SPARCstation 20 model 61 — and has substantially more RAM and storage, too. And the Raspberry
l on tasks where all cores can be put to use it's **forty one times** faster.

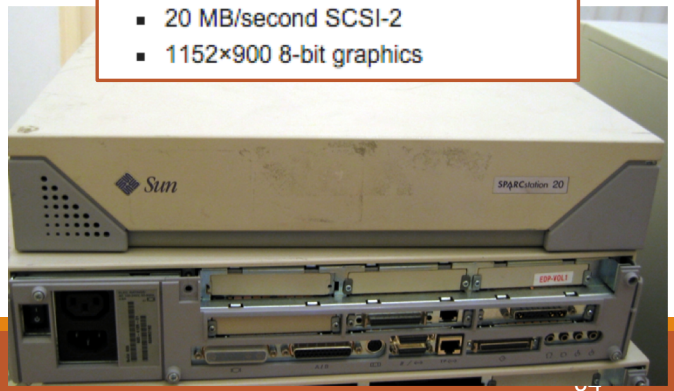
$35.00



- A 900MHz quad-core ARM Cortex-A7
- 1 GB RAM

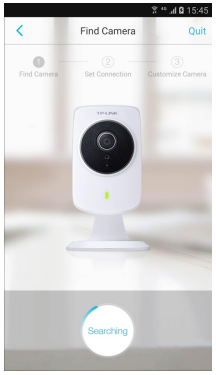
16-41x

- One 60 MHz SuperSPARC CPU
- 1 MB of cache
- 32MB RAM (expandable to 512MB)
- 20 MB/second SCSI-2
- 1152×900 8-bit graphics



http://eschatologist.net/blog/?p=266

Scaling IoT up



one device

apartment building

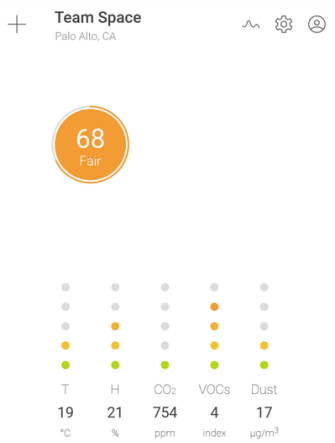
$(10^2 – 10^4)$

city+

$(10^6 – 10^8)$

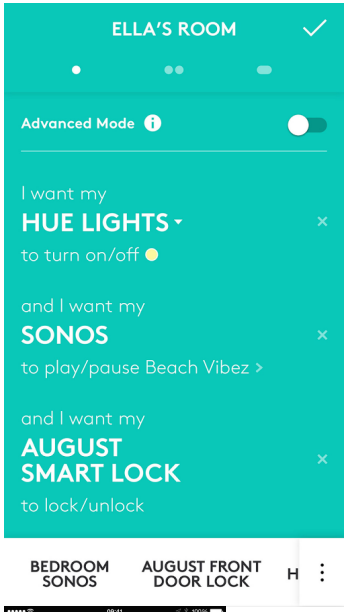
One Thing, one app

Awair



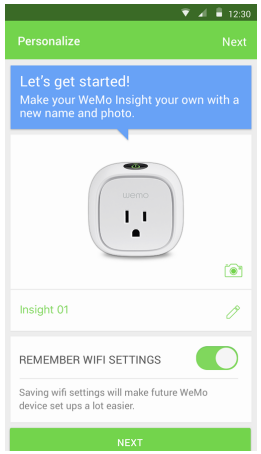
Honeywell

Logitech

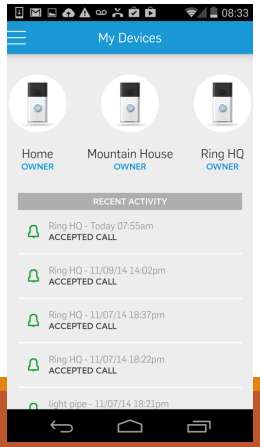


SATIS

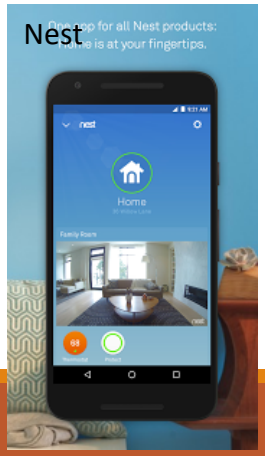
WeMo



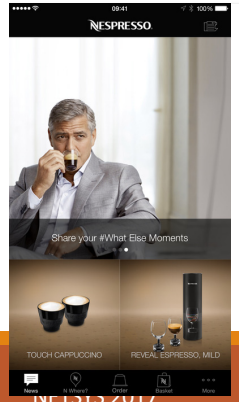
Ring



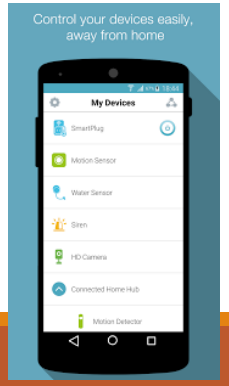
Nest



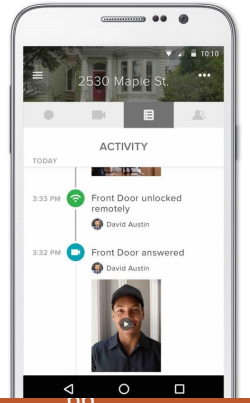
Nespresso



D-link



August



IoT = Internet at scale

Security at scale
- still largely “add password to configuration file”
- identify by IP address

Management at scale
- device-focused
- SNMP, at best
- CLI, at worst
- no performance diagnostics capabilities (“why is this so slow?”

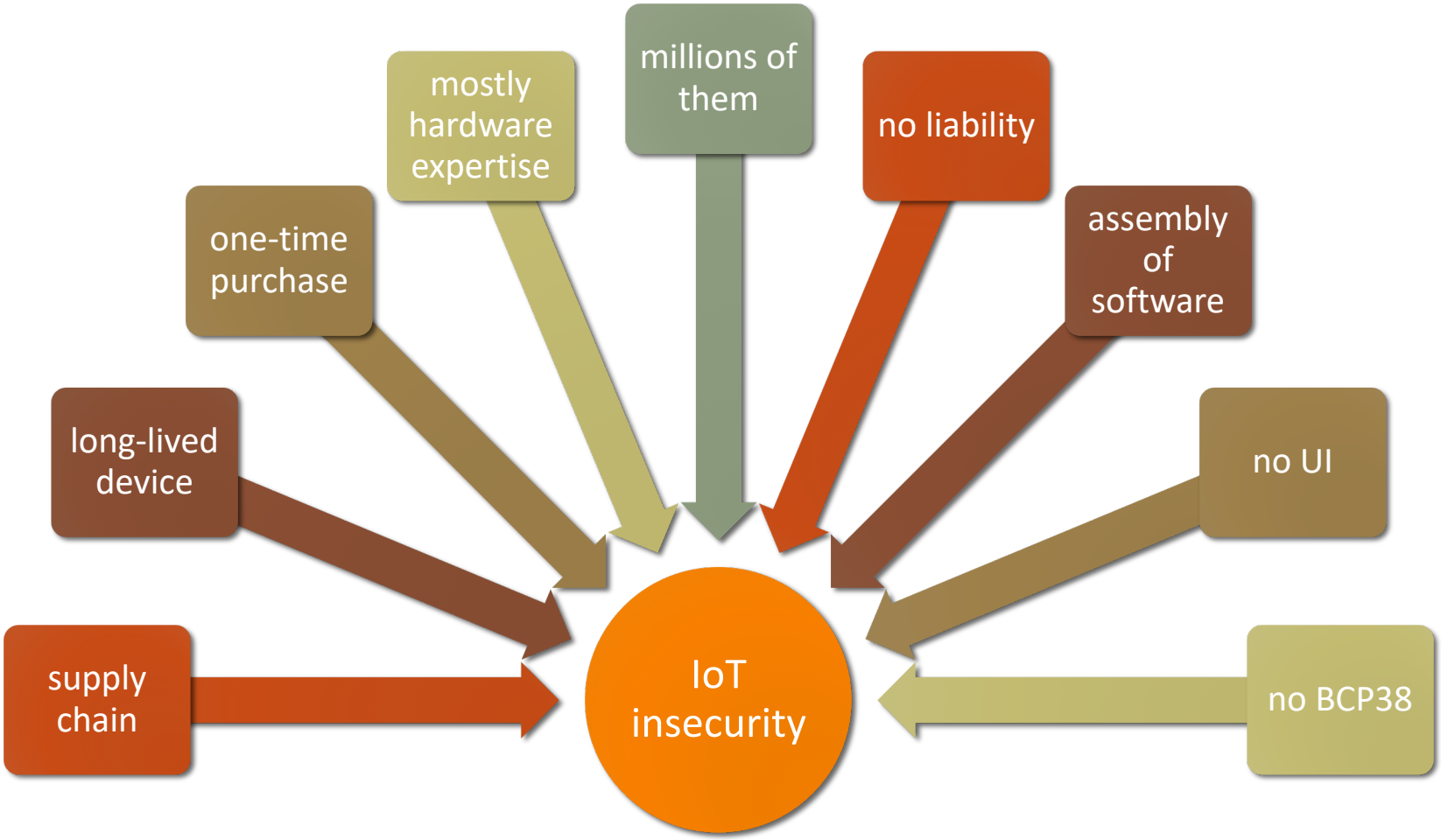
Naming at scale
- identify by node name

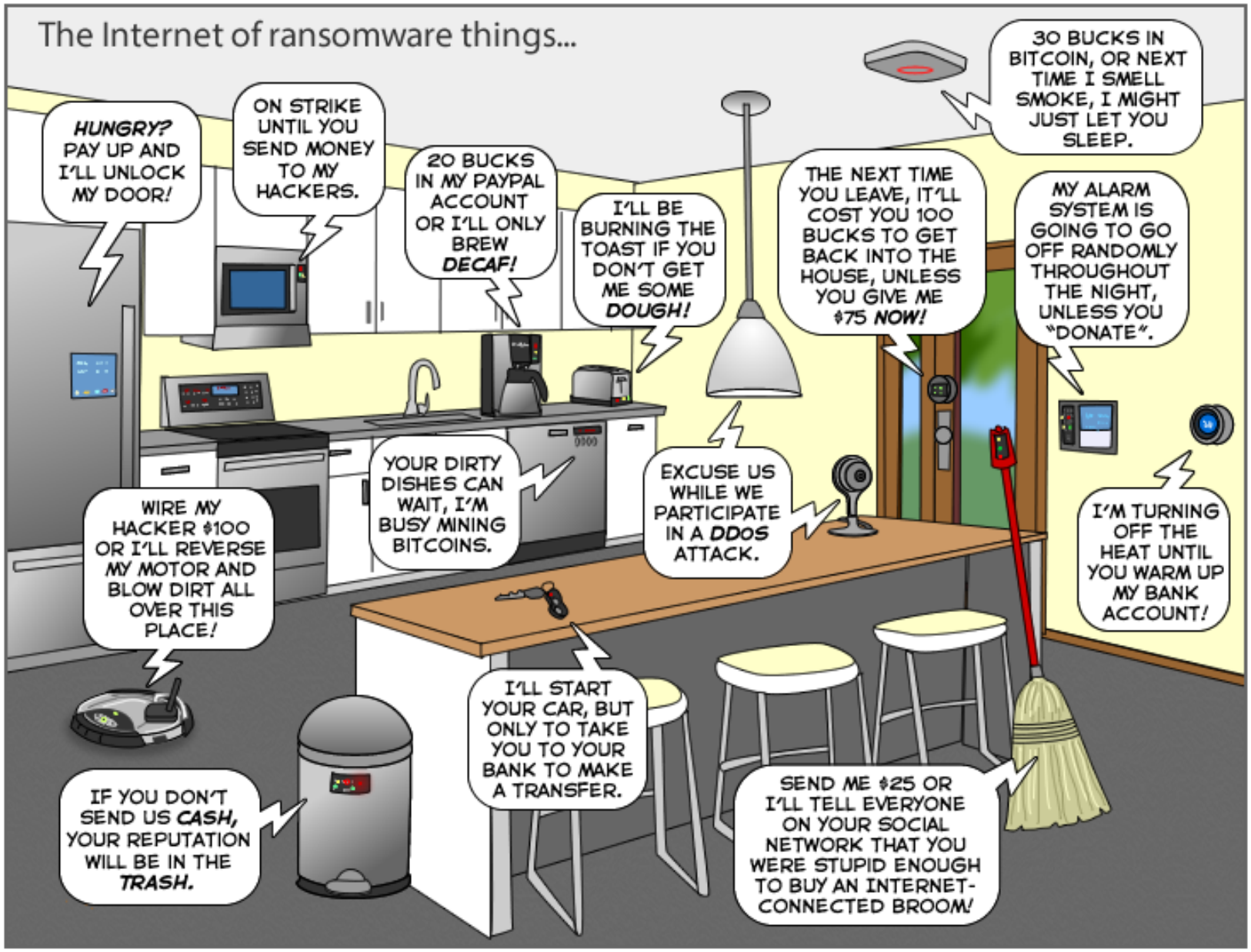
Programming at scale

system & rack

data center

IoT security confluence





Summary

Unlike 3G → 4G, 5G is mostly about capacity, not features or per-user speed

Boring is better → reduce network OpEx (and CapEx)

IoT security is exposing almost all the security deficiencies of the Internet eco system

- “thoughts and prayers” approach
- continuing to do the same thing for the next 5 years and hoping for better results is not a strategy

Start thinking beyond stove pipes of applications and home automation

→ engineering large scale systems x 10