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Old ideas needed for 6G: Layering, controllability, and modularity

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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)	FWA	\$1?

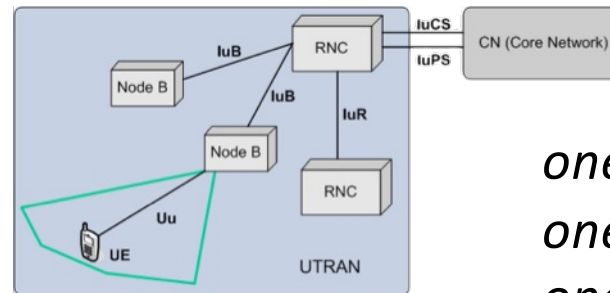
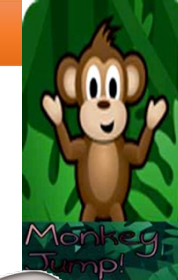
- underestimated cost and fixed-equivalence as drivers
- are the even generations the successful ones?

What has changed in network technology since 3G?

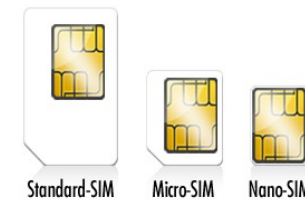
- Cheap & universal GNS (GPS, Beidou, Galileo, ...)
 - → accurate time and position for every device → mobility and discovery
- Multiple simultaneous connections
 - → simplify hand-off and spectrum discovery
- Voice matters less
 - → most applications are nomadic and can tolerate (short) disruptions
- Low-cost Certificate Authorities (e.g., letsencrypt.org)
 - → simplify authentication
- Trusted execution environments on all but lowest-end devices
 - → simplify authentication and device integrity
- FTTH
 - → easy fiber to base stations → distributed ownership of network infrastructure

Networks 1G through 4Gish

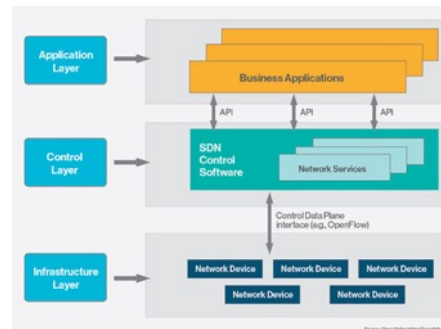
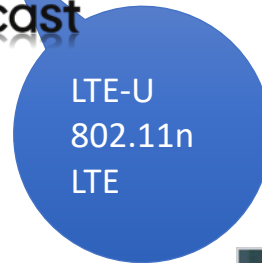
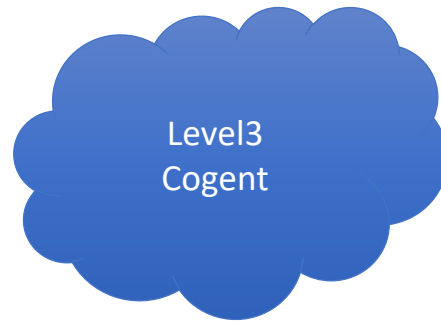
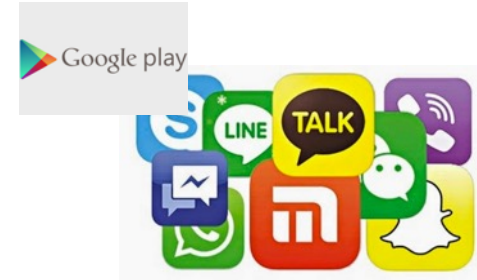
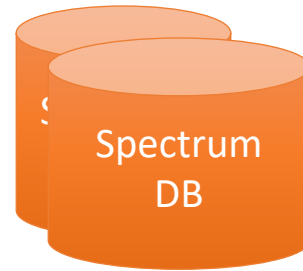
national carrier



*one subscriber,
one phone,
one provider*



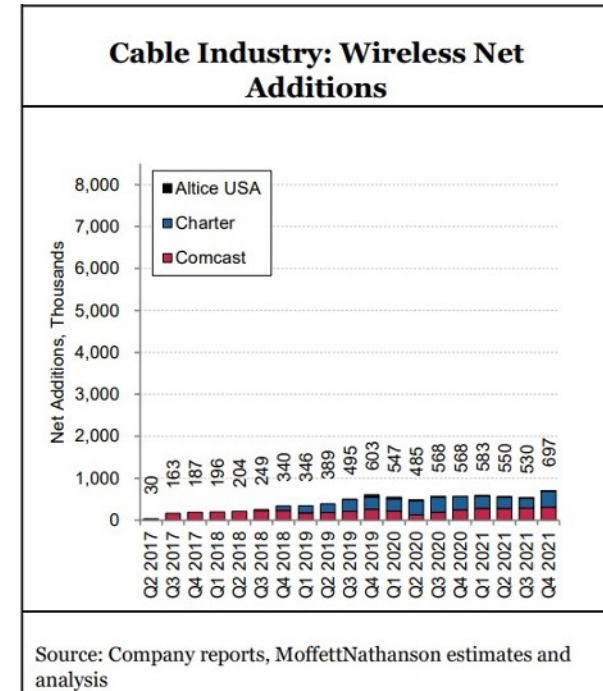
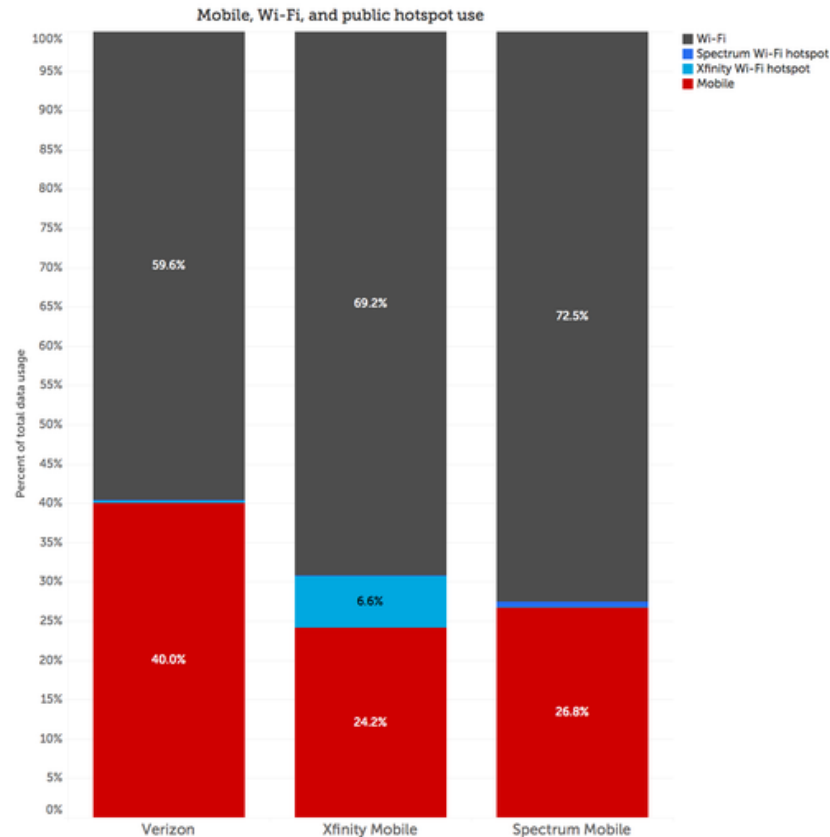
What exactly is a carrier?



New operator models – cable (HFC) industry

All major US cable operators are offering cellular service

hybrid model:
MVNO + Wi-Fi + CBRS



Comcast	4M
Charter	3.56 M
Altice	186k

LightReading, 3/22

The Things Network

We are a global collaborative Internet of Things ecosystem that creates networks, devices and solutions using LoRaWAN®.

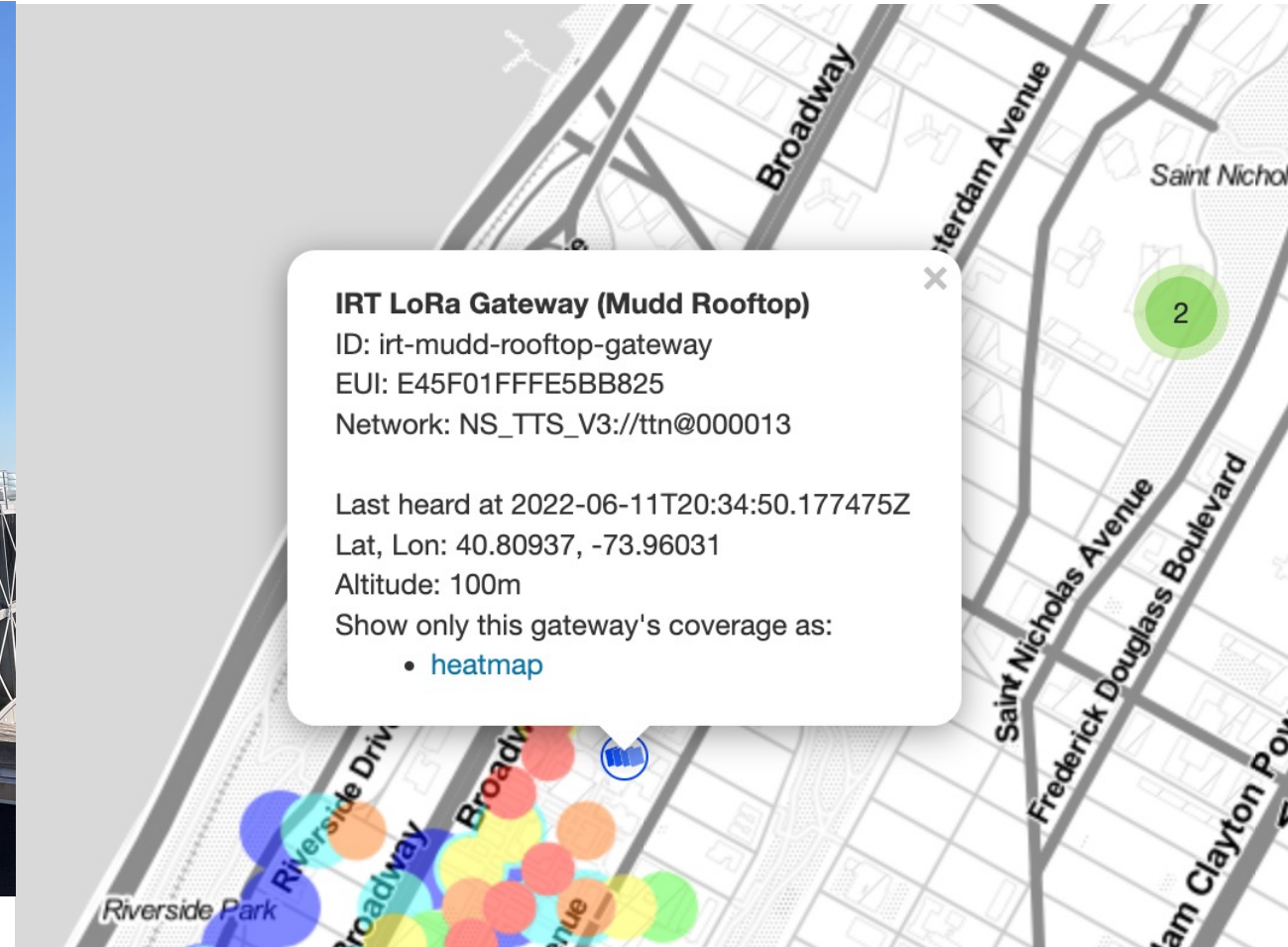
[Start building](#) [Learn more](#)

A globe showing the global reach of The Things Network. The globe is centered on Europe and Africa, with a dense cluster of black dots representing network nodes in Europe and Africa. The globe is set against a light blue background.

The Things Network

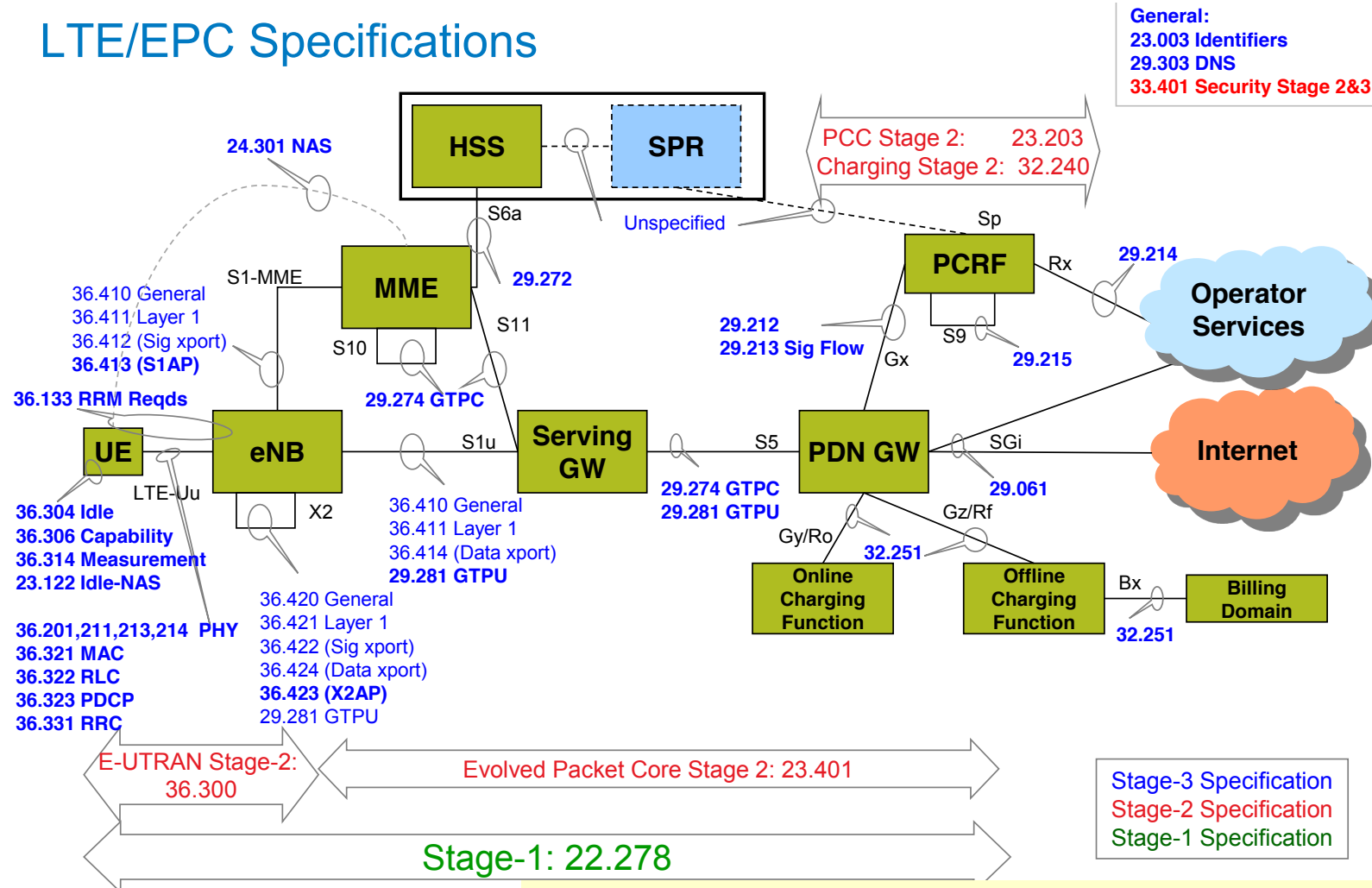


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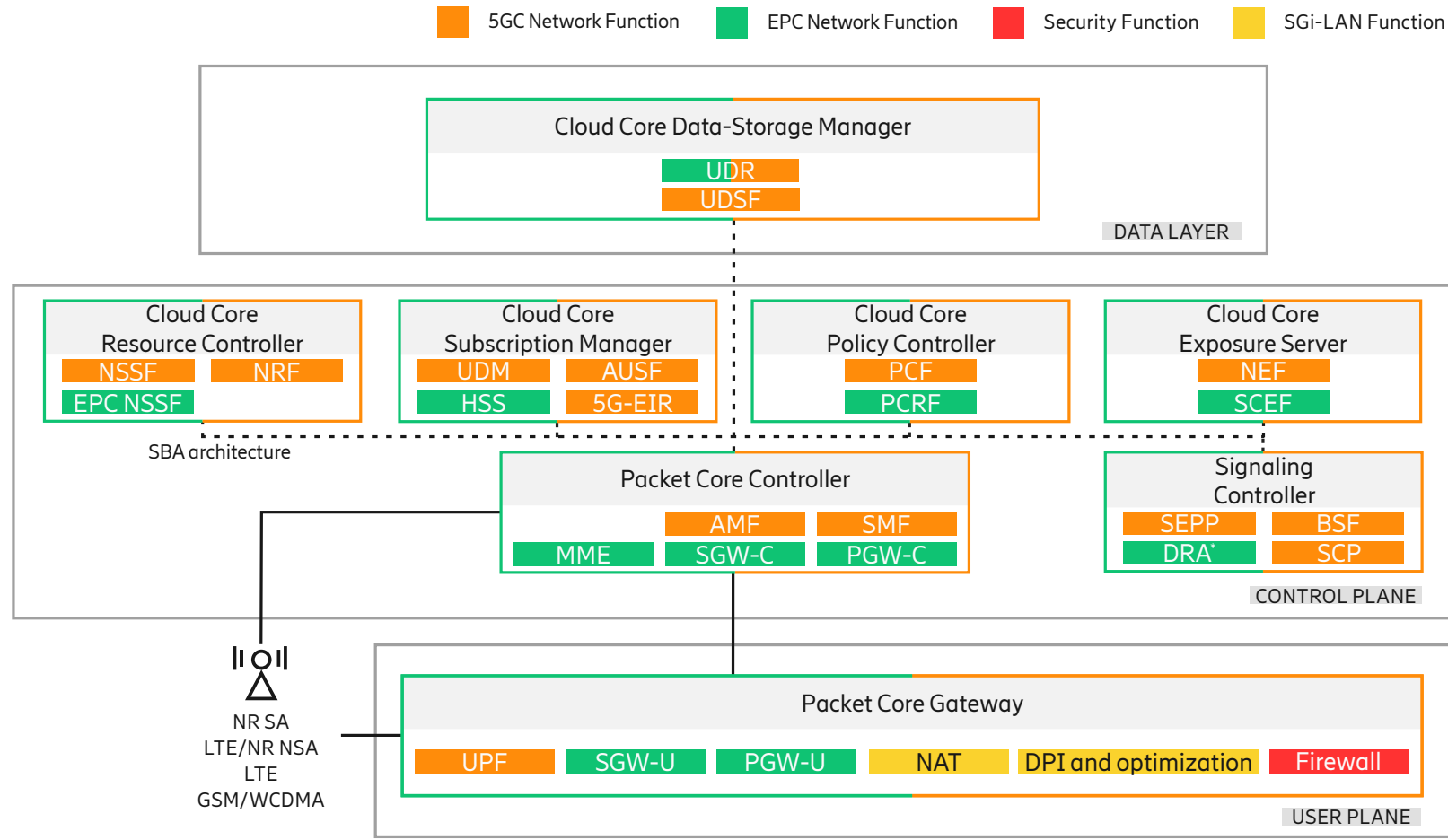
LTE EPC

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



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

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

Layering and modularity

- Single 6G “AP” that can work stand-alone
 - L2 (“Ethernet”) only
 - no mobility, no “gateway”
 - no NFV, no need for cloud services
 - no eSIM needed (see later)
 - no tunneling
- Layering
 - No cross-layer dependencies *except* control and reporting functionality (“API”)
 - assume availability of IPv6

Controllability and automation

- Every function should be settable individually
 - not obvious that NETCONF/YANG are the right approach
 - see cloud management APIs
- Self-placement: Any device should be able to discover its role and parameters by attachment
 - generic, out-of-the-box device
 - with a device-specific PKI certificate to govern admission
 - “Did I purchase this RAN device?”
 - “stem cell” model for controllers, too
 - allow networks to recreate themselves locally if partitioned

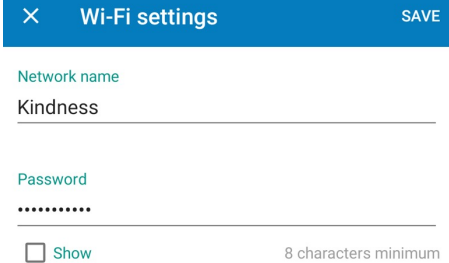
What made Wi-Fi successful?

- 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

Current authentication models

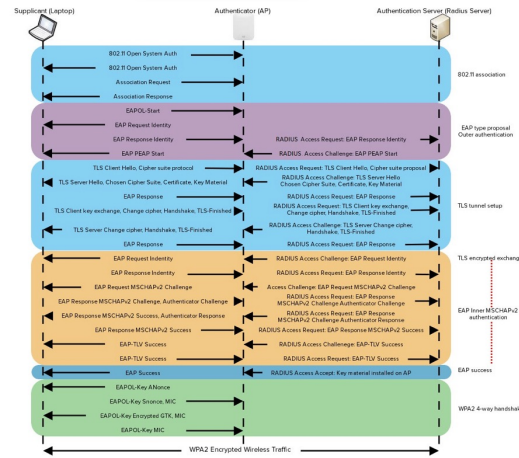
picket fence security

hard to scale to IoT

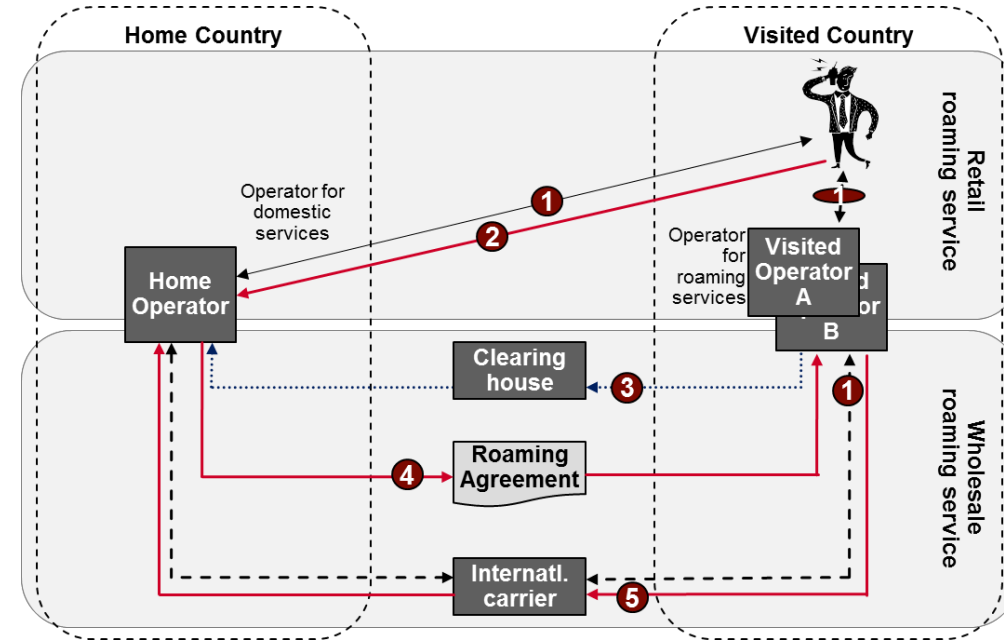


WPA2-Personal

802.1x



international roaming



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

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

federated (RADIUS, DIAMETER)



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

Conclusion

- The key performance metric is \$/GB (and maybe \$/km² coverage)
- The key challenge is incentivizing investment
- 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
- Learn from Wi-Fi & LoRa