Scaling networks up and down: new network architectures for 6G

Henning Schulzrinne
Columbia University
Classical requirements pyramid

>10Gbps

Extreme Mobile Broadband

Massive machine communication

Critical machine communication

1M devices per km²

Radio latency < 1ms

mostly PHY requirements!
The most important metric is missing!

Comcast Median Household Usage in GB/month

- Average: 500 GB/month
- Roughly 35% AAGR since 2017

BLS data (Internet services and electronic information providers)

Average: $0.12/GB
Without cost (and price) decrease, no advanced applications

➔ The key performance metric is $/GB (and maybe $/km$ coverage)
Network cost and price are highly variable

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

March 2020
Mobile data usage

Ericsson Mobility Report Nov. 2021

US ARPU (2022) = $35 ➔ $2.40/GB

~20 times more expensive per GB than home (“Wi-Fi”)
Networks 1G through 4Gish

national carrier

one subscriber, one phone, one provider
What exactly is a carrier?
Investment incentives for 5G are modest – are they going to be better for 6G?

Some of the world’s first real 5G networks are coming online this year, sparking plenty of buzz and noise. However, a wide range of industry experts are cautioning that North American wireless network operators don’t appear poised to invest in 5G networks like they did with 3G and 4G.

“We’re negative on the prospects for a 5G investment ‘cycle’ from wireless operators -- at least over the near- and intermediate-term,” wrote the Wall Street analysts at Jefferies Research. “Based on our analysis, we believe that the conditions for an acceptable return on investment (ROI) on 5G infrastructure are poor. Moreover, the 5G investment ROI looks drastically lower than the ROI associated with prior wireless investment cycles -- specifically 3G and 4G.”

Why? It all comes down to flagging revenues in a saturated market. "The wireless service market is now a mature business," the analysts continued. "As such, operators’ motivations for major capital investments will be reduced. To be clear, we still believe that 5G infrastructure deployment will happen. We expect that it will simply be a cutover of existing 4G investments to 5G technology. Most
Cell towers as cost driver (or revenue source)

What are cell tower leases worth in 2022?

On average, wireless carriers entered into new lease with landowners at an average of $1,050/mo. on a nationwide basis. There is a wide variation though in what landowners are offered. Generally, most offers are between $500/mo. and $1,500/mo. for new ground leases for telecommunication towers. The average lease rate for all ground leases in our database in 2022 is just under $1,300/mo. It hasn’t changed from 2021 but is up from 2018 when it was $1,220/mo. These averages include rural, suburban, and urban towers including newly-built 5G towers.


* Cost does not include radio equipment and backhaul!
New operator models – cable (HFC) industry

All major US cable operators are offering cellular service

hybrid model: MVNO + Wi-Fi + CBRS

<table>
<thead>
<tr>
<th>Cable Industry: Wireless Net Additions</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Q1 2018</td>
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<td>Q2 2018</td>
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<td>Q3 2018</td>
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<td>Q4 2018</td>
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<td>Q1 2019</td>
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<td>Q4 2021</td>
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<td>Q1 2022</td>
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<td>Q2 2022</td>
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<tr>
<td>Q3 2022</td>
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<tr>
<td>Q4 2022</td>
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</tbody>
</table>

Source: Company reports, MoffettNathanson estimates and analysis

<table>
<thead>
<tr>
<th>Operator</th>
<th>Subscribers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comcast</td>
<td>4M</td>
</tr>
<tr>
<td>Charter</td>
<td>3.56 M</td>
</tr>
<tr>
<td>Altice</td>
<td>186k</td>
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</tbody>
</table>

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
The Things Network

April 2022 (Columbia U.)

IRT LoRa Gateway (Mudd Rooftop)
ID: irt-mudd-roof-top-gateway
EUI: E45F01FFFE5BB825
Network: NS_TTS_V3://tttn@000013

Last heard at 2022-06-11T20:34:50.177475Z
Lat, Lon: 40.80937, -73.96031
Altitude: 100m
Show only this gateway's coverage as:
  - heatmap
Helium LoRa model for IoT

Helium: **0.001c per 24-byte message → $416/GB**

→ $3.46 per month and hotspot
5W of energy → $0.37 electricity

Dish Network will be the first major carrier to use the Helium Network’s blockchain-based incentive model – with customers deploying their own 5G hotspots using Citizens Band Radio Service (CBRS) spectrum.
Helium in Manhattan
But blockchain models are volatile

Market stats

- **Market Cap**: $935.9M
- **Volume (24H)**: $42.4M, +6.08%
- **Circulating Supply**: 119.6M HNT
- **All Time High**: $55.22

https://www.coinbase.com/price/helium

[Graph showing price changes from July 2021 to May 2022]
LTE EPC

LTE/EPC Specifications

UE

24.301 NAS

S6a

S1-MME

S10

S11

S1u

S6a

Unspecified

PCC Stage 2: 23.203
Charging Stage 2: 32.240

Operator Services

Internet

UE

eNB

X2

LTE-Uu

36.410 General
36.411 Layer 1
36.412 (Sig xport)
36.413 (S1AP)
36.133 RRM Reqds
36.304 Idle
36.306 Capability
36.314 Measurement
23.122 Idle-NAS
36.201, 211, 213, 214 PHY
36.321 MAC
36.322 RLC
36.323 PDCP
36.331 RRC

MME

HSS

SPR

PCRF

Serving GW

PDN GW

Internet

S1u

S6a

29.272

29.274 GTPC

Gx

Sg

Sgi

Sp

Rx

Bx

Gz/Rf

S5

S10

29.215

29.212

29.213 Sig Flow

29.274 GTPC

29.281 GTPU

Gy/Ro

Stage-1: 22.278

Stage-2: Evolved Packet Core Stage 2: 23.401

Stage-3: 36.300

E-UTRAN Stage-2: 36.300

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

General:
23.003 Identifiers
29.303 DNS
33.401 Security Stage 2 & 3

Irfan Ali
5G & 4G EPC

Cloud Core Data-Storage Manager
- UDR
- UDR

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
- SECE

Packet Core Controller
- AMF
- SMF
- MME
- SGW-C
- PGW-C

Packet Core Gateway
- UPF
- SGW-U
- PGW-U
- NAT
- DPI and optimization
- Firewall

* DA and DEA functions also supported

SBA architecture

NR SA
LTE/NR NSA
LTE
GSM/WCDMA

Ericsson, Oct 2020

NextG Summit 06/2022
Users per ASN roughly constant

roughly unchanged at 60k users per AS (slight decrease in users / routing table entry)

https://www.cidr-report.org/

Home networks are now small enterprise networks

The average U.S. household has 25 connected devices – more than double the 11 that the average household had in 2019, according to a new Deloitte report.

Largely self-managed:
• routing (mesh)
• device management
• device & user authentication
Scaling down is harder than scaling up

no PhD (or carrier training) needed!

firewall
DNS
edge computing

large enterprise management

identity management and trust still deficient

mesh backhaul
# Network value is (much) more than PHY

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

- **picket fence security**
  - hard to scale to IoT

- **WPA2-Personal**

- **802.1x**
  - federated (RADIUS, DIAMETER)

- **international roaming**

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**Figure 1. Overview of IMR technology and operations**

As the above diagram illustrates, when you make the call, you initiate an international roaming session. The call proceeds through an operator in the home country and is then routed to an operator in the visited country.

**Figure 2. Commercial links required for international mobile roaming**

The diagram shows the commercial links necessary for an international roaming session. These links include:

1. **Home Operator**
2. **Clearing house**
3. **Roaming Agreement**
4. **Internatl. carrier**

**TAP**: Transferred Account Procedure

Source: A.T. Kearney analysis

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**Wi-Fi settings**

- Network name: [ ]
- Kindness: [ ]
- Password: [ ]
- Show: [ ]

8 characters minimum

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**NextG Summit 06/2022**

6/17/2022
Stacks always focus on data – complexity is in control.
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
What’s needed for down-scalable networks?

• Better frequency coordination for CBRS GAA (and similar systems)
  • e.g., allow time-domain (slot?) coordination
• Support simple self-contained EPC that can run on AP
  • or OpenRAN with many untrusted participants → zero-trust networks
• Simplified roaming and settlement mechanisms
  • GSMA unlikely to scale
• May need new mobility models, but most new applications are likely nomadic and (somewhat) disruption-tolerant, not mobile and voice-like
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
Two evolutionary paths for 6G
mostly not a PHY problem

lowest bandwidth cost

like 4G & 5G, just more highest mobility

6/17/2022

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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
• Opportunity to bridge the Wi-Fi - cellular chasm