CSE 291: Wireless and Communication in the Internet of Things

Mobile Networking Origins

Pat Pannuto, UC San Diego

ppannuto@ucsd.edu

Today's Goals

- Understand fundamentals of cellular technology
- Learn how "older" cellular technology works
  - And why it is relevant to the IoT today

Outline

- Early mobile, cellular networks
  - Caveat: Somewhat of US-biased history

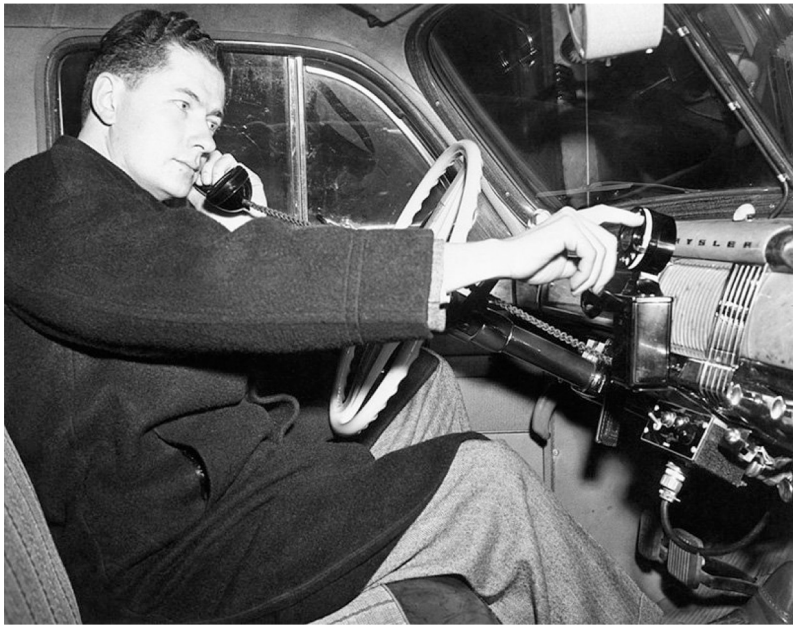
- "2G"

Poll: What decade was the first commercial mobile phone?

1. 1910-1920
2. 1920-1930
3. 1930-1940
4. 1940-1950
5. 1950-1960
6. 1960-1970
7. 1970-1980
8. 1980-1990
9. 1990-2000

The first commercial mobile phone was in 1946!

- By 1948, 5000 users placing around 30,000 calls weekly



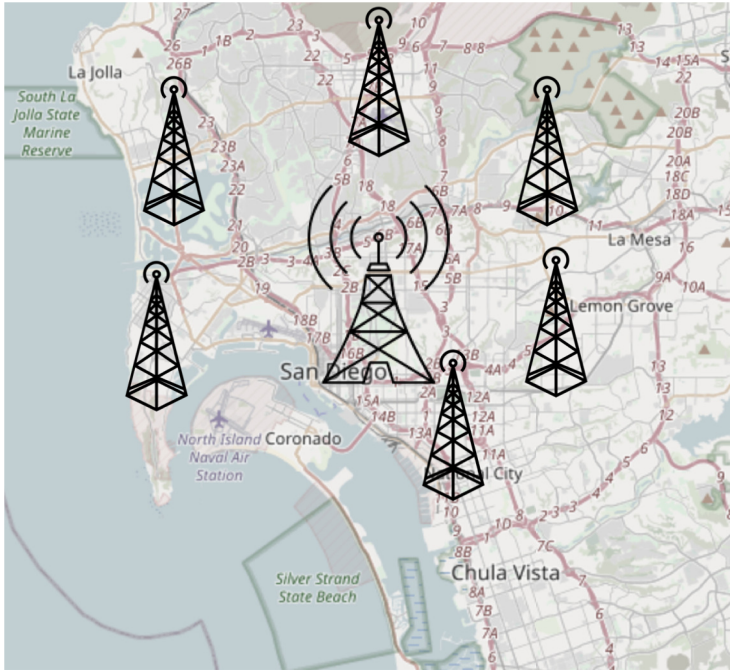
https://www.smithsonianmag.com/innovation/first-mobile-phone-call-was-made-75-years-ago-180978003/

  - "The equipment, of course employing vacuum tubes, **weighed eighty pounds, filled much of a vehicle's trunk and drew so much power that it would cause the headlights to dim.** Service cost $15 per month, plus thirty to forty cents per local call, equivalent to $175 2012 dollars, plus $3.50 to $4.65 per call. "

https://ethw.org/The_Foundations_of_Mobile_and_Cellular_Telephony

The first `mobile` network architecture

- Single transmitter, multiple receiver
  - Why?
- Medium Access Control?
  - Push-to-talk [half-duplex]
  - City-wide "party line"
  - Maximum of three concurrent callers



1965: The Improved Mobile Telephone Service

- "More spectrum"
  - Bell: VHF Low (35-44 MHz, 9 channels), VHF High (152-158 MHz, 11 channels), and UHF (454-460 MHz, 12 channels) — It's good to be a monopoly [well 85%]
  - 7 channels at VHF, and 12 channels at UHF for "RCCs" (Radio Common Carriers)
    - These will end up becoming pagers, mostly
- "Full Duplex"
  - Implemented as channel pairs (two half-duplex)
- Spectrum alone is not enough
  - Limited to 40,000 total subscribers
  - E.g. NYC had 2,000 people on 12 channels with a typical wait of 30 minutes to place a call

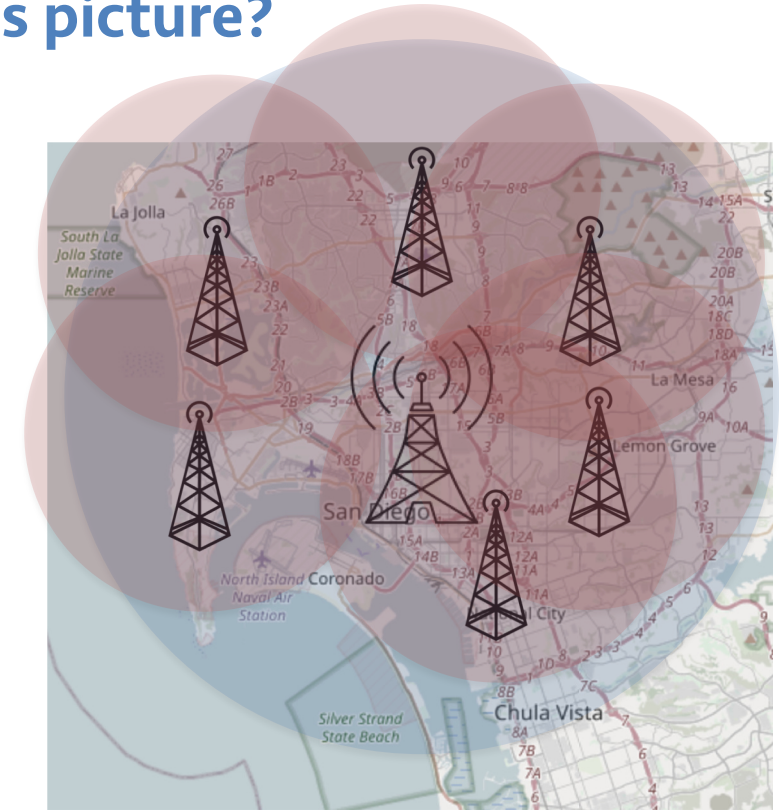
Phones fit in a briefcase now

Quick review: How can we share spectrum?

- Frequency division
  - Already doing that
- Time division
  - Already doing that
- Code division
  - Won't come to [US…] mobile networks until the 80's
- …?

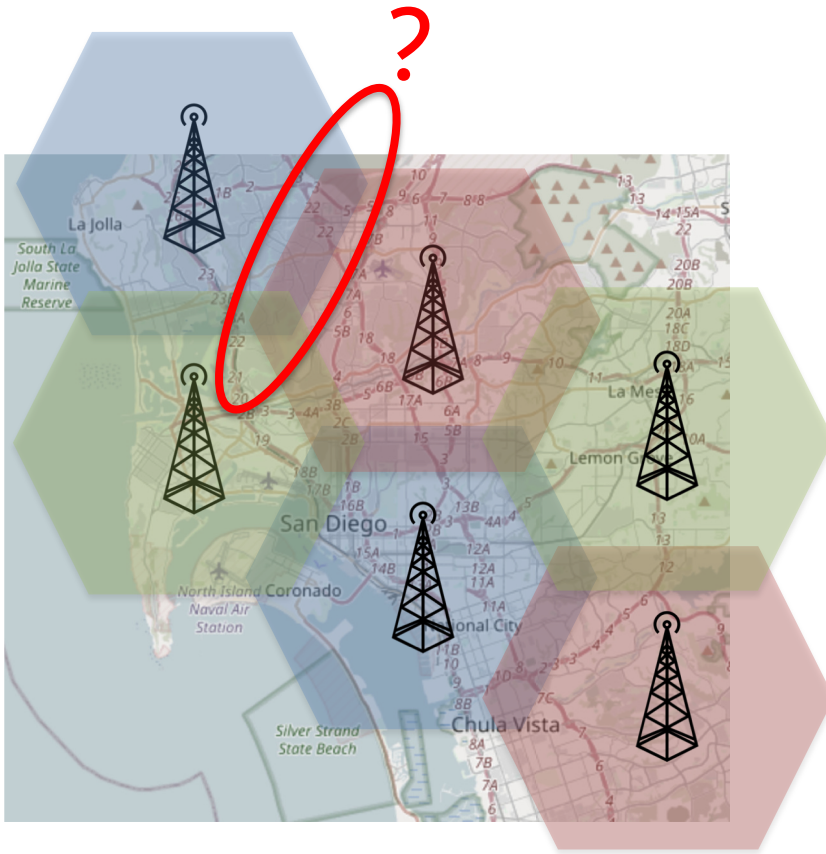
What's ~~wrong~~ inefficient with this picture?

- Early mobile networks handled the mobility challenge with wide-area coverage
- The active user could be anywhere in the 40~60 mile range of the transmit tower
  - So they had exclusive access to that whole area!
- 12 frequency channels → 12 users



The `cell` in cellular networks

- Cell is *spatial* division
  - Reduce transmit power, smaller area
- Now…
  - 12 / 3 = 4 channels per cell
  - * 6 cells in area
  - = 24 users of same spectrum!
- And if we keep making cells smaller…



Spatial division tradeoffs

- Need more infrastructure (more towers)
- Need logic to support handoff
  - Cellular concept in Bell labs at 1947 [one year after mobile], but no handoff

How often does handoff need to happen anyway?

- Really a question of `how big are cells`
- In AMPS, a back-of-envelope answer:

	Speed (mph)	Speed (kph)	Cell Radius (km)	Handoffs
Freeway, rural	65	104	16	0.33
Freeway, urban	65	104	1.6	3.25
Surface streets, urban	30	48	1	2.4
Pedestrian, urban	1.5	2.4	1	0.12
Pedestrian, microcell	1.5	2.4	0.1	1.2

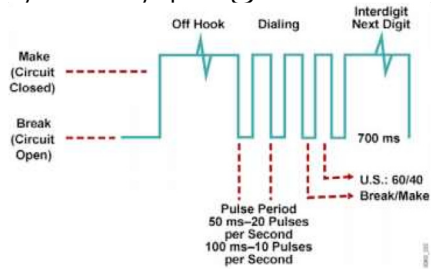
Table data from Arthur H. M. Ross, PhD: http://www.cdg.org/technology/cdma_technology/a_ross/handoff.asp

Introducing 1G!

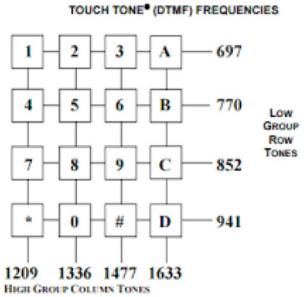
- AMPS — Advanced Mobile Phone Service
  - Other 1G's:
    - Nordic Mobile Telephone (NMT) — Nordics, Eastern Europe, Russia
    - Total Access Communications System (TACS) — UK, West Germany, Portugal South Africa
    - Radiocom 2000 — France
    - …
- 1G is defined by:
  - Analog voice channels
  - Established by digital control channel ← handoffs

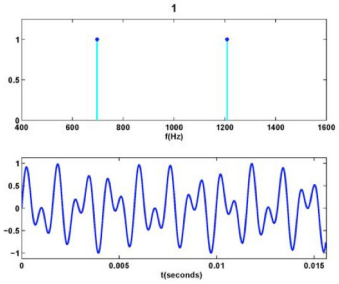
Quick Aside: DTMF Signalling

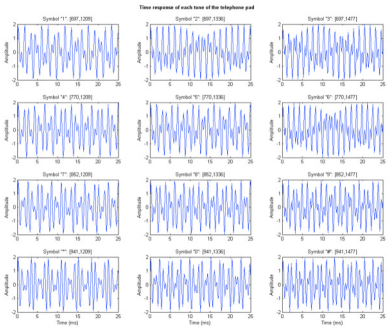
- How do you dial a phone number?
  - Early on: switchboard operators [physically plug wires to make connections]
  - Pulse dialing:



  - Dual Tone Multi Frequency:



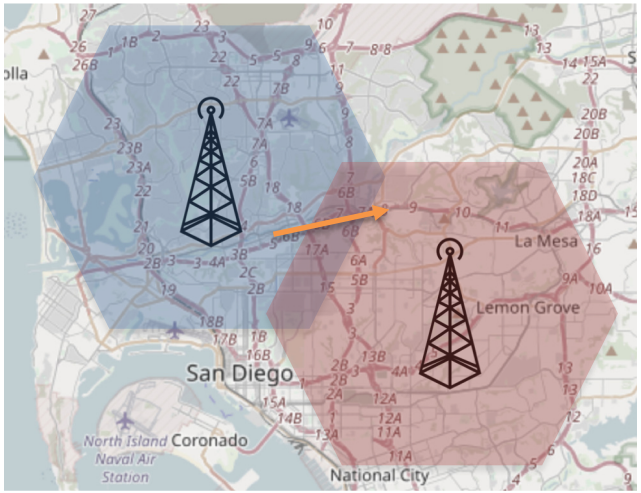




- What info for handoff?

How to implement handoff?

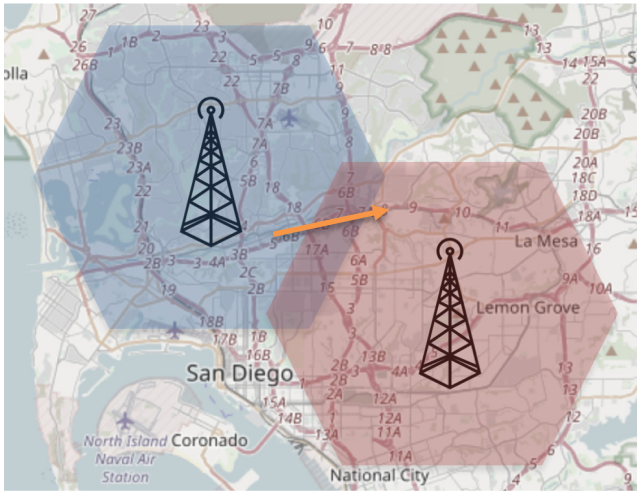
- <brainstorm>



How does AMPS implement handoff?

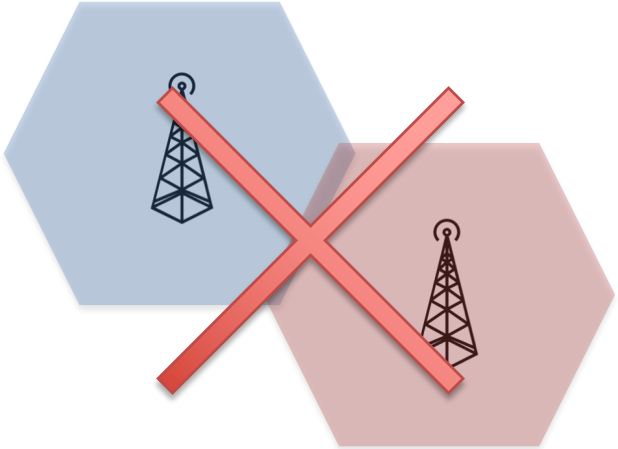
- Base station detects weak signal
- Base station tells mobile about new, better tower
- Base station sends cutover trigger

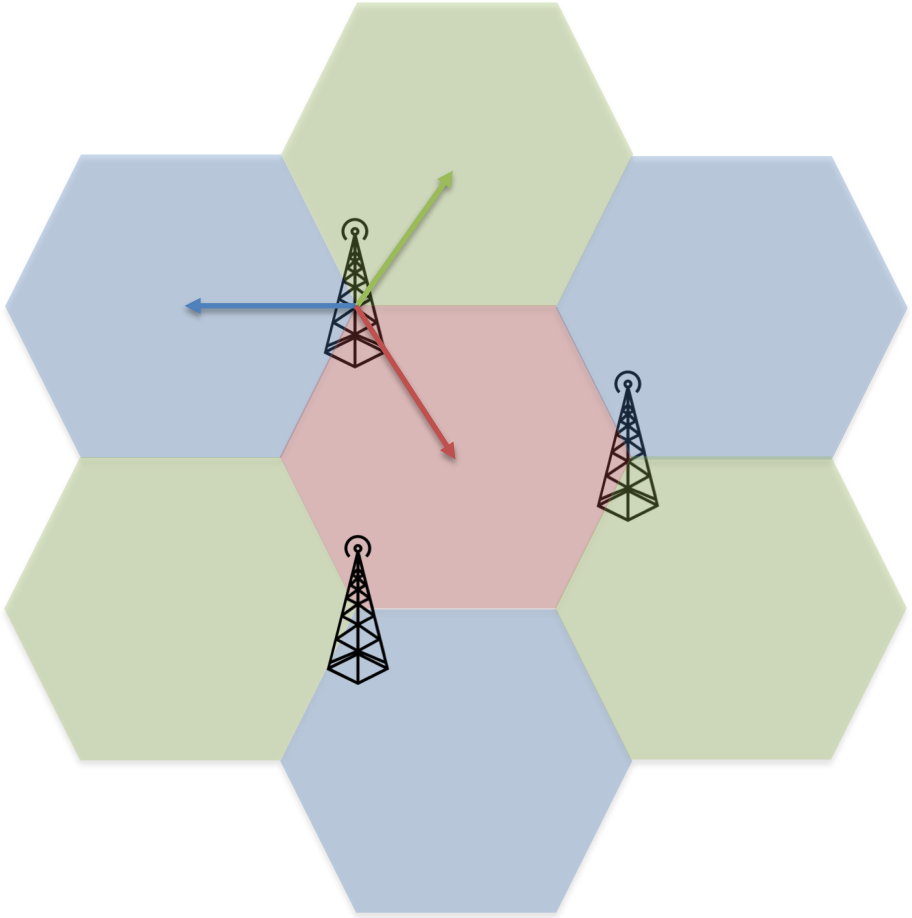
- Lots bad about this:
  - No `make before break` — many drops!
  - Mobile has better estimates than base station



Spatial division in practice

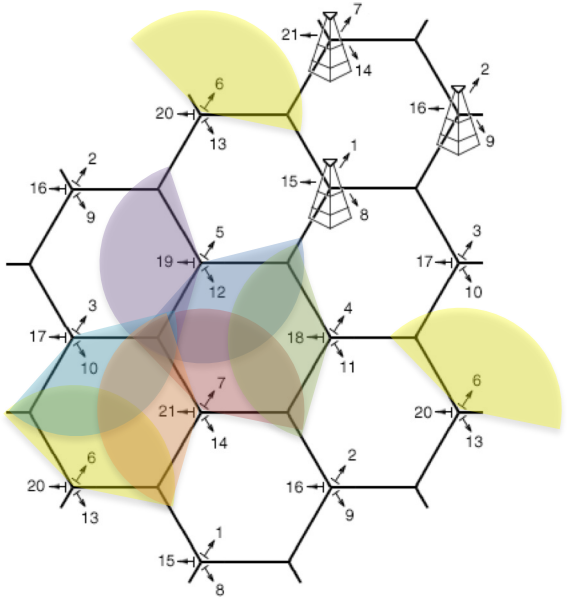
- Directional antennas at tessellation corners provide redundant coverage [robustness!]





Spatial division in practice

- Directional isolation is imperfect, requires many bands in practice



Over time, APMS did also get more frequencies

- APMS in the US:
  - 850 MHz band
  - Divided into "A" block and "B" block
    - Granted to local phone company and 'wireless company' respectively
  - Each block had 21 control, 395 voice channels
- Several expansions of this frequency block
  - Most interesting, in 1989, UHF TV channels 70-83 added 666 more channels

Cellular phone or walkie-talkie?

https://www.youtube.com/watch?v=JsEgUA4z_SM

The first “sunset”

- Single-user analog channels is not very efficient
- Wireless carriers want to replace 1G
  - *Key Takeaway:* Spectrum allocation is the most scarce resource, therefore want to maximize efficiency of its use [*efficiency*, n., paying customers / spectrum?]
- But many things in the built environment rely on AMPS
  - Because when *they* were built, AMPS was the most reliable
    - OnStar
    - ADT home alarms [got sued!]
  - What options do you have as the owner of an AMPS device during a sunset?

Poll: When did AMPS turn off in the United States?

(turned on ~1979)

1. 1980-1985
2. 1985-1990
3. 1990-1995
4. 1995-2000
5. 2000-2005
6. 2005-2010
7. 2010-2015
8. 2015-2020
9. AMPS is still active

Aside: Super cool hackaday projects

- Building your own 1G network!
  - https://hackaday.com/tag/amps/
  - https://github.com/unsynchronized/gr-amps
  - ⚠️⚠️⚠️ This uses spectrum you do not own ⚠️⚠️⚠️
    - "The FCC can levy fines of up to $11,000, per transmitter, per day, with up to six months in federal prison, for violations of the Code of Federal Regulations."
    - Could deploy with wired connections though…

Outline

- Early mobile, cellular networks
  - Caveat: Somewhat of US-biased history

- ”2G”

IS-54 aka 2G aka TDMA aka D-AMPS (Digital AMPS)

- Deployed ~1993
- Used TDMA to share AMPS channels
  - Each AMPS analog channel-pair was 30 kHz
  - Digital compression allowed for 3 time slots per channel — tripled capacity!
    - Later iterations would compress further, 6 time slots per channel
- Beat out competing FDMA analog solution from Motorola
  - Narrowband AMPS, "N-AMPS", compressed calls to fit in 10 kHz channels
- Also encrypted [poorly: CMEA broken publicly in 1997]

GSM **aka** 2G **aka** TDMA

- Wait, didn't the last slide say 2G was something else?

  IS-54 aka 2G aka TDMA aka D-AMPS (Digital AMPS)

- What is "2G" then?
  - Exactly.
- What does it mean when my phone says "TDMA" then?
  - Exactly.

The first 2G sunset happened in 2008

- D-AMPS was sunset when AMPS was sunset
- Modern "2G" is all GSM
- And if you think this is confusing, it only gets worse
  - Anecdata: Pat as a Qualcomm intern in 2010 asked everyone I met there "what actually is 4G," and every engineer just laughed at me

GSM

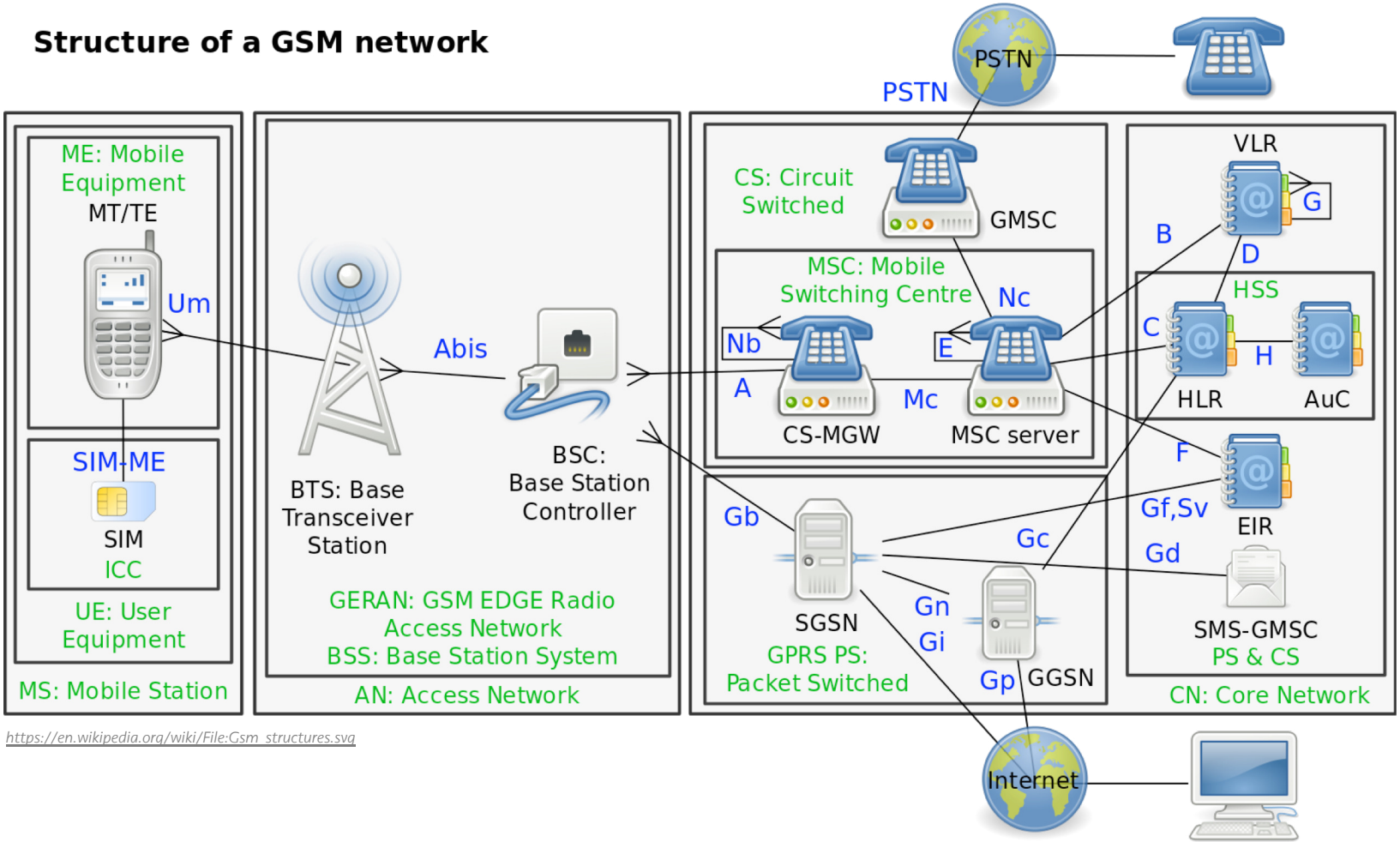
- So can we just call modern 2G "GSM"?
- "Global System for Mobile Communications"
  - It is a standard [the dominant 2G]
  - GSM meant "phone" for a while in parts of Europe
    - (and apparently still in Belgium?)
  - GSMA is the GSM Association; which a lot of people just call GSM
    - Because GSM made [a] 3G and LTE [which is a 4g?] and 5g [ish! more next time]
  - Yay.

Origins of GSM

- An incredible sweet spot of timing, technology need, and politics?

- 1987: 13 European countries sign accord to use one wireless standard
  - 10 months later: GSM standard ratified
  - Insight: Not a ton new in GSM by '87, just a *lot* of arbitrary design decisions

Structure of a GSM network



https://en.wikipedia.org/wiki/File:Gsm_structures.svg

The real innovation of GSM was the indirection and interoperability it enabled

- Europe hit this problem before the US because the US is large
  - (and US telecoms owned/operated subsidiaries in Canada)
- Coincided with major growth in global mobility
  - Mobile devices needed to be able to use other carriers infrastructure
- Early GSM isn't anything fancy in modulation, data, etc
  - It's all about the control channels

GSM evolved over time to add data

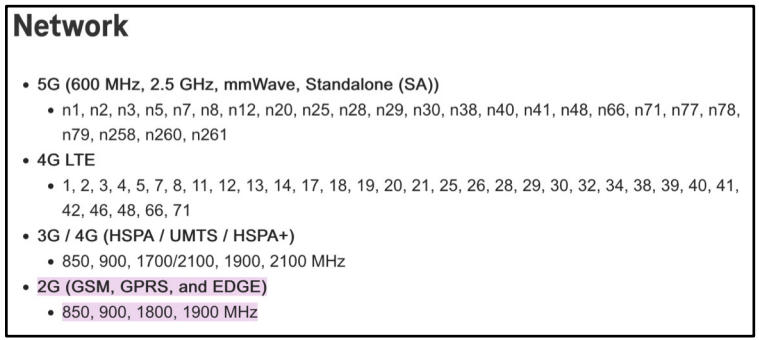
- GSM was voice-only at first
- Then overlaid data on the voice channel
  - Circuit Switched Data (CSD)
    - 9.6 — 14.4 kb/s
    - Previous hacks were literally cell phone calling a modem (~3.5 kb/s); same concept
- Then added actual packetized data ["2.5G"]
  - General Packet Radio Service (GPRS)
    - Throughput 9.2 – 21.55 kbit/s/timeslot [goodput 8-20 kbit/s/timeslot]
  - Enhanced Data Rates for GSM Evolution (EDGE)
- Why is packetized more efficient use of spectrum than circuit switched?

So why does the IoT care about 2G?

1. It's easy
   - 2G == GMSK, 3G = QPSK [requires linear PA], 4G = …
2. It's cheap
   - More on this in lab Friday
3. It's low power*
   - *For select IoT workloads
   - Energy-per-bit of continuous stream improves each generation
   - Energy-per-event of infrequent events…

Why might 2G continue to survive [globally]?

1. It's cheaper coverage
   - 2G has longer range than 3G
2. It fills the legacy niche
   - High performance HW includes fallbacks
     - 2G/3G radios, then 2G/3G/4G radios, now 2G/3G/4G/5G radios
     - Consider the iPhone 13 Pro:
   - Brick phones still popular!

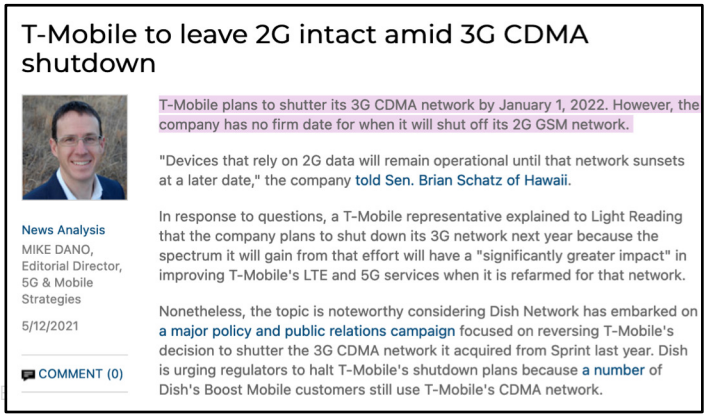


Network

- 5G (600 MHz, 2.5 GHz, mmWave, Standalone (SA))
  - n1, n2, n3, n5, n7, n8, n12, n20, n25, n28, n29, n30, n38, n40, n41, n48, n66, n71, n77, n78, n79, n258, n260, n261
- 4G LTE
  - 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 17, 18, 19, 20, 21, 25, 26, 28, 29, 30, 32, 34, 38, 39, 40, 41, 42, 46, 48, 66, 71
- 3G / 4G (HSPA / UMTS / HSPA+)
  - 850, 900, 1700/2100, 1900, 2100 MHz
- 2G (GSM, GPRS, and EDGE)
  - 850, 900, 1800, 1900 MHz

2G in the US…
[Plans…]

- AT&T stopped servicing 2G networks in 2016
- T-Mobile will roll up the sidewalks on 2G in December 2020
- Verizon Wireless will also phase out its 2G CDMA network at the end of 2020
- Sprint will shut down their 2G CDMA network in December 2021



T-Mobile to leave 2G intact amid 3G CDMA shutdown

News Analysis

MIKE DANO, Editorial Director, 5G & Mobile Strategies

5/12/2021

COMMENT (0)

T-Mobile plans to shutter its 3G CDMA network by January 1, 2022. However, the company has no firm date for when it will shut off its 2G GSM network.

"Devices that rely on 2G data will remain operational until that network sunsets at a later date," the company told Sen. Brian Schatz of Hawaii.

In response to questions, a T-Mobile representative explained to Light Reading that the company plans to shut down its 3G network next year because the spectrum it will gain from that effort will have a "significantly greater impact" in improving T-Mobile's LTE and 5G services when it is refarmed for that network.

Nonetheless, the topic is noteworthy considering Dish Network has embarked on a major policy and public relations campaign focused on reversing T-Mobile's decision to shutter the 3G CDMA network it acquired from Sprint last year. Dish is urging regulators to halt T-Mobile's shutdown plans because a number of Dish's Boost Mobile customers still use T-Mobile's CDMA network.

Does GM ever learn? [Could they have?]

- What would you put in cars if you were the PM of OnStar today?

What is the 2G network sunset and how does it affect my OnStar service?

As cellular carriers transition to 4G or 5G connectivity, vehicles using a 2G connection will lose OnStar service. In the U.S., most major network providers will complete the transition in December 2022. After the transition, 2G network connectivity will no longer be provided. The decision to sunset these networks was made by the wireless network providers and the need to upgrade to newer technology.

Certain GM vehicles on the road today currently leverage the 2G network for OnStar connectivity. Once the 2G network sunsets, the three-button interface in your vehicle will be deactivated.

Which GM vehicles are impacted by the deactivated 2G network?

In the U.S. and Canada, certain 2015 model year and older GM vehicles will be affected when 2G networks are upgraded. This also may include former GM brands, such as Pontiac, Saturn and HUMMER.

What options are available to Members after the 2G sunset occurs?

GM is actively working to evaluate options for OnStar Members who will be impacted by the 2G network sunset. Due to ongoing semiconductor shortages, GM is discontinuing the previously announced OnStar Link adapter program. Program updates will be announced at a later date.

Next Time: More G's — how does newer cellular work?

- 3g
- 4g
- 5g
- 6g [kidding]