“AT THE TONE, THE TIME WILL BE… UNKNOWN”

A PERSPECTIVE ON THE EVOLUTION OF TIME IN TELECOMMUNICATIONS

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AGENDA

- Networks
  - A time when time got respect
  - IP, and disrespect
- Mobile
  - Fundamentals
  - Air Interfaces and newer issues of time
- Challenges and Conclusions

WHEN TIME GOT RESPECT

- In the beginning, time was revered
- The phone became the time authority
  - Initially Mabel (or Ernestine) at Central, then
  - Human speaking clock, then
  - Mary Moore and Jane Barbe

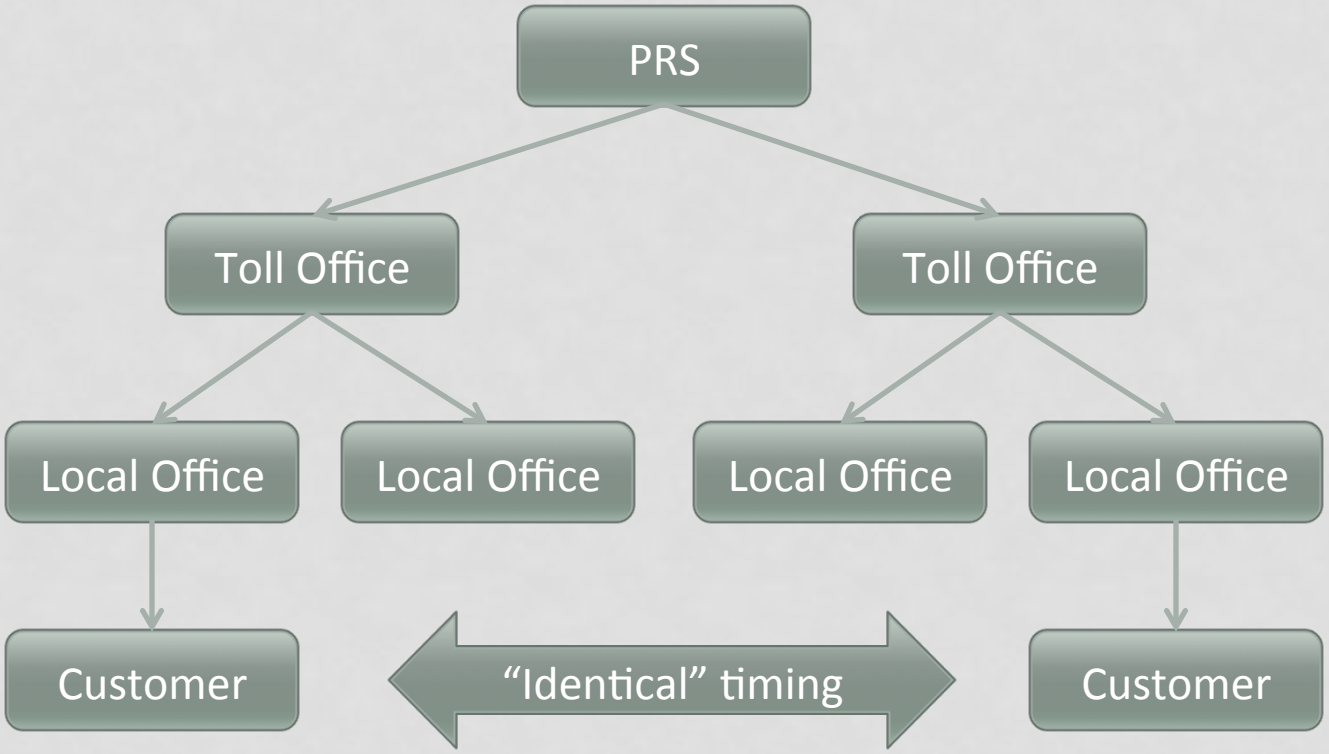
NIST: *"The audio portions of the WWV and WWVH broadcasts can also be heard by telephone. The time announcements are normally delayed by less than 30 ms when using land lines from within the continental United States, and the stability (delay variation) is generally < 1 ms*"

Source: http://www.nist.gov/pml/div688/grp40/ttds.cfm

THEN DIGITAL HAPPENED

- Initially, time gets more respect
- A synchronous NA "T1" network
  - 1.544 Mbps (~648 nsec/bit)
- With a master clock
  - "Primary Reference Source"
- Dedicated digital circuits from/to anywhere; bit timing under control
  - Jitter tolerated with a modicum of protocol and buffering
  - No such thing as "wander"

TIME AS AN INTEGRAL ELEMENT OF PROTOCOL

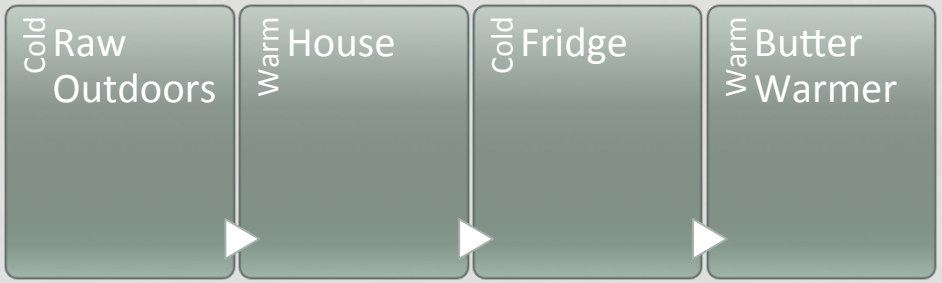


BUT THEN TIMES CHANGED

- AT&T Divestiture and economics drove a (de-)evolution
  1. Installed plant was lots of raw copper circuits
  2. Overlaid digital coding to get nailed-up, dedicated T1's: **synchronous**
  3. Carved up and shared the T1's statically: Frame Relay
  4. Supported multiple carriers / clocks: **plesiochronous**
  5. Statistically shared but bandwidth-guaranteed: ATM (**isochronous**)
  6. Dynamically shared with no guarantees: IP (**asynchronous**)
- Time did not govern the network; network could not convey time
- Buffering went through the roof; QoS went down

IP-BASED NETWORKS AND QOS

- Contention-based channel access (Ethernet, 802.11)
- Best Efforts routing
  - *I'd tell a joke about UDP… but I don't know if you'll get it*
- Bufferbloat
- Statistical channels may be good business, but they disrespect time
  - VoIP: isochronous protocol over statistical network
  - Idea! Use MPLS as an overlay on an IP network to restore guarantees



There is **no substitute** for real timing guarantees in telecommunications networks

When mobile phones or voice over IP networks are used, the delays can be as large as 150 ms."

MOBILE NETWORKS

- 2G: things were rather orderly: GSM / TDMA (*the 217 Hz Buzz*)
  - Core network used circuit switching
- 3G: switch to CDMA
- 3.9G(LTE)/802.11: OFDM, requiring more accurate time and frequency
  - Frequency errors manifest as inter-carrier-interference (ICI)
  - Bandwidth is spent synchronizing and estimating channel
    - e.g., 802.11 maxes out at 12 MHz of usable bandwidth in a 20 MHz channel
    - Can better local time reduce lost bandwidth?
- 4G and beyond: OFDMA (channel access) adds further need for accurate time
  - Statistical multiplexing – core network is IP!

FUNDAMENTALS OF MOBILE COMPUTING

- Scale is staggering
- **Power** three-watt limit based on physics, not chemistry
- **Performance** aggressive and powerful apps, cloud-integrated
- **Privacy** and security – a huge target
- Pixels great web experience
- Pointing evolve beyond PC
- Programmability embedded thinking failed
- Policy Management BYOD

*Mobile **will** overtake desktop computing in economic significance*

HOW *NOT* TO THINK ABOUT MOBILE

Initially	Led to	But Now
Memory expensive	Conservative design, phone-as-phone	Memory cheap, apps creating value
Computing expensive	Fixed-function, embedded approach	Computing cheap, most functionality moving to software based design
Costly RF system engineering	Closed chip ecosystem, frequency monopolies	SDR, unlicensed networks, **near-Shannon-limit coding schemes**
Closed, circuit-switched networks	Proprietary and closed backhaul	**Open, packet-switched networks**
No software building blocks	Closed, proprietary software	**Readily-available, high quality software linked to cloud services**

WHY DO MOBILE AND EMBEDDED DEVICES NEED ACCURATE TIME?

- Device-to-device and Device-to-cloud
  - Example: online gaming requires millisecond-level eye-hand fidelity
    - Intersection math over 3G is 100's of msec (improving with 4G)
    - Need accurate distributed time and predictive system for intersections
  - Example: online **or offline** sensor fusion
    - Non-repudiation of event logs based on accurate, hard-to-hack, local time
- Communication protocols (as discussed)

DO EXISTING APPROACHES MEET THE NEEDS?

Scheme	Time accuracy	Frequency Accuracy
HF Radio	1-10 milliseconds	down to 5 parts per 10^{12}
Omega nav and VLF	2-10 microseconds	several parts per 10^{11}
LORAN-C	several microseconds	1 part per 10^{11}
Portable cesium clock	microsecond	2 parts per 10^{12}
GPS	100-500 nanoseconds (SA)	Comparable to LORAN-C

GPS only works outdoors (we spend 80% of our time indoors)

Current GPS solutions are very power hungry

Denial of Service → Denial of Position → Denial of Time attacks

CHALLENGES AND CONCLUSIONS

- Rotten to the Core: Retro networking is needed
  - Time and Network Protocols must come back together.
- GPS is great… 20% of the time
  - Make pseudolites (pseudo-satellites) commonplace, not just at airports
- We've only heard the first stories of GPS hijacking
  - Mobile devices need hard-to-hack, ultra-precise **internal time reference**
- Harvest wireless bandwidth
  - Systematic losses from synchronization are tragic. Reclaim them.
- Don't under-estimate the significance of mobile as a driving force!

Thank you!