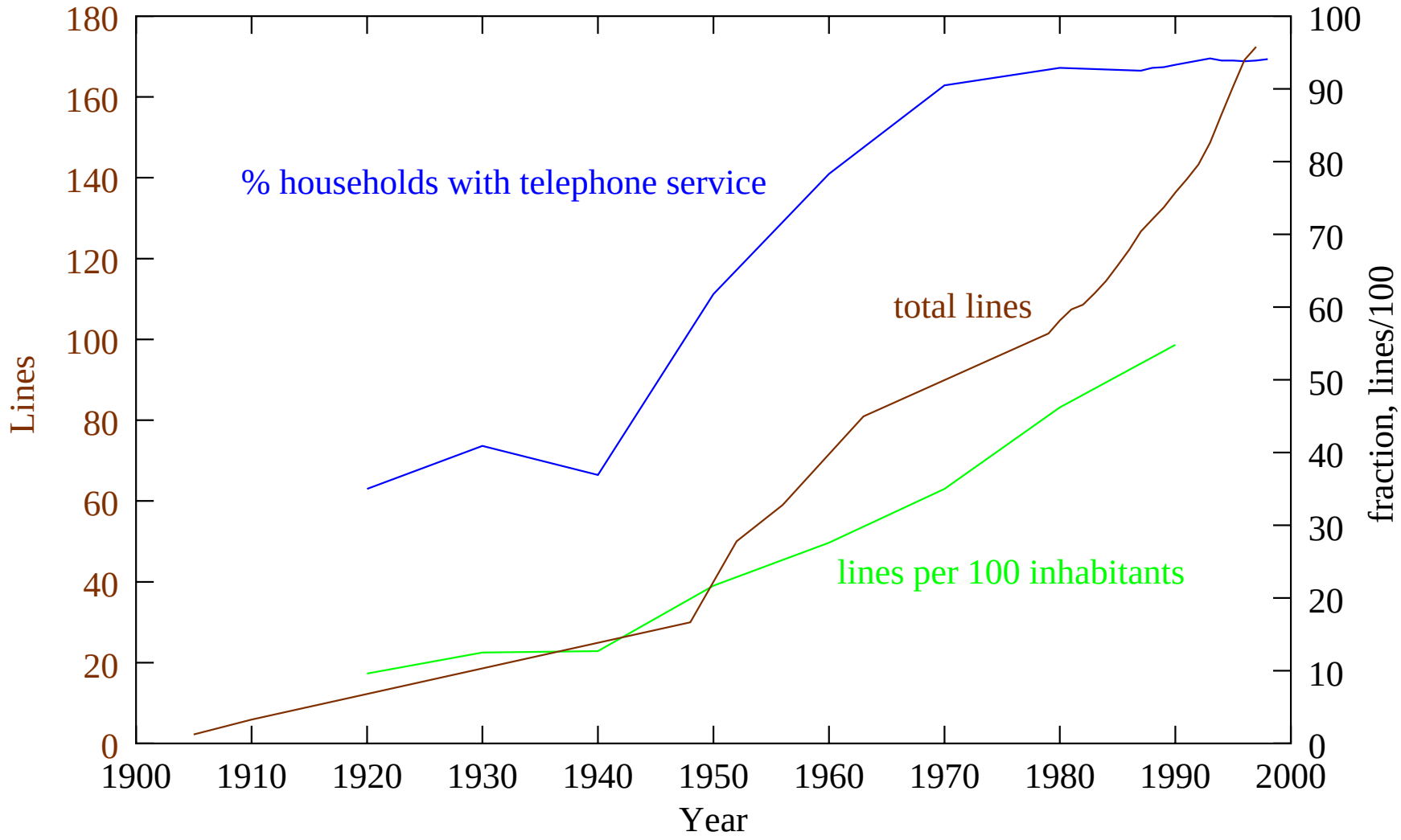
The Public Switched Telephone System

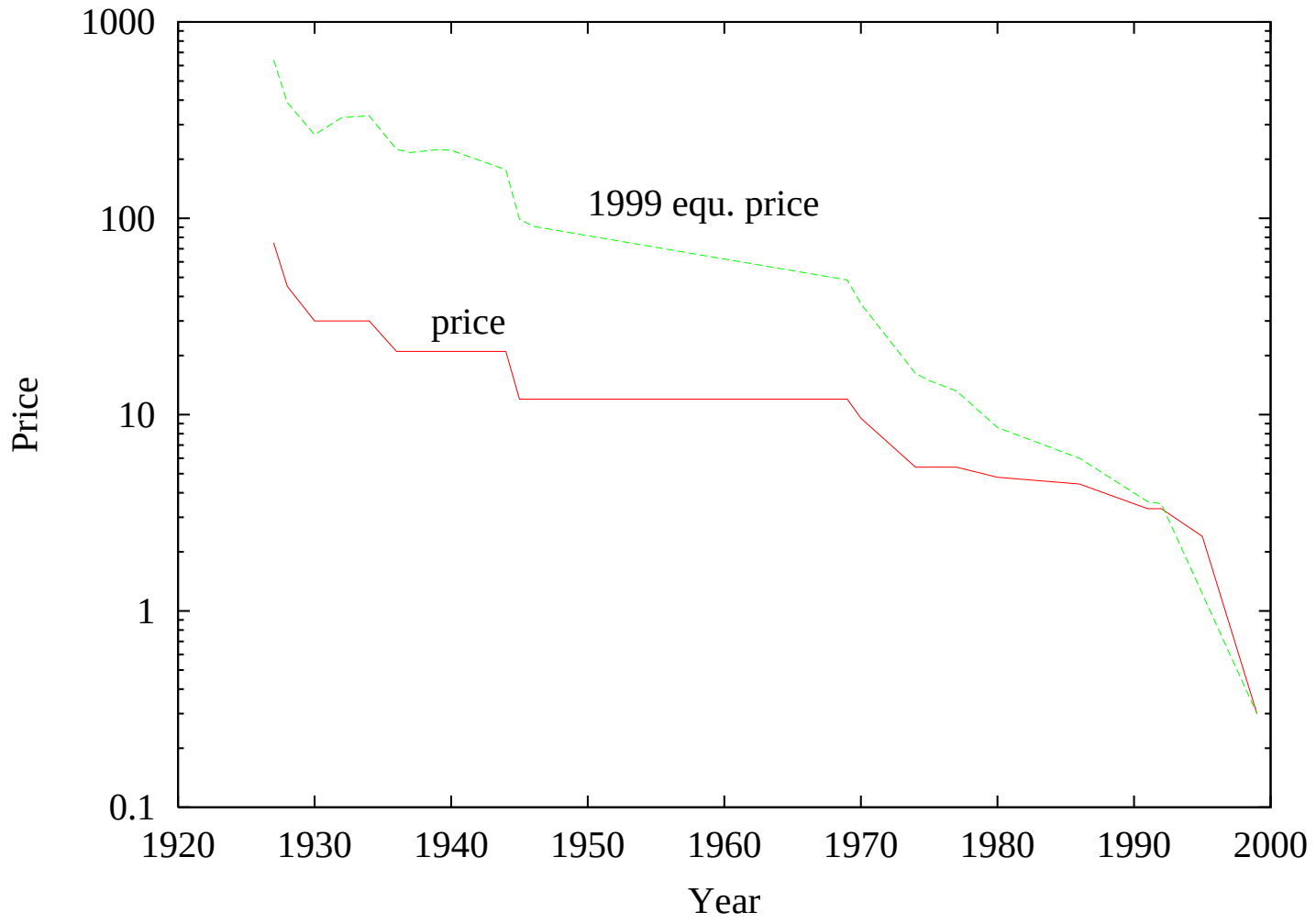
Historical perspective

1876	invention of telephone
1915	first transcontinental telephone (NY–SF)
1920’s	first automatic switches
1956	TAT-1 transatlantic cable (35 lines)
1962	digital transmission (T1)
1965	1ESS analog switch
1974	Internet packet voice
1977	4ESS digital switch
1980s	Signaling System #7 (out-of-band)
1990s	Advanced Intelligent Network (AIN)
1992	Mbone packet audio

Telephone service in the U.S.



Price of phone calls (NY – London)



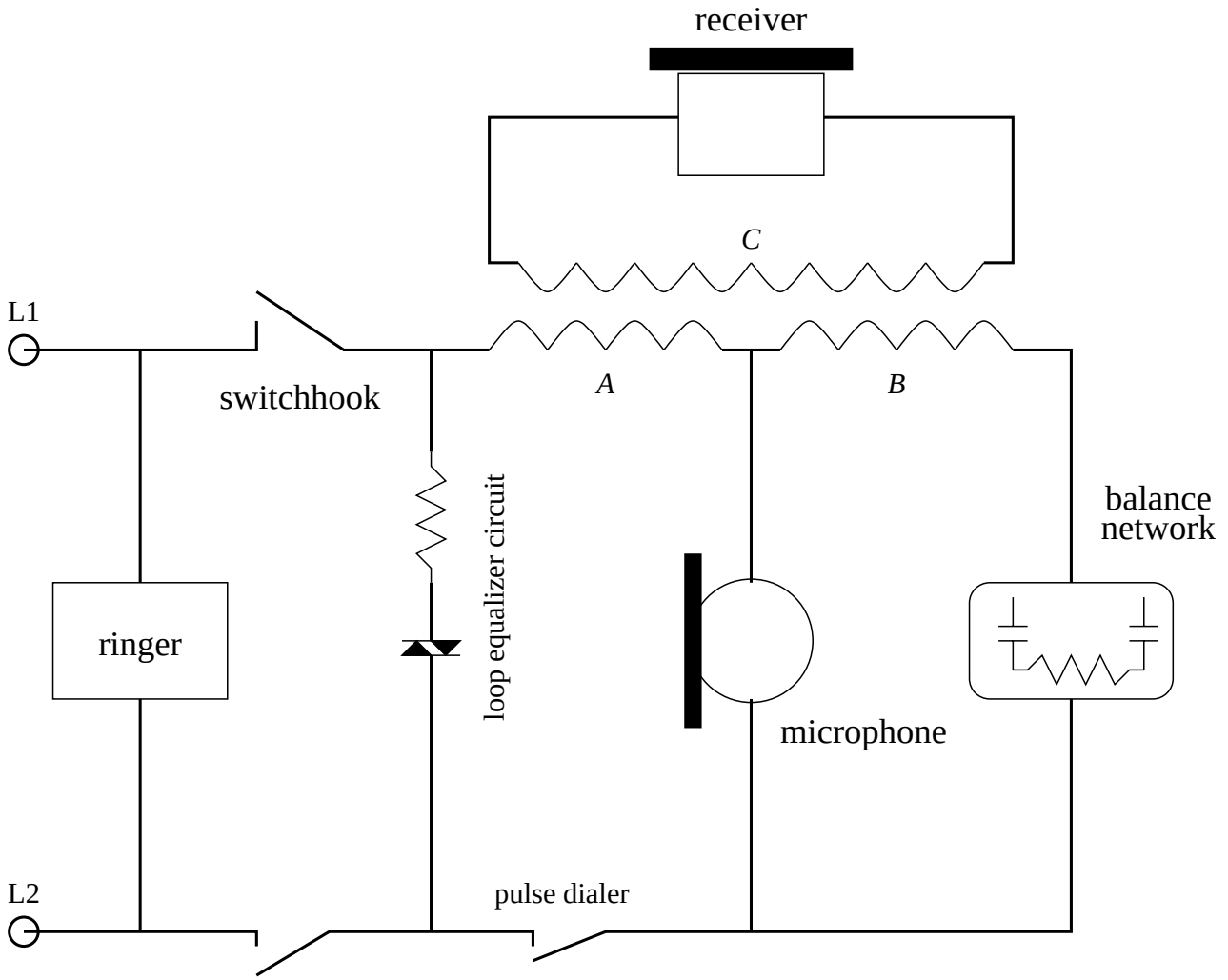
Transatlantic cable systems

System	19xx		cost	circuits	$/circuit	$/minute
TAT-1	56	C	$49.6M	40	213,996	2.443
TAT-2	59	C	42.7M	44	167,308	1.910
TAT-3	63	C	50.6M	79	111,027	1.267
TAT-4	65	C	50.4M	62	140,238	1.601
TAT-5	70	C	70.4M	648	18,773	0.214
TAT-6	76	C	197.0M	3,200	10,638	0.121
TAT-7	83	C	180.0M	3,821	8,139	0.093
TAT-8	88	F	360.0M	6,048	10,285	0.117
TAT-9	92	F	406.0M	10,584	6,628	0.076
TAT-10	92	F	300.0M	18,144	2,857	0.033
TAT-11	93	F	280.0M	18,144	2,667	0.030
TAT-12	96	F	378.0M	60,480	1,080	0.012
TAT-13	96	F	378.0M	60,480	1,080	0.012
Gemini	98	F	520.0M	214,920	371	0.004
AC-1	98	F	850.0M	483,840	304	0.003
TAT-14	00	F	1500.0M	4x2.5M	<75	0.001

Overview of telephone system

- analog narrowband circuits to “central office”
- 64 kb/s continuous transmission, with compression across oceans
- μ-law: 12-bit linear range $\longrightarrow$ 8-bit bytes
- everything clocked a multiple of 125 μs
- clock synchronization $\leftrightarrow$ framing errors
- AT&T: 136 “toll”switches in U.S.
- interconnected by T1 and T3 digital circuits $\longrightarrow$ SONET rings (AT&T: $\approx$ 50)
- call establishment “out-of-band” using packet-switched *signaling* system (SS7)

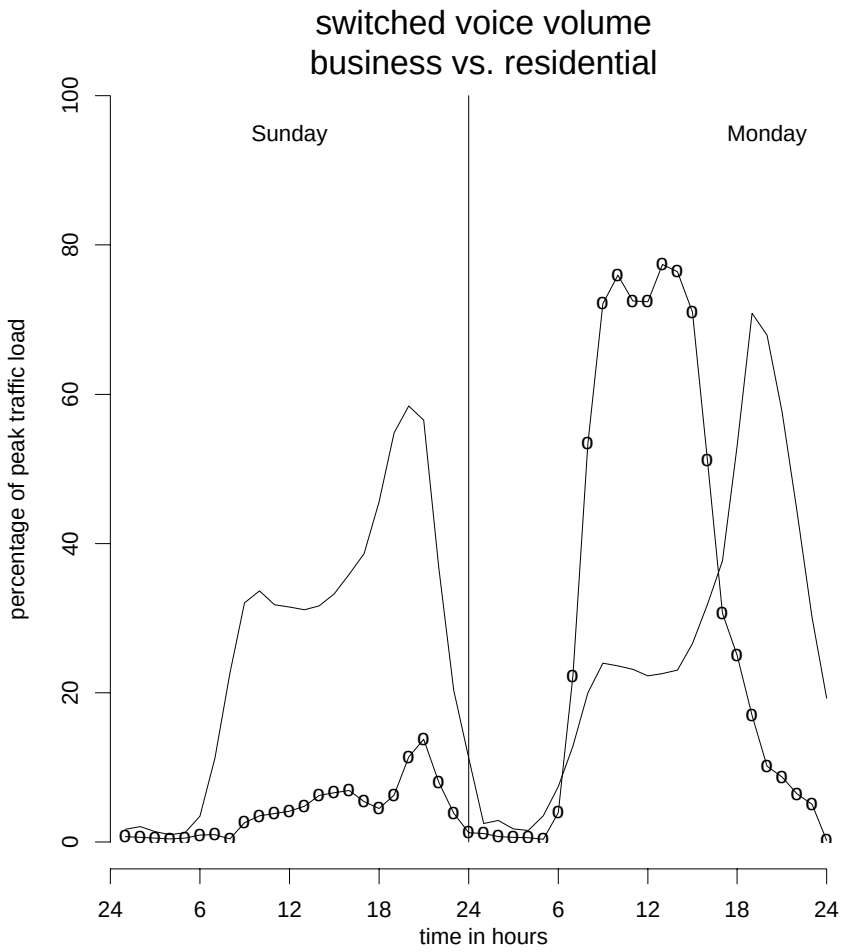
The basic analog telephone



Telephone load measurements

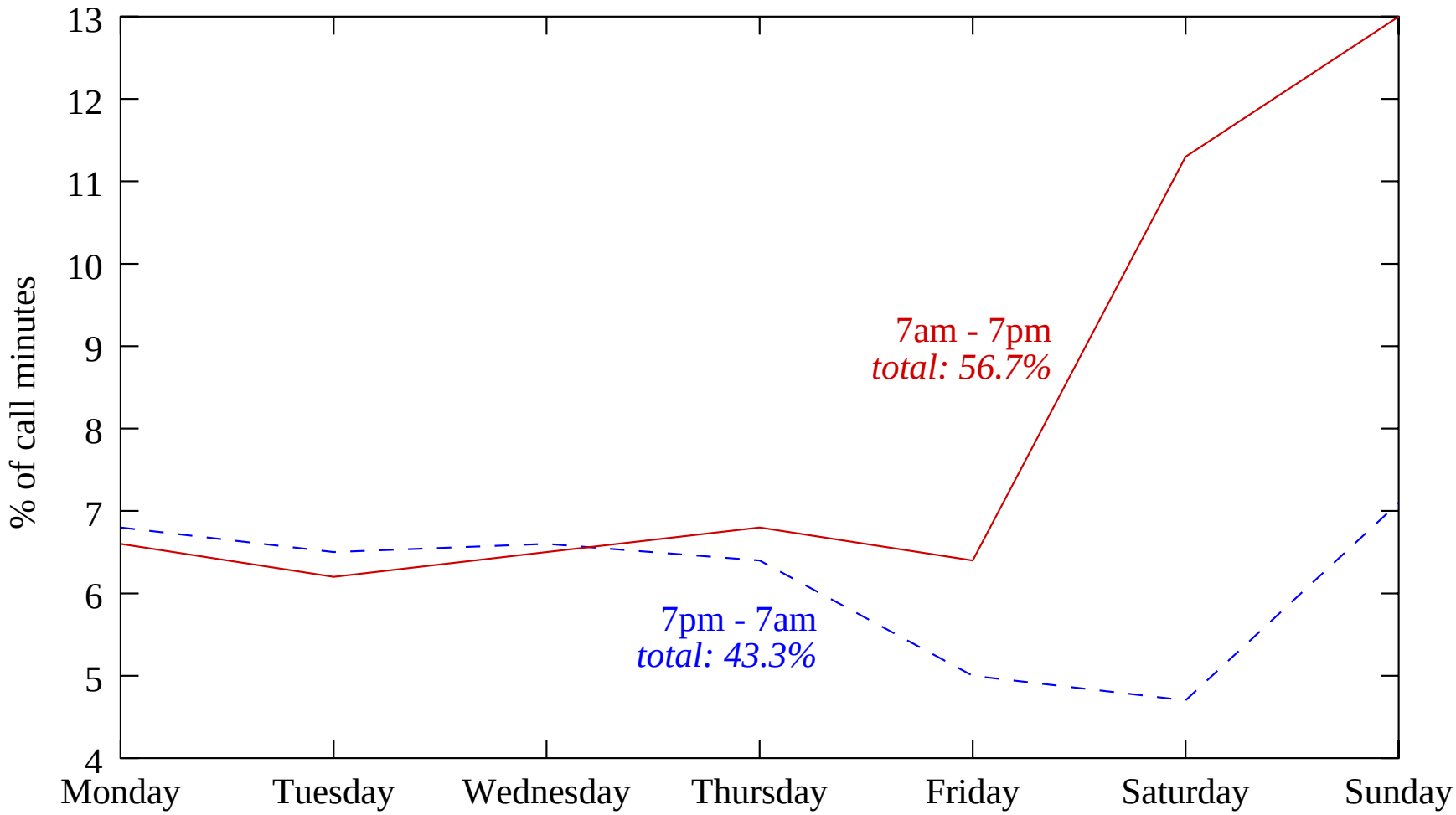
- 0.1 erlang = busy 10% of the time
- CCS = hundred call seconds/hour ➠ 36 CCS = 1 Erlang
- signaling: BHCA = busy hour call attempts

Telephone load variation



The Internet and other networks: Utilization rates and their implications, A. M. Odlyzko. Sept. 1998

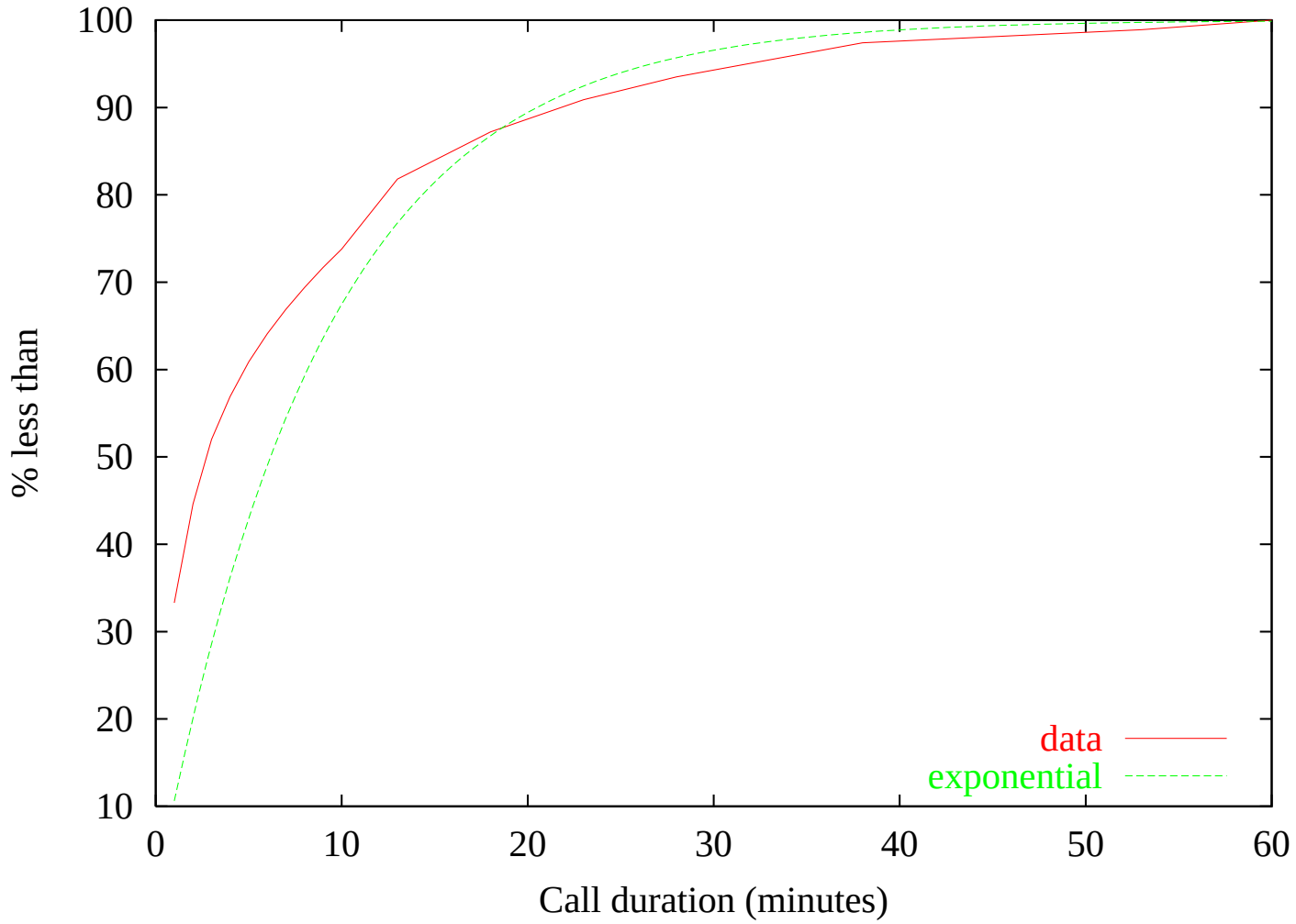
Call load as a function of weekday



Call duration

- functional vs. social calls
- local call: 2.4 minutes
- business call: 3.5 minutes
- residential toll: avg. = 8.9 minutes, with a median of 3 minutes
- international calls: 5.1 minutes (U.S.-originated are longer)

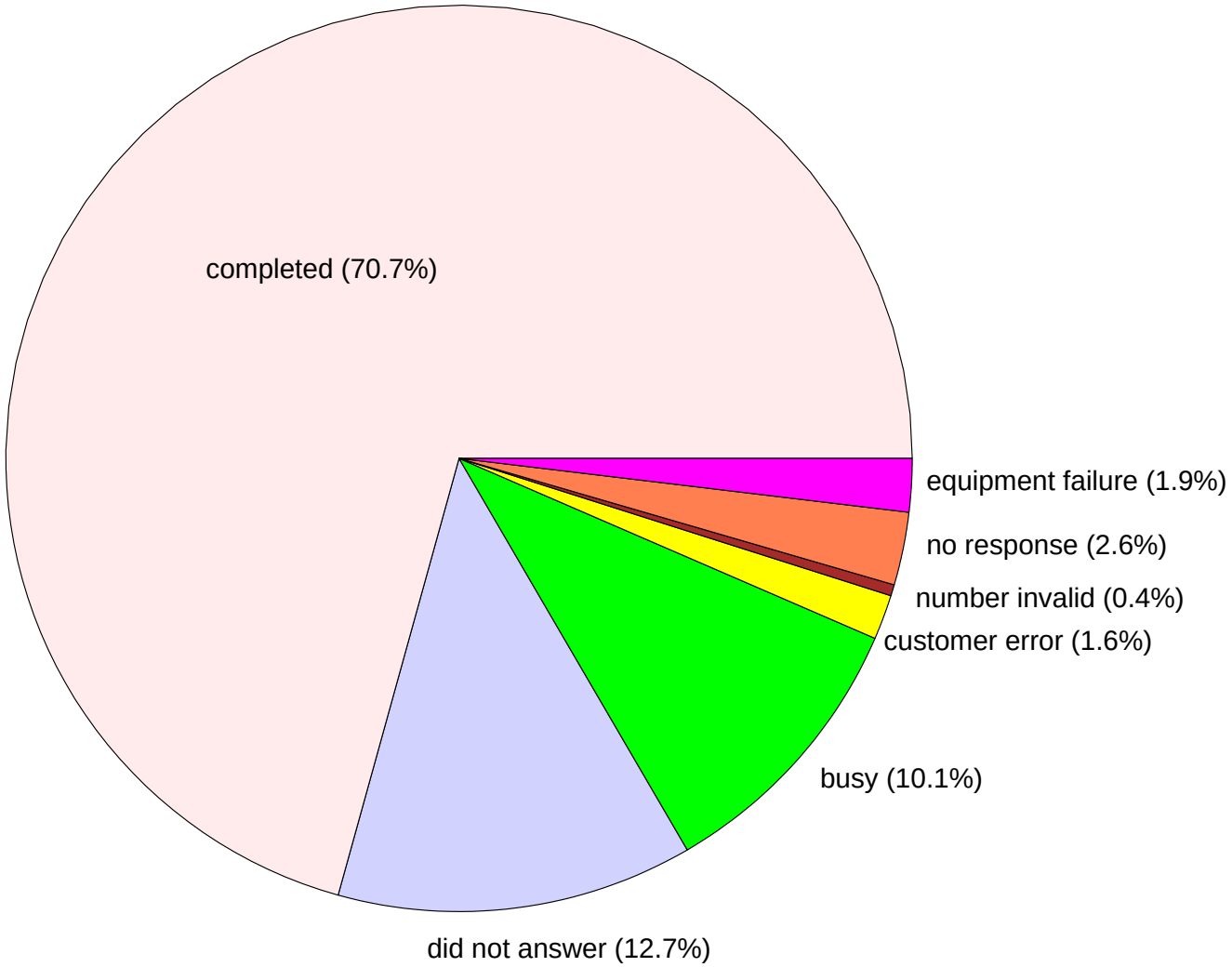
Telephone call duration



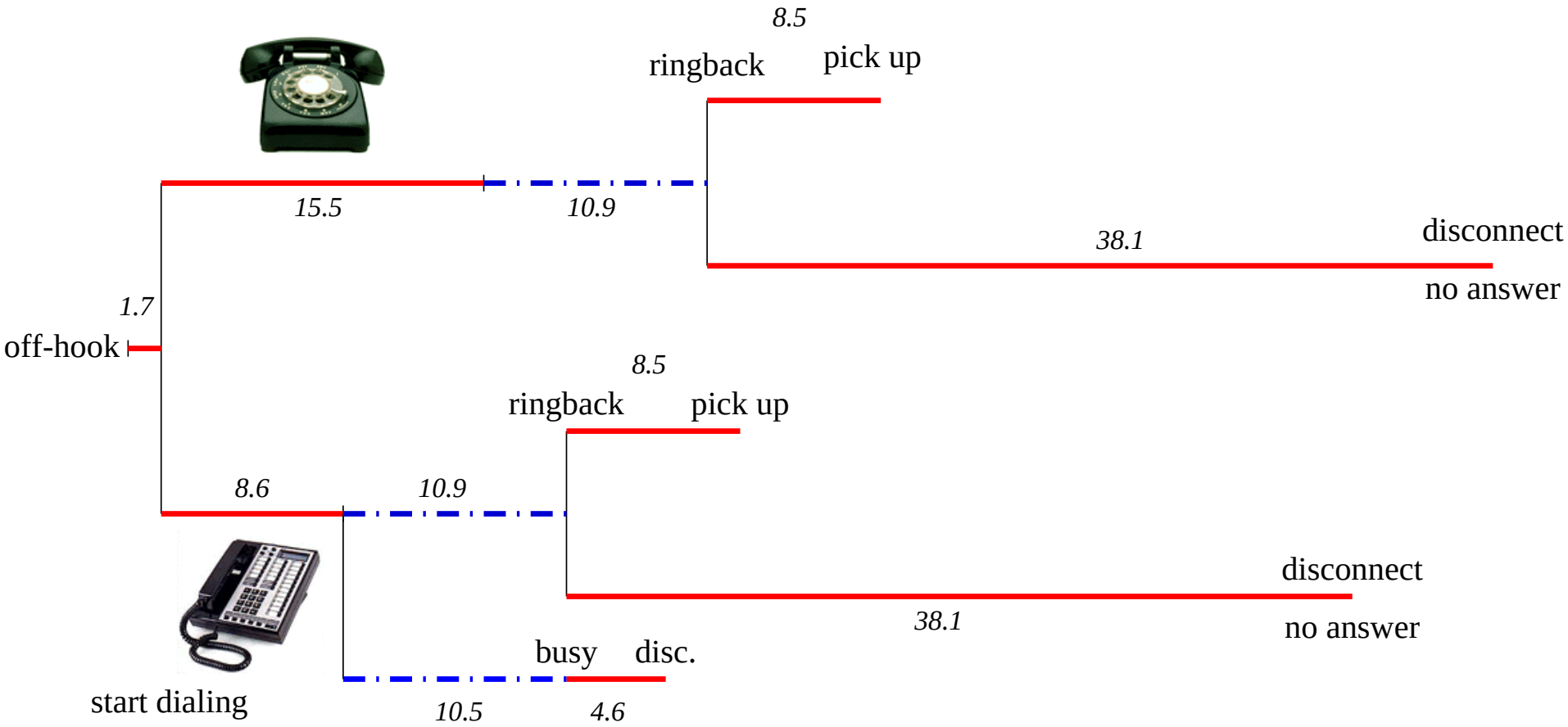
Residential toll call distribution and duration as a function of distance

distance (mi)	% calls	duration (min.)
1 – 10	5.1	4.6
11 – 22	20.2	5.1
23 – 55	23.2	5.9
56 – 124	13.3	7.7
125 – 292	12.1	9.4
293 – 430	4.6	10.4
431 – 925	9.7	11.9
926 – 1910	8.5	11.9
> 1910	3.2	11.2
average	310 mi.	7.8
median	60 mi.	3.0

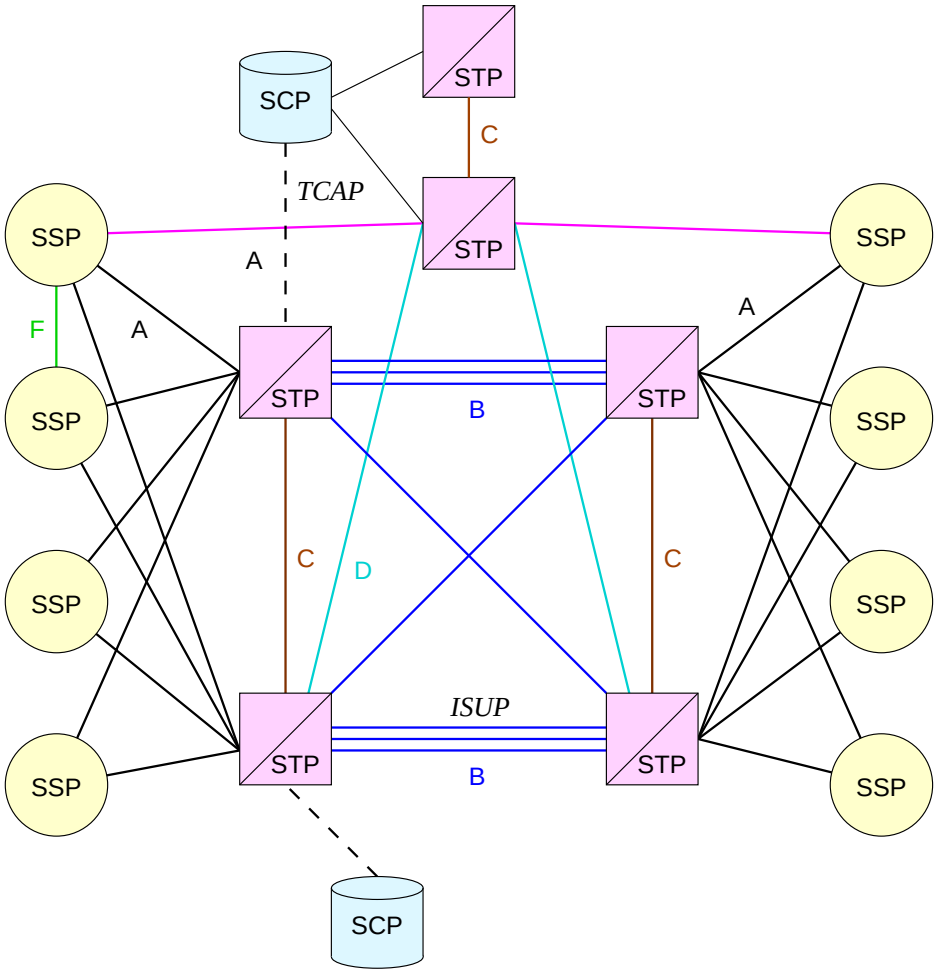
Telephone call attempts



Call setup duration



Signaling System #7



Signaling System #7

SSP: service switching point = voice switch + adjunct

STP: signal transfer point $\approx$ router

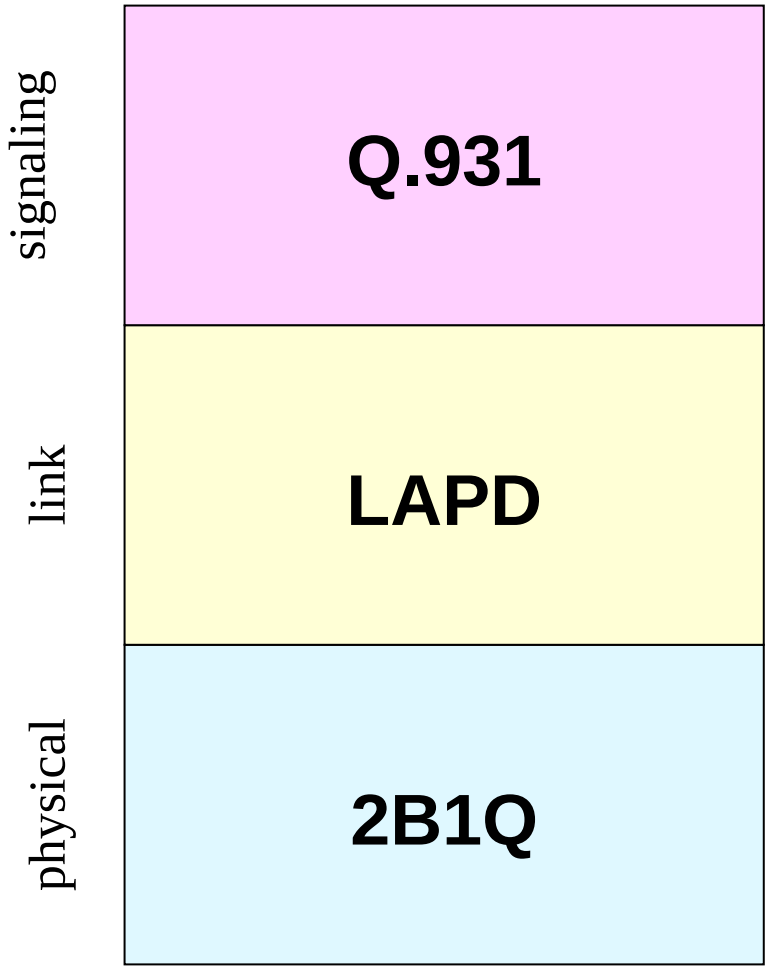
SCP: service control point = interface to databases

- call management service database
- line information database
- home location register
- visitor location register

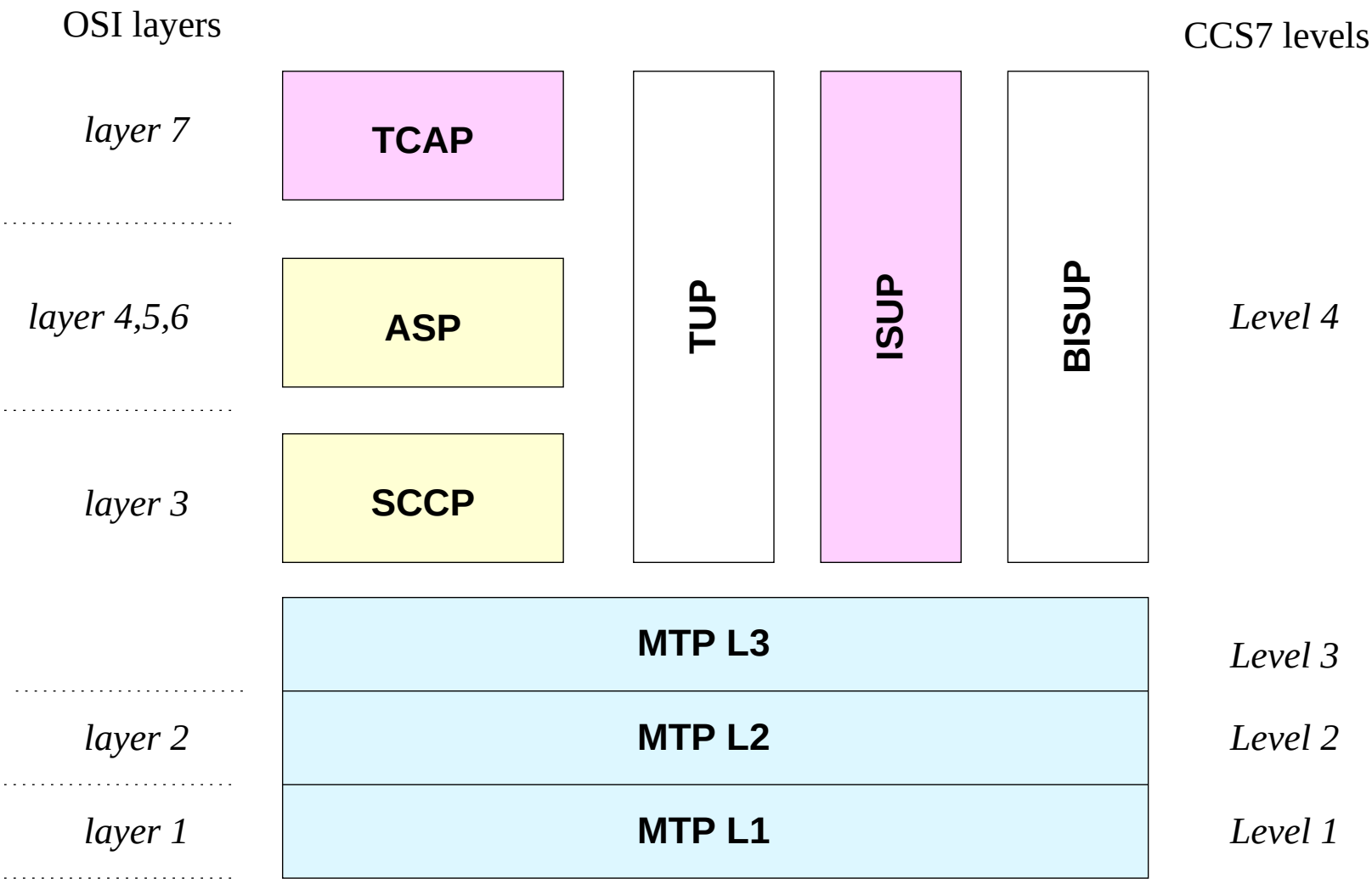
- traditionally, 64 kb/s leased lines
- future: IP ($\rightarrow$ IETF Sigtran WG)

ISDN protocol stack

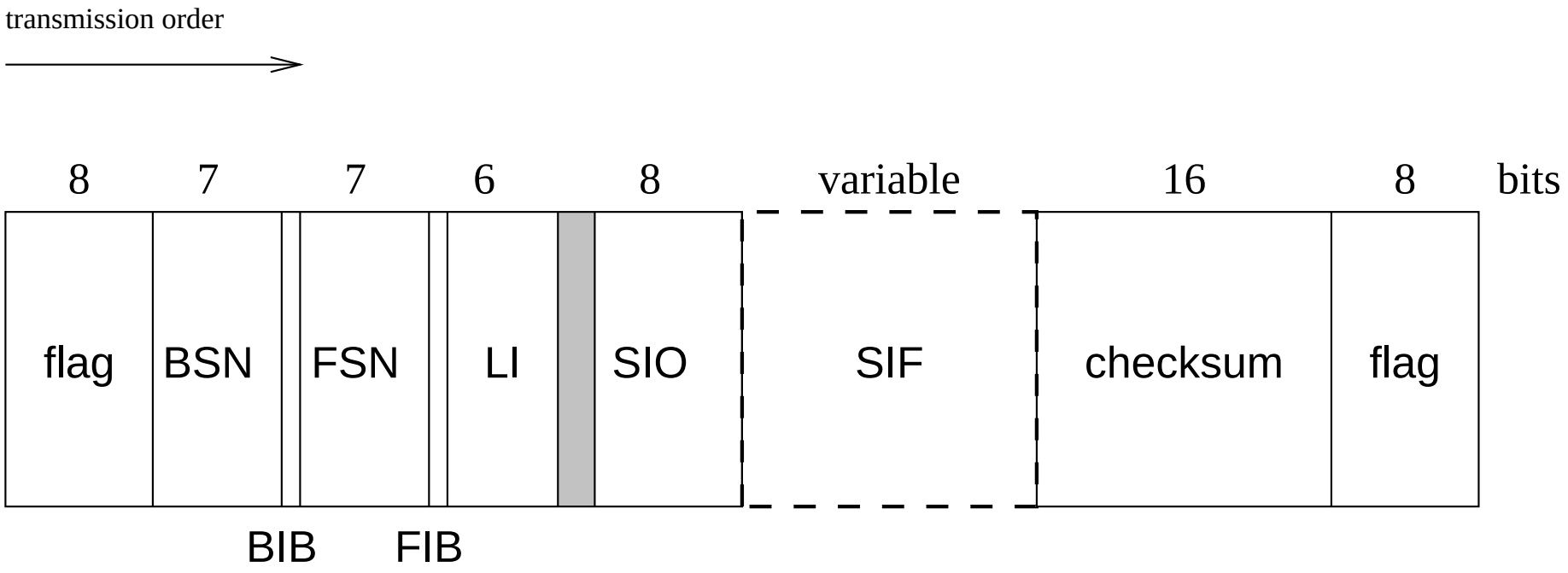
ISDN = BRI (2B+D in 192 kb/s “raw”) or PRI (23B+D)



SS7 protocol stack



ISUP MTP format



BIB: backward indicator bit
FIB: forward indicator bit
BSN: backward sequence number
FSN: forward sequence number

SIO: service information octet
SIF: service information field

SS7 protocol stack

Level 1 (physical): DS0A = 56/64 kb/s in DS1 facility

Level 2 (data link): error detection/correction, link-by-link

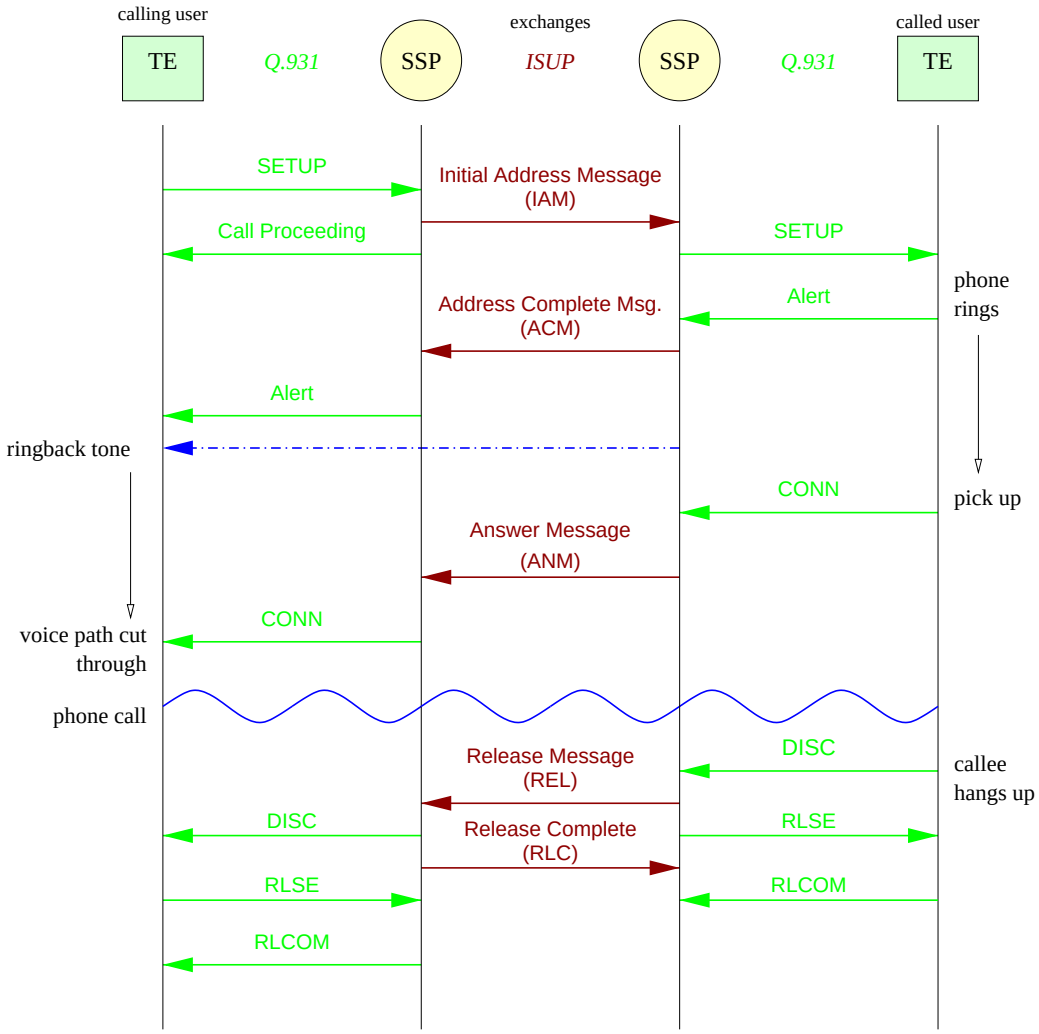
Level 3 (network):

- routing
- message discrimination ➠ “point codes”
- distribution

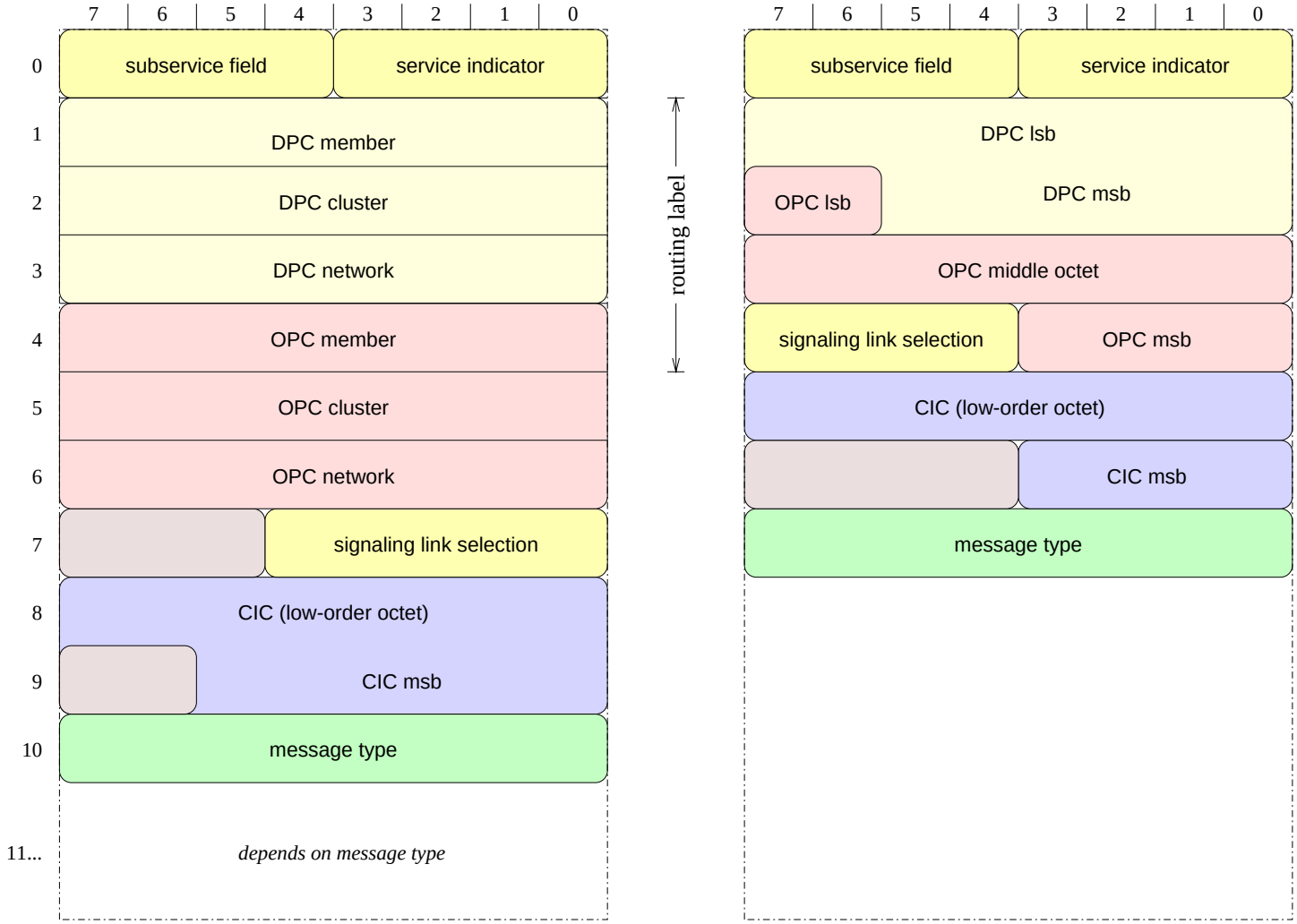
Level 4 (user parts):

- basic signaling: TUP $\longrightarrow$ ISUP
- Transaction Capabilities Application (TCAP)
- Operations, Maintenance, Administration (OMAP)
- Mobile Application Part (MAP)

ISDN and SS7 call



ISUP message format



ISUP messages

→ **Initial Address Message (IAM):** called number *en bloc*

→ **Continuity Message (COT):** loopback test successful

← **Address Complete Message (ACM):** callee being rung

← **Call Progress Message (CPG):** report call set-up event

← **Answer Message (ANM):** callee has answered the phone

↔ **Release Message (REL):** request release of connection, with cause

↔ **Release Complete Message (RLC):** confirm REL

ISUP messages

← **Suspend Message (SUS):** suspend call, but keep connection

↔ **Resume (RES):** resume suspended call

↔ **Forward Transfer Message (FOT):** outgoing operator requests incoming operator

↔ **Information Request Message (INR):** terminating exchange wants more information

↔ **Information Message (INF):** response to INR

↔ **Pass-along Message (PAM):** tunnel another message

Reliability: “Nines”

1	90%	36.5 days/year	
2	99%	3.65 days/year	
3	99.9%	8.8 hours/year	good ISP?
4	99.99%	53 minutes/year	
5	99.999%	5 minutes/year	phone system
6	99.9999%	32 seconds/year	

Reliability indications

- FCC incidents: $\geq$ 90,000 customers, $\geq$ 30 minutes (972 between 1992 and 1997)
- FCC ARMIS (Automated Reporting Management Information System)
- ANSI T1A1: logarithmic outage index = f(duration, # affected, time, functions, . . .)
- call defects per million (e.g., AT&T 173 ppm)

Outage Statistics

- median outage lasts 2.9 hours (natural disasters: 13.4 hours)
- causes: facilities (45%), local switches (18%), CCS (13%), CO power (7.3%)
- facility failures: dig-ups (“back-hoe fade”, 58%), cable electronics (8%)
- ARMIS example: Bell Atlantic 1998: 180 switches, combined downtime of 628 minutes, or $6.6 \cdot 10^{-6}$