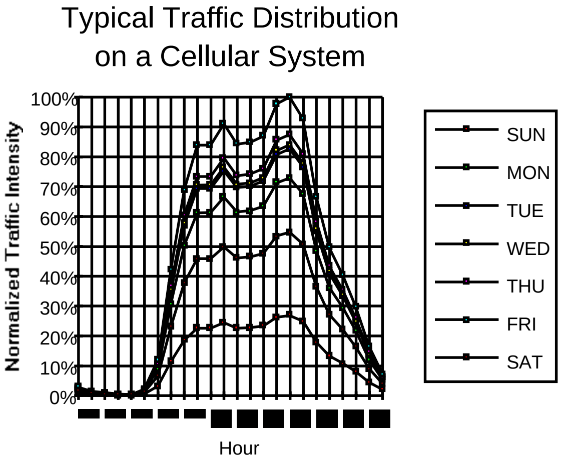
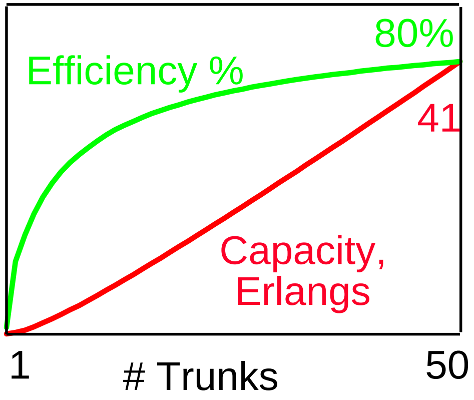
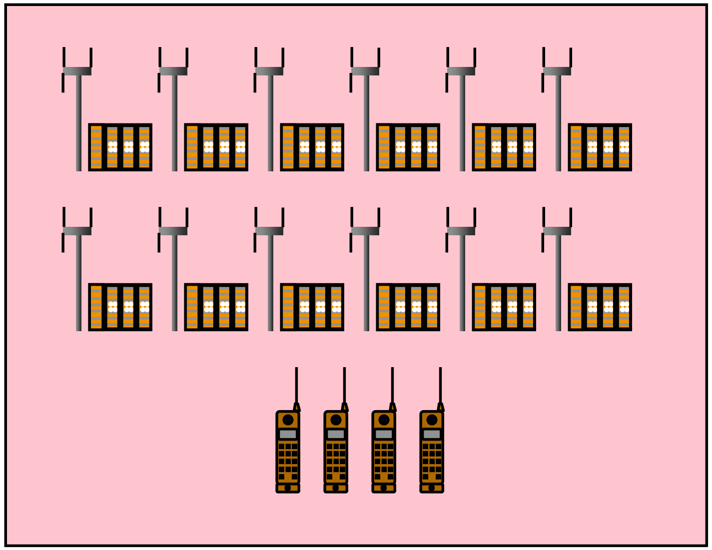
Chapter 6

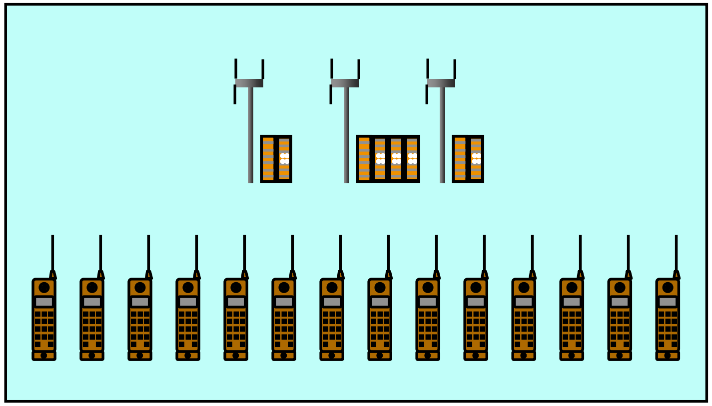
Traffic Engineering





A Game of Avoiding Extremes



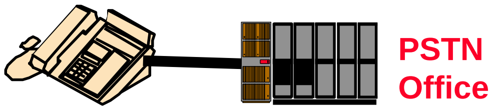


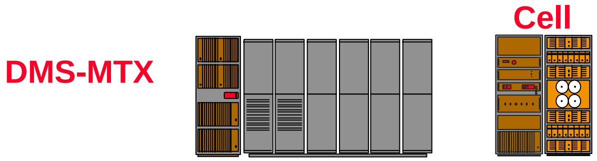
The traffic engineer must walk a fine line between two problems:

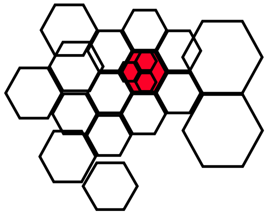
- **Overdimensioning**
  - **too much cost**
  - insufficient resources to construct
  - traffic revenue is too low to support costs
  - very poor economic efficiency!
- **Underdimensioning**
  - **blocking**
  - poor technical performance (**interference**)
  - capacity for billable revenue is low
  - revenue is low due to poor quality
  - users unhappy, cancel service
  - very poor economic efficiency!

Dimensioning the System:
An Interactive, Iterative Process

- Some traffic engineering decisions trigger resource acquisition
  - additional blocks of numbers from the local exchange carrier
  - additional cards for various functions in the switch and peripherals
  - additional members in PSTN trunk groups; additional T-1/E-1s to busy sites
- Some traffic engineering decisions trigger more engineering
  - finding more frequencies to add to blocking sites
  - adding additional cells to relieve blocking
  - finding short-term fixes for unanticipated problems
- This course is concerned primarily with determining **the number of voice channels required in cells**, with the related site engineering and frequency or code planning



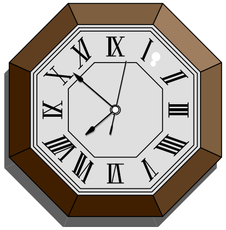




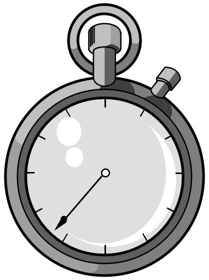
Basics of Traffic Engineering
Terminology & Concept of a Trunk

- Traffic engineering in telephony is focused on the **voice paths which users occupy**. They are called by many different names:
  - **trunks**
  - **circuits**
  - **radios (AMPS, TDMA), transceivers ("TRXs" in GSM), channel elements (CDMA)**
- Some other common terms are:
  - **trunk group**
    - a trunk group is several trunks going to the same destination, combined and addressed in switch translations as a unit , for traffic routing purposes
  - **member**
    - one of the trunks in a trunk group

Units of Traffic Measurement



Traffic is expressed in units of Circuit Time



General understanding of telephone traffic engineering began around 1910. An engineer in the Danish telephone system, Anger K. Erlang, was one of the first to master the science of trunk dimensioning and publish the knowledge for others. In his honor, the basic unit of traffic is named the **Erlang**.

- An **Erlang** of traffic is one circuit continuously used during an observation period one hour long.

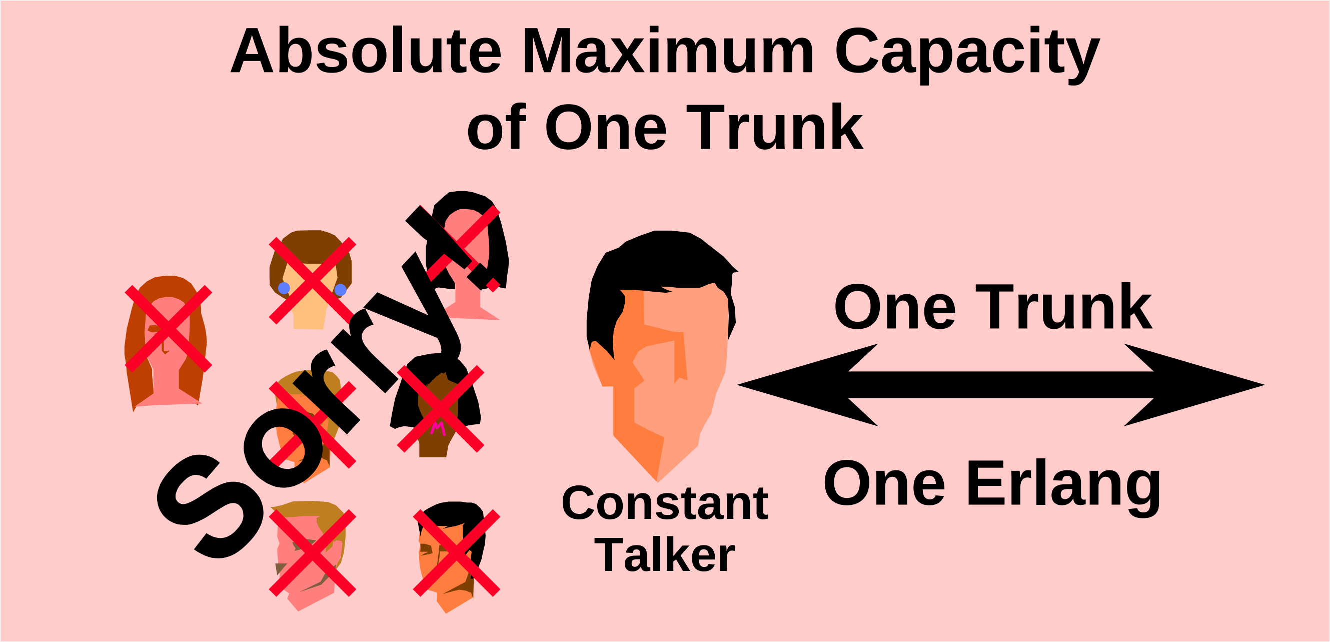
Other units have become popular among various users:

- **CCS** (Hundred-Call-Seconds)
- **MOU** (Minutes Of Use)
- It's easy to convert between traffic units if the need arises:

1 Erlang = 60 MOU = 36 CCS

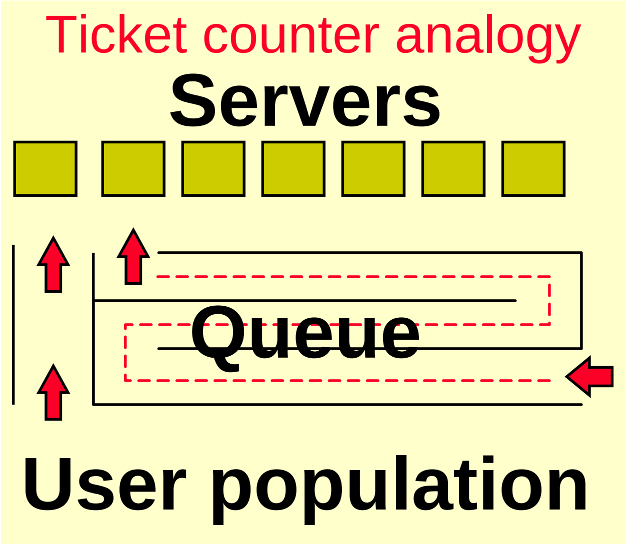
How Much Traffic Can One Trunk Carry?

- Traffic studies are usually for periods of one hour
- In one hour, one trunk can carry one hour of traffic -- *One Erlang*
- If nothing else matters, this is the limit!
- If anyone else wants to talk -- sorry!



- We must not plan to keep trunks busy all the time. There must be a reserve to accommodate new talkers! How much reserve? next!

Traffic Engineering And Queuing Theory



Ticket counter analogy

Servers

Queue

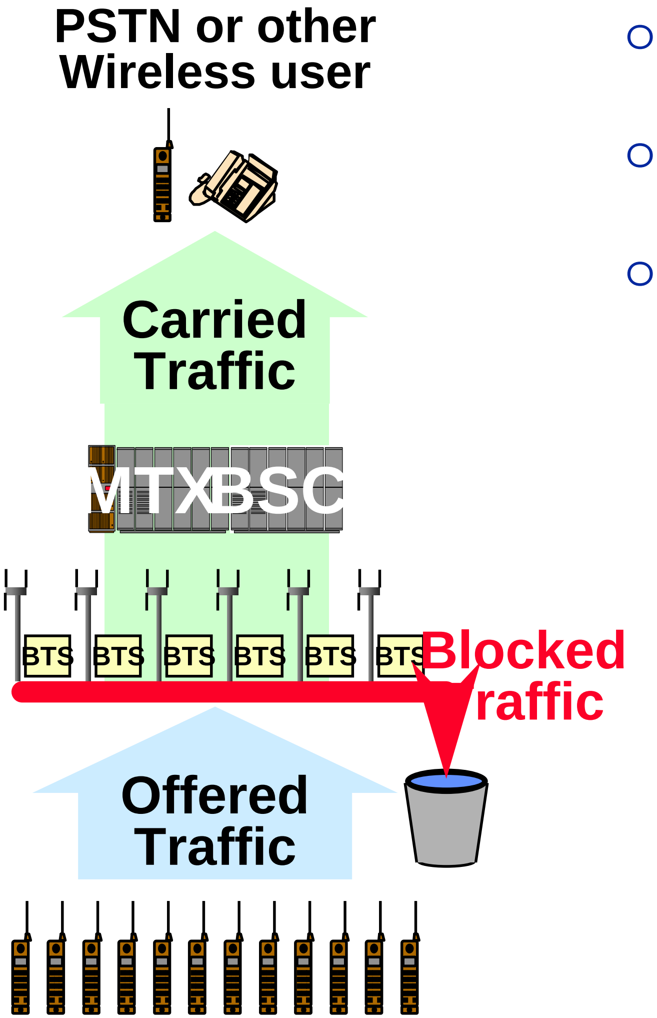
User population

Queues we face in everyday life

1) for telephone calls
2) at the bank
3) at the gas station
4) at the airline counter

- Traffic engineering is an application of a science called *queuing theory*
  - Queuing theory relates user arrival statistics, number of servers, and various queue strategies, with the probability of a user receiving service
  - If waiting is not allowed, and a blocked call simply goes away, *Erlang-B* formula applies *(popular in wireless)*
  - If unlimited waiting is allowed before a call receives service, the *Erlang-C* formula applies
  - If a wait is allowed but is limited in time, *Binomial & Poisson* formulae apply
  - *Engset* formulae apply to rapid, packet-like transactions such as paging channels

Offered And Carried Traffic



- *Offered traffic* is what users attempt to originate
- *Carried traffic* is the traffic actually successfully handled by the system
- *Blocked traffic* is the traffic that could not be handled
  - Since blocked call attempts never materialize, blocked traffic must be ***estimated*** based on number of blocked attempts and average duration of successful calls

Offered Traffic =
Carried Traffic + Blocked Traffic

$$T_{Off} = N_{CA} \times T_{CD}$$

T_{Off} = Offered traffic

N_{CA} = Number of call attempts

T_{CD} = Average call duration

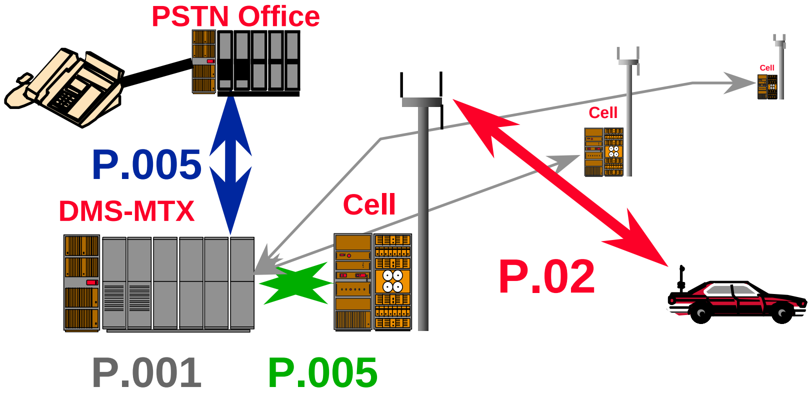
Principles of Traffic Engineering

Blocking Probability / Grade of Service

- Blocking is inability to get a circuit when one is needed
- Probability of Blocking is the likelihood that blocking will happen
- In principle, blocking can occur anywhere in a wireless system:
  - not enough radios, the cell is full
  - not enough paths between cell site and switch
  - not enough paths through the switching complex
  - not enough trunks from switch to PSTN
- Blocking probability is usually expressed as a percentage using a “shorthand” notation:
  - **P.02** is 2% probability, etc.
  - Blocking probability sometimes is called **“G**rade **O**f **S**ervice”
- Most blocking in cellular systems occurs at the radio level.
  - P.02 is a common goal at the radio level in a system

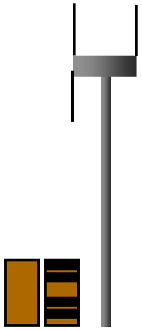
Typical Wireless System

Design Blocking Probabilities



Number of Trunks vs. Utilization Efficiency

- Imagine a cell site with *just **one** voice channel*. At a **P.02** Grade of Service, how much traffic could it carry?
  - The trunk can only be used 2% of the time, otherwise the blocking will be worse than 2%.
  - 98% *availability* forces 98% *idleness.* It can only carry .02 Erlangs. Efficiency 2%!



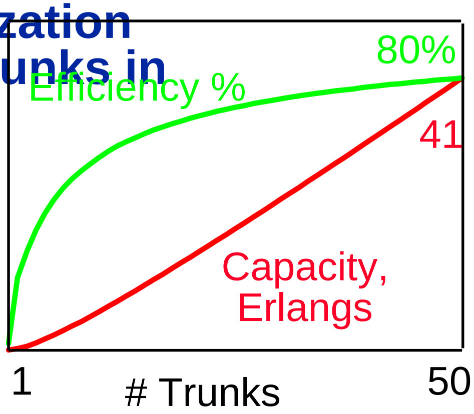
- Adding just one trunk relieves things greatly. Now we can use trunk 1 heavily, with trunk 2 handling the overflow. Efficiency rises to 11%

Erlang-B P.02 GOS

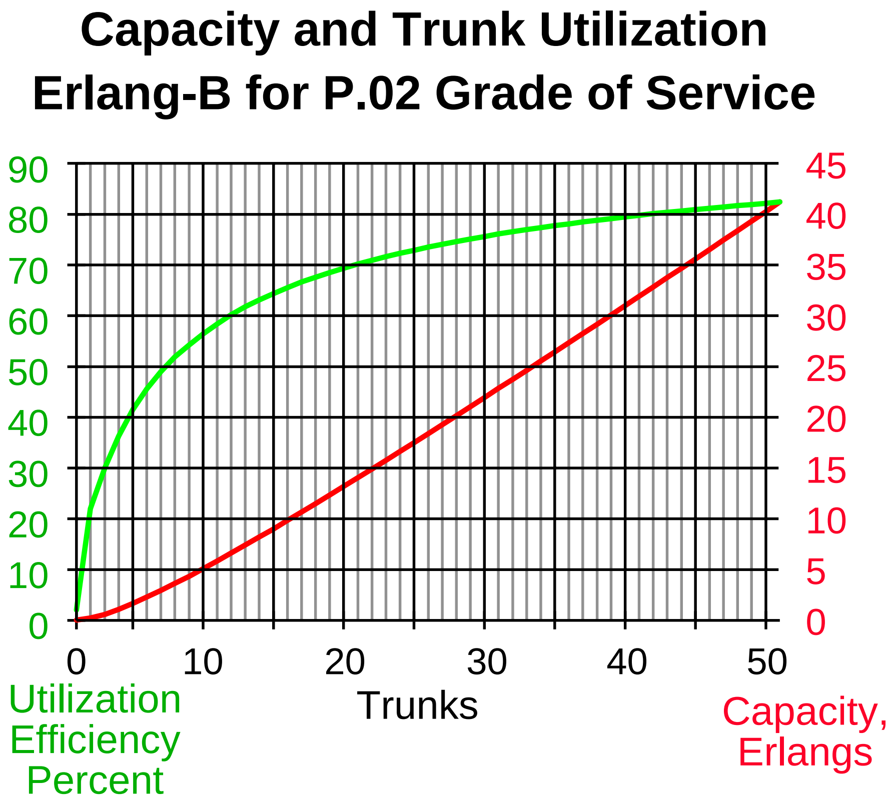
Trks	Erl	Eff%
1	0.02	2%
2	0.22	11%

The Principle of Trunking Efficiency

- **For a given grade of service, trunk utilization efficiency increases as the number of trunks in the pool grows larger.**
  - For trunk groups of several hundred, utilization approaches 100%.



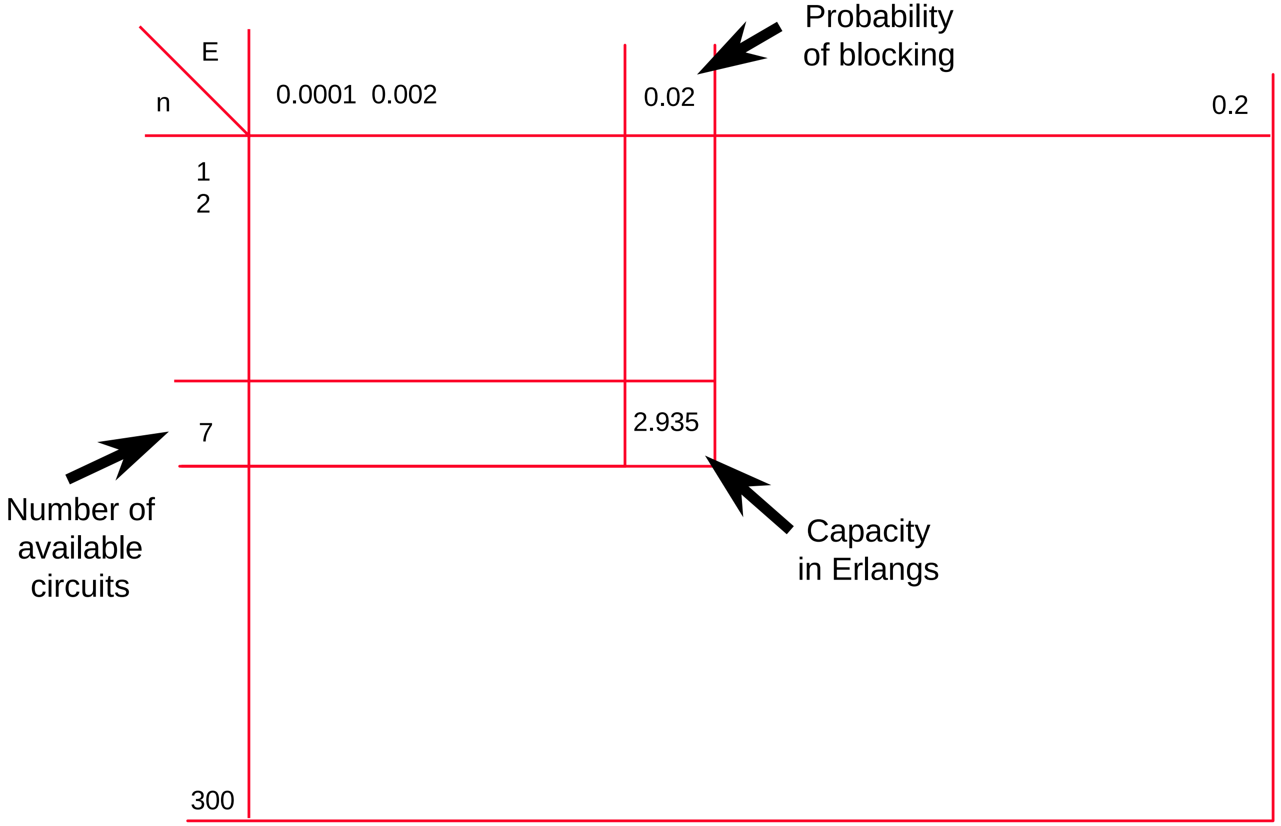
Number of Trunks, Capacity, and Utilization Efficiency



- The graph at left illustrates the capacity in Erlangs of a given number of trunks, as well as the achievable utilization efficiency
- For accurate work, tables of traffic data are available
  - Capacity, Erlangs
  - Blocking Probability (GOS)
  - Number of Trunks
- Notice how capacity and utilization behave for the numbers of trunks in typical cell sites

Traffic Engineering & System Dimensioning

Using Erlang-B Tables to determine Number of Circuits Required



E

n

0.0001 0.002

0.02

0.2

Probability of blocking

1
2

7

2.935

300

Number of available circuits

Capacity in Erlangs

A = f (E,n)

Erlang-B Traffic Tables

Abbreviated - For P.02 Grade of Service Only

#Trunks	Erlangs
1	0.0204
2	0.223
3	0.602
4	1.09
5	1.66
6	2.28
7	2.94
8	3.63
9	4.34
10	5.08
11	5.84
12	6.61
13	7.4
14	8.2
15	9.01
16	9.83
17	10.7
18	11.5
19	12.3
20	13.2
21	14
22	14.9
23	15.8
24	16.6
25	17.5

#Trunks	Erlangs
26	18.4
27	19.3
28	20.2
29	21
30	21.9
31	22.8
32	23.7
33	24.6
34	25.5
35	26.4
36	27.3
37	28.3
38	29.2
39	30.1
40	31
41	31.9
42	32.8
43	33.8
44	34.7
45	35.6
46	36.5
47	37.5
48	38.4
49	39.3
50	40.3

#Trunks	Erlangs
51	41.2
52	42.1
53	43.1
54	44
55	44.9
56	45.9
57	46.8
58	47.8
59	48.7
60	49.6
61	50.6
62	51.5
63	52.5
64	53.4
65	54.4
66	55.3
67	56.3
68	57.2
69	58.2
70	59.1
71	60.1
72	61
73	62
74	62.9
75	63.9

#Trunks	Erlangs
76	64.9
77	65.8
78	66.8
79	67.7
80	68.7
81	69.6
82	70.6
83	71.6
84	72.5
85	73.5
86	74.5
87	75.4
88	76.4
89	77.3
90	78.3
91	79.3
92	80.2
93	81.2
94	82.2
95	83.1
96	84.1
97	85.1
98	86
99	87
100	88

#Trunks	Erlangs
100	88
102	89.9
104	91.9
106	93.8
108	95.7
110	97.7
112	99.6
114	101.6
116	103.5
118	105.5
120	107.4
122	109.4
124	111.3
126	113.3
128	115.2
130	117.2
132	119.1
134	121.1
136	123.1
138	125
140	127
142	128.9
144	130.9
146	132.9
148	134.8

#Trunks	Erlangs
150	136.8
152	138.8
154	140.7
156	142.7
158	144.7
160	146.6
162	148.6
164	150.6
166	152.6
168	154.5
170	156.5
172	158.5
174	160.4
176	162.4
178	164.4
180	166.4
182	168.3
184	170.3
186	172.4
188	174.3
190	176.3
192	178.2
194	180.2
196	182.2
198	184.2

#Trunks	Erlangs
200	186.2
202	188.1
204	190.1
206	192.1
208	194.1
210	196.1
212	198.1
214	200
216	202
218	204
220	206
222	208
224	210
226	212
228	213.9
230	215.9
232	217.9
234	219.9
236	221.9
238	223.9
240	225.9
242	227.9
244	229.9
246	231.8
248	233.8

#Trunks	Erlangs
250	235.8
300	285.7
350	335.7
400	385.9
450	436.1
500	486.4
600	587.2
700	688.2
800	789.3
900	890.6
1000	999.1
1100	1093

The Equation behind the Erlang-B Table

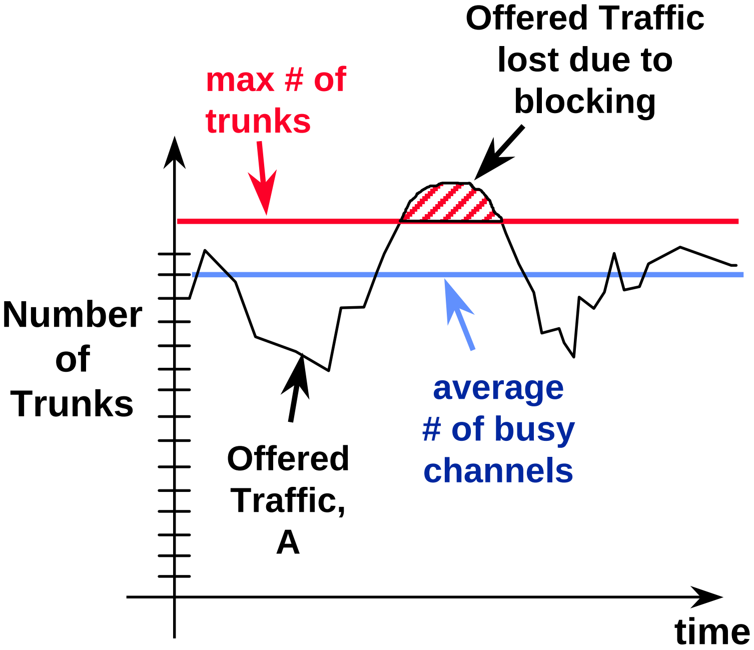
The Erlang-B formula is fairly simple to implement on hand-held programmable calculators, in spreadsheets, or popular programming languages.

$$P_n(A) = \frac{\frac{A^n}{n!}}{1 + \frac{A}{1!} + \ldots + \frac{A^n}{n!}}$$

$P_n(A)$ = Blocking Rate (%)
with n trunks
as function of traffic A

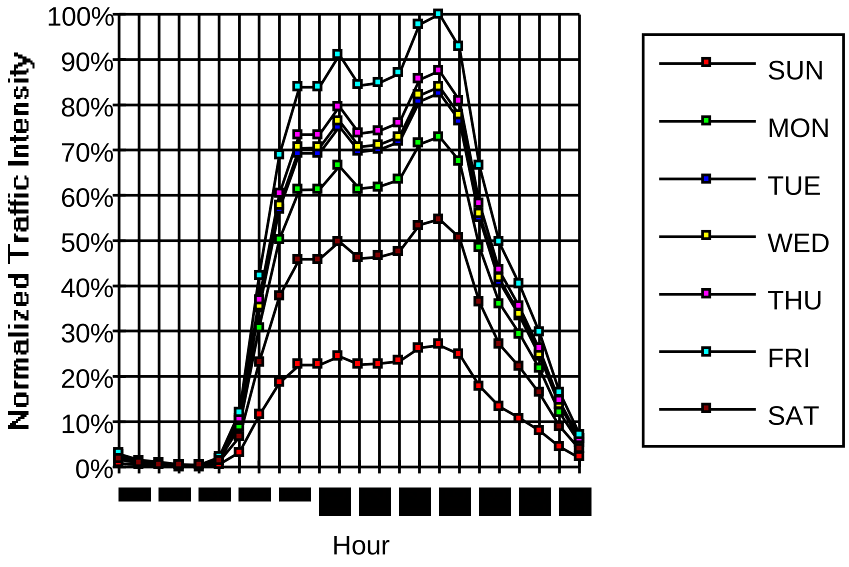
A = Traffic (Erlangs)

n = Number of Trunks



Wireless Traffic Variation with Time: A Cellular Example

Typical Traffic Distribution
on a Cellular System



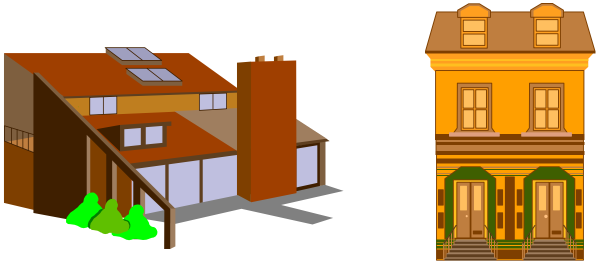
Actual traffic from a cellular system in the mid-south USA in summer 1992. This system had 45 cells and served an area of approximately 1,000,000 population.

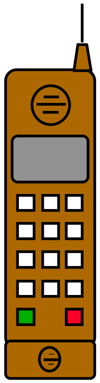
- Peak traffic on cellular systems is usually daytime business-related traffic; on PCS systems, evening traffic becomes much more important and may actually contain the system busy hour
- Evening taper is more gradual than morning rise
- Wireless systems for PCS and LEC-displacement have peaks of residential traffic during early evening hours, like wireline systems
- Friday is the busiest day, followed by other weekdays in backwards order, then Saturday, then Sunday
- **There are seasonal and annual variations, as well as long term growth trends**

Busy-Hour

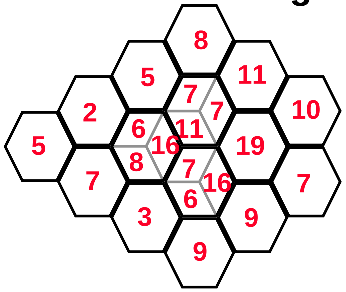
- In telephony, it is customary to collect and analyze traffic in hourly blocks, and to track trends over months, quarters, and years
  - When making decisions about number of trunks required, we plan the trunks needed to support the busiest hour of a <u>normal</u> day
  - Special events (disasters, one-of-a-kind traffic tie-ups, etc.) are not considered in the analysis *(unless a marketing-sponsored event)*
- Which Hour should be used as the Busy-Hour?
  - Some planners choose one specific hour and use it every day
  - Some planners choose the busiest hour of each individual day ("floating busy hour")
  - Most common preference is to use "floating (bouncing)" busy hour determined individually for the total system and for each cell, but to exclude special events and disasters
  - In the example just presented, 4 PM was the busy hour every day

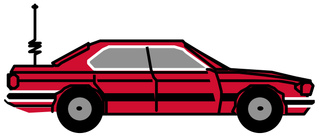
Where is the Traffic?





Existing System Traffic In Erlangs





- Wireline telephone systems have a big advantage in traffic planning.
  - They know the addresses where their customers generate the traffic!
- Wireless systems have to ***guess*** where the customers will be next
  - on **existing** systems, use measured traffic data by sector and cell
    - analyze past trends
    - compare subscriber forecast
    - trend into future, find overloads
  - for **new** systems or new cells, we must use all available clues

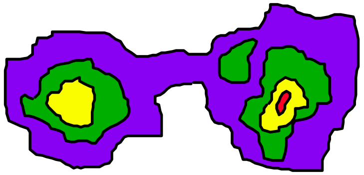
Traffic Clues

27 mE/Sub in BH

103,550 Subscribers
1,239,171 Market Population

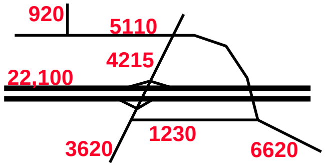
adding 4,350 subs/month

Population Density



new
Shopping Center

Vehicular Traffic



Land Use
Databases

- Subscriber Profiles:
  - Busy Hour Usage, Call Attempts, etc.
- Market Penetration:
  - # Subscribers/Market Population
  - use Sales forecasts, usage forecasts
- Population Density
  - Geographic Distribution
- Construction Activity
- Vehicular Traffic Data
  - Vehicle counts on roads
  - Calculations of density on major roadways from knowledge of vehicle movement, spacing, market penetration
- Land Use Database: Area Profiles
- Aerial Photographs: Count Vehicles!

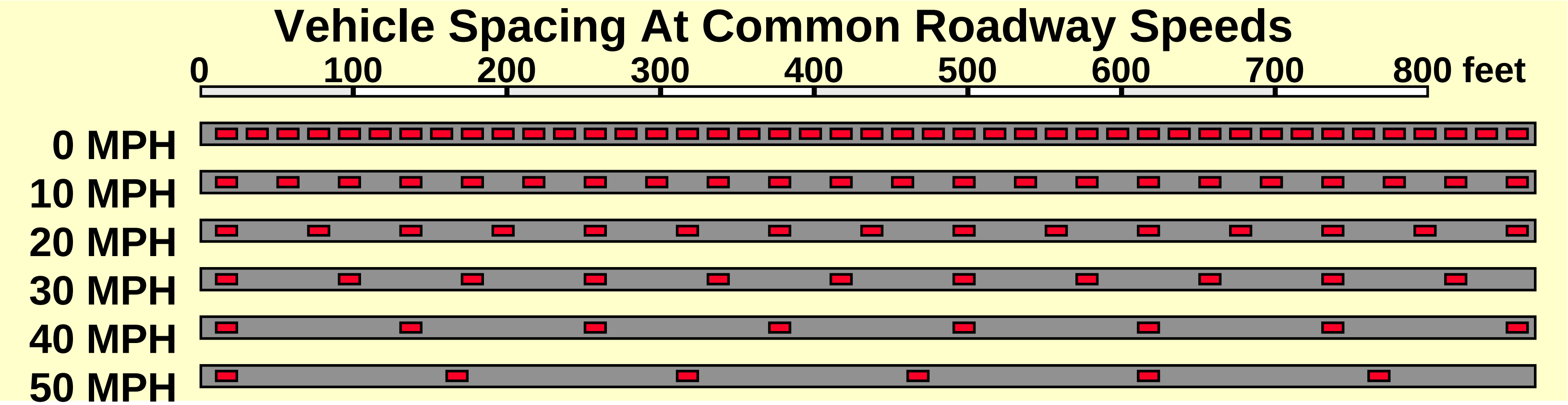
Traffic Density Along Roadways

Vehicles per mile

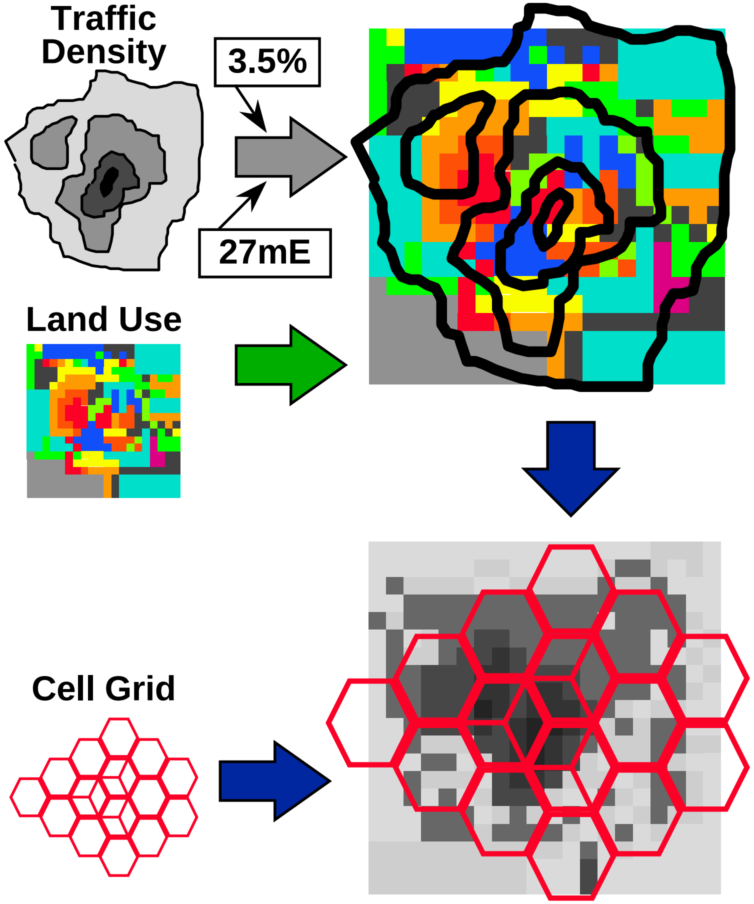
Vehicle Speed, MPH	Vehicle Spacing, feet	Vehicles per mile, per lane
0	**20**	**264**
10	**42**	**126**
20	**64**	**83**
30	**86**	**61**
45	**119**	**44**
60	**152**	**35**

Vehicle spacing 20 ft. @stop
Running Headway 1.5 seconds

- Number of lanes and speed are the main variable determining number of vehicles on major highways
  - Typical headway ~1.5 seconds
  - Table and figure show capacity of 1 lane
- When traffic stops, users generally increase calling activity
- Multiply number of vehicles by percentage penetration of population to estimate number of subscriber vehicles



Methodical Estimation of Required Trunks



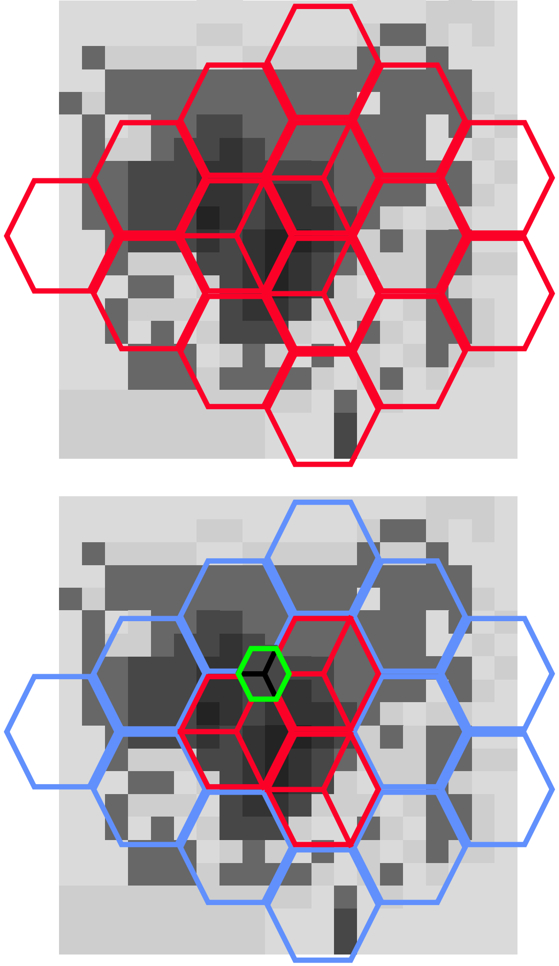
Modern propagation prediction tools allow experimentation and estimation of traffic levels

- Estimate total overall traffic from subscriber forecasts
- Form traffic density outlines from market knowledge, forecasts
- Overlay traffic density on land use data; weight by land use
- Accumulate intercepted traffic into serving cells,
  - obtain Erlangs per cell & sector
- From tables, determine number of trunks required per cell/sector
- Modern software tools automate major parts of this process

Profile of Typical Cellular Usage

Offered Traffic, mE per subscriber in busy hour	25 mE
Number of call attempts per subscriber in busy hour	1.667
Average Call Duration	150 sec. (41.7 mE)
Mobile originated calls	
proportion of total calls on system	87 %
successful calls	70 %
Calls not answered	15 %
calls to a busy line	15 %
Mobile terminated calls	
proportion of total calls on system	13 %
successful calls	15 %
Calls not answered	10 %
paging requests not answered	75 %
Number of handoffs per call	0.87
Registration attempts per subscriber during busy hour	2

Determining Number of Trunks required for a new Growth Cell



When new growth cells are added, they absorb some of the traffic formerly carried by surrounding cells

- Two approaches to estimating traffic on the new cell and on its older neighbors:
  - **if blocking was not too severe**, you can estimate redistributed traffic in the area based on the new division of coverage
  - **if blocking is severe**, (often the case), users will stop trying to call in locations where they’ve learned to expect blocking. ***Users are self-programming!!***
    - reapply basic traffic assumptions in the area, like engineering new system, for every nearby cell
    - watch out! overall traffic in the area may increase to fill the additional capacity and the new cell itself may block as soon as it goes in service

Dimensioning
System Administrative Functions

System administrative functions also require traffic engineering input. While these functions are not necessarily performed by the RF engineer, they require RF awareness and understanding.

- **Paging**
  - The paging channel has a definite capacity which must not be exceeded. When occupancy approaches this limit, the system must be divided into zones, and zone paging implemented.
  - Impact of Short Message Service (and others) must be considered
- **Autonomous Registration**
  - Autonomous registration involves numerous parameters and the registration attempts must be monitored and controlled to avoid overloading.